Proceedings of the
Nova Scotian Institute of Science
Volume 54, Part 1 • 2025

Continued

Research Articles cont'd

Book Reviews

Continued

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 1-4

EDITORIAL

Stand strong for science – support our American colleagues

We live in very challenging times, environmentally and politically. Climate change is the number one environmental threat that is affecting our lives in Canada annually, with heat waves, wildfires, hurricanes, floods and tornadoes. This general environmental uncertainty also affects us globally. Tragically, due south of us, the world is being turned upside down with the irrational actions undertaken by a highly unpredictable autocrat, US President Donald Trump, who once again occupies the White House. Not only do he and his appointees not believe in anthropogenic climate change, but they are intentionally attempting to ignore, reduce and destroy American science on many fronts.

Since January 2025, scientific and medical programs and employment in the US federal government and in the universities have been drastically curtailed, with serious implications for that country and others around the globe. The cutbacks have been enormous and unnecessary (i.e., they are ignorant ideological decisions) and are likely to push American science and society back many years. As a concerned scientist, I have followed the development of this situation closely, especially through coverage in the AAAS journal *Science*. From January to August 2025, over 100 articles have described the situation[1]. Highlights of the changes and impacts are summarized here, with a commentary on how the NSIS and its membership should respond in this crisis. Given previous decadal US leadership and contributions in science, we are all affected and must respond. As Caplan (2025) and others (e.g. Thorp 2025) have said, “don’t wait out four hard years, speak truth to power now, and come together and not be silenced”. Above all, speak up for science!

The suspensions and cuts to the US federal government employees and programmes to date have decimated the weather forecasting service and climate research programs of NOAA, health research in many federal departments charged with disease control, vaccine development and distribution, advanced medicine, and overseas aid for food and medicine. The department of education is now shut down.

[1] A bibliography of these articles is available upon request.

The enormously influential and effective US Aid program has been closed completely, putting millions of lives at risk in many developing countries. Environmental regulations governing water, land and chemical risks are being changed or abolished, with massive layoffs of world-leading EPA staff and huge reductions to budgets. Staff and programs at the highly respected US National Academies have been reduced and funding for research conducted at key universities such as Harvard has been interrupted or cancelled. Independent research at many universities is threatened and fewer overseas students are being allowed to enroll and study at US universities. Sanctions have been so severe that many US scientists are leaving the country. Even space science in NASA has been reduced or disrupted, with universal condemnation. Tragically, the impact on staff and programs in both the federal government and the universities is profound, especially on young researchers who are just starting their careers. US science will take many years to recover, as data, expertise, promising recruits, and institutional knowledge are lost.

The US administration has also upset the long stability of the international order, by reducing US involvement or withdrawing all together from the World Health Organization, World Meteorological Organization, World Trade Organization, Paris Agreement, Intergovernmental Panel on Climate Change (IPCC), and UN Sustainable Development Goals Program (SDG). As with the elimination of USAid, this has threatened the security and health of millions of people. Sadly, the US may rapidly lose its place in both global science and influence.

Lately though, in the face of this tsunami of attacks on government and university science, members of the US Congress and Senate have woken up. Bipartisan committees have refused to approve some of the suggested cutbacks. In addition, many cutbacks have been challenged in court and well-attended public protests have taken place nationwide, objecting to the anti-democratic and destructive behaviour of the White House.

However, the crisis is ongoing. Science and freedom of speech are under attack by this rogue Administration and will likely continue for the next three and one-half years. Hence, the NSIS should stand shoulder to shoulder with our American friends, colleagues, and science-based organizations to offer moral and research support, including a place for their data to be stored safely if required, and an alternate place to work as availability permits. Hence, the NSIS must speak out, as should other science-based organizations and universities in Canada and beyond. These sentiments are echoed by the scientific community around the world (M.H. Depledge, pers. comm.). We need strong science (natural sciences and health sciences) in all of our countries, to under-pin rational, level-headed and defensible leadership and policies across the full spectrum of science, health services, and international affairs. We must counter Trump behaviour and policies.

There are approximately nine million scientists world-wide. Through contact with many of the large scientific groups such as the American Association for the Advancement of Science (AAAS), and the Union of Concerned Scientists (UCS), and especially individual colleagues, we must let American scientists and other researchers know that we stand with them during this crisis. As citizens, we should write to politicians at home and in the US, letting them know our views. We must draw attention to the many negative effects of the White House's misguided and morally bankrupt policies on people and the environment. The NSIS has a clear and major role here. We should be heard loud and clear, expressing the consequences of such cutbacks to science both in the US and Canada posed by the self-serving policies and actions of the current US administration (Quirion 2025).

Please write your letters now, to politicians, science organizations, and your friends and colleagues on both sides of the border. Especially write to the AAAS at The American Association for the Advancement of Science, 1200 New York Avenue, NW, Washington, DC. 20005. USA. Attention: Editor-in-Chief, Dr. Holden Thorp. Be sure to copy both Ottawa and the White House.

To be silent at this pivotal time is not an option (Caplan 2025, Goldman and Chenoweth 2025, Nowogrodzki *et al.* 2025, Phillips 2025, Thorp 2025). The NSIS must always stand strong for science conducted on behalf of our global community.

ACKNOWLEDGEMENTS

Many thanks to Drs. David Richardson, Michael Depledge, and Hank Bird for their comments on this article. An early version was published in the CSEB Bulletin, 82(2): 4-5, Summer edition, 2025. Any errors in content or interpretation are mine alone.

BIBLIOGRAPHY

Caplan, A. (2025). Don't wait out four hard years: Speak truth to power. *Nature* 639(8055): 548. doi.org/10.1038/d41586-025-00791-z

Goldman, G. & Chenoweth, E. (2025). Editorial. Scientists' role in defending democracy. *Science* 389(6761): 667. August 14.

Nowogrodzki, J., Basilio, H., Ledford, H., Maher, B. & Witze, A. (2025). "Scientists will not be silenced": Thousands protest Trump research cuts. *Nature* 639(8055): 551-552. March 20. doi.org/10.1038/d41586-025-00704-0

Phillips, P. (2025). Letters. Science, not silence: Save US economic growth. *Science* 388(6745): 370. April 25.

Quirion, R. (2025). Uphold US-Canada science. *Science* 387(6739): 1127. doi.org/10.1126/science.adx2966 March 14.

Thorp, H.H. (2025). Editorial. Come together, right now. *Science* 387 (6737): 909. Feb 28.

Peter G. Wells, Dalhousie University, and Editor, PNSIS
Oceans2@ns.sympatico.ca

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 5-11

GARNETS FROM SHELBURNE: A CASE STUDY OF THE VALUE OF GEOHERITAGE

TIM J. FEDAK*

Curator of Geology, Nova Scotia Museum
Halifax, NS

ABSTRACT

A report of curatorial work recognizing of the value of geoheritage in museum collections. Tracing the history of a garnet specimen donated to the Nova Scotia Museum in 1905 provides opportunity to learn about the life and contributions of Thomas Vardy Hill. While the market value of natural history collections is difficult (or impossible) to estimate, the role of collections for representing citizens who contributed to the history of science has geoheritage value.

THE VALUE OF MUSEUM SPECIMENS

As a Curator of the Nova Scotia Museum of Natural History, I often think about the Museum's collections and why they are important. I also often wonder, how do we estimate the value of museum collections? The most common and easiest concept of value is market value. If an item is put up for sale at an auction, how much would someone pay for the particular item in the open market? Older things generally become rare over time, and items of exceptional quality will increase in market value. Although easy to understand, this supply and demand model is difficult to apply when the rare items are not, or seldom, offered for sale.

Items in museum collections also have scientific and historical value. Specimens of animals or plants that have become extinct are valuable in terms of the genetic and biological diversity that no longer exists (Cranbrook 1997). Other natural history specimens represent the first one described of a species, the holotype, and stands as the global reference specimen that defines a taxonomic name. Some rock samples in museum collections were obtained with great effort and expense, from sources that are no longer available.

* Author to whom correspondence should be addressed: tim.fedak@novascotia.ca

Other artifacts have a significant history, in terms of time and place and stir emotional responses or have cultural importance that give them an elevated value (Trinchillo 2015). For all of these reasons, estimating the monetary value of museum specimens can be very challenging.

GEOHERITAGE COLLECTIONS

There is growing interest in recognizing and conserving our geoheritage, especially in terms of establishing global geoparks such as the Cliffs of Fundy UNESCO Global Geopark here in Nova Scotia. The Geological Society of America has defined *geoheritage* as “a generic but descriptive term applied to sites or areas of geologic features with significant scientific, educational, cultural, and/or aesthetic value” (National Academies of Sciences 2021). However, there are also new efforts to recognize and assess the geoheritage value of museum collections (Henriques and Pena dos Reis 2015).

CURATORIAL WORK

In the Nova Scotia Museum of Natural History, the geology collection includes many beautiful and interesting minerals. I was recently putting away some mineral specimens that had been on exhibit. I photographed the specimens and updated the database in order to make the records available for a new online display. One of these minerals is a beautiful, deep purple garnet, about the size of a grape. Garnet minerals have crystals that are twelve sided and remind me of small soccer balls. The label that had accompanied this specimen on exhibit read “Garnet, variety Spessartine. From Shelburne, Shelburne County.” The label also had a small map of Nova Scotia with a red arrow pointing to the location. That was all the information that had been with the specimen on exhibit.

Critical information about museum specimens is kept in museum records. Historically, these records were stored in large ledger books that recorded the details of where specimens were from, who provided them to the museum and when, as well as the specific features and history of the specimen. Today, curatorial staff maintain this data in a digital database. The data about specimens is organized and connected to the specimen via a unique museum number. The number is physically attached to a specimen, and connects all the relevant information with the object.

The particular garnet I was putting away is Nova Scotia Museum number 967GM201.36 (Fig 1). The number was written on the garnet and also written on the back of the exhibit label that was on public display. When I looked up the number in the Museum database, the digital record was not very complete. The collector and date fields were empty, but the database did say the specimen was normally stored in drawer #5 of cabinet #17. I checked that drawer and found the empty tray where the specimen had been stored, and it had another small label with the specimen number and basic information about Shelburne. Based on the structure of the number, I knew that this specimen number had been assigned by a museum curator in 1967. However, a specimen can get renumbered and re-catalogued. Some of the collections in the Nova Scotia Museum date back to the 1850s or older, and they may have been assigned several different types of numbers over the years.

Fig 1 A new museum collections photograph of the garnet specimen 967GM201.36.

I looked at other specimens in the drawer, many were interesting and beautiful, but I noticed one particular rock sample labelled Aplite, that contained much smaller garnets but of similar colour, and this Aplite rock sample was also from Shelburne. I looked up the Aplite rock sample in the database and found it had been originally given the number 2819 by an earlier curator, Harry Piers, in 1905. Harry Piers kept excellent records of museum specimens, each carefully recorded in an accessions ledger. Looking at Harry Piers' ledger for

Fig 2 **The garnet specimen now associated with its aplite matrix (left), next to three pieces of aplite with smaller garnet samples (right).**

the smaller garnets, I found a series of eighteen geology samples that had been donated by Thomas V. Hill. One of these specimens, #2821, was listed as “Garnet in Aplite”.

I again examined the Aplite sample with numerous tiny garnets, and found there were three pieces of rock that clearly fit together, as if the rock sample had been dropped and broken at sometime in the past (Fig 2). There was a fourth piece, clearly similar, but I could not find any way to connect it to the other three. Then I took this fourth piece of Aplite and found that the large garnet specimen clearly fit onto one of its surfaces. Thus, the fourth aplite piece belonged with the large garnet, but it had been stored and numbered with the tiny garnet samples. As a result of this research, I was able to conclude that the large garnet was one that had been donated by Thomas V. Hill in 1905.

The Museum records include everything we know about specimens and also information on the people associated with them. However, the only information available about Thomas V. Hill was that Harry Piers had written his name as the donor in the ledger. This led me to ask: who was Thomas V. Hill?

THOMAS VARDY HILL

Today, access to digital archives has revolutionized ability to do research on people. Records can be accessed faster, more easily, and from wider sources than ever before. However, it is still important to know where to look. The Nova Scotian Institute of Science (NSIS) formed in 1862 and has had an important relationship with the Nova

Scotia Museum of Natural History ever since the museum was established in 1868. Searching the digital archives of NSIS, we find "T. Vardy Hill" gave a presentation to NSIS in December 1903, entitled "*The Creation and Development of the Inorganic Foundation of the Earth*" (Secretary NSIS 1906).

The Census for 1901 lists Thomas Vardy Hill, age 63 years, living in Halifax. However, his obituary from 1923 conveys the fullest breadth of his interesting life.

> **"Thomas Vardy Hill**
> There passed away on Saturday at 136 Edward Street, and after an illness of but one day, Thomas Vardy Hill, who was born eighty-six years ago in Sheffield, England, and came of fine old Sheffield stock. For a number of years he was connected with a number of business houses in that place, including that of Samuel Plimsoll. He was also a member of staff connected with the adjustment of claims when the Sheffield Water Works broke their dam, causing much damage to property. Mr. Hill was a close friend of Charles Green, a well known Sheffield artist, of the last generation, and he had himself a keen appreciation of real art. He was master of a facile pen, and contributed to one of the leading Sheffield papers a series of articles on "Rambling in and about Sheffield" which were admirable and the subject of much comment by a wide circle of readers, describing a racy style yet with intimate knowledge the scenery, antiquities and artistic attractions about the Peak district, and within some thirty miles of his native town, with every foot of which and every tradition connected with which he was perfectly familiar. Interspersed were artistic reflections on small matters which would escape the notice of most observers.
>
> He came to Halifax about 1886 and was for a time employed as a nurse at the Victoria General, where he practiced massage, being probably the first to practice it in Halifax. He was a keen observer and had a large fund of accurate information regarding places, people and industries of various kinds; was a great walker, and for some years made a close study of the geology of the district immediately about Halifax, and as an amateur became quite a local authority on the subject. He also took an interest in "local antiquities" and prepared a card index of all the gravestone in

> St. Paul's cemetery, and the cemetery of the Old Dutch Church, a work which took considerable time.
>
> In disposition he was most genial and kindly, unfailingly cheerful, and most active for his years – a characteristic which he retained up to the very day of his death. He is survived by his widow, for whom deep sympathy is expressed, and a number of children, one of the sons being Henry Hill, traveller for the Sherwin Williams Company. A few years ago, Mr. and Mrs. Hill celebrated most auspiciously their golden wedding anniversary on which occasion friends vied with one another in expressions of good will."
>
> (*Evening Mail*, Monday Jan 22, 1923, p. 16)

With this description of Thomas Vardy Hill's life, the eighteen geology samples that were donated to the museum now carry additional value. These specimens represent significant items that were collected and studied by this 'amateur' who had attained recognition for his knowledge of local geology. Thomas Hill was clearly an innovative individual, trained as nurse and being the first to practice Massage in Halifax. He was a polymath being interested in art, an accomplished writer, and documented records in Halifax's historic cemeteries.

In his early years, Thomas was a "member of staff connected with adjustment of claims" when the Sheffield Water Works dam broke, on March 11, 1864. This was an event of significance to the history of civil engineering. When the dam broke, over 250 people died and more than 500 houses were lost. Thomas Hill would have had exposure and dealings with many of the families and communities affected by the tragedy. The impact of these social interactions and his knowledge related to the dam's failure related to local geology, would surely have remained with him throughout his life.

BACK TO THE STONES

Garnets can be beautiful and gemstone-quality minerals. Today, we know that geologically, garnets can form in igneous and metamorphic rocks. In metamorphic rocks such as aluminum-rich sedimentary rocks (eg. shales) exposed to increased heat and pressure, mineral bonds break and reform. In modern geology, garnets are used by geologists to document the depth and temperature that geological formations have been exposed to throughout geological time.

When we look at the specimen of spessartine garnet that was on display, what is more important – being an example of a mineral with a specific shape and chemical formula, or the history of the person who found and studied it; and the contributions that person has made to Nova Scotia society? Do we value this particular garnet more, now that we know it was collected by Thomas Vardy Hill and kept in the museum collection for the past 120 years?

CONCLUSION

With a geoheritage view, we can see that this specific garnet specimen has increased value because of the history of who collected it and what it has represented through time. This specimen is not just a crystal shape and chemical formula. It is not just a geology data point that identifies ancient geological processes of metamorphism and continent building. This specimen provides a connection to a rich heritage of geological inquiry, of amateur contributions and important lessons from history of civil engineering. It is more than just a specimen of a garnet, it is an important part of our geoheritage. The specimen connects us all to knowledge of contributions that citizens like Thomas Vardy Hill have made to the culture of Nova Scotia.

REFERENCES

Cranbrook, E. (1997). 'The Scientific Value of Collections'. In *The Value and Valuation of Natural Science Collections*, 3-10. Geological Society, London, Special Publications.

Henriques, M.H. & Rui Pena dos Reis. (2015). 'Framing the Palaeontological Heritage within the Geological Heritage: An Integrative Vision'. *Geoheritage* 7: 249-59.

National Academies of Sciences, Engineering, and Medicine. (2021). 'America's Geoheritage II: Identifying, Developing, and Preserving America's Natural Legacy: Proceedings of a Workshop'.

Secretary NSIS. (1906). 'Second Ordinary Meeting, 21st of December, 1903.' *Proceedings and Transactions of the Nova Scotian Institute of Science* 11(2): xxvii.

Trinchillo, D. (2015). 'Piecing Together the Puzzle of a Heliodor Crystal's Past'. *The Mineralogical Record* 46(2): 221-27, 232-33.

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 13-21

MAPPING AND CIVIL SERVICE: SAMUEL GASKIN'S CONTRIBUTIONS TO NOVA SCOTIA GEOLOGY, 1950-1977

TIM J. FEDAK[1*] AND DAVID E. BROWN[2]

[1]*Curator of Geology, Nova Scotia Museum*
Halifax, NS

[2]*Senior Advisor Geology (Retired), CNSOER (ex-CNSOPB)*

INTRODUCTION

Tracing the historical contributions of African Nova Scotians to geoscience provides an opportunity to reflect on their personal challenges, determination, and achievements. Samuel Gaskin worked in the mapping unit of the Nova Scotia Department of Mines (now Department of Natural Resources) from 1950 to 1977 and was (perhaps) the first African Nova Scotian to work in the provincial geoscience department. Due to the impact of the maps he contributed to, Samuel's knowledge and technical expertise in mapping provided a foundational contribution that positively impacted Nova Scotians through advances in geoscience but also resulted in the production of maps used for tourism and natural sciences.

EARLY YEARS

Samuel's father and mother immigrated from Barbados to Nova Scotia in 1903/1904. This was a period of increased immigration from Barbados to Nova Scotia, with many immigrants settling in Cape Breton after gaining work at the Dominion Iron and Steel Company (Bonner 2017). However, Abraham Gaskin (1881-1951) worked as a carpenter in Halifax in 1907,[3] and later owned a shop on Brunswick Street with his second wife Lillian in the mid-1920s when Samuel (b. 1926) and his brother Kenneth Gaskin (1922-1967) were born.

The Gaskin name in Halifax during the early 1920's was also associated with "Gaskin's Menthol Liniment" (Fig 1), but this was

* Author to whom correspondence should be addressed: tim.fedak@novascotia.ca

3 McAlpine's City Directory 1907-08 p. 145. Gasken (sic) Abraham, carpenter, 203 Grafton, h 205 do. archives.novascotia.ca/directory/page/?Place=&Letter=&Page=145.

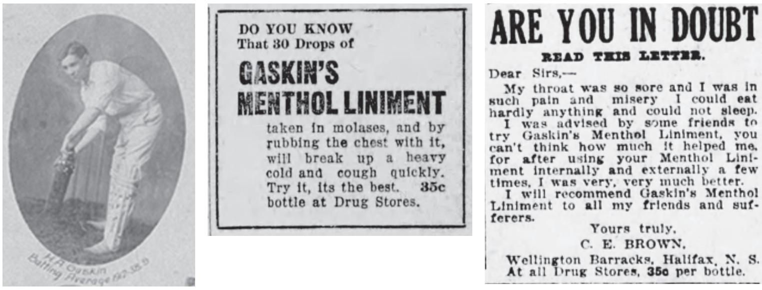


Fig 1 Hugh Gaskin, a member of the Sydney Cricket team during the 1912-13 season, (Beaton Institute/Cape Breton University) and Gaskin's Menthol Liniment ads in The Evening Mail (Halifax) on Dec 30, 1920 (centre) and Feb 17, 1921 (right).

produced by Philip Gaskin and his brother Hugh, pharmacists who were also prominent cricket players in Nova Scotia during the time (Reid 2020). Shortly after Philip left Nova Scotia in August of 1923, an advertisement for a competing brand, Vicks VapoRub (Fig 2), featured a testimonial from "*Mrs. A. Gaskin of 2 Brunswick St. Halifax, N.S. says: I find great relief in the use of Vicks. I inhale the vapors for hoarseness and other cold troubles and it gives excellent results. Vicks is the most valuable household remedy I have ever used*." Dec. 23, 1923. This testimonial from Lillian Gaskin, Samuel's mother, was likely incorporated in the Vicks VapoRub print ads due to the similarity in her name with the competing brand.

Abraham had a previous marriage and a family with Miriam (Jones). Abraham and Miriam were married in 1906 and their first son Marcus was born the year later. There were other children although several died at a young age. The family would have also experienced the Halifax Explosion of 1917. Miriam died in January of 1919, perhaps, given the date from the Spanish Flu. The 1921 Census shows Abraham and Marcus were living at 2 Brunswick Street, the same year that Abraham married Lillian (Rawlins). Marcus graduated from Grade 10 in 1928 and participated in an exhibition of carpentry work that he did while at St. Patrick's School.[4]

Abraham and Lilian had a shop at 746 Brunswick Street in 1925. In March of that year, two young boys who burgled their shop were

[4] June 16, 1927 *The Evening Mail* (Halifax), pg. 20, "Display of Work By Boys Won Praise". August 9, 1928, *The Evening Mail* (Halifax), p. 18, "Showing of Student's is Excellent".

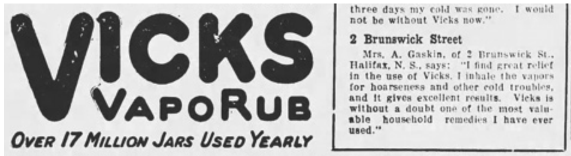


Fig 2 Vicks VapoRub ad in *The Evening* Mail Dec. 23, 1923 - featuring testimonial from Mrs. A. (Abraham) Gaskin, who was Lillian Gaskin, mother of Kenneth and Samuel Gaskin.

charged and convicted. A newspaper article describes stolen goods from the shop that included "women's wearing apparel, soap, tobacco, stationary, handkerchiefs, etc."[5] A shop in Halifax run by a Black family was not likely common in 1925, and the Gaskin children's early years were likely surrounded by the activities associated with the business.

In the 1931 Census the Gaskin family was located at 2 Brunswick Street. Abraham is listed as owning the dwelling valued at $3000, occupation of "Peddler notions" and the religion of the family is listed as Plymouth Brethren. The family members names and ages include:

Abraham	54	Kenneth	8
Lilian	44	Samuel	5
Marcus	24	Phyllis Grena	2

Samuel's older brother Kenneth attended Bloomfield High School in 1939 (Fig 3). Later, when this school merged with another, Kenneth became a member of the first graduating class of the new Queen Elizabeth High School in 1943 (Fig 4). Samuel likely finished high school several years after his older brother Kenneth, perhaps in graduating in 1945. Although some of Kenneth's records known, those of Samuel remain to be located.

The Gaskin children's education experience is significant for the challenges that African Nova Scotian's faced at this time. Their success in public school seems likely to have contributed to public service becoming a prominent aspect of Gaskin family life. In later years, Kenneth worked as a secretary and clerk, and was an active member (Recording Secretary, Army) of the Nova Scotia Civil Service Association (now NSGEU) when he died in 1967. Samuel's public service would be with the Canadian military.

5 March 26, 1925, *The Evening Mail* (Halifax), p. 9 "Industrial Home Boys Arrested". April 9, 1925, *The Evening Mail* (Halifax) p. 18. "Youths Sentenced to City Prison".

Fig 3 Bloomfield School 1939-40, Kenneth Gaskin, back row fourth from right.

Fig 4 First Graduating Class of the new Queen Elizabeth High School, 1943. Halifax Regional Municipality Archives. Kenneth Gaskin, backrow second from left.

SAMUEL IN THE CORPS

Samuel was recruited into the Canadian Intelligence Corps (CIC) of the No. 3 Intelligence Company, Halifax (Skaarup, 2024), and was among the earliest recruits, joining in 1951 and serving until at least 1968 (Fig 5). Early in his tenure at the CIC, Samuel established expertise in aerial photography and mapping and was a member of a team that won three trophies for intelligence competitions held at Camp Borden (Fig 6).

Fig 5 **Members of the No. 3 (C) Intelligence Company (Halifax) at Camp Borden, Ontario, summer of 1966. Kneeling (L-R): WO1 Samuel (Sammy) Gaskin, Sgt. Alfred E. (Al) Brown, Maj. William (Bill) Landry Sgt. Edward (Ed) D. Kirby, Lt. Sherman R. Veinotte, Lt. L.A. (Al) McAulay. Standing (L-R): Ken Lord, Claude Laroux, James (Jim) McNutt, David (Dave) Bryson, Neil Walsh, Ken Smith.**

Fig 6 **WO1 Samuel Gaskin, Lt. Sherman Veinotte, and Sgt. Alfred Brown, with the first awarding of the Canadian Military Intelligence Association trophy for aerial photography interpretation in 1964. The award was an original wooden Thunderbird carving by well-known West Coast Kwakwaka'wakw artist Henry Hunt (1923-1985).**

Fig 7 **Detail of Plate XV from the report "Preparation of Maps and Plans from Aerial Photographs", 1950. Eva Duncan in front and Samuel Gaskin seated in the back.**

SAMUEL GASKIN JOINS DEPT OF MINES

In 1950, Samuel Gaskin was hired along with Miss Eva Duncan as "draftsman for map compilation" in the Department of Mines (Nova Scotia 1951). That same year the Department published a report titled "Preparation of Maps and Plans from Aerial Photographs" (Nova Scotia 1950). The report includes several photographs documenting the team's work and equipment, including one photograph that shows Samuel Gaskin and Eva Duncan at the mapping desks (Fig 7). The Department had initiated a new project to produce an updated map of Nova Scotia for registration of mineral rights. The Deputy Minister, J. P. Messervey, published a report of progress on "Maps of Nova Scotia" (Nova Scotia 1953, p. 73-79).

The knowledge that Samuel brought from the Intelligence Corps would likely have been of great value in these projects. The earliest map in which Samuel was a cited contributor is the Minerals of Nova Scotia Map of 1957 (Fig 8).

A departmental photo from the 1960s shows Samuel with colleagues in the mapping group (Fig 9), including Don Bernasconi, Director of the Cartographic Section. Departmental Reports do not seem to mention his work or contributions directly, although Samuel's

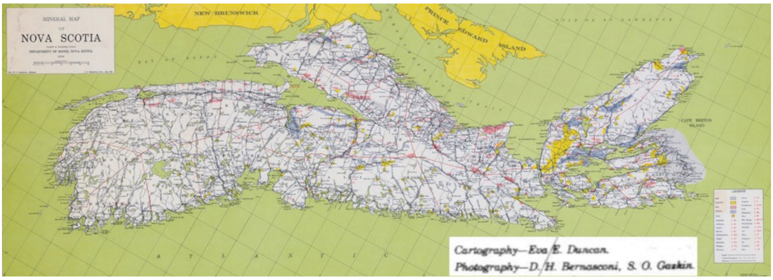


Fig 8 **Mineral Map of Nova Scotia (Duncan 1956).**

Fig 9 **Samuel Gaskin with colleagues in the mapping section, including (L-R) Eva Duncan, J. Campbell, and Don Bernasconi.**

salary is listed in the Public Accounts documents for "Drafting – Making Maps" as $4500 in 1966 and $10,390 in 1977.

According to memories of retired members who worked with him (Fig 10), Samuel left the department soon after 1977, and died shortly thereafter, the exact date and cause of his death remains unknown. It seems Samuel and his siblings did not have any children so if he had kept any photographs or journals they are now unknown.

CONCLUSION

The research behind this report started after seeing the photograph of S. Gaskin among the Departmental Portraits of 1977. Having uncovered this important story, we wanted to share information about

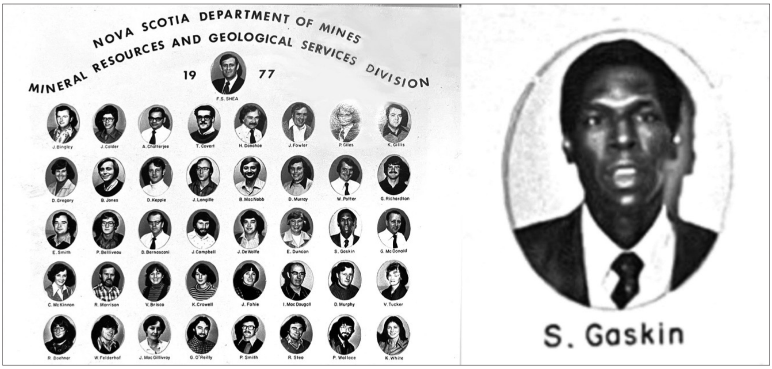


Fig 10 Members of the Nova Scotia Department of Mines, Mineral Resources and Geological Services Division, 1977.

the man behind the portrait. With over 27 years of service to Nova Scotia geoscience, Samuel Gaskin had a tremendous impact on Nova Scotians through his service to map making in the Department of Mines. His expertise of aerial photography and mapping were used to produce maps of Nova Scotia used by industry and citizens, and for tourism. These included maps used to document the geology of Nova Scotia in the 1960-70s, a post-war era of rapid expansion of geoscience knowledge.

The education success and later public service of Samuel Gaskin and his brother Kenneth was influenced by the social position obtained by their parents. The neighbourhoods of #2 Brunswick Street (1921) and #750 Brunswick Street (1925) were two locations the Gaskin family lived and later had a store. Uncovering the history of Brunswick Street buildings and businesses in 1920-1930s is challenging due to several changes to civic numbers in 1950s. However, additional information about the Gaskin's early life might be uncovered in future research related to these neighbourhoods.

As Bajan immigrants to Nova Scotia in the early 1900s, the Gaskin family faced many obstacles yet made significant contributions to the province through the public service. Samuel Gaskin faced limited opportunities in education but overcame adversity through applying knowledge gained in the military service to improving maps used across Nova Scotia. Samuel's contributions impacted everyone who lived and visited Nova Scotia by making maps of the province more accurate and useful.

Note: In February 2025, the Atlantic Geoscience Society financially supported the printing of a commemorative poster based on this article. The posters were displayed at Acadia University to celebrate African Heritage Month and then made available to the Black Cultural Centre of Nova Scotia for educational programs.

REFERENCES

Bonner, C. (2017). *Industrial Island - African-Caribbean Migration to Cape Breton Canada, 1900-1930* (Masters Thesis). Dalhousie University, Halifax, NS.

Duncan, E. (1956). *Mineral Map of Nova Scotia*.

Nova Scotia. (1950). *The Production of Maps and Plans from Aerial Photographs.* Department of Mines, Halifax, NS.

Nova Scotia. (1951). *Annual Report on Mines, 1950.* Department of Mines, Halifax, NS.

Nova Scotia. (1953). *Annual Report on Mines, 1952.* Department of Mines, Halifax, NS.

Reid, J.G. (2020). *The Life and Times of the Nova Scotia Cricket League, 1906–1914. Acadiensis* 49: 69-122.

Skaarup, H.A. (2024). *Canadian Military Intelligence History: 1946 to 1968* [WWW Document]. Military History Books. www.silverhawkauthor.com/post/canadian-military-intelligence-history-1946-to-1968 (Accessed 8.10.25)

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 23-35

CHEMISTRY AND COMPUTERS – A PERSONAL RECOLLECTION

JOHN C.O'C. YOUNG*

Department of Chemistry, Saint Mary's University
Halifax, NS B3H 3C3

PREAMBLE

Employment as a senior chemical research engineer with a US oil company led me to a two year loan assignment to its refinery in Dartmouth, Nova Scotia, in 1967-69. During this period, I came to like living in Nova Scotia, so in January, 1970, I resigned and became a computerization advisor to then President of Saint Mary's University (SMU), Dr. Henry Labelle, S.J. Subsequently in 1972, I was offered the position at SMU as an associate professor of physical chemistry with a particular research interest in computerization of analytical chemistry procedures.

EARLY COMPUTERIZATION (1970-72)

My first task in 1970 was to upgrade the University's computerized registration and timetable system. At that time, computerization at SMU consisted of a single small mainframe unit, an IBM Model 1130 (Fig 1). It sat in air conditioned splendor in its own room and probably had no more computing capacity than a modern day laptop. The IBM 1130 Computing System was introduced in 1965 aimed at price sensitive, educational and engineering technical markets.

Data input to this computer was by key punching Hollerith cards that were then optically scanned by a reading machine (Fig 2).

I vividly remember the twin evils of punched Hollerith card data input and batch processing. After hours and hours sitting at a card punching machine, I would submit my humble offering of a box or two full of these punched cards to the tender mercies of the attendants of the computer who looked after "batch processing." I would return the next day, often to find one of my boxes sitting on a shelf with one card turned on its side pointing upwards from its fellows indicating

* Author to whom correspondence should be addressed: john.young@smu.ca

Fig 1 The IBM 1130 computer and system layout.

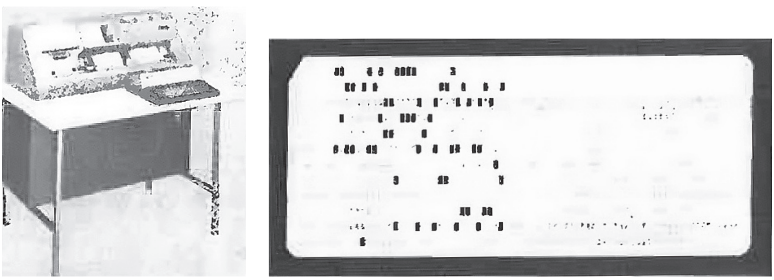


Fig 2 Card punching machine and punched card.

that, after key punching numerous entries in several hundred cards correctly, I had made an error of entering a colon instead of a semi-colon in that one card. This would cause the computer to imperiously reject my offering. I then had to re-punch this card, resubmit my card boxes and return once again the following day to collect the results.

With luck, all would be well with the handed in cards but after a card deck had been submitted and read a few times, the card reader had a tendency to chew up cards. Another problem was that the card punch would get slightly out of line and not place slots in exactly the right places for the optical card reader to find them.

The eventual replacement of this technology by direct entry of data from a keyboard into computer memory came as a merciful relief.

COMPUTERIZED INFORMATION ACCESS (1972-77)

I introduced undergraduate courses at SMU in “Environmental Chemistry” (CHE 371.0) in 1972 and “Marine Chemistry” (CHE 372.0) in 1974. As part of the laboratory components of these courses, I required my students to make supporting, mainframe-based computerized, background studies.

In 1977, we upgraded our exploration of information data bases and their search engines when, in collaboration with a Research and Reference Librarian, Douglas Vaisey, we began computerized information searching on the mainframe computer using the WATDOC data base of the of Department of Fisheries and Environment, Canada. Somewhat later, we switched to the more sophisticated DIALOG and CAN/OLE systems.

THE APPLE II MICROCOMPUTER (1976-1980)

Steve Wozniak designed the original Apple computer and formed Apple Computer Inc. with Steve Jobs in 1976. The Apple II microcomputer was introduced by the two Steves in 1977 and was followed in 1979 by the amazingly capable and very successful upgraded Apple II Plus version (Fig 3).

This microcomputer eventually sold over five million units mostly for educational purposes. Shown in Fig 4, it featured data input from and data storage on floppy disks and a pair of “game paddles” to manipulate screen images, precursors of the computer mouse. Student members of my group and I played many happy primitive computer games of “Pong” and “Little Brick Out” on this setup. We also connected sensors of temperature, pressure and pH to the computer’s game port to monitor the progress of analytical experiments.

Fig 3 **The Apple II Plus microcomputer.**

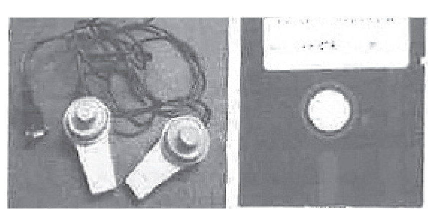


Fig 4 **A pair of game paddles and a floppy disk.**

DEVELOPMENTS (1981-1990)

In 1981, physics teachers, David and Christine Vernier, started Vernier Software & Technology, a US company to produce and market software for analyzing and presenting experimental data from the Apple II Plus microcomputer, an event of major later importance for us at SMU.

At around the same time, John Moore founded “Project Seraphim” to collect, evaluate and distribute chemistry-related computer software as part of a U.S. National Science Foundation funded initiative to bring active learning methods to the chemistry curriculum. This initiative produced a substantial library of chemistry and physics experiments that was made available on 5 1/4 inch floppy disks for Apple Il Plus and PC microcomputers through the U.S. Journal of Chemical Education’s “JCE Software” program.

In the late 80s, we took our first faltering steps into real-time computerized data logging. Using a combination of an Apple II Plus microcomputer, Vernier’s Voltage Input (A/D) Unit, and a thermistor temperature probe run by Vernier’s Unit Plotter software program, we monitored the temperature of my research laboratory. Based on these early experiences, I introduced courses on “Scientific Uses of Microcomputers” in 1989 and 1990 (CSC 387.1 and 388.2).

THE ARRIVAL OF THE MACINTOSH (1984-1990)

Somewhat earlier, back at Apple Computer Inc. in Cupertino, the two Steves were busy introducing the first of their line of Macintosh computers in 1984. This model had a measly 128 K of RAM and a fragile power supply that delighted in frying itself. Apple rapidly replaced this original version with a 512 K Model and then got it right in 1986 when the Company introduced the Apple Mac Plus with a luxurious 1 meg of RAM and a decent fan to cool its power supply.

The Mac Plus (Fig 5) was the first commercially successful microcomputer to feature a mouse accessible, graphical user interface (GUI) (Fig 6).

I and fellow SMU faculty members, Vic Catano and David Swingler, purchased Mac Plus microcomputers from the first batch of forty of these machines imported into Canada, whereupon I abandoned our venerable Apple II Plus microcomputers. My original Mac was eventually stolen!

Fig 5 The Apple Mac Plus microcomputer.

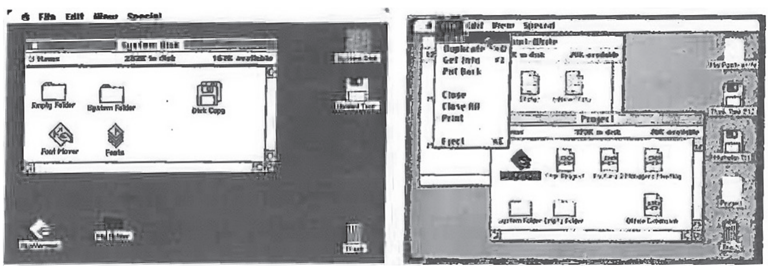


Fig 6 The Mac Plus desktop layout.

In the early 1990s, Vernier introduced its Serial Box Interface, the simple but very capable, two channel 12-bit A/D converter (Fig 7) in which the analog signals from sensors of physical properties such as temperature and pressure were digitized and delivered to Vernier's Data Logger program for analysis. With all the essential features of a modern data logging, analysis and presentation system, this was the combination we had been waiting for.

The outcome of a Boyle's Law validation experiment obtained with this data logging and analysis system is shown in Fig 8.

In July 1996, I retired from the university, the last year of mandatory retirement. However as a professor emeritus, the university provided me with modest office and laboratory facilities and, with a generous annual operating grant from the Federal Department of Energy, Mines and Resources, my research group of undergraduate students continued its studies of computerized analytical chemistry procedures.

Fig 7 **The Serial Box Interface.**

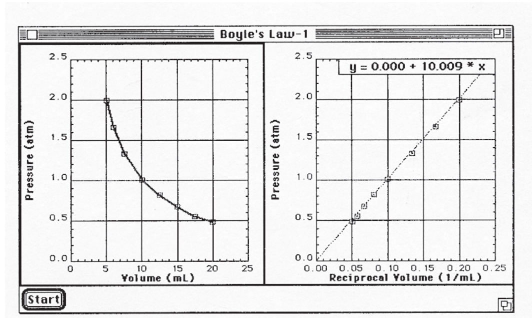


Fig 8 Boyle's Law relationship investigation.

In the Spring of 1996, I became the chairperson of the Nova Scotia – Gambia Association, a Halifax based NGO that carried out health education programs for high school students in The Gambia. It also provided on-site administration of a university course extension program there for SMU, that small African country not having its own university at the time. Under this extension program, faculty members from Maritime universities were recruited by SMU to teach undergraduate program courses in a compressed, five full day a week, six to eight week format, the students only taking one course at a time.

In November 1996, the notice (Fig 9) appeared on information boards around the Chemistry Department announcing my talk on "Computerization of the Introduction Chemistry Laboratory."

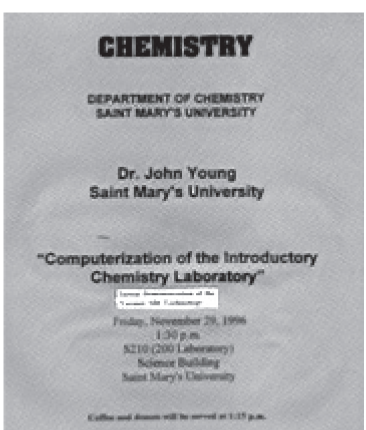


Fig 9 A chemistry meeting notice.

Despite free coffee and cookies, my talk failed to convince my colleagues to introduce the Data Logger and SBI computerized data collection and analysis system as part of the Department's first year general chemistry course. However, having anticpated this outcome, I had planned ahead.

OFF TO THE GAMBIA

Earlier in the summer of 1996, I began my plan to deliver our regular first year chemistry course in The Gambia, coupled with my computerized version of the associated laboratory course beginning in January, 1997. I purchased glassware and chemicals with a contribution from the Canadian High Commission in Dakar, Senegal, scrounged a dozen used Macs "from somewhere", and shipped these laboratory requirements off to Vernier in the United States. The company there combined these items with its contribution of Data Logger program disks and sets of pH electrodes, conductivity probes, pressure sensors, temperature probes and colorimeters sensors, and shipped everything off in a container to the port city of Banjul, the capital of The Gambia.

After a short flight from Halifax to Newfoundland, I was one of a few passengers as we took off again from St. John's for Heathrow at close to midnight on December 31st 1996. Air Canada gave me a celebratory New Year offering of warm champagne in a paper cup!

I was on my way to the first of three very enjoyable visits to The Gambia in 1997 and 1999 to teach my computerized chemistry course, and in 2000 as a member of team sent there to advise its government on how to establish a university which it did subsequently.

Somewhat to my surprise, upon my arrival in The Gambia, I found that my various boxes of supplies and equipment had all arrived, were intact, had been cleared through local Customs, and were waiting for me at the Gambia Technical Training Institute (GTTI) where I was to deliver the course with the help of my able Gambian assistant, Momodou Jain.

Over my first weekend in The Gambia, Momodou and I set up a dozen laboratory stations with glassware, solutions and of course the Macintosh microcomputers with their Serial Box Interfaces and Data Logger operating program (Fig 10).

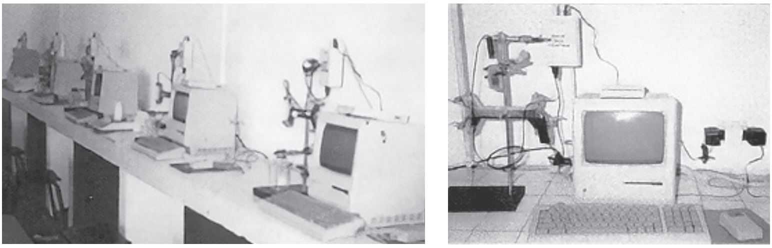


Fig 10 Computerized chemistry at the Gambia Technical Training Institute (GTTI).

I began the lecture component of the course the following Monday morning. Momodou and I delivered an introduction to the laboratory component in the afternoon.

The contents of this laboratory program were as follows:

The Gambia Laboratory Program, January – March 1997

EXP01: Boyle's Law: Pressure-Volume Relationship in Gases
Pressure Sensor/Event Mode (*Calculation of R*)

EXP02: Charles' Law: Pressure-Temperature Relationship
P and T Sensors/Event Mode (*Absolute zero of temperature*)

EXP03: Vapor Pressure of Liquids: Clapeyron-Clausius
P and T Sensors/Time Mode (*Two liquids,* D*Hvap*)

EXP04: MW Determination by Freezing Point Depression
Temperature Sensor/Time Mode (*Kf determination*)

EXP05: Heat of Reaction, Hess's Law of Heat Summation
Temperature Sensor/Time Mode (*Plastic cup calorimeter*)

EXP06: Heat of Combustion of Magnesium
Temperature Sensor/ Time Mode (*Three step reaction*)

EXP07 : Chemical Equilibrium Constant Determination
Colorimeter Sensor/Event Mode (*Beer's Law calibration*)

EXP08: Acid and Base Titration
pH Sensor/Event Mode (*End point from second derivative*)
EXP09: Diprotic Acid Titration
pH Sensor/Event Mode (*Buffering, pK determination*)

EXP10: Solubility Product by Conductometric Titration
Conductivity Sensor/Event Mode .(*BaCl2, H2SO4*)

EXP11: Weak Acid Dissociation Constant Determination
pH Electrode/Event Mode (*Acetic acid)*

EXP12: Crystal Violet Decolorization Kinetics
Colorimeter Sensor/Time Mode (*Orders of CV+ and OH-*)

The first year chemistry course is one of the most difficult that students face and Momodou and I were determined that no student would fail our version in The Gambia. We worked the students hard during the week, injecting enough humour to keep the stress level low, and Momodou's boot camp review sessions on Saturday and Sunday mornings ensured that not one of our twenty students finished with a grade level lower than C and there were a number of As. Some years later, Momodou obtained a doctoral degree in chemistry from the Norwegian University of Bergen, then became the first Registrar of the fledgling University of The Gambia.

Our chemistry lecture and laboratory program garnered a considerable amount of favorable local publicity in The Gambia and a long and interesting visit to the lab by Dr. Federico Mayor. Dr. Mayor, a chemist and then the Director General of the United Nations Educational Scientific and Cultural Organization (UNESCO), was in Banjul to determine whether the GTTI should receive financial support from UNESCO. I made sure that news of these events leaked back to Halifax.

RETURNING FROM THE GAMBIA

When I returned from The Gambia in April, 1997, the Chemistry Department Chairperson, Michael Zaworotko, asked me to set up the "Gambia Laboratory System" and implement it in September, 1997, as the laboratory component of the Fall offering of the Department's first year general chemistry course.

In the summer of 1997, student Andrew Corbett and I set up twenty four computerized laboratory stations in the first year teaching laboratory. As shown in Fig 11, so as not to occupy laboratory surface space, we constructed a dozen stands on which we installed the computers in pairs above the laboratory sinks. Each pair of Mac Plus computers shared a printer and each computer system was fitted with the Data Logger program, a serial box interface, a set of sensors, a mouse and a stirrer-heater unit. The set of sensors included a thermistor, a pressure

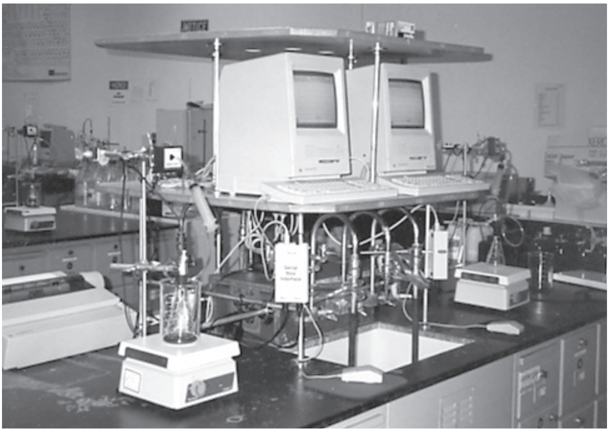


Fig 11 A pair of 1997 laboratory workstations.

sensor, a pH electrode, and even a personal spectrophotometer for each pair of students.

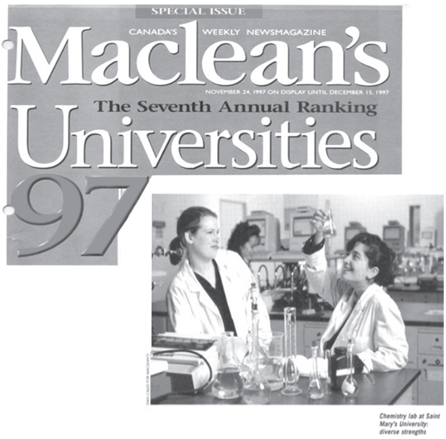
We then tested procedures for twelve experiments, wrote up a laboratory manual, and made everything ready for a September 1997 beginning. Also of note, Andrew graduated from SMU in 1997, obtained his Ph.D. degree from McGill University, and at last report was the Director of Production Chemistry for the Toronto Research Chemicals company.

Our delivery of this first year chemistry laboratory program in Fall, 1997, attracted some national attention shown in Fig 12.

SUBSEQUENT DEVELOPMENTS

In September, 2001, we switched from Macs to PCs because, aside from our laboratory and the Psychology Department, SMU was a PC shop. At that time, Vernier only offered a PC version of its new Logger Pro software to replace its venerable Data Logger program. To make this change, I scouted second-hand computer stores in Nova Scotia and New Brunswick and came up with an assortment of very used, Model 486 desktop microcomputers which we set up to run the SBI / Logger Pro system under the Windows DOS 3.1 operating system.

The first year chemistry laboratory in 2001 is shown in Fig 13 and the original desktop display of the Logger Pro program is shown in Fig 14.



Two parts chemistry, three parts ingenuity

by Peggy Berkowitz

Dr John Young works with a student in Saint Mary's chemistry laboratory.

A retired professor's insp...ion from teaching in The Gambia has gone to show, once again, that necessity ...ally is the mother of invention.

John Young, professor emeritus of ...hemistry at Saint Mary's University in ...alifax, went to The Gambia two years ...go to teach a first-year chemistry course, ...nowing that the small West African coun...y couldn't afford to buy the standard ...ieces of equipement that are found in every ...ndergraduate chemistry lab. Dr Young's ...olution to the problem was so elegant ...at Saint Mary's chemistry faculty voted ...o convert their entire first-year chemistry ...b to a model first tested in the Gambian ...apital of Banjul.

Typically, an undergraduate chemistry ...b program consists of a set of old and ...ell-tried experiments involving the use ...f a limited range of instruments (pH meters, ...pectrophotometers, conductivity bridges, ...nd the like). These instruments are generally ...uite expensive, take up scarce lab bench ...

Dr Young replaced these types of instruments with sets of compatible sensors which measure acidity/alkalinity, light absorbance, electrical conductance, temperature, pressure and various other parameters. The analog (or voltage) signals from these sensors are fed to a single interface at each work station, which digitizes this signal information and transmits it to the data processing computer. The system permits "mixing and matching" of different sensors for different experiments, as well as simple procedures for analysing relationships between the outputs of the sensors used.

The sensors, interfaces and much of the software come from Vernier Software, a U.S. company. Dr Young scrounged yard sales, among other places, for obsolescent Macintosh computers and PCs. Voilà! a flexible, low-cost system which allows students to process, analyse, graph and report the results of a wide variety of experiments in real time.

"It's the best innovation I've seen in a long time for first-year chemistry labs," says Robert Singer, a young chemistry professor at Saint Mary's, ...

"In first-year chemistry labs, you have these traditional tried, tested and true experiments that everyone's doing across the country. They're about 20 years old and are getting pretty boring. So when Dr Young did this, I thought, Yeah! we've made it to the '90s!"

Cheaper system

In The Gambia, the main spur was price. When they weren't donated, old Macs cost from $100 to $150 each. Each Vernier sensor costs about $100 and the analog/digital interface, about $150. Some sensors aren't very sophisticated — the light absorption sensor measures only two or three wavelengths — but they're adequate for a first-year lab. For his course in The Gambia, Dr Young shipped 12 work stations worth $1,000 each plus $8,000 of chemical supplies and equipement. (The total cost of $20,000 was covered by a grant from the Canadian Embassy ...

8 UNIVERSITY AFFAIRS MARCH 1998

Fig 12 Some national attention of SMU's chemistry laboratory program.

Fig 13 The first year chemistry laboratory in 2001.

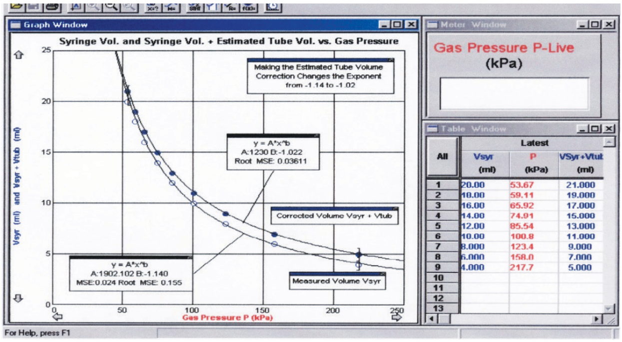


Fig 14 The original Logger Pro desktop display.

Fig 15 The renovated first year chemistry laboratory at SMU.

In 2003, we switched from Vernier's venerable Serial Box Interfaces to its more capable LabPro Interface, each of which provided four analog and two digital sensor ports in place of the two analog sensor ports of the SBI.

At about the same time, the Dean of Science, David Richardson, gave me some cash and once again I went shopping in second-hand computer stores. This time, I landed in Moncton where I picked up forty Dell Pentium III computers at $75 apiece. They had been disposed of by a government department that was upgrading.

The outcome of a major re-construction of the first year general chemistry laboratory that took place in 2007-08 is shown in Fig 15.

While many program changes have been introduced subsequently, the backbone of our chemistry laboratory is still the PC microcomputers, the LabPro interfaces, the physical property sensor sets, and the remarkable Logger Pro data logging, analysis and presentation program that puts Excel to shame. A few examples of views of activities in the lab are shown in Fig 16 and complete this overview of the evolution of chemistry and computers at SMU.

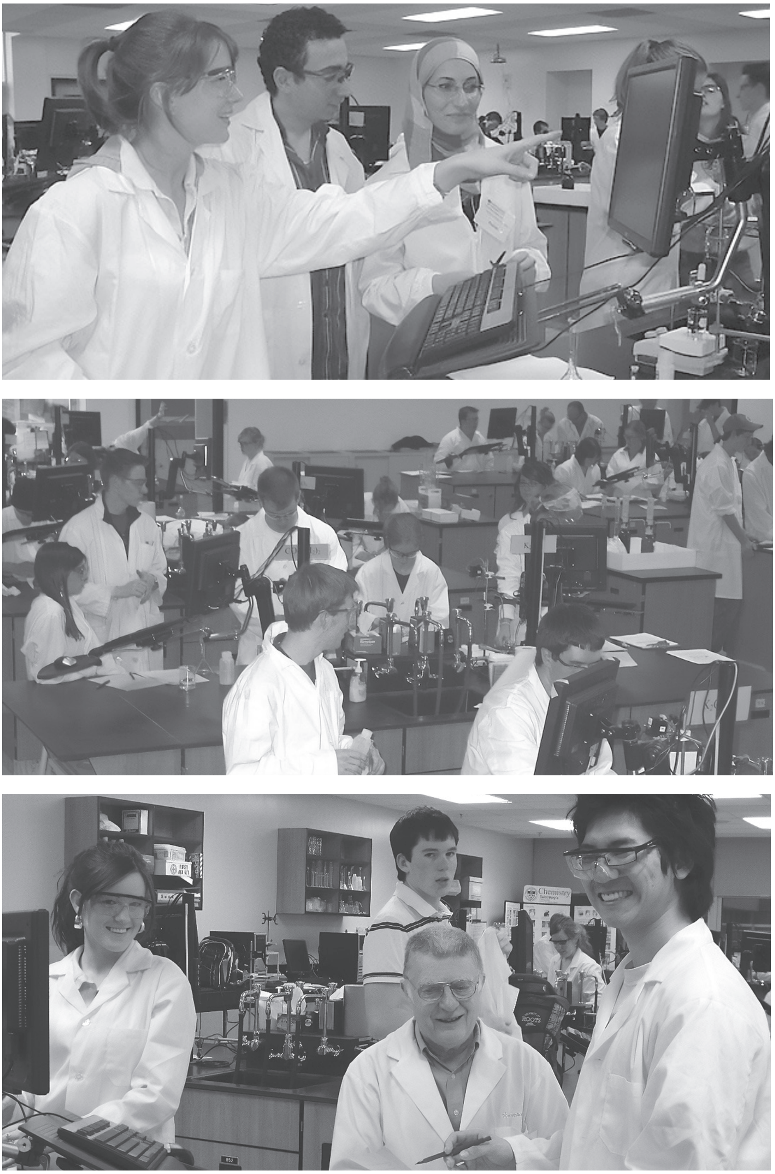


Fig 16 At work in the chemistry laboratory at SMU. The author is shown in the third photo, along with happy hard working students.

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 37-88

SEARCHING FOR BOTANICAL KNOWLEDGE: THE PLANT HUNTERS OF THE NOVA SCOTIAN INSTITUTE OF (NATURAL) SCIENCE, 1862-1902

RICHARD H. FIELD*

Former Adjunct Professor, Atlantic Canada Studies Program, Saint Mary's University, Halifax, NS

ABSTRACT[1]

Accepting Suzanne Zeller's notion that maddening historical and scientific enticements are lurking in the 150 years [now 162 years] of the *Proceedings and Transactions* of the Nova Scotian Institute of Science, this paper examines the botanical contributions of eight prominent Institute plant hunters who published papers on their findings between 1863 (volume one) and 1902 (volume ten). Some members of this varied group of clergy, naturalists, botanists, lawyers and physicians, whose interest in nature often transcended their professional and private lives, studied plants and assembled herbaria as leisurely indulgences; others viewed the natural world through a theological lens, but many considered the accumulation of botanical knowledge an essential science. Rather than a single narrative thread, this paper intertwines a series of brief biographies of each plant hunter, followed by summaries of published reports about important botanical questions that occupied the Institute during its formative years and contextually relevant commentaries to tell the wider story of the evolving and often controversial relationship between the Institute and the role of natural history to both science and society during its first four decades.

Keywords: botany, plant hunters, NSIS, herbarium, phenology, natural history, natural science

* Author to whom correspondence should be addressed: A00002239@outlook.com

1 The reader should keep in mind that the various operational practices that make up the search for botanical knowledge were intrinsically embedded in a series of global networks that enslaved humans, exploited Indigenous knowledge and resources, and disenfranchised people from the geography of their birth. Therefore, the author acknowledges the existence of harmful content in some of the sources referenced in this manuscript. Equally important is the awareness of ongoing, often contentious efforts to decolonize the history of plant collecting from its imperial past by natural history museums and collectors. These activities may include explaining how the plant was acquired, commenting on or removing derogatory notes on plant labels, identifying the practitioners who assisted plant collectors in finding a plant and informing plant hunters about its uses and properties, and giving greater recognition to the importance of plants in the Indigenous and non-Indigenous societies where the specimens were acquired.

INTRODUCTION: PLANT HUNTING AS SCIENCE[2]

"I Staid [sic] at 13000 ft. very much on purpose to collect the seeds of the rhododendrons and with cold fingers, it is not very easy…. Botanizing during March is difficult. Sometimes the jungle is so dense that you have enough to do to keep hat and spectacles in company, or it is precipitous…certainly one often progresses spread-eagle fashion against the cliff, for some distance, and crosses narrow planks over profound Abysses, with no handhold whatever."

John Hooker [1817-1911] to William Hooker [1785-1865] from Darjeeling, 1849. Kew Royal Botanic Gardens, 2023. Joseph Hooker Correspondence Project. JDH/1/10, ff. 146-147.

Several years ago, I purchased an old volume of the complete plays of Shakespeare at a secondhand bookstore, dedicated on the title page in fine italic script to a woman named Virginia. As I thumbed through the pages of the Bard's comedies and dramas, many with hand-printed annotations along their margins, a dried, red tulip slipped from its silent resting place and fell to the bookstore floor. Unwittingly, I conjured the moment Virginia pressed the flower between the pages of the book, opening a portal into her past in another time and another place, and although I could not extract the stored memories that the flower contained, I was able to access them from an outsider's point of view. Whether the pressed tulip symbolized pleasure, love, loss or unbridled desire was now up to my imagination.

As much as I enjoyed finding an exquisite one-volume edition of Shakespeare's complete plays and surmising that Virginia pressed the tulip, symbolic of eternal love and passion, between its pages to memorialize a loved one, the one thing that I knew absolutely nothing about was the flower's origin, where it was picked and by whom and what species of tulip it was. As Ann Shteir observed, the publication of the hierarchal system of plant identification by Carl Linnaeus in 1735 delineated the boundary between botany as a serious science

[2] Before the terms science and scientist were invented at Cambridge in 1833 by William Whewell [1794-1866] as parallels to the terms art and artist, people who studied nature were known as naturalists and natural philosophers. The shift from naturalist to scientist marked a turning point in the way the natural world was studied, which the German sociologist Max Weber [1864-1920] described as "the disenchanting of the world" (Bergland 2024).

carried out by enlightened gentlemen from the genteel forms of plant activities "associated with girls and women in the polite culture of eighteenth and nineteenth-century Britain and its colonial and imperial domains" (Shteir 2022).

The point here is that where a plant comes from, whether it be found in an urban or rural setting, deep within a tropical rainforest or pressed between the pages of an old book, has nothing to do with its value as a viable botanical specimen unless accompanied by the date and place where it was collected, its specific habitat, the composition of the soil, the plant's colour, smell, height and growth habits. Traditionally, this documentation is recorded in a notebook (Field 2023) or directly onto the sheet of paper on which the plant is pressed and mounted to create a "dry garden" or *hortus siccus*.[3] As Walter Lack wrote, "The triad of specimens, printed description and printed illustration, plus supplementary annotations such as the specific location where the specimen was found, is to this day regarded as the ideal standard because it provides a comprehensive notation of the plant in question" (Lack 2009). Consequently, plant hunting only becomes a science when this information accompanies each species collected.

As Hooker recounted, searching for and documenting undiscovered plants or collecting seeds and type specimens of known species in hazardous terrains could be a challenging and sometimes dangerous enterprise. Michel Sarrazin [1659-1734], exploring the meadows, bogs and forests of the St. Lawrence River Valley in the summer of 1707, faced humid weather, ravenous mosquitoes and black flies, capricious Indigenous informants and good fortune at not being abandoned by his Voyageur guides in his efforts to collect plants (Young 1993). Once collected, it was necessary to preserve them, which Sarrazin accomplished by creating a large herbarium at the Hôtel Dieu in Québec (Young 1993). Here, he studied, conserved and prepared his botanical specimens for shipment to the Jardin du Roi, now the Jardin des Plantes, in Paris (Young 1993). Although destroyed by fire, Sarrazin's Québec herbarium was an early 18th-century example of a research station serving as a specialized site of scientific activity to acquire botanical knowledge (Livingstone 2003). Over 30 years,

[3] Luca Ghini [1490-1556] revolutionized plant collecting with his *hortus siccus*, or herbarium, a system that provided plant hunters with the ability to preserve living specimens. (Livingstone 2003, Pavord 2005, Flannery 2023).

Sarrazin collected and shipped thousands of seeds and plants to Paris. In 1704, his Québec herbarium contained over 200 species of plants waiting for transport. Sarrazin, who died in 1734 at age 74, was one of the most remarkable field naturalists and plant hunters of the 18th century.

No matter how carefully one collected, prepared and mounted their specimens, preserving and shipping plants remained challenging. Listen to the lamentations of Alexander von Humboldt [1769-1859] in a letter to his mentor Carl Ludwig Willdenow [1765-1812]. "But Oh! We open our boxes of plants almost in tears…. The endless humidity of the American climate and the rankness of the vegetation, which makes it so difficult to find mature, fully-grown leaves, have ruined over 1/3 of our collection. Every day we find new insects that destroy paper and plants" (Lack 2009). But few losses can compare to those of Alfred Russel Wallace [1823-1913] and Henry Walter Bates [1825-1892]. After more than four years [1848-1852] of collecting thousands of birds, beetles and butterflies from Brazil's Amazon rainforest, on their return to England, their ship caught fire and sank with almost all of their specimens and field notes. Dampness, darkness, neglect, insects and even fire urgently necessitated appropriate devices and shipping methods to protect plant specimens during hazardous sea voyages and overland journeys.

One of the earliest pieces of equipment used to collect and safely transport field specimens was a vasculum, an oval-shaped, flattened cylinder fabricated from tin and similar in construction to 17th-century candle boxes. William Dampier [1652-1715], the first Englishman to collect plants from parts of New Holland, New Guinea, Java, Timor and Brazil, whose patrons included Samuel Pepys [1633-1703] and John Evelyn [1620-1706], used vasculums and plant presses to preserve his living and dried specimens (Stuart 2002, Preston & Preston 2004). While the London apothecary James Petiver [1663-1718] printed a broadside in 1689 for his correspondents and plant suppliers with instructions for preserving, packaging and preparing seeds and young plants for shipment (Magee 2007), it was only in the late 18th century that protecting botanical material became more efficient using an array of tin and wooden box designs. In 1770, John Ellis [1710-1776] published *Directions for Bringing Over Seeds and Plants from the East Indies,* and two years later, John Coakley Lettsom [1744-1815] published *The Naturalist's and Traveller's Compan-*

ion, which included a chapter devoted to preparing and packaging plant specimens.

Finally, in 1833, Nathaniel Ward [1791-1868] revolutionized the transportation of plant material with his Wardian case when he successfully shipped ferns, mosses and grasses in two sealed glazed wooden boxes from London to Sydney, which were then replanted with specimens for the return voyage to England. Arriving eight months later, when Ward and his nursery-owner friend George Loddiges [1786-1846] inspected the shipment, they found the healthy fronds of a delicate coral plant unknown in Britain and black wattle seedlings sprouting from the soil (Keogh 2020). Ward's invention, which he never patented, led to two types of Wardian cases: the ornamental case, which was the forerunner of the Victorian terrarium that often housed delicate orchids and ferns, and the nautical case designed to protect plants from the perils of long sea voyages secured on the decks of ships where they benefited from sunlight, were watered by the condensed moisture that collected inside the glazed case and protected the plants from salt sea spray (Keogh 2020).

For the patient, self-confident plant hunter, botanizing requires observing and recording empirical data and knowing how to survive in an unfamiliar wilderness. Consider the experiences of Francis Masson [1741-1805], Kew Gardens' first official plant hunter, who made three journeys into the southern parts of Africa between 1772 and 1774. "January 10, 1773: I endured this day much fatigued in these sequestered and unfrequented woods, with a mixture of horror and admiration. The greatest part of the trees that compose them are unknown to botanists. Some I found in flower; others, were not so. I was obliged to leave for the research of those who may come after me in a more fortunate season" (Masson 1776). Again, during his second journey, Masson seemed overwhelmed by the vast assortment of new plants he saw. "September 27, 1773: From Saldana Bay, we journeyed to Witte Klip, a white granite stone of enormous size, from the top of which we had a charming view of the seacoast from St. Helena Bay to the Cape of Good Hope. The whole country affords a fine field for botany, being enamelled with the greatest number of flowers I ever saw, of exquisite beauty and fragrance" (Masson 1776). Some plant hunters, however, are driven to the point of addiction, as exemplified by Hooker freezing his fingertips at 13,000 feet in the

Eastern Himalayas, in the northernmost region of the Indian state of West Bengal, trying to collect Rhododendron seeds.

DISCUSSION
THE INSTITUTE PLANT HUNTERS[4]

"We must consider the distinctive characters and the general nature of plants from the point of view of their morphology, their behaviour under external conditions, their mode of generation and the whole course of their life." Theophrastus [371-287 BCE] *Historia Plantarum*.

Ball, E.H. (*fl.* 1870-1890)

Reverend Ball[5] arrived in Nova Scotia as an itinerant evangelist missionary for the Society for the Propagation of the Gospel in Foreign Parts, founded in 1701 to provide clergy to minister to settlers and convert non-believers in the colonies. Shortly after his arrival, he joined the Nova Scotian Institute of Natural Science [hereafter NSIS] as a correspondent on 29 November 1871. Between 1871 and 1890, Ball preached to congregations at different parishes throughout Nova Scotia, including Mahone Bay, Springhill, Maccan and Tangier on the Eastern Shore. In his first botanical contribution to the NSIS *Proceedings and Transactions* [hereafter *Proceedings*] published in 1876, Ball provided an extensive list of ferns endemic to Nova Scotia, "taking some care not to repeat what has already been published by Dr. Asa Gray [1810-1888] in his *Manual of Botany* and by Dr. George Lawson [1827-1895] in his 'Synopsis of Canadian Ferns'" (Ball 1876, Lawson 1864 and 1864a, Moore *et al.* 2010). In his second contribution, published six years later in 1882, Ball specifically examines the varieties of *Aspidium spinulosum*, commonly referred to as the shield fern. Ball's interest in this particular species possibly stemmed from the plant's indecisive characteristics, as discussed in an article published by George E. Davenport in November 1878 in *The American Naturalist* (Davenport 1878).

[4] The scientific and common plant names are those supplied by the authors. Confirmed birth and death dates for individuals mentioned in this paper and ancillary comments by this author are in brackets. Also, note the occasional disconnect between the date a paper was read, sometimes by someone other than its author, and its date of publication.

[5] In the *Cumulative Author and Subject Indices* for the NSIS *Proceedings*, there is only one entry for an E.H. Ball, to which both the 1876 and 1882 published articles on ferns are attributed. The attribution of one of these papers to an E.N. Ball is a typographical error.

* * * *

It is clear from Philip Carteret Hill's [1821-1894] inaugural presidential address delivered in 1863 and published in the NSIS *Proceedings* in 1867 that some of the Institute's earliest members pushed back against Charles Darwin's [1809-1882] evolutionary theory of natural selection. Although Darwin's work was published in 1859, three years before the founding of the NSIS, Hill and Reverend Ball remained "supportive of the missions of natural theology [the search for the Christian God in the natural world] and inventory science" that defended divine creation against Darwin's perceived heresy, which denied the beginning that Genesis demanded (Pittman 1993, Reynolds *et al.* 2020).

Hill received his law degree from King's College in 1858, was mayor of Halifax from 1861 to 1864 and premier of Nova Scotia from 1875 to 1878. He was one of the original founding members of the Institute, described by Harry Piers [1870-1940] as a "man of education and literary, but not scientific tastes, who possessed cultivated manners and financial means" (Piers 1913). Hill believed that the works of nature were the manifestations of the Creator's skill and one of the reasons for the Institute's foundation (Hill 1867, Reynolds *et al.* 2020). "It is then to aid in this important work and to afford a well-constructed and organized channel for the contributions to the general stock of knowledge of those among ourselves who are interested in the fascinating fields embraced in the term 'natural science' that the Nova Scotian Institute has been established" (Hill 1867, Lawson 1896).

In the first decades of the NSIS, some members of Nova Scotia's scientific community, such as Ball and Hill, remained firmly locked in a theological form of conservativism that viewed the study of nature as proof and knowledge of God beyond divine revelation, providing corroboration for the truths of Christianity through the living world (Reynolds *et al.* 2020). For those believers, studying plants was more a spiritual pursuit than a scientific endeavour. As Ball stated, "Botany is essentially a healthful study. Everything green speaks to the botanist. Flora, if I may be allowed the personification, is a companion that is ever by His side; and if but an attentive ear be turned towards much that she has to impart–for she is a holy handmaiden–she will teach (as the lilies of the field are being considered) that 'the works of the Lord are great'" (Ball 1876).

Hardy, Campbell (1831-1919)

On 12 May 1919, during the monthly meeting of the Nova Scotian Institute in the Physiological Lecture Room at Dalhousie College on Carleton Street, Harry Piers and Dr. Alexander Howard MacKay [1848-1929], Principal of Pictou Academy, announced with deep regret the death of Major General Campbell Hardy, R.A. Born in Norwich, England, in 1831, he died at Dover on 11 April 1919. In his lengthy obituary published in the Institute *Proceedings*, Piers stated that Hardy was the last "surviving original member of 1862, one of its former vice presidents, [who] possessed a splendid Christian character, was a good naturalist and an admirer of nature, a fine sportsman, and was gifted with an accomplished pen and a brush, [with] which portrayed local scenery with skill and fidelity" (Piers 1919). Hardy followed in the footsteps of other military artists stationed in Halifax, including Richard Short [*fl.* 1754-1766], Joseph Partridge [1792-1832] and John Elliot Woolford [1778-1866] who also depicted the province's nature, landscapes, European settlements and Indigenous encampments. His drawing depicting the diggings at Gold River published in the *Illustrated London News* on 14 September 1861 and his panoramic view of the same river from Mahone Bay published on 1 October 1870 in the *Canadian Illustrated News* are particularly notable. But his painting titled "Cow Moose and Calf on the Edge of a Nova Scotia Lake," dated 1863, is one of his finest works.

Hardy was an avid sportsman and hunter who shot his first moose near Ship Harbour shortly after arriving in Halifax, "a fine bull nearly 7 feet to the shoulder and weighing 1100 or 1200 pounds" (Piers 1919). Andrew Downs [1811-1892], the founder of the first Zoological Garden in North America north of Mexico City at the head of the Northwest Arm, mounted Hardy's numerous trophies and served as his naturalist mentor. While Hardy's submissions to the Institute *Proceedings* covered a wide range of subject matter, including one on the Beaver in Nova Scotia (Hardy 1867d), a long article "On provincial acclimatization" (Hardy 1867b), a study of the "nocturnal life of animals in the forest" (Hardy 1867), a review of the distribution of conifers throughout the North American colonies (Hardy 1867c) and a report on the caplin (*Mallotus villosus*), a small forage fish of the smelt family (Hardy 1867a), his final submission, read to the members on 11 March 1907, was dedicated to his friend and mentor Andrew Downs (Hardy 1908).

However, it was Hardy's love of the sporting life for which he was best known through his illustrated two-volume *Sporting Adventures in the New World, or Days and Nights of Moose-hunting in the Pine Forests of Acadia,* published in 1855, followed in 1869 by his *Forest Life in Acadia: Sketches of Sport and Natural History in the Lower Provinces of the Canadian Dominion.* Hardy's revealing observations and comments about the disposition of Nova Scotia in the mid-19th century, boldly expressed in his *Sporting Adventures in the New World*, concern us here. He described Nova Scotia as a young country, only partly cleared and settled. "The traveller or casual passenger through Halifax, one who has landed there on his way from Europe to Canada, or the United States, and perhaps been a few miles into the country out of curiosity, might leave the capital of Nova Scotia with a very poor and erroneous opinion of the fertility, romantic beauty, and internal resources, developed or undeveloped, of the province, though gratified by the manners, air of contentment, and hospitality evinced by its inhabitants" (Hardy 1855). While Hardy attempts to put a positive spin on the poor appearance of Halifax and the surprising underdevelopment of the province's resources, the simple fact is the colony had changed little since its founding in 1749.

* * * *

In 1774, two farmers from York, John Robinson and his friend Thomas Rispin, travelled to Halifax to investigate economic opportunities in Nova Scotia. They published their experiences and observations in *A Journey through Nova Scotia: Containing a particular account of the country and its inhabitants; with observations on the management in husbandry, the breed of horses and other cattle, and everything material relating to farming; to which is added an account of several estates for sale in different townships of Nova Scotia, with their number of acres and the price at which each is set,* which remains a superior example of 18th-century travel writing describing the colony's people, customs, culture and potential development while also advancing Britain's imperialist agenda to attract new colonists. (De Wolfe 1997, McNairn 2007). As they and their fellow passengers entered Halifax Harbour on board *Prince George*, "The prospect appeared very discouraging; nothing but barren rock and hills presented themselves to our view along the coast. This unfavourable appearance greatly damped the spirits of most passengers, and several of them wished themselves in old England before they had set foot in Nova Scotia" (Robinson and Rispin 1774).

Their disappointment at seeing the bleakness and apparent desolation of the settlement was understandable for those passengers who based their expectations on the optimistic portrayals of Halifax published in popular London magazines. British outposts in North America were not exact replicas of English towns. Repeated mimesis fixed the standardized image of the British colony by emulating, copying and transferring a common assemblage of social, cultural and material traditions from centre to periphery through which the "original" model was replicated, creating a network of colonial settlements symbolic of imperial authority. Britain's colonial identity-making also generated a parallel between old and new familiar to everyone, which was the explicit graphic reality portrayed in the maps and illustrations of the colony printed in various London magazines, and anticipated, if not expected, by the passengers arriving with Robinson and Rispin in Britain's newest North American Colony (Lennox 2007, Crowley 2005, 2011, Jiménez 2010).

"It is indeed surprising what commercial notions many persons entertained of Nova Scotia previous to their leaving this country with a view to settling at this place. They imagined they would find lands cultivated, fields sown, and houses built…and they would have nothing to do but take possession" (Robinson and Rispin 1774). Like Hardy, Robinson and Rispin also found signs of English gentility and refinement among the residents regardless of class or wealth, noting, "Indeed the inhabitants, in general, poor, as well as rich, possess much common grace and good manners with which they treat each other as well as strangers." Two years later, when Walter Barrell [1737-1815] arrived in Halifax accompanied by his wife and six children with General Howe's [1729-1814] fleet following the evacuation of the Loyalists from Boston, his assessment of the colony was much less diplomatic. "Halifax was little more than a hamlet; at best it was a miserable village, inhabited chiefly by fishermen [and] most of the houses were in a dilapidated state, letting in the bleak winds of the season through manifold chinks, hardly a room ever having known the luxury of being plastered" (Stayner 1951). Undoubtedly, this reaction influenced Barrell's decision to return to London.

When Lord Durham [John George Lambton, 1st Earl of Durham, 1792-1840] arrived in Canada in 1837 to investigate the circumstances surrounding the Rebellions of Louis-Joseph Papineau [1786-1871] and William Lyon Mackenzie [1795-1861], Halifax had a population of less than 18,000 residents. Following a series of commissions, Durham compiled information about the people, geography, resources, agriculture and immigration in Lower Canada, Upper Canada, the Eastern Provinces and Newfoundland. In his final report, Durham's description of the Eastern Provinces was indeed bleak. While they had none of the alarming political features of the two Canadas and their loyalty and attachment to the Mother Country were warm, their varied and ample resources were turned to little account, and the scanty population exhibited an aspect of poverty, backwardness and stagnation. Several of Durham's assistant commissioners went so far as to describe them as melancholy, with lands abandoned and falling into decay, comments that reflected Titus Smith Jr.'s [1768-1850] testimony about the disposition of Nova Scotia (Durham 1839, Durham and Buller 1839).

In September 1838, Smith was selected as one of the delegates to testify before Lord Durham's Commission about the natural history, geography, geology, agriculture, fishing, mineral resources and people of Nova Scotia (Durham 1839, Durham and Buller 1839). After informing the commission that he had travelled extensively throughout the province for the government, a reference to his 1801-1802 surveys of the interior of Nova Scotia for Lieutenant Governor John Wentworth [1737-1820] and explaining that Nova Scotia consisted of 14 counties, the commissioners interrogated Smith about each county in turn, beginning with Digby and Annapolis. Most of the questions concerned the nature of the soil, the capabilities for agriculture and the availability of mineral resources, particularly iron and coal. Smith stated that the lands in Digby and Annapolis bordering the sea were considerably cultivated and the lands in the interior were good for cultivation but not settled for lack of roads. When asked about the slowness of improvement in Annapolis County, Smith replied that the general depression that existed for a long time was slowly improving. Other delegates from Nova Scotia[6] gave similar

[6] The other delegates from Nova Scotia included: J.S. Morris, Esq.; Sir Rupert George Bart, Secretary of the Province of Nova Scotia; Richard Brown, Esq., Mining Engineer; James McKenzie, Draftsman in the Surveyor-General's Office; John Fairbanks, Esq.; Laurence Hartshorne, Esq.; The Honourable Samuel Cunard; William Mackay, Land-Surveyor; The Honourable Thomas Baillie; The Honourable George Shore; and R. Hayes, Commissioner, N.B. and N.S. Land Company.

opinions about increasing the population and attracting investment capital to take advantage of natural resources, particularly fisheries, agriculture and mining (Field 2020). In 1841, two years after Durham's report, Halifax was incorporated, but little had changed. The population was down to 15,000, and except for the elegant neoclassical Province House, it remained a wooden town. Long rows of old "dirty" and "dingy" houses dating from the colony's founding had earned Halifax "its reputation of being the meanest-looking city in the civilized world in proportion to its wealth and other advantages" (Buggey 1980).

Regardless of these depressing and desolate assessments, seemingly unaccounted for by Durham and his commissioners were the educated colonists coming from places with well-established intellectual and literary enjoyments who encouraged efforts to improve the social and cultural prospects of the colony. Consequently, it was not the development of natural resources as Durham had predicted that would lead Nova Scotia out of its doldrums. Instead, the founding of educational institutions, subscription libraries, scientific and literary associations, and mechanics' institutes led the way. While the King's College Library in Windsor, founded in 1789, contained works that gentlemen would own on classical literature, agriculture, mathematics, theology and medicine, the colony's earliest public subscription library was formed in Truro in 1812. In 1817, as part of Britain's policy to provide recreational and educational opportunities for troops active in colonial service, George Ramsey [the 9th Earl of Dalhousie, 1779-1838], Lieutenant-Governor of Nova Scotia [1816-1820], established the Garrison Library in Halifax, which "served both the military community and the general public as a centre for reading and social interaction" (Elliott 1988).[7] One year later, in 1818, Lord Dalhousie founded Dalhousie University on the Grand Parade in downtown Halifax.

[7] The Garrison Library was renamed the Cambridge Military Library in 1902 after His Royal Highness Prince George, Duke of Cambridge [1819-1904]. Currently housed at Royal Artillery Park in Halifax, it is the oldest military library in Canada. Notably, in the 1860s, the library received a transfer of books from Corfu after the British evacuation in 1864, which included early works on voyages and travels, natural history, geography, science and military history. By 1886, the library contained over 30,000 volumes. Surprisingly, the list of subscribers between 1818 and 1835 included several women who were mostly the wives of officers, including Lady Dalhousie (Halifax Garrison Library 1835, Elliott 1988).

In 1821, subscription libraries opened in Newport and Amherst, followed by Yarmouth and Pictou in 1822 (Bruce 2018), the same year Phillip Holland [*fl.* 1821-1837], co-owner of the *Acadian Recorder* with his brother Anthony [*fl.* 1813-1837], deplored the lack of a library in Halifax and challenged Halifax's men of influence to come forward to form one. Supported by a successful subscription drive, the Halifax Library opened in a room in Province House in August 1824. However, it soon became evident that the library's elite location and membership costs created an exclusive clientele, which the Hollands jointly lamented in an editorial urging the library to lower its fees and admit more members.[8] Dissatisfaction with the exclusive nature of the Halifax Library eventually led Joseph Howe [1804-1873], a self-educated journalist and reformer, to advocate for the establishment of a mechanics' library and institute similar to those in Glasgow and London (Smith 2004).

Howe's proposal recognized the increasing need for mechanics' institutes to help prepare workers to meet the challenges of mechanized production replacing long-established handcrafted traditions. In 1827, the editors of *The Colonial Patriot*, *The Novascotian* and the *Acadian Recorder* proposed establishing a mechanics' institute and library of useful knowledge to benefit workers, artisans, apprentices and journeymen (Fergusson 1960). Four years later, on 17 October 1831, the first books donated by subscribers to the Mechanics' Library Association were available to the public. As Karen Smith pointed out, the goals of the two libraries were very different. The Province House Library was established to advance the social and cultural image of its leading citizens, while the Mechanics' Library was intended to serve the educational needs of the working classes (Smith 2004). On Christmas Eve of that same year, the library association advertised a meeting for 27 December in Mr. George Thompson's schoolroom on Argyle Street to discuss the creation of a mechanics' institute. Finally, on Wednesday evening, 11 January 1832, in a room rented at Dalhousie College located on the Grand Parade, Joseph Howe rose to deliver his inaugural address to the 52 members of the newly formed Halifax Mechanics' Institute.

[8] The number of shareholders was limited to 120, and each share was valued at nine pounds with an additional annual fee of 30 shillings paid by each shareholder for expenditures related to procuring books and maintaining the Institution (*Rules* 1833).

Howe had just turned 28 and was on the verge of becoming a political force in the province. His remarks on that cold winter evening posed the organization as a new fixture in the city's social, economic and cultural life, and he devoted much of his lecture to how science and the mechanical arts strengthened and elevated the mind and improved national prosperity. Howe catalogued Newton, Galileo and Franklin as men who effectively combined science with the mechanical arts, stating, "That its successful cultivation has an important effect, not only on the character, influence, and fortunes of individuals but also upon the advancement, resources, and happiness of nations." Howe also encouraged his audience to remember that "these anticipations [are not] damped by anything in the natural aspect of Nova Scotia," and boldly suggested that "Nova Scotia may, at some future period, stand in relation as important to the New World as Britain now does to the Old World" (Howe 1832). The influential men meeting on that chilly January evening were confident about the benefits and improvements the Halifax Mechanics' Institute could contribute to Nova Scotia's educational and economic growth.

Following the mandate of the Institute to aid craftsmen, artisans and journeymen weather the uncertainties posed by industrialization, the members present adopted as their primary aim the public instruction of the populace in the mechanical and applied sciences. In line with these objectives, a resolution passed that evening set forth a series of goals that included sponsoring lectures, accumulating scientific apparatus and mechanical models, acquiring technological knowledge and introducing mechanical improvements. While the Institute "became very popular and a most interesting series of lectures were given, by prominent local men, on scientific subjects, the fine arts, literature, etc., and art exhibitions were held, all of which were well attended," the promising future that Howe predicted never materialized (Piers 1913).

But Howe's dream remained alive. Even before the Institute became dormant in 1860, a newly established Nova Scotia Literary and Scientific Society "was doing some active work, no doubt formed about then, from the salvaged wreckage of the mechanics' institute" (Piers 1913). The initial meeting of this Society on 4 January 1859, at which members of the original Mechanics' Institute were present, "met in No. 1 Dalhousie College, at 3 P.M., to promote the formation of a Society "for the discussion of interesting and important questions in literature, science, commerce, and the arts" (Canadian Research Knowledge Network 2023). Called to attention by Andrew Mackinley, Esq. [1800-1867], who was the last President of the Halifax Mechanics' Institute, the mission statement adopted that evening proposed "that a society be established in this province to meet in Halifax, or at times in other places, for the reading and discussion of original communications on such subjects as literature, science, political economy, commerce, statistics, and the arts as may tend to draw forth talent and useful information…to encourage the study of history, natural history, products and the capabilities of the province; to foster a spirit of enquiry and enterprise; and to generally promote the advancement of science, learning, and the useful arts" (Canadian Research Knowledge Network 2023). But as Piers pointed out, almost immediately conflict erupted among those attending the meeting over the plan to endorse a range of subject matter similar to that of the dormant Halifax Mechanics' Institute.

"There seems to have been various interests working in this society, which possibly did not harmonize, and the scientific men proposed to form an organization that would be all their own" (Piers 1913). One of the driving forces behind this conflict was the disagreement over provincial representation at the second International Exhibition in London that opened on 1 May 1861, which was considered an opportunity to bring Nova Scotia to the attention of the world. "Those who had been engaged in this work felt the need for more scientific help and fuller information regarding our animal, vegetable, and mineral resources. Thus, it was suggested that the necessity of a permanent organization might foster the scientific spirit among us. In other words, a few men of scientific tastes had individually devoted energy to studying our flora, fauna, and geology, but it was felt that they should have a technical society of their own to publish the results of their observations" (Piers 1913).

The hoped-for cooperation between scientists, politicians, tradesmen and merchants, who had created the Halifax Mechanics' Institute in 1832 to once again come together and combine the study of science, nature and the fine arts into a new organization, failed. As Campbell Hardy explained, "We were a band of enthusiastic lovers of nature, hunters and woodsmen, zoologists and geologists, botanists and fishermen, historians and antiquarians, each zealous of improvement in his own particular sphere of knowledge" (Piers 1913).

Consequently, on 31 December 1862, a new scientific association established itself, like the Halifax Mechanics' Institute once did, as the newest fixture in the scientific, social, political and economic life of the province. Forged by former members of the Halifax Mechanics' Institute [1832-1862] and the Nova Scotia Literary and Scientific Society [1859-1862], the Nova Scotian Institute of Natural Science would eventually break Nova Scotia's intellectual and philosophical dependence on Britain and Europe, successfully segregate natural philosophy from science and science from the arts [see footnote 2], and over time introduce a modern methodological system of scientific inquiry based on empirical proof (Zhu and Goyal 2018, Field 2020).

During its first two decades, scientific activities focused on an inventory tradition of observing, describing, collecting and classifying what John Pickstone described as Natural Historical Ways of Knowing (Pickstone 2001), eventually opening out "to analytical searches for units in nature as components of larger systems" (Zeller 2015), which drew inspiration from Alexander von Humboldt.[9] "Scientific knowledge accrued, in the Humboldtian view, through the cooperation of widely dispersed participants using standardized instruments in synchronized observations. In return, it promised the greatest possible accuracy in the search for patterns in nature that would ultimately reveal natural laws" (Zeller 2015).

As the 19th century waned, however, questions about the value of natural history to a society preparing for the scientific, social, economic and technological revolutions of the 20th century were heatedly being debated on a national level. As David Pearce Penhallow [1854-1910], a Canadian-American botanist and educator who assisted Asa Gray at Harvard University and who later became the first Macdonald Chair of Botany at McGill, stated in his *Review of Canadian Botany from the First Settlement of New France to the Nineteenth Century*, "So far as we are aware, no attempt has yet been made to bring together in connected form the more important facts relating to the development of botanical science in Canada.... One of the first and most striking facts...is the very great paucity of botanical works prior to the present century, which can be regarded as in any sense Canadian.... Finally, it must be kept in mind that the

[9] In Humboldt's view, nature and humans are interconnected. The biological web of life, or biosphere, is inextricably linked to the human web of life, or ethnosphere, where fluctuations in one realm rebound in the other, a concept easily visualized by the algebraic lemniscate for infinity (∞).

titles given to the writings of many of the early travellers are often sadly misleading as to the actual contents of the volume, and while an elaborate title conveys the impression that a rich store of information may be found within, nothing but disappointment is met with" (Penhallow 1887). More importantly, he observed that when natural history is discussed, it is often solely referred to animals, while plants are dealt with briefly (Penhallow 1887, De Vos 2007).

These conflicting viewpoints were an extension of the larger 19th-century conversation about the negative impacts of industrial capitalism on nature and society that first emerged in Nova Scotia in the writings of Titus Smith Jr. In 1835, his paper published in London's *The Magazine of Natural History* deplored the consequences of the mechanized destruction of old-growth forests and other natural resources to feed the needs of science and industry (Field 2019). The implications of this union between "man and machine" gave humans unchecked powers that reduced nature to an exploitable commodity and sent struggling tradesmen and farmers to look for work in the ever-expanding, poverty-ridden urban centres of industry so eloquently portrayed by Charles Dickens [1812–1870] (Field 2019).[10]

As Zeller (2015) observed, even as science and industry "came under unprecedented critical examination, the Institute chose not to retreat but advance." An ambitious institution dedicated to the advancement of science could not ignore the emerging domination of the physical and industrial sciences as a means to once again "find its Nova Scotia moorings" and redefine its place in the world. Consequently, on 10 October 1888, Dr. James Gordon MacGregor

[10] There were many imaginative responses in Britain by various authors cautioning the public about the dangers of science and mechanization. Mary Shelley [1797-1851], the controversial muse of the Romantic Age, was one of the first to condemn the failure of science to save humankind. In 1826, Shelley published *The Last Man*, an existentialist, apocalyptic novel set in England in the 21st century governed by an elite ruling class. Science fails to cure humanity ravaged by a viral pandemic, reminiscent of the recent Covid-19 outbreak, sweeping across the globe, resulting in conflict, violence, social injustice and near-species extinction (Hunt 2022). Other mid-19th-century "industrial novels" included Elisabeth Gaskell's [1810-1865] *Mary Barton* (1848) and *North and South* (1855), *Sybil* (1845) by Benjamin Disraeli, written before he became prime minister of Great Britain in 1864, *Felix Holt* (1866) by George Eliot [1819-1880], and *Hard Times* (1854) by Charles Dickens with its grim portrayal of Coketown, an industrial nightmare "of red brick or brick that would have been red if the smoke and ashes allowed it, but as matters stood it was a town of unnatural red and black like the painted face of a savage. It was a town of machinery and tall chimneys, out of which interminable serpents of smoke trailed themselves forever and ever and never got uncoiled" (Dickens 1854, Watson 2005).

[1852-1913] assumed the chair as the newly elected president of the NSIS (Piers 1913). Born in Halifax in 1852, MacGregor graduated from Dalhousie University, where he was awarded the Gilchrist Scholarship to study with Peter Guthrie Tait [1831-1901] at the University of Edinburgh and Gustav Heinrich Wiedeman [1826-1899] at the University of Leipzig. He returned to Dalhousie in 1879 as the George Munro [1801-1878] Professor of Physics at age 27. As the late Peter Busby Waite [1922-2020] observed, “MacGregor was brilliant, energetic, nervous, and impatient” (Waite 2003), all personality traits that drove his confidence to prepare the Institute for the 20th century by making revisions to a founding principle that Piers would describe “as an epoch-making one in the annals of the society” (Piers 1913).

Recognizing that the Institute had reached a critical point, MacGregor found that the period of its greatest activity was in the first few years of its existence when it was easier and more acceptable to make contributions to natural history and geology. And in what proved to be the “epoch-making” event Piers alluded to, after much lively opposition and debate from the older members, it was decided by majority vote on 24 March 1890 that the word “natural” should be dropped from the Institute’s name so it would not be considered merely an association of naturalists. MacGregor felt that “natural science” was implied in its new title, which in his opinion also “widened the scope of the society.” Changing the Institute’s identity also appeased those members who still felt constrained by the Institute’s original mandate. As early as 1872, the Edinburgh-trained physician Dr. A. P. Reid [1836-1919] urged members to embrace the interest in modern physical science and technology already reflected throughout its *Proceedings and Transactions*, and despite resistance from George Lawson and others, successfully moved a resolution in 1874 to divide the NSIS into three sections (natural history, ethnology, and technology), a decision that seemingly altered little in the Institute’s unified operations until MacGregor assumed the presidency (Zeller 2015).

The new name not only downplayed the importance of natural history but altered the Institute’s public persona, which remained a point of contention for several years. President George Lawson defended the importance of plant catalogues at the Annual Business Meeting that closed the 1893-1894 session, suggesting that some members deemed plant collections unimportant to the Institute’s scientific aims. “Such lists as these, when prepared with care, form valuable material for the preparation of local floras, as well as for provincial or more general works, and the opportunity should not be lost to call attention to the substantial service that may be rendered to botanical sciences by the preparation of such lists for localities throughout the province by those who have opportunities, by residents or otherwise, for local observation and collection” (Lawson 1894).

For Lawson, the public members who did the work of plant collection and study remained a valuable resource. Lawson ended his remarks by noting the decline in new members and monthly papers: “In conclusion, I would like to call attention in a prominent manner to the fact that we are no longer limited to the domain of *natural science.* With the abbreviation of the name made some years ago to that of the Institute of Science, we extended our range so as to embrace all departments. Our membership has not, in consequence, increased in the proportion that might have been expected. With our advanced civilization and industrial development, surely there must be more persons in the province devoting some portion of their time to scientific work than those [whose names] are inscribed on the membership roll of the Institute of Science” (Lawson 1896).

Four years later, at the annual business meeting that ended the 1898-1899 session, President Alexander Howard MacKay expressed similar concerns about the unexpected difficulty in attracting new members and in securing papers for presentation at the regular monthly meetings. “I should, at the beginning of another year’s work at this institute, review briefly the progress made during the past year. This was, in many respects, most unsatisfactory. Never before did we have so much difficulty in securing papers for our ordinary meetings” (MacKay 1899b). In a nostalgic reverie, he stated, “A little enthusiasm, a vasculum, an insect net, and a pocket glass comprised all the outfits necessary to enable a man to write valuable papers and to give him a good standing in our institute. Now he requires thorough scientific training, costly scientific apparatus, and years of patient toil to be able to add a single new or valuable idea to our scientific knowledge” (MacKay 1899b). The study of nature was no longer a spiritual or personal pursuit; many Institute members were professional academics with advanced degrees in various branches of science and medicine who represented the educated elite of provincial society, which undoubtedly discouraged less well-informed practitioners from becoming members.

As previously noted, “There were long-term challenges faced by an ambitious institution dedicated to the ‘promotion of science’ – a mission that began as a measure of Nova Scotia’s material and cultural progress in a modern world, changing its meaning over time in ways that repeatedly challenged the Institute’s understanding of its place in the world” (Zeller 2015).

How, Henry (1828-1879)

Born in London on 11 July 1828, How died in Windsor, Nova Scotia, on 28 September 1879. After graduating from the Royal College of Chemistry, he assisted the accomplished, multitalented scientist, administrator and politician, the Rt. Honourable Lord Playfair, F.R.S. [1818-1898], who was a professor of chemistry at the College for Civil Engineers at Putney. Lord Playfair had a profound influence on How and encouraged him, at age 18, to submit his first scientific paper to the journal of the Chemistry Society of London. However, after arriving in Nova Scotia in 1854 at age 26 to become a professor of chemistry and natural history at the University of King’s College, Windsor, his wunderkind reputation received a mixed reception from his Nova Scotia colleagues. “From the moment he landed in this country, fresh from the wonderful laboratories of Europe and glowing with enthusiasm for the prosecution of his favourite studies, he lived a life of obscurity, almost seclusion. A few there were, and only a few, who had come to appreciate his talent as an analyst, his great learning as a chemist, and his industry in the fields of original research. I may add that the last sentence is true as regards this province alone, for abroad his great ability was recognized fully” (Piers 1913).

While Piers does not provide the reasons for How’s apparent social isolation, his 1870 lecture on scientific education, delivered at the Encoenia Festival of Founders at King’s College, Windsor, provides a tantalizing clue. He asked his audience, “How carefully should we preserve the characteristics of those people who still persist in asking what the use of studying science is, for they are the lingering types of beings prevailing in the pre-modern period.” Later in the lecture, he elaborated on this point. “In fact, the answer which a majority of scientific men might give to the question I am speaking of might well be: The material advantages derived from our labours, so far as they benefit all, we share, but the greater part of them is for others only: they turn our thoughts into money and live more or less luxuriously while we are no better off than the juniors in some good mercantile establishment" (How 1870).

Those views suggest a familiarity, if not agreement, with the previously mentioned public debates concerning the social evils and inequities brought on by capitalism and industrialization [see footnote 10]. It seems, like Titus Smith Jr., who bemoaned the impact "of unbounded luxury and extravagance, which turned the labour of multitudes from producing the necessities of life to furnishing articles of luxury for a few very rich individuals" (Smith 1835, Field 2019), How also shared some of the same critiques of capitalism that Smith did. For a province, which Joseph Howe suggested in 1832, "may, at some future period, stand in relation as important to the New World as Britain now does to the Old World" (Howe 1832), these anti-capitalist, egalitarian ideas would have made How an unpopular and unwelcome "outsider" by some members of Halifax's upper and middle classes whose cultural and intellectual bonds and shared political, social and economic interests helped to govern the city and create its cultural, scientific and educational institutions, which reinforced the founding hierarchy of Halifax's social network based on class distinctions.

As a polymath, Professor How moved easily between disciplines ranging from geology, mineralogy, chemistry, natural history and botany (Piers 1913). In his lifetime, he published over 44 books and articles in various scientific and philosophical journals in London, Edinburgh, Dublin and Halifax (Piers 1913). As a founding member of the NSIS, he helped to prepare the collections of minerals for both the London International Exhibition of 1862 and the Paris Exposition of 1867. As a Professor of Chemistry and Natural History at King's College, his main contributions were in the fields of mineralogy and botany. His most important publications were his five-part groundbreaking series titled "Notes on the Economic Mineralogy of Nova Scotia," published in the Institute *Proceedings* between 1867 and 1869, which eventually led to *The Mineralogy of Nova Scotia, a report to the provincial government* published in Halifax in 1869 (Piers 1913, Blakeley 2003).

Two years after How's death in 1879, the once-hoped-for industrial future of Nova Scotia, as touted by Joseph Howe, Lord Durham and Campbell Hardy, finally materialized, thanks in some part to How's research and his numerous reports on mineralogy. Between 1881 and 1891, the industrial growth of Nova Scotia outstripped all other provinces in eastern Canada following a significant transfer of capital and human resources into a new manufacturing base (Acheson 1972, Inwood 1991).

* * * *

On 14 January 1878, Dr. George Lawson delivered before the members of the Nova Scotian Institute Dr. Henry How's paper on the herbarium of East Indian plants at King's College, Windsor (How 1878). According to Lawson, this herbarium of 168 specimens was formed at the close of the 18th century by Dr. Johan Peter Rottler [1749-1836] and Dr. Johann Gottfried Klein [1766-1821], who worked as missionaries and botanists in southern India (Stewart 1982). In 1804, the Honourable Sir Thomas Strange [1756-1841], who received the collection from Rottler and Klein two years earlier, donated the specimens to King's College, where on their arrival they were inspected by Rev. Dr. William Cochran [1757-1833] before being placed into storage. How inspected them again in 1877 in preparation for his report and found the specimens in an excellent state of preservation, with some unmounted plants on sheets of coarse paper accompanied by identifying labels (How 1878). Lawson added that Dr. Cochran, who served as President of the College for more than forty years, had amassed another large herbarium of Nova Scotia plants, which for some reason did not become the property of the College but were "diverted to other keeping in an Upper Province" (How 1878). Lawson concluded his introduction by personally noting that, while this is not a large collection of plants considering the "richness of Indian Flora and the immense territory it occupies," he hoped "to be able to go over the Windsor Herbarium with Dr. How and, by comparing the specimens with those in my own Indian Herbarium, to identify them with modern names" (How 1878).

Herbaria of pressed and mounted plants were compiled and maintained by several of the NSIS plant hunters discussed in this paper. Unfortunately, those for whom botanizing was a gentlemanly vocation often were not taxonomically trained or sophisticated enough to correctly identify plant species within an existing genus and tended to see a plant with different traits as a novelty. Piers, who rarely criticized colleagues, stated that the plant determinations of John

Somers/Sommers[11] [1840-1898], who joined the NSIS in 1875 and served as president for two terms from 1880 to 1883 and from 1885 to 1888, "were sometimes too hastily made" (Piers 1913). Piers noted, "Somers had formed a large herbarium, which was, unfortunately, destroyed after his death, which [made] a revision of identifications impossible." Other herbaria compiled by NSIS members between 1862 and 1902 include Henry How, Alexander Howard MacKay and Andrew Walter Herdman Lindsay [1851-1915], which now form part of the Nova Scotia Museum of Natural History botany collection.

But the King's College East Indian herbarium of dried plants was special, from a mysterious realm filled with exotic human and natural marvels that, even before Benjamin Disraeli [1804-1881] had Queen Victoria [1819-1901] proclaimed Empress of India and India the jewel of Victoria's crown in 1877, attracted European and British explorers, plant hunters and adventurers. As early as 1830, Lady Dalhousie [1786-1839], the wife of the newly appointed Governor General and Commander-in-Chief of India [1830-1832] Lord Ramsey, who as Governor of Nova Scotia [1816-1820] had founded the Garrison Library and Dalhousie University in Halifax, collected, catalogued and preserved plants after they arrived in India. "She amassed hundreds of specimens of plants there, with ferns and orchids notably among them, and shipped large collections to Hooker" (Shteir and Cayouette 2019). In one of her many letters to Hooker, Lady Dalhousie expressed her disbelief at how unfamiliar the flora was. "You can scarcely even imagine the extreme confusion caused to a mere 'tyro' [slang for novice or amateur] & unknowing Dabbler in Botany such as I am by being plunged at once into an extremely new & unknown vegetation — when <u>all</u> is strange it is some time before <u>one</u> tree can be distinguished from another."[12] (Shteir & Cayouette 2019).

[11] Somers' surname is also spelled Sommers throughout the Institute *Proceedings*. They are apparently the same person.

[12] Lady Dalhousie carried out botanical research wherever her husband was posted, which included Nova Scotia between 1816 and 1820, when Lord Dalhousie served as Lieutenant Governor. In 1824, she delivered a paper to the Literary and Historical Society of Quebec about her catalogue of Canadian plants and donated her Nova Scotian specimens to the society (The Countess of Dalhousie 1829). In 1837, two years before her death, her entire East Indian herbarium was donated to the Botanical Society of Edinburgh, now the Royal Botanic Garden.

Jones, John Matthew (1828-1888)

Born in Wales on 7 October 1828, Jones was the son of Admiral Sir Charles T. Jones [1778-1853], descended from the Jones of Frontraith, a family seat since 1608. He was educated to be a barrister at the Middle Temple but never practiced law. In 1854, he travelled with his eldest brother, who was flag-lieutenant to Admiral of the Fleet Sir Alexander Milne [1806-1896], intending to shoot game in the Rocky Mountains. However, after arriving in London, Ontario, a cholera outbreak forced him to travel to Halifax, where he took up residence with his relative, the Earl of Mulgrave [Henry Phipps, 1st Earl of Mulgrave, 1755-1831], who was governor of the province (Piers 1902 & 1913). Jones was a fellow of the Linnaean Society of London and the Royal Society of Canada and served as the second president of the NSIS from 1863 to 1873, publishing 15 of his 23 publications in the *Proceedings* on a wide range of natural subjects, including ichthyology, herpetology, marine zoology, geology, lepidopterology and botany. Jones passed away in Halifax on 7 October 1888, coincidentally the same day as his birth exactly sixty years earlier.

While many 19th-century men born into a legacy of privilege and independent means turned to natural history as a gentlemanly pursuit, Jones chose to study zoology as a serious vocation. He wisely left Nova Scotia in the winter months to reside at "The Hermitage" in Bermuda. These winter sojourns also committed Jones to complete his life's work focused on the natural history of those islands, which he published in 1859 as *The Naturalist in Bermuda: A Sketch of the Geology, Zoology and Botany of that Remarkable Group of Islands, together with Meteorological Observations*. Darwin, who owned a copy of this work, made numerous comments in the page margins and on the end slips of the book, which reflected his interest in human influences on natural adaptations that occurred throughout the island complex following European discovery. These included, "Sea-birds tame on the discovery of Island" (annotation ix), "At discovery 1609, no rats and mice" (annotation 12), "Hogs run wild and swarmed" (annotation x), and (annotation 43) "variation in tail feathers in Snipes" (Biodiversity Heritage Library).

In 1860, Jones purchased "Ashbourne," a charming country estate at Dutch Village that is now the Ashburn Golf Club, from his meteorologist father-in-law, Colonel W.J. Myers [1807-1867], who was not only one of the original founding members of the NSIS but also the first president of The Halifax Club, founded in the same year as the NSIS on 20 January 1862 (*The Rules of the Halifax Club* 1863). Jones erected a new building at Ashbourne to display his collections of fauna and flora, which by 1866 numbered close to 8,000 specimens. He also provided important examples of plants and animals to the British Museum, the Smithsonian Museum and the Provincial Museum of Nova Scotia (Piers 1902, 1913).

Following the publication of his natural history of Bermuda (Jones 1859), Jones presented three papers on this subject to members of the Institute (Jones 1867, 1867b, 1873). In his 1873 paper on vegetation, Jones attributed the origin of endemic plant life throughout Bermuda's seven main islands to the accidental distribution of seeds, shrubs and plants carried by the Gulf Stream, undoubtedly a conclusion he based on Charles Darwin's research that proved seeds could travel between islands and across oceans and still germinate on reaching new land. Darwin experimented by soaking seeds of various species in beakers of seawater. Most of these simply drifted to the bottom, but some germinated after one month, and a few even after four months. Darwin postulated that seeds did not travel alone but became attached to leaves, twigs and small logs (Darwin 1855, 1857). Jones also attributed the introduction of European species of flora to consignments of field and garden seeds forwarded by the Bermuda Company of London, also known as the Somers Isles Company [1612-1684], and to the packets of seeds sent from the Royal Botanic Gardens at Kew, representing no less than 600 species, principally of trees and shrubs suited to sandy coastal soils (Jones 1873). The introduction of English flora by the British into foreign ecosystems intended to "civilize" the wilderness was at the heart of imperial enterprises designed to portray distant colonies as familiar, conquered and primed for British investment and colonialization (Rojas-Sandoval *et al.* 2017).

Shortly after Jones arrived in Halifax, he had the opportunity to join an expedition sent to report on the state of the timber in the Admiralty Reserves in the western part of the province, just north of Shelburne (Jones 1867c). This was the same western region that Titus Smith Jr. surveyed during his 1801 journeys through Nova Scotia looking for naval resources, which included mast-grade pine [*Pinus strobus*] and, like Smith, Jones also mentioned the ravages caused by the extensive fires in and around Shelburne, leaving the present growth of small and stunted timber (Jones 1867c, Field 2020, 2023).

The two weeks Jones spent exploring the backwoods around Shelburne and Weymouth are a mid-19th century example of "nature writing," in which the natural realm serves as the dominant subject matter of the narrator. In these diary-like accounts, nature is often glorified either by breathtakingly spiritual encounters experienced by naturalist clergymen or the philosophical and sometimes harsh life-threatening realities faced by the lone European explorer. Surprisingly, in a romantic-style reverie, Jones described the western woods as a wild and untamed realm. "It would be useless for me to dilate upon the feelings of one who, fresh from the cultivated vales of old England, finds himself suddenly placed in the midst of the 'forest primeval,' with no sounds of civilization to mar the sweet stillness which reigns amid these western wilds; and especially upon those of a naturalist, who loves to look upon nature in her pristine garb; to see the land untouched, and the trees and shrubs in every stage of decay, just as they have lived and died through succeeding ages; to listen to the unknown sounds and cries proceeding from animals and birds, and participate in the many other events hourly taking place as he journeys on through these trackless solitudes" (Jones 1867c). In the year Jones wrote this, nature writing was transitioning from romantic responses to studies on the lives and habits of birds and animals and then to scientific papers that often advocated for the protection of wildlife and the conservation and maintenance of natural habitats, as exemplified by the writings of George Perkins Marsh [1801-1882], Susan Augusta Fenimore Cooper [1813-1894][13] and John Muir [1838-1914].

* * * *

The inclusion of Bermuda in the Institute's purview revealed the challenges faced by the newly formed Nova Scotian Institute of Natural Science in finding its rightful orbit in the global scientific community during its first decades (Hill 1867, Zeller 2015). With the Institute's desire to study and accumulate natural knowledge well beyond the geographical limits of Nova Scotia, the decision to include

[13] The daughter of novelist James Fenimore Cooper [1789-1851], Susan Cooper's *Rural Hours*, published in 1850, is considered the first major work of American literary environmentalism that anticipated and influenced Henry David Thoreau's [1817-1862] W*alden*, published in 1854 (Walls 2009).

Bermuda expanded its scientific sphere of study, as did the Institute's aspirations concerning the pivotal role that the *Proceedings and Transactions* could perform as a channel of communication between the NSIS and other scientific and philosophical societies. As Philip Carteret Hill noted in 1867 in his inaugural address, "Should our hopes not be disappointed, we look forward to the time when our 'transactions' shall be exchanged with older and more important institutions, and any new and well-authenticated fact, having passed the ordeal of our own local organization, shall be transmitted to the great centres of science and become the property of the whole world" (Hill 1867).

Following Hill's remarks, a brisk trade in journals and books began almost immediately. Between 1863 and 1871, the works exchanged between the NSIS and other associations included the *Proceedings of the Boston Society of Natural History*, the *Proceedings and Transactions of the Dumfries and Galloway Natural History and Antiquarian Society*, the *Annals of the Lyceum of Natural History* [New York], the *Journal of the Franklin Institute* [Philadelphia] and the *Proceedings of the Essex Institute* [Salem]. The works presented to the NSIS by authors and other institutions included books on meteorology, astronomy, geology and mining, with additional contributions from the *Boston Society of Natural History*, the *Essex Institute* and the *Smithsonian Institute* (NSIS 1867). Over time, the exchange program proved amazingly successful, particularly after MacGregor increased the print run of the *Proceedings* to 1,000 copies, "adding 300 international exchanges during the first year alone" (Zeller 2015), prompting Lawson to declare in 1894, "There is now no country under the sun whose scientific societies (where such exist) do not have our Transactions on their library shelves as exchanges for our own" (Zeller 2015). When Piers delivered the Librarian's Report to the membership in 1911, Hill's desire for the NSIS to be known worldwide was finally realized. "The Provincial Science Library (with which those of the Institute were incorporated) had received 3,088 books and pamphlets, while the total number in the Science Library on 31st December 1911, was 45,497, and of these, 34,085 [c. 75%] belonged to the Institute and 11,412 to the Science Library proper" (Piers 1913).

Lawson, George (1827-1895)

Lawson was born in Scotland on 12 October 1827. Privately schooled as a youth, following his apprenticeship to a solicitor in Dundee, he left to enroll at the University of Edinburgh to study the natural and physical sciences. Lawson strongly believed that scientists had a responsibility to instill in the public a wider appreciation for the role of science in society through the establishment of natural history societies and publications. Even before Lawson left Scotland, he was responsible for founding the monthly *Dundee Natural History Magazine* and the Dundee Naturalists' Association. After arriving in Canada in the autumn of 1858 as a professor of chemistry and natural history at Queen's University in Kingston, Ontario, he founded the Botanical Society of Canada, which folded in 1863 after Lawson left Kingston for Halifax to take up his post as professor of chemistry and mineralogy at Dalhousie College (Connor 1986).

Lawson consistently championed scientific collaboration and engagement with laypersons and the general public, whom he believed could provide valuable meteorological and botanical information (Lawson 1894, Guinel and Doubt 2023). At Dalhousie, he successfully applied popular forms of experiential and hands-on learning to the study of nature by incorporating both field and laboratory assignments in his courses on botany and medical chemistry (Zeller 2003, Connor 1986). Considered by many as the "father of Canadian botany," Lawson passed away in Halifax on 10 November 1895, "just as professional botany was becoming an established discipline in Canadian universities" (Zeller 2003). Unfortunately, labelling Lawson "the father of Canadian botany" does not truly capture his expansive interdisciplinary knowledge before science became specialized, and a single mind like Lawson's, MacKay's or How's could move seamlessly between disciplines, allowing each to inform the other.

In the year the NSIS was founded, the study of plants was overshadowed by several ongoing scientific preoccupations relating to plant distribution, the misidentification of species, and the relationship between native North American plants and those found in Britain. As early as 1867, Lawson addressed these issues in one of his first articles published in the NSIS *Proceedings* about discovering heather (*Calluna vulgaris*) at St. Ann's Bay on Cape Breton Island (Lawson 1867b). Lawson's opening remarks are enthusiastic, woven with that sense of discovery which often enthralls plant hunters when they find, or think they have discovered, a new or unexpected species in an unexpected place. "It gives me much pleasure to bring under the notice of members of the Institute information and specimens that will, I trust, be sufficient to show that *Calluna vulgaris*, the common heather of Scotland, is a genuine native of our Province of Nova Scotia" (Lawson 1867b). Lawson arrived at this conclusion after examining a specimen of *Calluna* discovered in boggy land among stumps of spruce trees on Ulster Farm, belonging to John Robertson, Esq., President of the St. Ann's Agricultural Society.

One of the reasons for Lawson's enthusiasm about this discovery was the similarity between the geographical and ecological associations of the St. Ann's specimen to those found in Scotland. "The surroundings of the heather at St. Ann's are most appropriate. Both the scenery and vegetation resemble those of the Scottish Highlands. The cloudberry (*Rubus chamaemorus*), sundew, and many other highland plants were abundant on the neighbouring hills. The *Calluna* station is probably not more than one hundred feet above sea level." Based on these observations, Lawson boldly stated, "I believe it to be a genuine native" (Lawson 1867b). Lawson was well aware that his enthusiastic declaration that the specimen of *Calluna* at St. Ann's evolved there naturally and not through human agency would be open to debate. "Within the last few years, an animated controversy has been going on among both European and American botanists as to whether *Calluna* is indigenous to the American continent or adjacent islands. This is, in reality, a matter of great interest from a strictly scientific point of view, for it has important bearings on the questions of distribution, age, and origin of species, and therefore, a reference to the opinions expressed and facts adduced by others may not be unacceptable as an appendix to my own observations" (Lawson 1867b).

Lawson, seemingly unable to accept the possibility that Scottish heather was an introduced species, returned to the subject nine years later in his submission to the NSIS *Proceedings* on "Notes on some Nova Scotian Plants" (Lawson 1876). Again, he suggested that heather was originally a widely distributed native plant that "still exists as such in very small quantity on the Peninsula of Halifax; that it is probably indigenous to other parts of Nova Scotia and Newfoundland; and that at Point Pleasant, at Dartmouth, and possibly other places, the stations for the plant are artificial, but the plants are probably native, having been transferred from one spot to another, or grown from seed dropped by plants that were so transferred; and lastly that the various traditions as to the foreign origin of the heather, are not unlikely to have been suggested by the desire to account for the presence of what was regarded as necessarily a foreign plant rather than by actual historical facts" (Lawson 1876).

Lawson also investigated the origins of other Nova Scotia plants. While reports reached him of *Sarothamnus scoparius* [English broom], growing abundantly around Shelburne, it was the lone specimen of *Rhododendron maximum*, discovered "in the wild country in Sheet Harbour," that created extensive public correspondence when reported in the *Agricultural Journal* and the Halifax papers, which spearheaded a much wider debate about the introduction of invasive species by colonists into North America. Seven pages of conflicting editorials by the likes of Henry How, George Lawson, Asa Gray and others once again fuelled the debate between endemic and introduced plant species in Nova Scotia and elsewhere (Lawson 1876, Gioria *et al.* 2018).

Londa Schiebinger described bioprospecting "as 'big science and big business' that radically transformed the global landscape and made vegetation into a key resource for facilitating economic and imperial expansion" (Schiebinger 2007, Kuhn 2023). The mutual exchange and circulation of plants and seeds between Britain and its colonies was a powerful botanical strategy for constructing a transnational identity between colony and homeland (Kuhn 2023). Sustained efforts by Lawson and others to discover species of native colonial flora, like English broom and heather, identical to the same species of plants found in Britain, were likely motivated by colonial notions of botanical nationalism. Proving that Heather was indigenous to Nova Scotia would have provided a powerful symbol of connection to Scotland and the empire. As it turns out, heather is an invasive species, albeit a popular one, likely introduced into Cape Breton by Scottish settlers. Found in Point Pleasant Park, on both Seal and Sable Islands, and in Kings, Victoria and Richmond counties, it is also known as common heather, Scotch heather, Ling and Bruyère commune. This sprawling, freely branched shrub grows in peat or damp organic soil, and its flowers, which appear in August, are pink or mauve on long terminal racemes (Munro *et al.* 2014).

Lawson's continuing pursuit to identify plants indigenous to North America before European settlement was often prompted by correspondence from botanists in America and Europe. In an article titled "On the northern limit of wild grape vines" (Lawson 1884), Lawson responded to a letter from Professor Axel Gudbrand Blytt [1843-1898], a Norwegian botanist and author of books on the flora of Norway[14] "about the Northern Limit of the Grape Vine [*Vitis vinifera*], as bearing upon the early discovery of America by Norwegian sailors" (Lawson 1884). In response to Blytt's query, Lawson reached out to the public through advertisements in Halifax's *The Morning Chronicle*, *The Morning Herald* and the *Acadian Recorder* asking for information from "old records or reliable traditions" about the distribution of wild grapes along the Atlantic Coast. In doing so, Lawson was acting on his belief that the public had an important part to play in botanical studies, mindful of the vast repository of communally shared information integral to historical systems of knowledge passed on through oral tradition and recorded in settler diaries and correspondence to friends and relatives in the home country (Carvalho and Frazão-Moreira 2011).[15]

As previously stated, the search for botanical knowledge was often hampered by the misidentification of plant species. Even though Carl Linnaeus published his hierarchal system of plant classification in 1735, issues relating to accurate species identification remained a problem for those who studied plants as a pastime. As Lawson remarked in his "Note on *Lemania variegata* of Agardh" (Lawson 1867c), "The correction of errors in science is a very slow process. In the first part of the second volume in Bishop Agardh's 'Species Algarum,' published in 1828, an alga said to have been found in "*fluviis Americæ borealis*" was described under the name *Lemania variegata*. Agardh's original description of the plant appears, however, to have been published in the Stockholm Transactions in 1814, to which

[14] Axel Blytt and Rutger Sernander [1866-1944] were co-developers of the Blytt-Sernander theory of climate change. Based on their study of Danish peat bogs, they identified a sequence of North European climatic phases.

[15] Wild grapes were frequently recorded by early explorers and illustrated by cartographers on their maps of Atlantic Canada. When Isaac de Razilly [1587-1635] landed at LaHave in Nova Scotia in 1632, he reported that Mass was celebrated with wine made from local wild grapes (Fernald 1910, Andrews 1913, MacBeath 2003, Dawson 2020). Of the sixty species of grapes scattered across the northern hemisphere, only two, the Fox Grape [*Vitis labrusca* L.] and the Riverbank or Frost Grape [*Vitis riparia* Michx.], are found in Nova Scotia (Munro *et al.* 2014).

I have no means of access at the present time. Not having been met with by subsequent observers, *Lemania variegata* has been looked upon as a long-lost plant" (Lawson 1867c). After outlining the history of the genus *Lamani*, Lawson suggested that "the various forms deserve a careful examination, and I would beg to direct the attention of British botanists to the subject" (Lawson 1867).

Even today, many plant specimens remain unidentified or misidentified for three main reasons. "First and most important, too few taxonomic revisions across the entire geographical distribution of taxa in recent times mean that the taxonomy and nomenclature of these groups are provisional, and many specimens remain wrongly named, unrecognized, and/or not determined for decades. Second, the number of available specimens for any sizeable group is considerable. Third, the number of herbaria has greatly increased, which means that there are too many herbaria for a given expert to visit or request loans from. Rapidly increasing numbers of specimens in increasing numbers of herbaria are not being revised because there are too few taxonomists" (Goodwin *et al.* 2015).

To address this expanding problem, in 2010, the Royal Botanic Gardens at Kew joined with the Missouri Botanical Garden to launch a project called "The Plant List" (TPL) in response to Target 1 of the 2002-2010 Global Strategy for Plant Conservation (GSPC). Originally designed to compile a digitized record of all known vascular plants and bryophytes in 2013, the TPL became the taxonomic backbone of the World Flora Online (WFO) in response to the new 2011-2020 GSPC initiative to achieve an online flora of all known plants. The searchable WFO Plant List (www.worldfloraonline.org) currently lists as of October 2024, 1,565,481 names, 383,054 accepted species and 1,498,445 names with associated content, which includes 57,419 images, 160,097 descriptions, 36,159 distributions and 1,498,375 references.

* * * *

On 29 May 1891, Lawson helped to organize the Botanical Club of Canada under the auspices of the Royal Society of Canada "to promote by concerted local efforts and otherwise the exploration of the flora of every portion of British America, to publish complete lists of the same in local papers as the work goes on, to have these lists collected and carefully examined to arrive at a correct knowledge of the precise character of our flora and its geographical distribution, and to carry on seasonal observations on botanical phenomena" (H.M.A. 1900, Connor 1986). The decision to establish a botanical club grew out of the broader scientific vision of "plant geography" championed by Alexander von Humboldt, particularly as it related to ecological factors such as elevation, temperature and humidity, which controlled what plants grew where (Lack 2009, Flannery 2019). As early as 1864, Lawson quoted Humboldt and applied his methodology to his plant studies. "Humboldt, with his great power of generalization and true appreciation of poetry as well as the science of nature, summed up the results of all our botanical statistics when he said 'The carpet of flowers and verdure spread over the naked crust of our planet is unequally woven; it is thicker where the sun rises high in the ever-cloudless heavens and thinner toward the poles'" (Lawson 1867). Consequently, Lawson embraced Humboldt's global vision and emphasis on "collective scientific work" by envisioning the Botanical Club as the central clearinghouse for a national "army of explorers" (Zeller 2015) to assist in collecting phenological observations, such as the first flowering of a specific plant or the date of the arrival and departure of migratory birds, which will be discussed in fuller detail in the biographical segment on Andrew Howard MacKay.

Waghorne, Arthur C. (1851-1900)

The Reverend Arthur Waghorne arrived in Newfoundland in 1875 as a Church of England missionary for the Society for the Propagation of the Gospel and, like the previously mentioned Reverend Ball in Nova Scotia, was assigned to various parishes throughout Newfoundland and Labrador. Although untrained, he is considered Newfoundland's first *resident* botanist. Beginning in 1887, at a time when much of the province was sparsely populated and most of the flora unidentified, Waghorne collected algae, mosses, liverworts, lichens and vascular plants while also corresponding with botanists in America and Europe, to whom he sent specimens for identification. Waghorne also augmented his meagre church stipend by selling individual plants and sets of specimens to museums and private collectors worldwide. Between 1893 and 1894, he collected in the plant-rich "limestone" areas of the "Labrador Straits," and between 1895 and 1899, in the region around Birchy Cove [now Curling] (Waghorne 1898a).

Waghorne's three reports on "The flora of Newfoundland, Labrador and St. Pierre et Miquelon" published in the NSIS *Proceedings* between 1893 and 1898 (Waghorne 1893, 1896, 1898) represent his daring attempt to compile a flora of not only Newfoundland and Labrador but also the islands of St. Pierre and Miquelon. The publication of these papers in the *Proceedings* also represented the ongoing efforts to extend the Institute's influence, expand its knowledge of the wider Atlantic World, and increase its membership through categories of Associate and Corresponding Members, who often served as local informants (Zeller 2015).

Besides his three NSIS contributions, Waghorne also published "A Summary Account of the Wild Berries and Other Edible Fruits of Newfoundland and Labrador" (Waghorne 1888), stating that his investigation is presented to the public "in preparation for a more ambitious and extended examination of the wild fruits and berries of Newfoundland." His interests also extended to folklore. Between 1892 and 1893, he produced a series of essays on "The Folk-Lore of Newfoundland and Labrador" for *The Evening Herald*, Newfoundland's oldest newspaper (Brassard 1980, Smith and Thorne 2010).

* * * *

Seventeen years after Halifax was founded and two years before Captain James Cook's [1728-1779] first voyage into the Pacific [1768-1771], a scientific expedition to Newfoundland and Labrador took place in 1766 when Sir Joseph Banks [1743-1820] sailed with Constantine John Phipps [The Lord Mulgrave, 1744-1792] on HMS *Niger* to collect specimens of flora and fauna. While the French were forced to abandon Newfoundland under the terms of the 1713 Treaty of Utrecht, the rich fishing grounds of coastal Labrador were not conceded to the British until the 1763 negotiations at Paris that ended the Seven Years' War, reducing 150 years of French influence and rule in Atlantic Canada to ownership of the islands of Saint-Pierre and Miquelon. The British acted quickly to secure administrative control of Labrador by placing it under the existing authority of the Commodore-Governor of Newfoundland, Captain Thomas Graves [1725-1802], who was responsible for conveying the English fishing fleet to and from the Grand Banks (Pringle 1995).

European plant hunting in Labrador began with the Moravian Brethren or *Unitas Fratrum*. Formed in Bohemia in 1457, they established their first Protestant mission in 1732 on the Danish island of St. Thomas in the West Indies, and in the following year, they founded missions to the Inuit of Greenland, where they learned of similar linguistic communities in Labrador. In 1752, their first voyage to Nisbet's Harbour on the Labrador coast ended when the Inuit murdered the foreigners for their goods (Whiteley 1966). In 1765, under the protection of the British, Jens Haven [1724-1796] joined Captain Thomas Adams [1738-1770] and Naval Governor Sir Hugh Palliser [1723-1796] on board HMS *Niger* bound for Chateau Bay to find suitable locations for new Moravian settlements along the Labrador coast. Haven was joined by three other Moravian Brethren: Christian Larsen Drachardt [1711-1778], who spoke fluent Inuit, having served previously as a missionary in Greenland; John Hill [1714-1775]; and Christian Andrew Schlöezer [*fl.* 1760-1775] (Gilbert 1911, Lysaght 1971). Moravian missionaries trained in European herbal remedies eagerly solicited botanical knowledge from Inuit practitioners to supplement the medicinal herb gardens and pharmacies that were traditional features of all Moravian settlements (Whiteley 1966).[16]

After arriving at St. John's on 11 May 1766, Banks immediately began collecting plants and shooting land and sea birds. Although snow still covered the ground in some places to a depth of five feet, he identified four species of lichen and several rare clubmosses. He also shot a Black-capped Chickadee [*Poecile atricapillus*] and an American Thrush with a reddish-brown breast that was either the common American Robin [*Turdus migratorius migratorius*] or the Black-backed Robin [*Turdus migratorius nigrideus*]. In August, when Banks arrived in Chateau Bay, Labrador, the plant collector and artist Christian Andrew Schlöezer presented him with specimens of *Solidago multiradiata*, a species of goldenrod used since medieval times as an aromatic and stimulant effective for bladder stones, and *Senecio pseudo-arnica* [Seaside Ragwort] collected by Schlöezer at Hancock's Inlet that was used as a poultice to drain cuts and boils, while the fleshy stems and young leaves were edible when cooked (Lysaght 1971).

However, this was not Banks's first encounter with the Moravians. As a young man, he had listened to tales about Greenland narrated by his Chelsea neighbours who resided at the London headquarters of

[16] The *Herbarium Barbiense* of the Moravian Church, dating from the mid to late 18th century, was recently rediscovered in Dresden, which contains plant specimens collected in India, Greenland, Labrador, Russia, North Carolina and Tahiti (Wagner *et al.* 2023).

the Moravian Church in Lindsey House at Cheyne Walk. Banks was also familiar with the Canadian plants in the nearby Chelsea Physic Garden and knew about the North American botanical specimens at the Fulham Nursery of Christopher Gray, so closely associated with Mark Catesby [1689-1749], the author of *The Natural History of Carolina, Florida and the Bahama Islands* (Lysaght 1971).

Banks spent five months collecting and identifying 91 species of birds, and a small number of fish from the coastal waters of Newfoundland and Labrador. Unfortunately, his herbarium of 340 species of flora (Lysaght 1971) was water-damaged on the return voyage to London. The surviving plants deposited in the British Museum were believed to be the only remaining specimens collected during his 1766 expedition until two centuries later. In 1986, two additional specimens were discovered in the National Herbarium of Canada, prompting the search for further material that revealed another forty-three sheets of mounted plants collected by Banks from Newfoundland and Labrador (Shchepanek and Darbyshire 1990).

Banks arrived back in England with groundbreaking ideas about scientific excursions that would prove revolutionary and provide a model for the famous maritime surveying and collecting expeditions of the 18th and 19th centuries, such as Cook's first voyage into the Pacific accompanied by Banks in 1768, Darwin's five-year circumnavigation of the globe on HMS *Beagle* [1831-1836] and the pioneering four-year expedition [1872-1876] of HMS *Challenger* to conduct scientific oceanic surveys in various latitudes that docked in Halifax in May 1873. (Zeller 2015, Mills 2023, Marsters 2024).

Lindsay, Andrew Walter Herdman (1851-1915)

Andrew Lindsay was born in Pictou, Nova Scotia, and educated at Pictou Academy and Dalhousie University, where, as an undergraduate, he was an assistant to Professor Lawson, graduating with his B.A. in 1870 at age 19 (Dalhousie University 1937). After earning his M.B. and C.M. [Bachelor of Medicine and Master in Surgery] in 1877 from the University of Edinburgh, he returned to Halifax, where he was appointed professor of anatomy at Dalhousie. Lindsay also served as the secretary to the Faculty of Medicine from 1885 to 1915 and was a member of the Medical Board of Nova Scotia for almost 30 years. He died of a heart attack in 1915 while attending a board meeting.

Lindsay's contribution to the *Proceedings*, "A Catalogue of the Flora of Nova Scotia," arranged according to Gray's *Manual of Botany* (Lindsey 1876), represents the findings of the first official botanical survey of Nova Scotia plants spearheaded by members of the Nova Scotian Institute that included Lindsey, Professor Lawson, Professor Sommers, A. H. MacKay, Reverend E.H. Ball and Dr. D.A. Campbell [1849-1917]. "Without pretensions to a checklist of native and naturalized plants so far described, it may be accepted as the most complete synopsis of Nova Scotian Flora yet offered. It has been compiled with care from materials supplied by several observers working independently in different sections of the province. Corrections and additions have been made previous to placing it in the hands of the publisher, and a further guarantee of its accuracy will be found in the correspondence existing between different observers" (Sommers 1876). Lindsay's catalogue marked the beginning of a coherent, systemized provincial program of plant classification and distribution, which eventually led to Albert E. Roland's [1911-1991] groundbreaking *The Flora of Nova Scotia*, first published in the Institute *Proceedings* in 1946, followed in 1969 and 1998 by independently published revised editions, and finally to the current online catalogue of *Nova Scotia Plants* by Marian C. Munro, Ruth E. Newell and Nicholas M. Hill published by the Province in 2014.

* * * *

With the publication in 1848 of Asa Gray's *The Manual of the Botany of the Northern United States, from New England to Wisconsin and South to Ohio and Pennsylvania* (Gray 1848), plant hunters finally had an authoritative field guide to identification and classification. Known simply as *Gray's Manual*, it was instrumental in unifying the taxonomic system for classifying flora in North America and also served as a link with Gray's network of collectors throughout America and Europe. "Keeping botanists well informed of the advances and ongoing research in their field was a challenging task in the 1840s. Correspondence between prominent botanists contained the most current information, yet those left out of the letter-writing circle were ignorant of what was being discovered day by day. Asa Gray realized the need for a work to be published that would be within the financial grasp and scientific understanding of both the professional botanist and the inquisitive amateur" (Moore *et al.* 2010, Harvard University

Herbaria and Libraries 2020). This Humboldtian view that nature, science and society are not distinct entities but deeply intertwined and that "inquisitive amateurs" have a part to play in the search for botanical knowledge encouraged members of the NSIS, such as Lawson and MacKay, to fully support the public's involvement in botanical studies, which remains important to our current community-based responses to climate change (Carvalho and Frazão-Moreira 2011).

MacKay, Alexander Howard (1848-1929)

Born on 19 May 1848, MacKay grew up in rural Pictou County, where he attended Pictou Academy. In 1873, he graduated from Dalhousie University with a B.A. in mathematics and physics, and in 1880, he received his B.Sc. in biology, during which time he compiled his herbarium of Nova Scotia plants. Like Lawson, MacKay also advocated for the public's involvement in the study of nature and as Superintendent of Education for Nova Scotia [1891-1926], introduced into the public school curriculum hands-on programs of science and nature studies. MacKay remained an active botanist throughout his life, contributing more than thirty papers to various scientific journals, particularly on his phenological observations. MacKay was president of the Institute from 1899 to 1902 and, beginning in 1908, editor of the NSIS *Proceedings and Transactions* until he died in 1929 (Guildford 2005, Zeller 2015).

* * * *

Nature is a perpetually repeating phenomenon. To understand nature's cyclical sequences, one must be able to calculate the beginning and the end of each recurrence. Phenology measures nature's periodic events by monitoring the seasonal cycles of plants and animals. Such data provide ongoing reference points about climatic trends, past fluctuations in species composition and distribution, the spread of invasive plant species, temporal changes in morphological traits and the impact of climatic variations on plant phenology (Delisle *et al.* 2003, Primack and Miller-Rushing 2009, Buswell *et al.* 2010, Vellend *et al.* 2013, Holopainen *et al.* 2023). While Robert Marsham [1712-1793] is generally credited with being the first in Britain to systematically record the indications of spring on his estate at Stratton Strawless in Norfolk (Marsham 1789), long before Europeans landed on the shores of the Americas, Indigenous societies were recording the predictable cycles of the tides, moon phases, seasons and species growth, which included phenological indicators such as the first blooming of flowers and the migration of birds, mammals and fish. The continued monitoring and deep knowledge of these seasonal indices allowed Indigenous peoples to successfully respond and adapt to environmental changes for generations (Turner and Reid 2022).

The phenological program in Nova Scotia, framed by MacGregor and Lawson but successfully implemented by MacKay, was directly inspired by Humboldtian ideas about the importance of collective scientific work (Zeller 2015). "While Lawson and MacGregor lent their broader scientific vision to this Humboldtian project, it was the Botanical Club's first secretary, the Nova Scotia-born Alexander Howard MacKay, whose Herculean efforts lent it longevity with increasing analytical sophistication" (Zeller 2015). Nonetheless, MacKay expressed reservations about the project in the introduction to his first report published in the NSIS *Proceedings*. "The observations…although not very complete, seem to be worth preserving in some such accessible form, not alone on account of their value, but as a stimulus to more complete, extensive, and systematic observations each year in the future" (MacKay 1893).

Between 1893 and 1903, MacKay compiled and published in the NSIS *Proceedings* a series of phenological observations for the earliest dates of the flowering of 10 plant species[17] recorded by students and trained observers connected to the public schools of the province at five stations: Yarmouth (Miss Janet Keith Bruce Kelley), Berwick, Kings County (Miss Ida A. Parker), Musquodoboit Harbour, Halifax County (Rev. James Rosborough), Wallace (Miss E.G. Charman) and East Wallace (Miss A.B. Mackenzie), both in Cumberland County. Other stations were located in Prince Edward Island (Charlottetown), Ontario (Beatrice, Muskoka), Assiniboia (Pheasant Forks), Saskatchewan (Willoughby) and Vancouver in British Columbia (Irish 1900, MacKay 1902b, Zeller 2015).

Unfortunately, MacKay's phenological program was perhaps too successful in meeting its goals. On 28 September 1910, at a meeting of the Royal Society of Canada, the Botanical Club of Canada was officially dissolved. The reasons given were:

[17] These were the mayflower (*Epigaea repen*s), blue violet (*Viola cucullata*), red maple (*Acer rubrum*), dandelion (*Taraxacum officiale*), strawberry (*Fragaria virginiana*), wild red cherry (*Prunus pennsylvanica*), blueberry (*Vaccinium angustifolium*), buttercup (*Ranunculus acris*), cultivated apple (*Pyrus malus*) and lilac (*Syringa vulgaris*).

"First, the impossibility of holding representative meetings of the Club on account of the great expense of its members meeting annually at one centre from the distant provinces of the 'Dominion.' Second, the only successful work of the Club was the collection of phenological statistics, the expense of which (with the exception of the printing of the phenological summaries by the Royal Society) was borne entirely for many years by the Secretary. Third, this work has now been very successfully undertaken by the Meteorological Service, and it is expected will in future be carried on even more effectively. Fourth, the stimulation of botanical exploration and research, one of the most important original objects of the Club, can now be more effectively guided by the botanical officials in Ottawa. The dissolution of the Club does not, therefore, indicate retrogression. It indicates evolution-expansion from voluntary club work to the permanently subsidized and well-staffed departments of Meteorology and Biology of the Dominion of Canada" (Royal Society of Canada 1910).

While MacKay continued compiling phenological data until 1923 (Vasseur *et al.* 2001), the Royal Society's decision to disband the Botanical Club of Canada in 1910 marked the beginning of the transfer of the study of natural history from the domain of private individuals and regional scientific associations to municipal, provincial and federal government agencies (Loydlangston 2006, Guinel and Doubt 2023). Nonetheless, the importance of MacKay's phenological records cannot be underestimated, particularly in light of the looming climate crisis. Historical phenological records, along with maps and land surveys, archival photographs, planting journals, meteorological records, field notebooks, herbaria and florilegia provide important points of reference to aid in "predicting future ecological impacts of global change drivers [by] understanding how these same drivers have acted in the past to produce the plant populations and communities we see today" (Vellend *et al.* 2013), further helping us to prepare for fluctuating plant dynamics across time and space (Crumley 1994, Balée 1998, Egan and Howell 2005, Scholl *et al.* 2010).

Currently, many online databases provide access to historical records, including the Pan European Phenological Project (PEP) with 12 million records dating from 1868 (Templ *et al.* 2018) and the Plant Phenological Online Database (PPODB) with over 16 million plant observations from Central Europe dating between 1880 and 2009 (Dierenbach 2013). Since 1996, Scotia Plantwatch has collected the earliest flowering dates for 12 plant species at 200 sites in Nova Scotia. When the 1996-1998 results were compared with records collected by MacKay, most flowering dates were not significantly different from the present except during the 1998 season of unprecedented warmth (Vasseur *et al.* 2001). While human observations remain important to phenological studies at the local level, the current employment of ground-based cameras and other remote sensing technologies to monitor seasonal phenological changes is providing an enormous amount of information on variations in plant flowering, distribution and biodiversity occurring across large-scale geographical regions (Katal *et al.* 2022). One can only imagine what MacGregor, Lawson and MacKay would have thought of these technological developments.

CONCLUSION

"Today people talk about our alienation from Nature, from the natural world, from 'wilderness' (Thoreau's 'wildness'), from the environment which we have been treating as a mere instrument, where it really should be a source of spiritual nourishment" (Taylor 2024).

By 1862, when the NSIS was founded, Britain's Empire was still expanding, driven by colonization, military conquest, and an extensive global trade and exchange network. After all, who can doubt the imperial origins of the exotic flora from far-flung colonies growing in Britain's public and private gardens, or the imposing tropical palms transplanted into the English soil of the Victorian glass-and iron-structured Palm House at Kew? While the beginning of the end of the British Empire was marked by the passing of Queen Victoria in 1901, more important were the influences of the moral and ideological social, scientific and political transformations impacting the traditional Victorian relationships between science and society as the 20th century loomed.

President MacGregor responded to these unfolding end-of-century developments as threats to the future of the Institute and its place in the world by moving away from the previous generation's romantic views of nature. "A society, such as ours, which exists in a community as yet but slightly developed in the direction of scientific education, ought to do something to stimulate outsiders to an interest in scientific work" (MacGregor 1889). In the end, what MacGregor did not understand, but Lawson and MacKay clearly did, was that studying natural history was more than just a leisurely pursuit but a serious science with sweeping social, cultural and environmental implications. By removing the word "natural" from the Institute's name, the long-established public support for scientific and literary associations extending back to the founding of the Halifax Mechanics' Institute in 1832 changed forever. Amateur stargazing, after-school nature clubs, the popular fashion of identifying plants using Linnaean classification, pressing flowers into books or mounting them in personal herbaria, collecting and identifying butterflies and beetles, displaying seashells, sand dollars and sea urchins retrieved from beach drift, and participating in public programs of phenological and meteorological observations were some of the portals through which young people and adults first learned about science and the natural and physical world they lived in, making "natural history" both relatable and relevant and outwardly all other forms of science more approachable.

Today, public trust in scientists and scientific organizations threatened by political, social and ideological conflicts is eroding the established affiliations between science and society, as demonstrated by the heated debates during the COVID-19 outbreak and the contentious, ongoing arguments about climate change. In a recent editorial, Peter Wells addressed these issues. "It is crucial to have the engagement of NSIS members with those from other societies in NS and the region – working together, sharing reliable information, encouraging the engagement of young people, discussing key issues, and looking for solutions that work" (Wells 2023).

Acknowledgements I want to thank the two anonymous peer reviewers for their comments and Julia Swan for her valuable editorial suggestions.

REFERENCES

Acheson, T.W. (1972). The national policy and the industrialization of the Maritimes, 1880-1910. *Acadiensis* 1(2): 3-28.

Andrews, A.L. (1913). Philological aspects of the "Plants of Wineland the Good." *Rhodora* 15(170): 28-35.

Balée, W. (1998). Historical ecology: premises and postulates. In: Balée, W. (ed.). Advances in Historical Ecology. Columbia University Press, New York, USA. p. 13-29.

Ball, E.H. (1876). The indigenous ferns of Nova Scotia. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 4(2): 146-157.

Ball, E.H. (1882). On Nova Scotian ferns. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 5(1): 13-15.

Bergland, R. (2024). Natural Magic: Emily Dickinson, Charles Darwin, and the Dawn of Modern Science. Princeton University Press. p. 1-2, 107-108.

Biodiversity Heritage Library. (nd.) Supplementary material in Darwin's copy of The Naturalist in Bermuda. www.biodiversitylibrary.org (Accessed 30 July 2024)

Blakeley, P.R. (2003). Henry How. Dictionary of Canadian Biography Online.
www.biographi.ca/en/bio/how_henry_10E.html
(Accessed 24 April 2024)

Brassard, G.R. (1980). Rev. Arthur C. Waghorne (1851-1990). *Canadian Botanical Association Bulletin* 12(2 Supp.): 17-18.

Bruce, L.D. (2018). Subscription Libraries for the Public in Canadian Colonies, 1775-1850. *Library & Information History* 34(1): 40-63.

Buggey, S. (1980). Building Halifax 1841-1871. *Acadiensis* 10(1): 90-112.

Buswell, J.M., Moles, A.T. & Hartley, S. (2010). Is rapid evolution common in introduced plant species? *Journal of Ecology* 99(1): 214-224.

Canadian Research Knowledge Network. (CRKN/RCDR). (2023). *Transactions of the Nova Scotia Literary and Scientific Society* 1: 7. (Accessed August 2024).

Carvalho, A.M. & Frazão-Moreira, A. (2011). Importance of local knowledge in plant resources management and conservation in two protected areas from Trás-os-Montes, Portugal. *Journal of Ethnobiology and Ethnomedicine* 7(36): 1-12.

Connor, J.T.H. (1986). To promote the cause of science: George Lawson and the Botanical Society of Canada. *Scientia Canadensis* 10(1): 3-33.

Crowley, J.E. (2005). A Visual Empire: Seeing the British Atlantic World from a Global British Perspective. In: Mancke, E. and Shammas, C. (eds.). The Creation of the British Atlantic World, The John Hopkins University Press, Baltimore, USA. p. 289.

Crowley, J.E. (2011). Imperial Landscapes: Britain's Global Visual Culture. Yale University Press, New Haven, USA. p. 47-73.

Crumley, Carole L. (1994). Historical Ecology: A Multidimensional Ecological Orientation. In: Crumley, C.L. (ed.). Historical Ecology: Cultural Knowledge and Changing Landscapes. School of American Research Press, Santa Fe, USA. p. 1-16.

Dalhousie University. (1937). Directory of Graduates and Former Students of the University. Dalhousie University, Halifax, NS. p. 84.

Darwin, C. (1855). Does seawater kill seeds? *The Gardeners' Chronicle and Agricultural Gazette* 21: 356-357.

Darwin, C. (1857). On the action of seawater on the germination of seeds. *Journal of Proceedings of the Linnean Society of London (Botany)* 1: 130-140.

Davenport, G.E. (1878). *Aspidium spinulosum* (Swartz) and its varieties. *The American Naturalist* 12(11): 707-717.

Dawson, J. (2020). LaHave, Capital of New France. Historic Nova Scotia. historicnovascotia.ca/items/show/156 (Accessed 4 January 2024)

Delisle, F., Lavoie, C., Jean, M. & Lachance, D. (2003). Reconstructing the spread on invasive plants: taking into account biases associated with herbarium specimens. *Journal of Biogeograph*y 30(7): 1033-1042.

De Vos, P. (2007). Natural History and the pursuit of empire in eighteenth-century Spain. *Eighteenth-Century Studies* 40(2): 211-212.

De Wolfe, B. (1997). Discoveries of America: Personal Accounts of British Emigrants to North America during the Revolutionary Era. Cambridge University Press, Cambridge, USA. p. 51-52.

Dickens, C. (1854). Hard Times. Penguin, London, UK. p. 27-28.

Dierenbach, J., Badeck, F.W. & Schaber, J. (2013). The plant phenological online database (PPODB): An online database for long-term phenological data. *International Journal of Biometeorology* 57(5): 805-812.

Durham, J.G.L. (1839). Report on the Affairs of British North America. Robert Stanton, Toronto, ON. p. 84-85, 134.

Durham, J.G.L. & Buller, C. (1839). Appendix (B.) to the Report on the affairs of British North America: from the Earl of Durham, Her Majesty's High Commission. London. p. 134. The original 1839 report and all appendices are available online: www.archive.org.

Eagan, D. & Howell, E.A. (2005). The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems. Island Press, Washington, DC, USA. p. xxiii-xxv.

Elliott, S.B. (1988). The Cambridge Military Library: A Library for the Garrison Town: A History of the Cambridge Military Library, Royal Artillery Park, Halifax, NS. *Epilogue* 8: 1-15. hmhps.ca/pdf/A-Library-for-the-Garrison-and-Town-Shirley-Elliott-1988.pdf (Accessed in September 2024).

Fergusson, C.B. (1960). Mechanics' Institutes of Nova Scotia. Public Archives of Nova Scotia, Halifax, NS. p. 27.

Fernald, M.L. (1910). Notes on the "Plants of Wineland the Good." *Rhodora* 12(134): 17-20.

Field, R. (2019). Titus Smith Jr. and the unity of nature: Environmental advocacy in early 19th century Nova Scotia. *Proceedings of the Nova Scotian Institute of Science* 50(1): 119-127.

Field, R. (2020). Into the wilderness: Rediscovering Titus Smith Jr.'s philosophy of nature. *Proceedings of the Nova Scotian Institute of Science* 50(2): 363-372.

Field, R. (2023). Arboretum Nova Scotia: Titus Smith Jr.'s observations of the nature and uses of trees. *Proceedings of the Nova Scotian Institute of Science* 53(1): 61-66.

Flannery, M. (2019). Humboldt: Essay on the Geography of Plants. Herbariumworld.wordpress.com (Accessed August 2024)

Flannery, M. (2023). In the Herbarium: The Hidden World of Collecting and Preserving Plants. Yale University Press, New Haven, USA. p. 188-201.

Gilbert, W.G. (1911). Labrador: its discovery, exploration and development. John Lane Company, New York, USA. p. 260-262.

Gioria, M., O'Flynn, C. & Osborne, B.A. (2018). A review of the impacts of major terrestrial invasive alien plants in Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy 118B* (3): 157-179. doi.org/10.3318/bioe.2018.15 (Accessed 3 May 2024)

Goodwin, Z.A., Harris, D.J., Filer, D., Wood, J.R.I. & Scotland, R.W. (2015). Widespread mistaken identity in tropical plant collections. *Current Biology* 25(22): 1066-1067.

Gray, A. (1848). Manual of the Botany of the Northern United States, from New England to Wisconsin and South to Ohio and Pennsylvania. James Munroe and Company, Boston and Cambridge, USA.

Guildford, J. (2005). MacKay, Alexander Howard. *Dictionary of Canadian Biography* 15. www.biographi.ca/en/bio/mackay_alexander_howard_15E.htm (Accessed 27 May 2024)

Guinel, F. & Doubt, J. (2023). The George Lawson Medal, Part I: An expanded portrait of George Lawson, an outstanding contributor to Canadian Botany. *The Canadian Botanical Association Bulletin* 50(1): 25-28.

Halifax Garrison Library, Rules and Catalogue. (1835). John Munro, Halifax, NS. p. 1-82.

Hardy, C. (1855). Sporting Adventures in the New World; or, Days and Nights of Moose-Hunting in the Pine Forests of Acadia, 2 Vols. London, Hurst and Blackett. Vol. 1: 2-3.

Hardy, C. (1867). Nocturnal life of animals in the forest. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(1): 11-19.

Hardy, C. (1867a). On the caplin (*Mallotus villosus*). *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(2): 4-13.

Hardy, C. (1867b). On provincial acclimatization. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(3): 15-30.

Hardy, C. (1867c). Nova Scotian conifers: *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(4): 120-130.

Hardy, C. (1867d). On the beaver in Nova Scotia. *Proceedings of the Nova Scotian Institute of Natural Science* 2(1): 17-25.

Hardy, C. (1869). Forest life in Acadia: Sketches of Sport and Natural History in the Lower Provinces of the Canadian Dominion. D. Appleton and Company, New York, USA. p. 1-371.

Hardy, C. (1908). Reminiscences of a Nova Scotia naturalist: Andrew Downs. *Proceedings of the Nova Scotian Institute of Science* 12(1): xi-xxix.

Harvard University Herbaria & Libraries. (2010). Asa Gray at 200: Gray's Manual of Botany. huh.harvard.edu/book/grays-manual-botany (Accessed 19 October 2023)

Hill, P.C. (1867). Inaugural address. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(1): 1-4.

H.M.A. (1900). The Botanical Club of Canada. *Science* 12: 229-230.

Holmes, R. (2009). The Age of Wonder: How the Romantic Generation Discovered the Beauty and Terror of Science. Harper Press, London, UK. p. xviii-xix.

Holopainen, J., Helama, S. & Väre, H. (2023). The written history of plant phenology: shaping primary sources for secondary publications. *The Science of Nature* 110(4): 34.

Hovenkamp, H. (1978). Science and Religion in America, 1800-1860. University of Pennsylvania Press, Philadelphia, USA. p. 1-272.

How, H. (1870). Address on scientific education: delivered at the Encaenia of King's College, Windsor, N.S., by Prof. How, D.C.L., Thursday, June 30th, 1870. p. 2-3. onlinebooks.library.upenn.edu/ (Accessed 27 May 2024)

How, H. (1878). The East Indian Herbarium of King's College, Windsor, by Professor How, D. C. L. with an introduction by George Lawson, Ph.D., LL. D of Dalhousie College, Halifax. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 4(4): 369-373.

Howe, J. (1832). An Opening Address, Delivered at the first meeting of the Halifax Mechanics' Institute on Wednesday, January 11, 1832, by Joseph Howe. P. J. Holland, Halifax, NS. p. 4-8.

Hunt, E.M. (2022). Mary Shelley's *The Last Man*: Existentialism and IR meet the post-apocalyptic pandemic novel. *Review of International Studies* 49(5): 832-854.

Inwood, K.E. (1991). Maritime industrialization from 1870 to 1910: A review of the evidence and its interpretation. *Acadiensis* 21(1): 132-155.

Irish, H.C. (1900). Phenological observations in Canada. *The American Naturalist*. 34(401): 445-446.

Jiménez, A. (2010). Reproducing Difference: Mimesis and colonialism in Roman *Hispania*. In: van Dommelen, P. and Knapp, A.B. (eds.). Material Connections in the Mediterranean: Mobility, Materiality and Identity. Routledge, London and New York, USA. p. 39-57.

Jones, J.M. (1859). The Naturalist in Bermuda: A Sketch of the Geology, Zoology and Botany, of that Remarkable Group of Islands; with Meteorological Observations. London, Reeves and Turner. 200 p.

Jones, J.M. (1867a). Contributions to the natural history of the Bermudas. Part I. Mollusca. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(2): 14-26.

Jones, J.M. (1867b). On the geological features of the Bermudas. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(4): 18-26.

Jones, J.M. (1867c). A fortnight in the backwoods of Shelburne and Weymouth. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 2(1): 48-60.

Jones, J.M. (1873). On the vegetation of the Bermudas. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 3(3): 237-280.

Katal, N., Rzanny, M., Mäder, P. & Wäldchen, J. (2022). Deep Learning in Plant Phenological Research: A systematic literature review. *Frontiers in Plant Science* 13. www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2022.805738/full (Accessed 26 May 2024)

Keogh, L. (2020). The Wardian Case: How a Simple Box Moved Plants and Changed the World. Kew Publishing, Royal Botanical Gardens, London and University of Chicago Press, Chicago, USA. p. 1-2, 5-6.

Kuhn, M. (2023). The Garden Politic: Global Plants and Botanical Nationalism in Nineteenth-Century America. NYU Press, New York, USA. p. 25-57.

Lack, W. (2009). Alexander von Humboldt and the Botanical Exploration of the Americas. Prestel, London, UK. p. 11, 28, 46.

Lawson, G. (1864). Synopsis of Canadian ferns and filicoid plants. *Edinburgh New Philosophical Journal* 19: 102-116, 273-291.

Lawson, G. (1864a). Synopsis of Canadian Ferns and Filicoid Plants. Neill and Company, Edinburgh, UK. p. 1-33.

Lawson, G. (1867a). On the flora of Canada. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(2): 75-77.

Lawson, G. (1867b). Notice of the occurrence of heather (*Calluna vulgaris*) at St. Ann's Bay, Cape Breton Island. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(3): 30-35.

Lawson, G. (1867c). Note on *Lemania variegata* of Agardh. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 1(3): 35-38.

Lawson, G. (1876). Notes on some Nova Scotian plants. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 4(2): 167-179.

Lawson, G. (1884). On the northern limit of wild grape vines. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 6(2): 101-109.

Lawson, G. (1894). Address to the Nova Scotian Institute of Science read at the opening meeting of session 1894-1895, November 12, 1894. Nova Scotia Printing Company, Halifax, NS. p. 6-7.

Lawson, G. (1896). Presidents Address. *Proceedings of the Nova Scotian Institute of Science* 9 (1): i-xxii.

Lennox, J. (2007). An Empire on Paper: The Founding of Halifax and Conceptions of Imperial Space, 1744-1755. *Canadian Historical Review* 88(3): 373-312.

Lindsay, A.W.H. (1876). (Appendix). A catalogue of the flora of Nova Scotia, arranged according to Gray's Manual of Botany for the N. United States of America. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 4(2): 184-222.

Livingstone, D.A. (2003). Putting Science in its Place: Geographies of Scientific Knowledge. University of Chicago Press, Chicago, USA. p. 21-23, 48-54.

Loydlangston, A. (2006). Women in Botany and the Canadian Federal Department of Agriculture, 1887-1919. *Scientia Canadensis* 29(2): 99-130.

Lysaght, A.M. (1971). Joseph Banks in Newfoundland and Labrador, 1766: His Diary, Manuscripts and Collections. Faber and Faber, London, UK. p. 443, 346-348, 44-46, 293-310.

MacBeath, G. (2003). Razilly (Rasilly), Isaac de. Dictionary of Canadian Biography, vol. 1. University of Toronto/Université Laval Press, Toronto. www.biographi.ca/en/bio/razilly_isaac_de_1E (Accessed 4 January 2024)

MacGregor, J. G. (1889). Opening address. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 7(3): 185-196.

MacKay, A.H. (1893). Natural history observations, made at several stations in Nova Scotia during the year 1892. *Proceedings and Transactions of the Nova Scotian Institute of Science* 8(3): 378-379.

MacKay, A.H. (1899b). Presidents Address. *Proceedings of the Nova Scotian Institute of Science* 10(1): i-iii.

MacKay, A. H. (1902b). 1: Phonological [Phenological] observations of the Botanical Club of Canada, 1900; 2: Abstract of phonological [sic] observations on the flowering of ten plants in Nova Scotia, 1900; with 3: Remarks on their phenochrons. *Proceedings and Transactions of the Nova Scotian Institute of Science* 10(3): 379-398.

Magee, J. (2007). The Art and Science of William Bartram. Pennsylvania State University and Natural History Museum, University Park. p. 83.

Marsham, R. (1789). Indications of spring, observed by Robert Marsham. Esquire, R.R.S. of Stratton in Norfolk. Latitude 52° 45'. *Philosophical Transactions of the Royal Society of London* 79: 154-156.

Marsters, R. (2024). HMS *Challenger*, Nova Scotia and the maritime world. *Proceedings of the Nova Scotian Institute of Science* 53(2): 185-194.

Masson, F. (1776). An account of three journeys from Cape Town into the southern parts of Africa; Undertaken for the discovery of new plants, towards the improvement of the Royal Botanical Gardens at Kew. By Mr. Francis Masson, one of His Majesty's gardeners. Addressed to Sir John Pringle, Bart. P. R. S. *Philosophical Transactions of the Royal Society of London* 66: 275, 278. www.jstor.org/stable/106280 (Accessed 19 October 2023)

McNairn, J.L. (2007). "Everything was new, yet familiar" British travellers, Halifax and the ambiguities of empire. *Acadiensis* 36(2): 8-54.

Mills, E.L. (2023). Endless novelties of extraordinary interest: The voyage of the H.M.S. *Challenger* and the birth of modern oceanography. *Proceedings of the Nova Scotian Institute of Science* 53(1): 147-150.

Moore, G., Macklin, J. & DeCesare, L. (2010). A brief history of Asa Gray's Manual of Botany. *Harvard Papers in Botany* 15(2): 277-286.

Munro, M., Newell, R. & Hill, N. (2014). Nova Scotia Plants. Province of Nova Scotia, Halifax, NS. p. 504, 981-982.

NSIS. (1867). Donations to the library. Nov. 20, 1865 to August 31, 1866. *Proceedings of the Nova Scotian Institute of Science* 1(4): 8-9.

Pavord, A. (2005). The Naming of Names: The Search for Order in the World of Plants. Bloomsbury, London, UK. p. 221-225.

Penhallow, D.P. (1887). A review of Canadian botany from the first settlement of New France to the nineteenth century. *Transactions of the Royal Society of Canada* 3(IV): 45-46.

Penhallow, D.P. (1897). A review of Canadian botany from 1800 to 1895. *Transactions of the Royal Society of Canada* 3(IV): 6-61.

Pickstone, J.V. (2001). Ways of Knowing: A New History of Science, Technology and Medicine. University of Chicago Press, Chicago, USA. p. 1-288.

Piers, H. (1902). Sketch of the life of J.M. Jones. *Proceedings and Transactions of the Nova Scotian Institute of Science* 10(3): lxxx-lxxxii.

Piers, H. (1913). A brief historical account of the Nova Scotian Institute of Science and the events leading to its formation; with biographical sketches of its deceased presidents and other prominent members. *Proceedings and Transactions of the Nova Scotian Institute of Science* 13(3): liii-cxii.

Piers, H. (1919). Obituary: Major General Campbell Hardy, R.A., sportman, naturalist, artist and author; last surviving original member of the Nova Scotian Institute of Science; born 1831, died 1919. *Proceedings and Transactions of the Nova Scotian Institute of Science* 15(1): vii-xvii.

Pittman, J.N. (1993). Darwin and evolution: three Nova Scotia religious newspapers respond, 1860-1900. *Acadiensis* 22(2): 40-60.

Preston, D. & Preston, M. (2004). A Pirate of Exquisite Mind. Walker and Company, New York, USA. p. 292-295.

Primack, R.B. & Miller-Rushing, A.J. (2009). The role of botanical gardens in climate change research. *New Phytologist* 182(2): 303-313.

Pringle, J.S. (1995). The history of the exploration of the vascular flora of Canada. *The Canadian Field-Naturalist* 109(3): 294-296.

Reynolds, A., MacNeil, C. & Jabalee, M. (2020). Reception of Darwinism in mid-to-late nineteenth-century Nova Scotia. *Scientia Canadensis* 42 (1): 5-28.

Robinson, J. & Rispin, T. (1774). A journey through Nova Scotia: Containing a particular account of the country and its inhabitants; with observations on the management in husbandry, the breed of horses and other cattle, and everything material relating to farming; to which is added an account of several estates for sale in different townships of

Nova Scotia, with their number of acres and the price at which each is set. C. Etherington, York, UK. p. 1-56.

Rojas-Sandoval, J., Tremblay, R.L., Acevedo-Rodríguez, P. & Díaz-Soltero, H. (2017). Invasive plant species in the West Indies: geographical, ecological and floristic insights. *Ecology and Evolution* 7(13): 4522-4533.

Roland, A.E. (1946). The Flora of Nova Scotia. *Proceedings of the Nova Scotian Institute of Science* 21(3): 94-642.

Royal Society of Canada. (1910). Dissolution of the Botanical Club of Canada. *Proceedings and Transactions of the Royal Society of Canada* Series 3 (4): cxiv.

Rules and Catalogue of the Halifax Library. (1833). J.S. Cunnabell. p. 3.

Schiebinger, L. (2007). Plants and Empire: Colonial Bioprospecting in the Atlantic World. Harvard University Press, Cambridge, USA. p. 5.

Scholl, M.D., Murray, D.S. & Crumley, C.L. (2010). Comparing trajectories of climate, class and production: an historical ecology of American yeoman. In: Vaccaro, I., Smith, E.A. and Aswani, S. (eds.). Enviromental Social Sciences: Methods and Research Design. Cambridge University Press, Cambridge, USA. p. 322-348.

Shchepanek, M.J. & Darbyshire, S.J. (1990). Collections of Sir Joseph Banks from his 1766 expedition to Newfoundland and Labrador at the National Museum of Natural Sciences, Ottawa, ON. *Taxon* 39(1): 33-44.

Shteir, A. (2022). Women and Plant Practices in Nineteenth-Century Canada beyond "the Usual Records." In: Shteir, A. (ed.). Flora's Fieldworkers: Women and Botany in Nineteenth-Century Canada. McGill-Queen's Press, Montreal, QC. p. 3-4.

Shteir, A. & Cayouette, J. (2019). Collecting with "botanical friends": four women in colonial Quebec and Newfoundland. *Scientia Canadensis* 41(1): 7-9.

Smith, K. (2004). Early libraries in Halifax. *Royal Nova Scotia Historical Journal* (7): 1-6.

Smith, P. & Thorne C. (2010). The Folk-Lore of Newfoundland and Labrador: Essays by the Reverend Arthur C. Waghorne from The Evening Herald 1892-1893, with contributions from Fanny D. Bergen, William Wells Newell and Albert J. Waghorne. Memorial University of Newfoundland, St. John's, NL. p. 1-55.

Smith, T., Jr. (1835). Conclusions on the results on the vegetation of Nova Scotia, and on vegetation in general, and on man in general, of certain natural and artificial causes deemed to actuate and affect them. *The Magazine of Natural History* 8(56): 660-662.

Sommers, J. [Somers]. (1876). Introduction to a synopsis of the flora of Nova Scotia. *Proceedings and Transactions of the Nova Scotian Institute of Natural Science* 4(2): 181-183. (Appendix).

Stayner, C. (1951). The Sandemanian Loyalists. *Collections of the Nova Scotia Historical Society*. Halifax, Halcraft Printing Limited. 29: 62-123.

Stewart, R.R. (1982). Missionaries and clergymen as botanists in India and Pakistan. *Taxon* 31(1): 57-64.

Stuart, D. (2002). The Plants That Shaped Our Gardens. Harvard University Press, Cambridge, USA. p. 7-8

Taylor, C. (2024). Cosmic Connections: Poetry in the Age of Disenchantment. Harvard University Press, Cambridge, USA. p. ix.

Templ, B., Koch, E., Bolmgren, K., Ungersböck, M., Paul, A., Scheifinger, H., Rutishauser, T., Busto, M., Chmielewski, F.M., Hájková, L., Hodzić, S., Kaspar, F., Pietragalla, B., Romero-Fresneda, R., Tolvanen, A., Vučetič, V., Zimmermann, K. & Zust, A. (2018). Pan European Phenological database: a single point of access for European data. *Int. J. Biometeorology* 62(6): 1109-1113.

The Countess of Dalhousie. (1829). Catalogue of Canadian plants, presented to the Literary and Historical Society. *Transactions of the Literary and Historical Society of Quebec* 1(1): 255-262. archive.org/details/transactionslit02unkngoog/page/n296/mode/2up (Accessed 7 September 2024)

The Rules of the Halifax Club. (1863). James Bowles and Sons, Halifax, NS. p. 1-12.

Turner, N.J. & Reid, A. (2022). When the wild roses bloom: Indigenous knowledge and environmental change in Northwestern North America. *GeoHealth* 6(11): 1-21.

Vasseur, L., Guscott, R.L. & Mudie, P.J. (2001). Monitoring of spring flower phenology in Nova Scotia: Comparison over the last century. *Northeastern Naturalist* 8(4): 393-402.

Vellend, M., Brown, C.D., Kharouba, H.M., McCune, J.L. & Myers-Smith, I.H. (2013). Historical ecology: using unconventional data sources to test for effects of global environmental change. *American Journal of Botany* 100(7): 1294-1305.

Waghorne, A.C. (1888). A Summary account of the wild berries and other edible fruits of Newfoundland and Labrador. St John’s, NL. p. 1-11.

Waghorne, A.C. (1893). The flora of Newfoundland, Labradour [sic] and St. Pierre et Miquelon. Part I. *Proceedings and Transactions of the Nova Scotian Institute of Science* 8(3): 359-373.

Waghorne, A.C. (1896). The flora of Newfoundland, Labrador and St. Pierre et Miquelon: Part II. *Proceedings and Transactions of the Nova Scotian Institute of Science* 9(1): 83-100.

Waghorne, A.C. (1898). The flora of Newfoundland, Labrador and St. Pierre et Miquelon: Part III. *Proceedings and Transactions of the Nova Scotian Institute of Science* 9(4): 361-401.

Waghorne, A.C. (1898a). Newfoundland and Labrador plants: List of plants collected in Newfoundland and Labrador and offered for sale by Arthur Waghorne. Bay of Islands, Newfoundland. Advertising pamphlet. p. 1-4. dai.mun.ca/PDFs/cns/NewfoundlandandLabradorPlants.pdf (Accessed August 2024)

Wagner, S.T., Ehrlacher, R., Frenzke, L., Müller, F., Neinhuis, C. & Rhuland, T. (2023). Network analysis of the herbarium collection of the Moravian Church from the 18th century. *Bauhinia* 29: 141-142.

Waite, P.B. (2003). MacGregor, James Gordon. *Dictionary of Canadian Biography Online.* www.biographi.ca/en/bio/macgregor_james_gordon_14E.html (Accessed 20 February 2024)

Walls, L.D. (2009). The Passage to Cosmos: Alexander von Humboldt and the Shaping of America. University of Chicago Press, Chicago, USA. p. 285.

Watson, P. (2005). Ideas: A History from Fire to Freud. Orion Books, London, UK. p. 745, 770.

Wells, P.G. (2023). Living in a global environmental emergency ward – the need to address problems with science, action and speed. *Proceedings of the Nova Scotian Institute of Science* 53(1): 1-4.

Whiteley, W.H. (1966). The Moravian missionaries and the Labrador Eskimos in the eighteenth century. *Church History* 35(1): 76-77.

Young, K.A. (1993). Crown Agent-Canadian correspondent: Michel Sarrazin and the Académie Royale des Sciences, 1697-1734. *French Historical Studies*. 18(2): 423-425.

Zeller, S. (2003). Lawson, George. *Dictionary of Canadian Biography Online.* www.biographi.ca/en/bio/lawson_george_12E.html (Accessed 02 November 2023)

Zeller, S. (2015). Reflections on time and space: The Nova Scotian Institute of Science in its first 150 years. *Proceedings of the Nova Scotian Institute of Science* 48(1): 5-61.

Zhu, L. & Goyal, Y. (2018). Art and science: Intersections of art and science through time and paths forward. *Science and Society* 20(2): 1-6.

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 89-97

FORAGE FISH PROVISIONING PELAGICS OFF GRAND MANAN, AND GUIDANCE FOR FISHERIES MANAGEMENT

GUY E. MELVILLE*

Independent Researcher
orcid.org/0000-0002-7346-8574
Freeport, NS B0V 1B0

ABSTRACT

Migrant Atlantic herring frequent Grand Manan waters, a major regional trophic hub, providing forage for seabirds, dolphins and other animals. Predators reveal much about the availability of the prey they eat. Publicly accessible monitoring data illustrate linkages between razorbill chick diets and juvenile herring via weir-fishery landings. Having been overfished, the status of extra-regional Gulf of Maine herring is dire, seemingly without institutional resolution. Many people hope that ocean 'literacy' – increased marine scientific knowledge in individuals across society at large – will guide legislative and bureaucratic institutions to be more responsible, take ethical actions and demonstrate accountability with respect to marine ecosystem conservation.

The waters around Grand Manan Island (Fig 1) serve as a major regional trophic hub for a great number of species, such as Atlantic herring (*Clupea harengus*). Herring in turn provide forage for other hub constituents. For many associated species, knowledge about food sources tells much about consumer populations. The reverse is also readily apparent. Ruefully, the Grand Manan region has lost many disparate ecological components at the hands of humans over at least the last 2 centuries (Lotze and Milewski 2004), however breeding populations of several seabird species, particularly Atlantic puffins (*Fratercula arctica*) and razorbills (*Alca torda*) (Fig 2) have rebounded in recent decades (Diamond 2021). Atlantic herring have a varied history in the region, mainly as a result of human fishing. With the prosecution of an intense gill-net fishery through the late 1800s, large (older?) herring effectively disappeared long ago (Huntsman 1953).

* Author to whom correspondence should be addressed: guymelville1@gmail.com

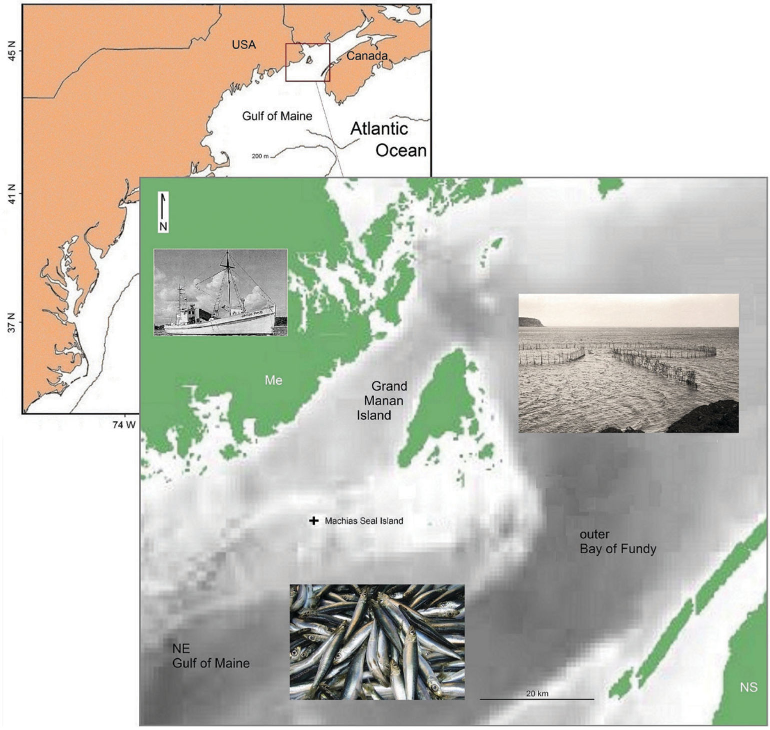


Fig 1 Map showing locations, including Grand Manan and Machias Seal Islands. Maine herring carrier – source M. Crowe; Grand Manan weir – source D. Ingalls; juvenile herring – FishWatch.

Juvenile herring aged 1-3y ('sardines') constitute the mainstay of the fish-based forage provisioning many pelagics off Grand Manan. These fish migrate from across the greater Gulf of Maine (GoM). A concentrated weir fishery for the juveniles, preferred age-2y but mixed ages developed in the 1880s, after many decades of widespread fishing along GoM coasts. Starting in the mid 1960s, intense offshore fishing by Soviet-era and later mobile-gear fleets brought the demise of herring over much of the greater gulf. After all this time, the decline of juvenile herring proximal to Grand Manan is dire – the juvenile population exhibits the basic characteristics of chronic extra-regional overfishing (Fig 3; see ASMFC 2024).

Seabird characteristics are well established as indicators of prey abundance internationally (Cairns 1987). Scopel *et al*. (2018) investigated the possibility that seabirds could serve the same function in the northern GoM. They used yearly chick diets, an immediate surrogate for prey availability (Parsons *et al.* 2008) in their analyses. Their study included Machias Seal Island (MSI; Fig 1), 19 km SW of Grand Manan, the largest seabird colony in the greater GoM and nesting grounds for several cold-water species (Diamond 2021). Although variable, the results of the chick study suggest relationships which could in turn aid the development of herring recruitment forecasts, thus enhance stock assessments. Currently, interest in the potential application of the findings to herring fishing management is mixed, and particularly problematic for the Grand Manan trophic hub. Fisheries managers responsible for most of the region are cited as dismissing use of the seabird analyses in their estimations, ostensibly because they and their industrial partners do not control the seabird monitoring (McBride 2023). In this respect, McBride also cites a lament of failure by seabird researchers, in view of fisheries attitudes that disregard the body of solid scientific work contributing fisheries-related knowledge of seabirds. These sentiments provide the impetus, at least in part, for the commentary here.

This document presents exemplary evidence that herring quantities in razorbill chick diets, the seabird catch, on MSI are positively correlated with herring weir-landings, the human catch (n = 27 years), in the Grand Manan region. Scopel *et al.* (2018) did not find any relationships between razorbills at MSI and regional weir-landings over a 22-year subset of very similar data. The fisheries management path referred to previously (McBride 2023) introduces another dimension – ocean 'literacy' (e.g., Salazar *et al.* 2022), recognized by UNESCO and an added qualification for the development of this presentation. Proponents aim to increase marine scientific literacy in individuals (e.g., MacKenzie 2006) across society at large, with emphasis on egalitarian inputs to scientific knowledge. In keeping with inclusiveness, I examine the seabird-fish example using published data, images and methods that are credible, readily available and referenced appropriately. The chick diet data (converted from graphed proportions to numerical ranks here) are published by Atlantic Laboratory Avian Research (ALAR 2023), the juvenile fish landings data originate with DFO (2023, and references), and robust analytical procedures can be found easily e.g., Statistics Kingdom (2017). Chick diets expressed as ranks provide the most reliable data type, at least in an initial analysis in that: ranks retain essential

Fig 2 **Examples of a razorbill pair – on Skomer, a chick (top) and an oblique view of Machias Seal Island (MSI; bottom), seabird nesting sanctuary. Pair photo – C.J. Sharp/CC-BY-4.0; chick photo – K.W. Wade; MSI -UNB.**

information, data are compared in a relative manner, no assumptions are made about underlying data distributions, and the rank form is more relevant to decision-model construction. Compared to standardized data, one can also preempt possible interpretive issues in analyses of data with a strong temporal component.

Data indicate a moderately strong association (Pearson $r = 0.588$, $P = 0.002$, df = 24, open circle outlier excluded) between the landings of juvenile herring and relative quantities (ranks) of herring fed to razorbill chicks (Fig 4). The smallest diet proportion is ranked the

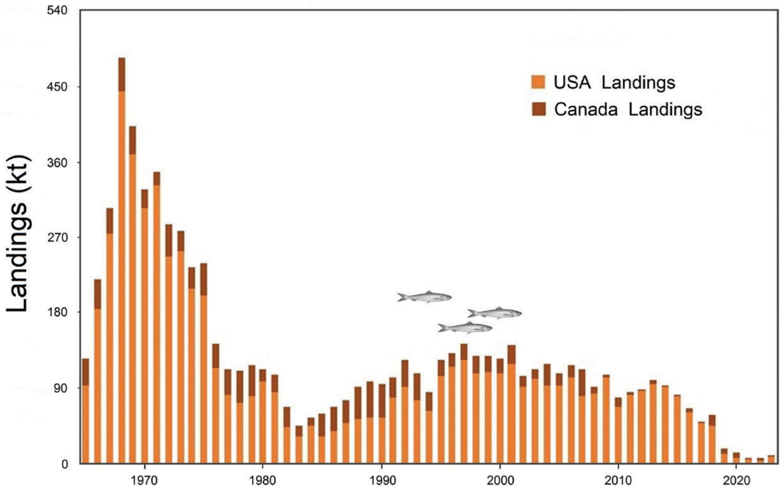


Fig 3 **Decline of USA GoM herring landings, primarily because of overfishing, the current retrospective designation by the NEFSC-NOAA (ASMFS 2024). Canada landings, ~ages 1-3y, fixed-gear areas adjacent boundary. Redrafted after ASMFS (2024).**

lowest, = 1, the largest proportion is ranked the highest and so on with the order of intermediate diet proportions Nominally, the landings for any given year represent herring aged 1-2+yr, therefore herring age distributions in landings are probably proportionately older than in chick diets (latter ~ more 1s, less 2s). This age bias probably adds to the scatter in Fig 4. Association assumes at least some herring are available to both fishers and razorbills. The figure indicates the extent of the residual data scatter accompanying relatively strong association metrics faced by fisheries modelers, even after exploring a datum as an (unexplained) outlier.

The herring-related patterns highlight the importance of ecological resilience across the complex predator-prey GoM ecosystem (e.g., Melville 2018). As a result of continued overexploitation, the herring prey-base has become highly unstable in the last few decades, with recovery from previous collapse in the western GoM arrested and decline accelerating in the east. Knowledge of the deleterious effects on other species caused by the herring exploitation is not new. After 2000, productivity in the puffin declined at MSI with the loss of juvenile herring as the principal food source (Diamond and Devlin 2003). Starting in the mid 2010s, unexplained near-shore deaths of humpback and minke whales increased dramatically, as herring

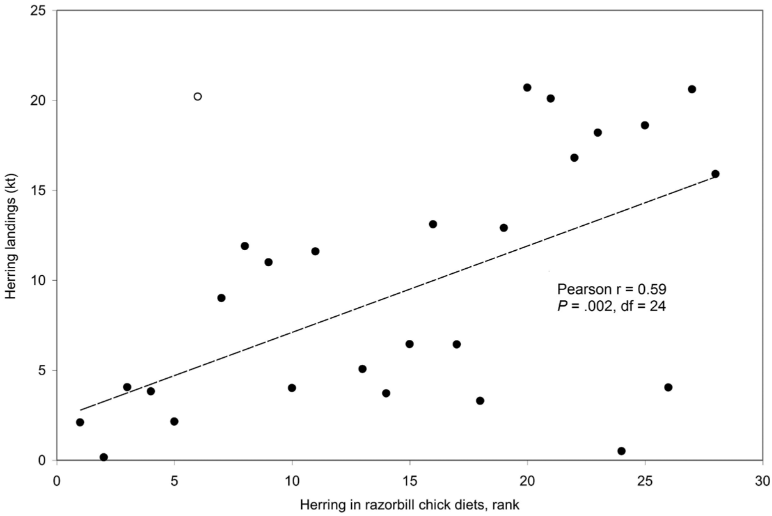


Fig 4 Association between the landings of juvenile herring and the relative quantities (ranks) of herring fed to razorbill chicks. Line – estimate of potential linearity, pretesting. Landings data, ages ~1-2+ from DFO (2018) and references. Diet data, ages ~1(-2). Open circle, prospective outlier excluded.

landings dwindled in and contiguous with the GoM region (Melville 2018); mortalities have probably resulted from poor nutrition, ultimately because of herring over-fishing. Alternate prey such as mackerel (*Scomber scombrus*) and pollock (*Pollachius virens*) for larger predators are even less abundant because of over-fishing (e.g., Sosebee 2022).

This commentary contributes independently to the continued development of potential ecosystem-based inputs (Cury *et al.* 2008), by non-fishery research, to herring fishery models. Archibald *et al.* (2021) conclude that progress is slow if not inadequate in the implementation of institutional tools to ensure a precautionary approach in Canadian fisheries management. Barnett and Anderies (2014) indicate that by restricting decision-making through centralization, the process fails to recognize the rights of individuals to organize and make collective choices. Often, ‘jobs’ becomes the ‘straw man’, deflecting attention away from the fact that a smaller number of well-compensated individuals make decisions which disrupt the long-term security of a great many hands-on fisherfolk. Security is obtained by way of broadly-based integrated social, economic and ecological structures (e.g. Andrews and Knott 2023) accommodating hands-on people who steward the conservation of marine ecosystems and resources. Some researchers go so far as to argue that tangible indicators of sense of place support the management of social-ecological systems (Knaps *et al*. 2022), which in this case would focus on herring fisheries. What better indicator to convey meaningfulness with respect to sense of place than a fuzzy razorbill chick making its way on a pile of rock such as MSI (Fig 2)?

Without robust ecological conservation, there are no positive social, economic and governance fisheries outcomes. Ultimately, fisheries legislation must include explicit fundamental statements about 'fisheries in an ecosystem context'. To this point, my report also illustrates the potential for reciprocal non-fishery inputs to scientific knowledge, central to current incarnations of ocean literacy (Salazar *et al*. 2022). The seabird-herring example can be repeated by a competent naturalist with a computer, internet, basic statistical skills and an interest in the subject. Furthermore, science-based approaches must be solid before other knowledge – experiential, local, and cultural – can be effectively incorporated into fisheries management.

A hint of optimism, 'Old Thom', the Fundy male killer whale (*Orcinus orca*) made several brief late-summer forays north of Grand

Fig 5 Male killer whale Old Thom with white-sided dolphins in Canadian waters north of Grand Manan, August 2022. Photo – FTRWW.

Manan starting in 2022 (Fig 5), but had not been reported there in previous years. He often appears to subsist on small schooling fish in the GoM, feeding with white-sided dolphins (*Lagenorhynchus acutus*). The northward excursions might be associated with a slight short-lived increase of local herring landings in the early 2020s. His movements have not included sightings to the NW in American waters, along the Maine coast; this absence was also observed in earlier years (Melville 2023).

Acknowledgements I thank everyone for providing logistical help, documents, photographs, and information leads. Thanks to Tony Diamond, UNB Fred., and BoFEP, for his interest in my presentation of this work. No funding was received.

REFERENCES

ALAR. (2023). www.msialar.wixsite.com/alar-msi/msi-summary-data

Andrews, E.J. & Knott, C. (eds.). (2023). Thinking big about small-scale fisheries in Canada. TBTI Global, St. John's, NL. 499 p.

Archibald, D.W., McIver, R. & Rangeley, R. (2021). The implementation gap in Canadian fishery policy: fisheries rebuilding and sustainability at risk. *Marine Policy* 129, 104490. doi:10.1016/j.marpol.2021.104490

ASMFC. (2024). Atlantic herring. Atlantic States Marine Fisheries Commission. Arlington. www.asmfc.org/contact/contact-us

Barnett, A.J. & Anderies, J.M. (2014). Weak feedbacks, governance mismatches, and the robustness of social-ecological systems: an analysis of the Southwest Nova Scotia lobster fishery with comparison to Maine. *Ecology and Society* 19: 39. doi:10.5751/ES-06714-190439

Cairns, D.K. (1987). Seabirds as indicators of marine food supplies. *Biological Oceanography* 5: 261-271.

Cury, P.M., Shin, Y-J., Planque, B., Durant, J.M., Fromentin, J-M., Kramer-Schadt, S., Stenseth, N.C., Travers, M. & Grimm, V. (2008). Ecosystem oceanography for global change in fisheries. *Trends in Ecology and Evolution* 23: 338-346.

DFO. (2023). Stock status update of 4VWX herring for the 2023 fishing season. DFO Canadian Science Advisory Secretariat Science Response 2023/026.

Diamond, A.W. (2021). Seabirds in a changing ocean: an overview of 20 years of research and monitoring on Machias Seal Island, Bay of Fundy, Canada. *Proceedings of the Nova Scotian Institute of Science* 51: 365-409.

Diamond, A.W. & Devlin, C.M. (2003). Seabirds as indicators of changes in marine ecosystems: ecological monitoring on Machias Seal Island. *Environmental Monitoring and Assessment* 188: 153-175.

Huntsman, A.G. (1953). Movements and decline of large Quoddy herring. *Journal of the Fisheries Research Board of Canada* 10: 1-50.

Knaps, F., Gottwald, S., Albert, C. & Herrmann, S. (2022). Using meaningful places as an indicator for sense of place in the management of social-ecological systems. *Ecology and Society* 27: 9. doi:10.5751/ES-13340-270409

Lotze, H.K. & Milewski, I. (2004). Two centuries of multiple human impacts and successive changes in a North Atlantic food web. *Ecological Applications* 14: 1428-1447.

MacKenzie, D. (2006). In: Evidence-FOPO-(39-1)-No.26-House of Commons of Canada. p. 7-9. www.ourcommons.ca/DocumentViewer/en/39-1/FOPO/meeting-26/evidence

McBride, A. (2023). Seabirds can help predict the size of fish stocks – if only we'd listen. *Hakai Magazine*. www.hakaimagazine.com/news/seabirds-can-predict-the-size-of-fish-stocks-if-only-wed-listen/

Melville, G.E. (2018). Atlantic herring (*Clupea harengus*) stock depletion off SW Nova Scotia and humpback whale (*Megaptera novaeangliae*) mortalities. In: J. McNeely *et al*. (eds.). Bay of Fundy Ecosystem Partnership Technical Report No. 11. Bay of Fundy Ecosystem Partnership, Tantallon, NS. p. 29-32. www.bofep.org/wp-bofep/wp-content/uploads/2018

Melville, G.E. (2023). Opportunistic observation effort and seasonal-spatial fidelity: a qualitative approach, applied to an *Orcinus orca* first record. *Journal of the Marine Biological Association of the United Kingdom* 103, e98: 1-11. doi:10.1017/S002531542300084X

Parsons, M., Mitchell, I., Butler, A., Ratcliffe, N., Frederiksen, N., Foster, S. & Reid, J.B. (2008). Seabirds as indicators of the marine environment. *ICES Journal of Marine Science* 65: 1520-1526. doi:10.1093/icesjms/fsb155

Salazar, J., Gili, J-M. & Vendrell, B. (2022). Ocean literacy: towards a science-literate society that is committed to the ocean. In: Pelegri J.L. *et al*. (eds.). Institut de Ciencies del Mar, Barcelona. doi:10.20350/digitalCSIC/14127

Scopel, L.C., Diamond, A.W., Kress, S.W., Hards, A.R. & Shannon, P. (2018). Seabird diets as bioindicators of Atlantic herring recruitment and stock size: a new tool for ecosystem-based fisheries management. *Canadian Journal of Fisheries and Aquatic Sciences* 75: 1215-1229. doi:10.1139/cjfas-2017-0140

Sosebee, K.A. (2022). United States research report for 2021. Northwest Atlantic Fisheries Organization NAFO SCS Doc. 22/14. 38 p.

Statistics Kingdom. (2017). www.statskingdom.com

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 99-107

OFFSHORE WIND ENERGY FOR NOVA SCOTIA: THE CHALLENGES AND THE OPTIONS

GRAHAM R. DABORN*

Acadia Centre for Estuarine Research
and Acadia Tidal Energy Institute,
Acadia University, Wolfville, NS

ABSTRACT

Concerns over the causes and effects of climate change have induced an enthusiastic political consideration of offshore wind developments in Nova Scotia. Marine wind turbine farms have been established elsewhere for more than 30 years, but they are a new venture for the Maritimes. Wind over the sea is often stronger, less turbulent and more consistent than over land, and there is also a growing demand for green hydrogen, that could be provided by the strong winds flowing over the Scotian Shelf. However, offshore wind development in Nova Scotia comes with significant challenges. The materials required for a wind farm and its installation (e.g. turbines, installation vessels etc.) currently need to be obtained from elsewhere. The article summarizes the results of a two year long Regional Assessment of the feasibility and acceptability of offshore wind development in Nova Scotia's waters.

INTRODUCTION

There is a prevailing irony in the Nova Scotia energy situation: in spite of having two world-class marine renewable energy sources surrounding the province – tidal energy in the Bay of Fundy and wind over the Scotian Shelf – we still generate almost half of our electricity from imported coal and petcoke (RA 2025). Fundy tidal power has been the focus of study for more than a century (Daborn *et al.* 2018) with only moderate success. Until recently, most wind energy exploitation has been on land. Wind blows over the sea more consistently and at higher velocities compared with that over land. However, there are significant challenges such as: conflicts with existing uses of the coastal region (e.g. fisheries and shipping); conservation concerns; the absence of capacity for manufacturing the

* Author to whom correspondence should be addressed: graham.daborn@acadiau.ca

needed wind farm components; the absence of a suitably trained workforce; the costs to upgrade port facilities and the electrical grid; uncertainty about the hazards for wildlife; and the social acceptability of wind turbines in view from the shoreline.

OSW developments in the North Sea have enabled several European countries – e.g. Denmark, Germany, United Kingdom, Norway etc. –to reduce their dependence on imported fossil fuels significantly, and have led to expectations that OSW generation there could increase from c. 280 GW in 2023 to >500 GW by 2030 (Wind Europe 2024). In North America expectations for OSW were increasing rapidly until 2024, when rising costs and approval delays began to increase (e.g. Musial *et al.* 2023). The recent US Presidential ban on future offshore wind lease approvals is likely to reduce activity in the industry significantly, although it is unclear whether existing leases awarded in New England will be affected (McCoy *et al.* 2024, Wasser 2025, Westwood Energy 2025). The political uncertainty may induce some developers to look to Nova Scotia for opportunities.

The recently-completed Regional Assessment of Offshore Wind Development in Nova Scotia (RA 2025) examined opportunities, issues and challenges related to OSW in the region, with a focus on a ~300,000 km^2 Study Area (Fig 1). Over 22 months the Committee

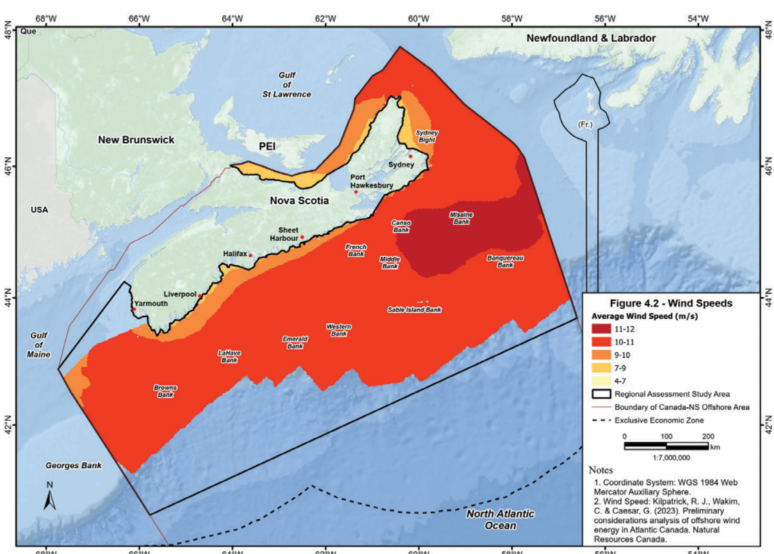


Fig 1 Study area for the Regional Assessment of OSW in Nova Scotia. (Source: Natural Resources Canada).

held 25 open public meetings, and many specialized meetings with knowledge-holders including First Nations, government departments, municipal governments, universities and representatives of fishers and the energy industry. We also engaged with experts from European and US OSW energy organizations, to investigate the socio-economic implications for Nova Scotia.

The Committee concluded that: a) there is substantial potential for energy production from wind over the Scotian Shelf, although little capacity to absorb it in the existing grid; b) there is very limited capacity within the Province at present to provide the equipment and skills needed for production and installation of wind farm components; c) there are significant potential environmental and socioeconomic conflicts with existing users of these coastal waters; and d) at present there is limited enthusiasm within local communities for a major development of OSW. It was also evident that the majority of people who participated, including fishers, accepted the urgent need for Nova Scotia to wean itself from fossil fuels, and recognised the potential of OSW to fill that role.

TECHNICAL ISSUES

There is no doubt that OSW development is technically feasible. OSW farms are rapidly developing around the world, using essentially the same design: a 3-bladed propeller-driven generator installed on a tall column called a *monopile,* and suitable for depths <60 m. Newer floating designs can be installed in much deeper water. Most existing turbines are rated at 6-14 MW, but turbines up to 24 MW maximum, with blades exceeding 120 m in length, are in development. Although the Scotian Shelf has extensive shallow banks, there are also areas of greater depth which may be more acceptable for reasons of conflict (e.g. with some fishing activities) or proximity to shore. These would likely require the floating designs which are considerably more expensive (Wind Europe 2024).

The wind regime on the Scotian Shelf is exceptionally suitable for wind farms further away from shore, to the east (i.e toward Banquereau Bank and Sable Island Bank) as average wind speeds are estimated[1] at 10-12 $m.s^{-1}$. These are far higher than over the adjacent land and similar to those in the North Sea. Substrate conditions vary across

[1] Reference height: 100 m.

the Shelf from relatively mobile sands and gravels to rock. However, many areas have not been studied enough to determine the feasibility of grounded or floating wind farms (Philbert *et al.* 2024, RA 2025).

The Province has set a clear target of 5 GW generation from OSW by 2030 (NSNRR 2022). Since the grid only requires 600-800 MW to replace its fossil fuel consumption, the excess is predicated on potential sales of green hydrogen. The RA Committee identified eight areas (Fig 2) that appeared to have appropriate depths and substrates together with relatively low levels of conflict with other activities – as far as these could be determined from data provided. These "potential development areas" are divided into 2 tiers. Tier 1 sites appear to have minimal conflict with other activities. Tier 2 sites were recognised as also possible, but more information is required on them. Because of the extensive use of nearshore waters for fishing, shipping, and recreation (etc.), the Committee recommended that a 25 km 'buffer zone' should be established along the coastline that would not be for wind farms. The Province, however, has not endorsed this recommendation.

ENVIRONMENTAL ISSUES

Large wind farms on the Scotian Shelf raise numerous issues. The Shelf is an extremely rich ecosystem that supports a wide variety

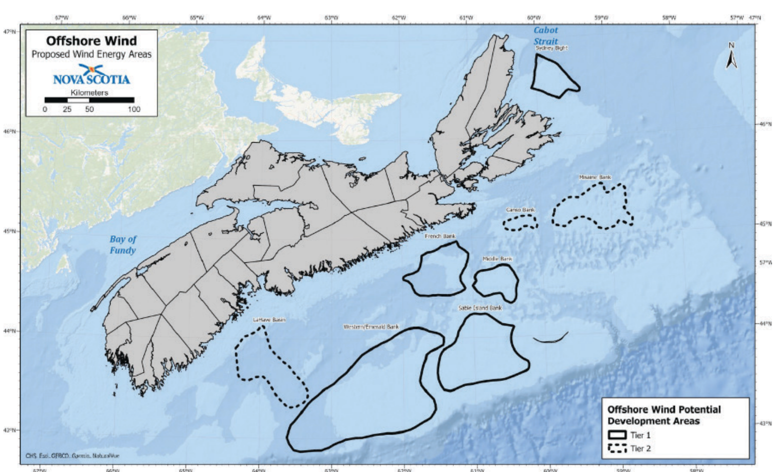


Fig 2 Potential Development Areas for OSW suggested by the RA Committee. (Source: Natural Resources and Renewables Nova Scotia)

of species, some of which are considered at risk, and others that are important for human use – especially fishing. Given Canada's commitment to conserve 30% of its ocean ecosystems by 2030 (DFO 2024) there is a potential conflict between OSW development on the Shelf and existing or proposed conservation areas (RA 2025). The high productivity of the Shelf ecosystem attracts migratory species from across the globe, and is also the economic mainstay of the Nova Scotia economy through its fisheries. However, ocean warming in the region is causing shifts in distribution of several important species.

Direct mortality of wildlife from OSW turbines is being studied. The primary victims are thought to be bats and birds (Zimmerling and Francis 2016, Guest *et al.* 2022, RA 2025) as a result of direct contact with moving blades. However, monitoring of bird movements in the North Sea suggests that the vast majority of birds, whether on migration or foraging, tend to avoid – or at least evade[2] – turbines (ADGC 2024). Finally, turbines may offer feeding, mating or roosting opportunities (Good *et al.* 2022).

The implications of OSW development for fish and marine mammals are much more complex. Some species will be attracted to new structures in the water, while noise, other vibrations and EMFs may deter other species. Fishery techniques vary widely. Long-line fisheries for tuna, swordfish etc., are clearly problematical in the vicinity of a wind farm because of the great length of trailing gear (up to 50 km) that could become caught in OSW structures, especially the mooring cables of floating designs. Dredge-based fisheries may or may not be affected, depending upon the substrate, electrical cables and distances between structures of the farm. Static fisheries, based upon traps or drift nets, or aquaculture, may be possible within a wind farm area, and may benefit from the 'reef effect' that many anthropogenic structures provide.

Capturing some of the wind energy over the Shelf has the potential to modify environmental conditions, especially the turbulent mixing of surface waters which are the basis of productivity, thereby changing the food web.

Planning for any wind farm involving a large number of turbines requires an assessment of the effects of one turbine on the operational

[2] For the distinction see May, R.F. 2015. A unifying framework for the underlying mechanisms of avian avoidance of wind turbines. Biological Conservation 190: 179-187.

efficiency of the next turbine located downwind. The same applies between wind farms: the output of an established wind farm can be reduced if a subsequent wind farm is installed on the upwind side within 30 to 50 miles (Ouro *et al.* 2024, 2025).[3] This needs to be considered at the planning phase of any offshore development.Existing wind farms in the North Sea vary in area from 10 km^2 to >450 km^2 (Nøst 2025). Economic returns tend to favour larger turbine sizes and number, with correspondingly greater distances between turbines, thereby increasing the potential conflicts between OSW and existing fisheries (RA 2025).

SOCIO-ECONOMIC ISSUES

Because of the fundamental importance of the Scotian Shelf to the economy and social structure of the Province, large scale development of wind farms requires very careful assessment. As fisheries wax and wane, so do their supportive communities. A major uncertainty is that of climate change: several fishers reported evidence that their traditional stocks are changing in distribution – particularly moving north into cooler waters. Other activities that could be affected by OSW installations include shipping – both commercial and tourist-related – recreational boating, aquaculture, military exercises and mining.

OSW developments require substantial investment in land-based facilities: ports, harbours, transportation corridors, storage and preparation areas, grid upgrades (etc). All these activities offer the potential for new economic input to communities in the Province. The RA concluded that none of the ports in Nova Scotia currently has the facilities to support the needs of the proposed 5 GW OSW developments, although both Sydney and Halifax have started to transition by servicing the developments in New England.[4] Upgrading their facilities for lay-down and assembly of turbines and accommodation of large vessels associated with assembly and deployment (etc.) could exceed 0.8 B $Can. Upgrading Nova Scotian ports would provide other benefits that include: enhancement of shipping and port capabilities, many thousands of jobs, and demands for more technical training. These may well compensate for any loss of existing economic mainstays of communities such as the fisheries (RA 2025).

[3] See also: Accusations of offshore wind theft hurled across North Sea – RenewEconomy.

[4] A necessity of the US Merchant Marine Act (1920) (a.k.a. the Jones Act).

RECOMMENDATIONS

In reviewing the existing state of knowledge and listening to numerous people, communities (including especially Mi'kmaq communities) and organizations that have an interest in Nova Scotia's marine environment, the RA Committee made 35 recommendations. These were listed under 7 categories: Existing knowledge gaps and necessary research; Socioeconomic feasibility and consequences; Project development; Coexistence and compensation; Cumulative effects; Governance; and Education and training. In reviewing the state of existing knowledge, the Committee determined that, despite broad capabilities for research and monitoring in several government agencies, academia and some industries, all the information necessary to assess environmental feasibility and effects is not yet available. It was recommended, therefore, that a co-ordinated research programme, entitled the Scotian Shelf Collaborative Research Initiative, should be established to combine the capabilities of all government agencies, universities and other knowledge-holders in the region. The objective is to ensure that future decisions regarding OSW in the region will be based on sufficient knowledge of the environmental and social implications of wind farm developments in the province, particularly recognising the potential impacts of climate change.

Other recommendations emphasize the need for accelerated training programmes, the development of consultation and management mechanisms involving First Nations and other communities, and policies related to long-term planning and compensation for losses. In general the Committee was satisfied that offshore wind from the Scotian Shelf is a viable and available renewable energy resource. However, careful, well-integrated planning is an absolute necessity to ensure that the huge investments required can be recovered, and the environmental and social implications are well understood before commitments are made.

Acknowledgements The RA Committee consisted of 5 people: Co-Chairs Ann Wilkie and James Wooder, Elder Lorraine Whitman, Stephen Parsons and the author. The Committee is indebted to the members of the Secretariat, whose knowledgeable and dedicated work made the completion of this project possible: Co-Chairs Carys

Burgess (IAAC) and Janice Ray (CNSOPB, now CNSER), Sydney Allen, Jeff Janes, Sara Lax, and Andrew Walter – all of IAAC.

The Committee also very much appreciated the contributions made by numerous knowledge-holding groups including First Nations, Advisory Group members, industry and fishers – especially the Nova Scotia Fisheries Alliance for Energy Engagement, which was created by local fishers to contribute to the Committee's deliberations, and the Guysborough County Inshore Fishermen's Association. We are much indebted to all of these people who gave of their time, data and opinions.

REFERENCES

ADGC (Avian Displacement Guidance Committee). (2024). Guidance for pre- and post-construction monitoring to detect changes in marine bird distributions and habitat use related to offshore wind development. Report to the OSW Environmental Technical Working Group. 100 p. www/nyetwg.com/avian-displacement-guidance.

Chirosca, A-M., Rusu, L. & Bleoju, A. (2022). Study on wind farms in the North Sea area. *Energy Reports* 8, Suppl. 16: 162-168.

Creech, A.C.W., Fruh, W-G. & Maguire, A.E. (2013). High resolution CFD modelling of Lillgrund wind farm. Proc. International Conference on Renewable energies and Power Quality, Bilbao, Spain. 6 p.

Daborn, G.R., Viehman, H. & Redden, A.M. (2018). Marine Renewable Energy in Canada – A Century of Consideration and Challenges. In The Future of Ocean Governance and Training. Essays in Honour of Elisabeth Mann Borgese. International Oceans Institute – Canada. Werle, D. *et al.* (eds.). Brill. p. 388-393.

DFO. (2024). Protecting Canada's Oceans by 2030 and beyond. Protecting Canada's oceans by 2030 and beyond.

Good, R.E., Iskali, G., McDonald, T., Durbridge, K., Azeka, M. & Tredennik, A. (2022). Curtailment and acoustic deterrents reduce bat mortality at wind farms. *Journal of Wildlife Management.* 86(6). e22244.

Guest, E.E., Stamps, B.F., Durish, N.D., Hale, A.M., Hein, C.D., Morton, B.P., Weaver, S.P. & Fritts, S.R. (2022). An updated review of hypotheses regarding bat attraction to wind turbines. Animals (Basel) 2022. February 12(3). 24 p.

McCoy, A., Musial, W., Hammond, R., Hernando, D.M., Duffy, P., Beiter, P., Perez, P., Baranowski, R., Reber, G. & Spitsen, P. (2024). Offshore Wind Market Report 2024. National Renewable Energy Laboratory. NREL/TP-5000-90525. www.nrel.gov/docs/fy24osti/90525.pdf.

Musial, W., Spitsen, P., Duffy, P., Beiter, P., Shields, M., Hernando, M.D., Hammond, R., Marquis, M., King, J., & Sriharan, S. (2023). Offshore Wind Market Report 2023. U.S. Dept. Energy, Office of Energy Efficiency and Renewable Energy DOE/GO-102023-6059. www.energy.gov/sites/default/files/2023-09/doe-offshore-wind-market-report-2023-edition.pdf

Nøst, O.A. (2025). Power production and area usage of offshore wind and the relationship with available energy in the atmosphere. PLoS One 20(5): e0321528. doi.org/10.1371/journal.pone.0321528

Nova Scotia Natural Resources and Renewables. (2022). Province sets Offshore Wind Target. Province Sets Offshore Wind Target | Government of Nova Scotia News Releases.

Ouro, P., Fernandez, R., Armstrong, A., Brooks, B., Burton, R.R., Folkard, A., Ilic, S., Parkes, B., Schulz, D.M., Stallard, T. & Watson, F.M. (2024). Environmental impacts from large-scale offshore renewable-energy deployment. Env. Res. Letters 19: 14 p. doi.org/10.1088/1748-9326/ad4c7d.

Ouro, P., Ghobrial, M., Ali, K. & Stallard, T. (2025). Numerical modelling of offshore wind-farm cluster wake. *Renewable and Sustainable Energy Reviews* 215 Article 115526. doi.org/10.1016/j.rser. 2025 115526.

Philbert, B., Todd, B.J., Campbell, D.C., King, E.L., Normandeau, A., Hayward, S.E., Patten, E.R. & Campbell, L. (2024). Updated surficial geology compilation of the Scotian Shelf bioregion, offshore Nova Scotia and New Brunswick, Canada. Rev. Geological Survey of Canada. Open File 8911, 31.

RA. (2025). Regional Assessment for Offshore Wind Development in Nova Scotia. Final Report to the Ministers for Environment and Climate Change Canada, Natural Resources and Energy. 535 p.

Wasser, M. (2025). Trump's pause on offshore wind leasing may have limited impact in New England. WBur News. 23 January 2025.

Westwood Energy. (2025). Unlocking the potential of offshore wind. www.westwoodenergy.com/news/westwood-insight/westwood-insight-unlocking-the-potential-of-floating-offshore-wind?

Wind Europe. (2024). Wind energy in Europe: 2023 statistics and outlook for 2024-2030. 56 p. Wind energy in Europe: 2023 Statistics and the outlook for 2024-2030 | WindEurope.

Zimmerling, J.R. & Francis, C.M. (2016). Bat mortality due to wind turbines in Canada, *Journal of Wildlife Management.* 80(8): 1360-1369.

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 109-110

OUR NEW HONORARY NSIS MEMBERS – 2025

In recognition of their outstanding contributions to science, two Nova Scotia scientists were elected by the NSIS Council in 2025 as Honorary Members of the Nova Scotian Institute of Science.

Dr. Zoe Lucas of the Sable Island Institute is recognized for her lifelong outstanding contributions to the study and protection of Sable Island's terrestrial ecosystems. She has spent over 50 years dedicated to the study and protection of the island, a unique ecosystem in the Northwest Atlantic. Through experiential learning and immersive, hands-on engagement, she transitioned from a background in goldsmithing and art to become a leading biological scientist and nature historian. Her extensive research spans topics such as the island's iconic horses, the impacts of marine litter, marine biodiversity, and ecological monitoring, resulting in numerous scientific publications and impactful outreach. Dr. Lucas has collaborated with dozens of scientists and students. She founded both the Friends of the Green Horse Society and the Sable Island Institute to support education, research, and conservation. Recognized with numerous awards, including an honorary doctorate from Dalhousie University and the Order of Canada, she is widely regarded as the foremost expert and unofficial steward of Sable Island.

Dr. John Young has made many significant contributions to science in Nova Scotia and beyond for more than 50 years. His academic contributions in mathematics and chemistry extend over 75 years, a landmark achievement! One of his many notable impacts was pioneering a computer-linked chemistry teaching laboratory at Saint Mary's University (SMU) and at the National Teacher Training Institute in The Gambia, West Africa in 1997. In addition to many years of successful teaching at SMU, during which he received many awards for teaching and student development, he had many senior administrative roles and was a prolific researcher and publisher. In recent years, his research has focused on improving standard chemical assessments and analytical tests, the results of which have been published in *Chemistry Educator* and widely read. He published three papers in his 95th year, a truly astonishing achievement. He is a long standing member of the NSIS and was a member of its Council from 2011 to 2017. John has an outstanding scientific research and academic record, with many contributions to the advancement of science, technology innovation and education, both globally and in Nova Scotia.

Compiled with assistance by
Peter G. Wells, Editor, PNSIS

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 111-134

MULTIPLEX PCR FOR SPECIES-LEVEL DISCRIMINATION OF YELLOW LAMPMUSSEL (*LAMPSILIS CARIOSA* (SAY, 1817)) AND TIDEWATER MUCKET (*ATLANTICONCHA OCHRACEA* (SAY, 1817))

SOPHIA BUTLER-DOUCETTE, KELLIE WHITE
AND TIMOTHY A. RAWLINGS*

Department of Biology, Cape Breton University
Sydney, NS B1P 6L2

ABSTRACT

Effective management of imperiled freshwater mussel populations (Order Unionida) is dependent on accurate field identifications. Standard methods of identifying living mussels utilizing external shell characteristics, however, can be unreliable for some species given high levels of phenotypic plasticity and morphological overlap with other taxa. In Canada, Yellow Lampmussel (*Lampsilis cariosa* (Say, 1817)), a species of Special Concern, is limited in distribution to isolated populations within Nova Scotia and New Brunswick. Efforts to monitor this species can be complicated by difficulties in distinguishing Yellow Lampmussel from the Tidewater Mucket (*Atlanticoncha ochracea* (Say, 1817)). Both species are known from the Saint John River and its tributaries in New Brunswick and are also sympatric within the Sydney River watershed in Nova Scotia. In our survey of biology students and faculty at Cape Breton University, participants correctly identified these two species based on photographs of external shells only 61.7% of the time, with even the most experienced individuals achieving a success rate of just 68.8%. To facilitate species-level identification, here we have developed a simple genetic-based tool to differentiate between live Yellow Lampmussel and Tidewater Mucket. Using custom-designed primers and a single multiplex PCR reaction, the identity of these two species can be determined based on amplification product size. This tool should be of enormous value to freshwater mussel ecologists working to monitor Yellow Lampmussel populations and to explore other aspects of their biology and ecology.

Keywords: Freshwater mussels, Unionida, Yellow Lampmussel, Tidewater Mucket, Multiplex PCR

* Author to whom correspondence should be addressed: timothy_rawlings@cbu.ca

INTRODUCTION

Freshwater mussels are among the most threatened taxonomic groups worldwide, with populations declining due to habitat loss, introduction of non-native species, and pollution (Lopes-Lima *et al.* 2018). More than half of all freshwater mussel species are considered Near Threatened, Vulnerable, or Endangered globally, and 7.7% are listed as Extinct (IUCN 2023). Given the important role of freshwater mussels within aquatic habitats and associated ecosystem benefits (Vaughn 2018), these species are in need of protection through targeted conservation and management plans (Haag and Williams 2014).

In the Canadian Maritimes, Yellow Lampmussel (*Lampsilis cariosa* (Say 1817)) is one of ten freshwater mussel species present and has been listed as a species of Special Concern federally under Canada's Species at Risk Act (SARA) since 2005, with additional designations of Special Concern in New Brunswick and Threatened in Nova Scotia (Fisheries and Oceans Canada 2010, Government of Canada 2024, Nova Scotia Department of Natural Resources and Renewables 2022). Management and recovery plans have been implemented at both the provincial and federal levels to support remaining populations. In Canada, this species is limited to the Saint John River and its tributaries in New Brunswick, and the Sydney River watershed, including Blacketts Lake, Gillis Lake, Forresters Lake, and Pottle Lake, in

Fig 1 **Two Yellow Lampmussel from Blacketts Lake, Cape Breton, in the summer of 2023, showing intraspecific variation in colour, size, and shape. Upper mussel: female; lower mussel: male. Scale bar: 1.5cm.**

Nova Scotia (Martel *et al.* 2010, COSEWIC 2013, NS Department of Natural Resources and Renewables 2022) (Fig 1). Across its broader global range, spanning the Northeast Atlantic slope of North America from eastern Canada to 15 eastern U.S. states, Yellow Lampmussel is considered extirpated or possibly extirpated in several jurisdictions (NatureServe 2024).

Accurate species identification is essential for estimating freshwater mussel population sizes and distributions, which directly inform conservation status assessments and management plans (Fisheries and Oceans Canada 2010, Shea *et al.* 2011). For Yellow Lampmussel, field identification is especially challenging due to its close resemblance to Tidewater Mucket (*Atlanticoncha ochracea* (Say 1817)) and their overlapping distributions in the Saint John and Sydney River watersheds (Johnson 1947, Nedeau *et al.* 2000, Sabine *et al.* 2004, Martel *et al.* 2010, Fig 2). Both species exhibit considerable morphological variation in shell shape and colour, influenced by age, sex, and environmental factors such as water flow and substrate type (Mehlhop and Cifelli 1997, Haag 2012, Howells *et al.* 2017, Keogh 2023). This intraspecific variability, particularly between males and females and among individuals from different environments, results in substantial overlap in external shell traits and has long contributed to species-level confusion (Johnson 1947, Nedeau *et al.* 2000).

The presence of fine green rays on the shell is often cited as a distinguishing feature of Tidewater Mucket (e.g. Massachusetts Division of Fisheries and Wildlife, n.d.), but ray expression can vary and is absent in some populations, notably those in the Sydney River watershed of Nova Scotia, limiting its usefulness where the two species co-occur (Nova Scotia Department of Natural Resources and Renewables 2022). Similarly, a bronze tinge to the external shell is listed as a diagnostic feature in Maine populations of Tidewater Mucket. It is not observed in Yellow Lampmussel (Maine Department of Inland Fisheries and Wildlife 2003). However, this colour difference is not evident in Nova Scotia populations within the Sydney River watershed. Tidewater Mucket is also generally smaller than Yellow Lampmussel (Nedeau *et al.* 2000), but this feature is unreliable in practice, as juvenile Yellow Lampmussels can resemble small adult Tidewater Mucket. As such, field identifications based solely on external shell morphology and size remain problematic, particularly in areas of sympatry and for species of conservation concern.

Fig 2 Similarity between Yellow Lampmussel and Tidewater Mucket sampled in Blacketts Lake, Cape Breton, May, 2025. The Tidewater Mucket specimen is shown on the top right. Note the eroded shells. Scale bar = 2cm.

Although internal shell features, such as muscle scars, hinge shape, and hinge teeth, are generally considered more consistent than external characteristics for distinguishing species (Nedeau *et al.* 2000, McAlpine *et al.* 2018), they are only visible in cleaned, opened shells and require lethal sampling. One of the most noted internal differences between Yellow Lampmussel and Tidewater Mucket is the morphology and position of the pseudocardinal teeth relative to the umbo. In Yellow Lampmussel, these teeth are described as stout, conical, and located directly beneath the umbo, while in Tidewater Mucket, they are described as being thinner, more lamellate, and situated farther anterior to the umbo (Johnson 1947, Massachusetts Division of Fisheries and Wildlife, n.d., Nedeau *et al.* 2000, McAlpine *et al.* 2018). Another frequently cited internal trait is nacre coloration: Tidewater Mucket typically has pink or salmon-coloured nacre, while Yellow Lampmussel has white to bluish-white nacre (Nedeau *et al.* 2000, Massachusetts Division of Fisheries and Wildlife, n.d.). As these internal characteristics require destructive sampling or dead specimens to examine, their utility in conservation monitoring is limited. Moreover, these morphological distinctions have not yet been validated using genetically confirmed individuals, so their reliability remains untested.

Molecular genetic approaches, including DNA barcoding and molecular identification keys (MIKs), provide alternative means of discriminating between species that are similar morphologically, and can often be undertaken without destructive sampling (Gerke and Tiedemann 2001, Kneeland and Rhymer 2007, Boyer *et al.* 2011). Customized molecular tools can also be developed to discriminate between pairs of species that are challenging to tell apart, such as Yellow Lampmussel and Tidewater Mucket. For instance, when DNA sequences are known for a gene region of the two taxa in question, a multiplex Polymerase Chain Reaction (PCR) test can be developed as a quick tool for species-level discrimination (e.g., Marshall *et al.* 2007). In multiplex PCR, custom primers for each species are included in the PCR reaction so that the DNA of each species can be amplified using the same starting mix. Because the positioning of primers is different for each species, the size of the amplification product determines the source DNA. These tests, therefore, only require a simple PCR test for the unknown sample, with subsequent screening for the size of the PCR product using agarose gel electrophoresis. As such, this method can provide a quick and reliable visual guide for differentiating between two species without requiring further downstream processing (e.g., DNA sequencing) of the PCR product (Marshall *et al.* 2007).

To implement an efficient and effective management plan for the Yellow Lampmussel, a reliable method is needed to distinguish this species from the morphologically similar Tidewater Mucket. Misidentifications can lead to overestimating Yellow Lampmussel population sizes, potentially undermining conservation efforts (Shea *et al.* 2011, Willsie *et al.* 2020). Although trained freshwater mussel ecologists may achieve higher rates of correct identification, field surveys are often conducted by individuals with varying levels of expertise (e.g., Willsie *et al.* 2020). Moreover, even with trained observers and quantitative morphometric tools, morphology alone may be insufficient to resolve closely related or cryptic species, further reinforcing the need for molecular confirmation (Keogh and Simons 2019)

Here, we present a customized multiplex PCR assay to reliably discriminate between Yellow Lampmussel and Tidewater Mucket using non-destructive mantle swabs from live mussels. To directly evaluate the reliability of field-based species identifications, we also conducted a survey assessing participants' ability to distinguish these two species based on photographs of external shell features traditionally used to identify mussels under field conditions. Survey results confirmed that these species are frequently confused, even among participants with field experience, demonstrating the importance of molecular confirmation to ensure accurate species assignments in conservation monitoring.

METHODS

Development of a Customized Multiplex PCR Assay

To develop a multiplex PCR assay, we targeted the mitochondrial (mt) NADH dehydrogenase subunit 1 (ND1) gene – a fast evolving protein-encoding region of the mt genome – using an existing dataset of ND1 sequences encompassing all ten extant species of freshwater mussels in the Canadian Maritimes, including Yellow Lampmussel (*Lampsilis cariosa*), Eastern Lampmussel (*Lampsilis radiata* (Gmelin 1791)), Tidewater Mucket (*Atlanticoncha ochracea*), Eastern Pearlshell (*Margaritifera margaritifera* (Linnaeus 1758)), Brook Floater (*Alasmidonta varicosa* (Lamarck 1819)), Triangle Floater (*Alasmidonta undulata* (Say 1817)), Alewife Floater (*Utterbackiana implicata* (Say 1829)), Eastern Elliptio (*Elliptio complanata* (Lightfoot 1786)), Eastern Floater (*Pyganodon cataracta* (Say 1817)), and Creeper (*Strophitus undulatus* (Say 1817)) (Rawlings and White 2022, Ryan 2022). Our assay comprised two species-specific forward primers positioned within the ND1 gene and a common reverse primer. The reverse primer selected was a variant of the unionid-specific primer, LoGlyR, used broadly in conjunction with unionid-specific primer, Leu-uurF, to amplify the ND1 gene and portions of two neighbouring tRNA genes (Serb *et al.* 2003). To develop the species-specific forward primers, we generated an alignment of all ND1 sequences of Yellow Lampmussel and Tidewater Mucket samples from multiple locations within the Canadian Maritimes (Table 1), and then selected regions spanning 18-22 base pairs that were invariant within each species, but different between species. Candidate primers were then tested against an alignment of ND1 sequences of all ten extant species of freshwater mussels in the Canadian Maritimes to test for non-target primer binding using Geneious Prime (v. 2023.1.1). When selecting custom forward primer sequences, we targeted primers with the following criteria: 1) each was 18-22 base pairs long, with a melting temperature between 50-60°C; 2) primers had a melting temperature within 5°C of each other;

3) each primer had a minimum of 4 mismatches with non-target species of freshwater bivalves, and base mismatches were near the 3' end of the sequence; and 4) PCR products differed in size between the two species when used in conjunction with the common reverse primer (ND1R-FWBIV). For the final vetting of custom forward primers, *in silico* testing was undertaken across all 10 species of freshwater bivalves spanning numerous localities within the Maritimes (Table 1) to determine the number of base-pair mismatches with non-target sequences and the size of PCR products, if amplified. We also tested these primers against the Dwarf Wedgemussel, (*Prolasmidonta heterodon* (I. Lea 1829)), historically present in the Canadian Maritimes, but now believed to be extirpated (COSEWIC 2000).

Validation of Multiplex PCR A*ssay*

Sample selection for *in vitro* testing: To validate the multiplex assay, we tested the assay on 5 Yellow Lampmussel and 5 Tidewater Mucket samples from the Canadian Maritimes, as well as 8 non-target species (Table 1). DNA for these samples was extracted between 2017-2022 from field-collected brush swab samples from sites in Nova Scotia and New Brunswick, as well as ethanol-preserved tissue samples collected across the Maritimes on loan from the New Brunswick Museum. The species identity of each of these samples was confirmed through DNA sequencing of PCR products, with subsequent phylogenetic analyses undertaken with additional sequences from GenBank to confirm the expected placement of these sequences within their species-specific lineages.

In the summer and fall of 2023, we also collected new tissue samples from Yellow Lampmussel and Tidewater Mucket from Blacketts Lake in Cape Breton, NS, in order to compare field-based identifications with species identifications resulting from our multiplex PCR assay. A total of 54 mussels were collected and identified to species in the field using shell and soft tissue features by one of us (Kellie White) with > 25 years of experience working with freshwater mussels in Canada. Specimens were photographed, sampled for DNA using a brush swab (see below) and then returned to the sediment. Of these specimens, 37 were given provisional field identifications of Yellow Lampmussel, and 17 were identified as Tidewater Mucket. Additional mussels were collected and brought back to the lab for photography and species confirmation using our assay. Photographs

Table 1 **Location and source of samples used in the development and testing of multiplex PCR assay for each of the 10 extant freshwater mussel species in the Canadian Maritime, and the Dwaft Wedgemussel (*Prolasmidonta heterodon)* historically present in this region. For each sample, we indicate the type of testing (*in-silico* and/or *in-vitro*) that was undertaken. GenBank numbers for DNA sequences used in *in silico* tests for each species are: *Atlanticoncha ochracea (*EF446103; PQ015210- PQ015217); *Lampsilis cariosa (*EF446096; PQ015218 - PQ015222); *Alasmidonta undulata* (EF446104; PQ015239 - PQ015242); *Alasmidonta varicosa (*EF446103; PQ015243 - PQ015257); *Elliptio complanata (*EF446099; PQ015230 - PQ015231 ; PQ015233 - PQ015238); *Lampsilis radiata* (EF446098; PQ015223 - PQ015229); *Margaritifera margaritifera (*EF446105; PQ015278 - PQ015287); *Prolasmidonta heterodon* (MG905826); *Pyganodon cataracta (*EF446102; PQ015268 - PQ015275); *Strophitus undulatus* (EF446100; PQ015276 - PQ015277); *Utterbackiana implicata (*EF446101; ON952510; PQ015258; PQ015260-PQ015262; PQ015264 - PQ015267). No detailed locality information was available for GenBank samples from Maine and Delaware, and a specimen of *Lampsilis cariosa* from the Saint John River. Abbreviations: NBM - New Brunswick Museum; CBU - Cape Breton University Collection.**

Species	Sample Locality	Province/State	Latitude, Longitude	Sample Source	Test Type
Target Species					
Atlanticoncha ochracea					
	Maine, USA*	ME	-	GenBank	*In-Silico*
	Canaan River	NB	45.93906, -65.74627	NBM-010238	*In-Silico* & *In-Vitro*
	Grand Lake	NB	45.94985202, -66.07231793	CBU	*In-Silico* & *In-Vitro*
	Middle Island, Saint John River	NB	45.8814, -66.42207	NBM-010227	*In-Silico* & *In-Vitro*
	Blacketts Lake	NS	46.06939, -60.30711	CBU	*In-Silico* & *In-Vitro*
	Joe's Lake	NS	46.06758, -60.215123	CBU	*In-Silico* & *In-Vitro*
Lampsilis cariosa					
	Maine, USA*	ME	-	GenBank	*In-Silico*
	Canaan River	NB	45.93906, -65.74627	NBM-010237	*In-Silico* & *In-Vitro*
	Saint John River*	NB	-	CBU	*In-Silico* & *In-Vitro*
	Blacketts Lake	NS	46.06939, -60.30711	CBU	*In-Silico* & *In-Vitro*
	Forresters Lake	NS	46.1412, -60.345	CBU	*In-Vitro*
	Pottle Lake	NS	46.204, -60.291261	CBU	*In-Silico* & *In-Vitro*

Non-Target Species					
Alasmidonta undulata					
	Maine, USA*	ME		GenBank	*In-Silico*
	Miramichi Lake	NB	46.4632, -66.96608	NBM-011251	*In-Silico*
	Petitcodiac River	NB	45.99774, -65.09127	NBM-011061	*In-Silico*
	Gays River	NS	45.03773, -63.369525	CBU	*In-Silico* & *In-Vitro*
Alasmidonta varicosa					
	Maine, USA*	ME	-	GenBank	*In-Silico*
	Bouctouche River	NB	46.35775, -64.899861	NBM-009147	*In-Silico*
	North River	NB	45.96151, -65.19885	NBM-011201	*In-Silico*
	East St. Mary's River	NS	45.391562, -62.253493	CBU	*In-Silico* & *In-Vitro*
	Gays River	NS	45.03773, -63.369525	CBU	*In-Silico*
Elliptio complanata					
	Maine, USA*	ME	-	GenBank	
	Middle Island, Saint John River	NB	45.8814, -66.42207	NBM-010226	*In-Silico*
	Miramichi Lake	NB	46.45713, -66.95721	NBM-011211	*In-Silico*
	North River	NB	45.93924, -65.1992	NBM-011188	*In-Silico*
	Petitcodiac River	NB	46.0237, -65.0332	NBM-010475	*In-Silico*
	Fredericton, Saint John River	NB	45.946032, -66.631343	CBU	*In-Silico*
	Spednic Lake	NB	45.6202, -67.4308	NBM-010201	*In-Silico*
	Joe's Lake	NS	46.06758, -60.215123	CBU	*In-Silico* & *In-Vitro*
Lampsilis radiata					
	Maine, USA*	ME	-	GenBank	*In-Silico*
	Grand Lake	NB	45.94985202, -66.07231793	CBU	*In-Silico*
	Miramichi Lake	NB	46.4634, -66.9654	NBM-011217	*In-Silico*
	Fredericton, Saint John River	NB	45.946032, -66.631343	CBU	*In-Silico* & *In-Vitro*
	Fredericton, Saint John River,	NB	45.95286, -66.62533	NBM-010223	*In-Silico*

Table 1 cont'd

Species	Sample Locality	Province/State	Latitude, Longitude	Sample Source	Test Type
Margaritifera margaritifera					
	Maine, USA*	ME	-	GenBank	*In-Silico*
	Belleisle Creek	NB	45.6824, -65.73034	NBM-011038	*In-Silico*
	Bouctouche River	NB	46.357806, -64.931306	NBM-009659	*In-Silico*
	Spednic Lake	NB	45.69912, -67.49832	NBM-010203	*In-Silico*
	Midgell River	PEI	46.36109, -62.59462	NBM-010235	*In-Silico*
	Naufrage River	PEI	46.44364, -62.41484	NBM-010239	*In-Silico*
	Balls Creek	NS	46.15179, -60.303632	CBU	*In-Silico*
	Gays River	NS	45.03773, -63.369525	CBU	*In-Vitro*
	Margaree River	NS	46.42591, -61.088691	CBU	*In-Silico*
Prolasmidonta heterodon					
	Delaware River, USA	NY	41.86382, -75.23724	GenBank	*In-Silico*
Pyganodon cataracta					
	Maine, USA*	ME	-	GenBank	*In-Silico*
	Cocagne River	NB	46.328611, -64.834917	NBM-009664	*In-Silico*
	Second Fowler Lake	NB	46.81276, -66.45778	NBM-011050	*In-Silico*
	MacNeill's Pond	PEI	46.26521, -63.15782	NBM-011021	*In-Silico*
	Joe's Lake	NS	46.06758, -60.215123	CBU	*In-Silico*
	Loch Lomond	NS	45.75967, -60.599794	CBU	*In-Silico* & *In-Vitro*
	Rotary Drive	NS	46.12183, -60.181694	CBU	*In-Silico*
Strophitus undulatus					
	Maine, USA*	ME	-	GenBank	*In-Silico*
	Bouctouche River	NB	46.312333, -64.896222	NBM-009661	*In-Silico* & *In-Vitro*
	Miramichi Lake	NB	46.4632, -66.96608	NBM-011252	*In-Silico*

Utterbackiana implicata					
	Maine, USA*	ME	-	GenBank	*In-Silico*
	Little River	NB	46.02144, -65.02198	NBM-010477	*In-Silico*
	Middle Island, Saint John River	NB	45.8814, -66.42207	NBM-010224	*In-Silico*
	Miramichi Lake	NB	46.4634, -66.9654	NBM-011216	*In-Silico*
	Petitcodiac River	NB	45.99774, -65.09127	NBM-011069	*In-Silico*
	Fredericton, Saint John River	NB	45.946032, -66.631343	CBU	*In-Silico*
	Fredericton, Saint John River	NB	45.96467, -66.669801	GenBank	*In-Silico*
	Midgell River	PEI	46.35931, -62.59206	NBM-010232	*In-Silico*
	East St. Mary's River	NS	45.06272, -61.910788	CBU	*In-Silico* & *In-Vitro*

* No detailed locality information available.

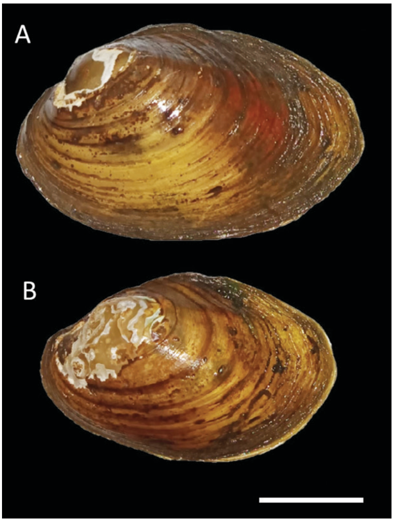


Fig 3 **Left valves of Yellow Lampmussel (A) and Tidewater Mucket (B) collected from Blacketts Lake in September, 2023. These photographs were used in the Mussel Identification Survey. Scale bar: 2cm.**

of these genetically-confirmed specimens were used in our Mussel Identification Survey (Fig 3).

DNA samples were collected from each mussel using a non-destructive technique (e.g., Karlsson *et al.* 2013, Massault *et al.* 2022). A dental brush (GUM Proxabrush®) was inserted into the mussel vertically between the valves and rotated 10 times in each direction. The brush was then removed and preserved in a 1.5 ml Eppendorf tube with 500µl of 95% ethanol. For photography, both in the field and in the lab, the right valve of each mussel was placed down on a whiteboard, so the left valve was facing the camera, and a piece of modelling clay was used to ensure each mussel was in a consistent position relative to the digital camera. A ruler was used for scale.

DNA extraction: DNA extraction for all samples was conducted using a QIAGEN DNeasy Blood and Tissue Kit following the manufacturer's instructions with slight modifications noted below. To prepare brush swabs for DNA extraction, the dental brush was removed from the ethanol and air dried for 2 hours. Brushes were then placed into sterile 1.5 ml Eppendorf tubes with 180µl ATL buffer and 20µl Proteinase K and incubated at 56°C for a minimum of 1 hour. After incubation, samples were spun down, and dental brushes removed from each tube and discarded. Recommended protocols of the kit were followed from this point onwards, with DNA eluted from each spin column in 75µl of AE Buffer. To ensure the successful extraction of high molecular weight DNA from each sample, 5µl of 1X DNA was mixed with 1.5µl of 6X loading buffer and loaded into a 0.8% TBE agarose gel stained with GelRed. Gel electrophoresis was carried out at 120V for 40 minutes. The gel was then imaged under UV light using AlphaImager™ to visualize the DNA bands associated with each sample.

Multiplex PCR testing on genetically-confirmed samples: To determine the success of our custom-designed multiplex PCR assay, we tested this on genetically-confirmed samples of Yellow Lampmussel, Tidewater Mucket, and Eastern Elliptio from the Canadian Maritimes. PCR amplifications were carried out in 25µl reactions for each DNA sample using GoTaq 2X Master Mix (Promega). Initial reactions contained 10µl of water, 0.5µl of 10µM LC-ND1-F primer, 0.5µl of 10µM AO-ND1-F primer, 0.5µl of 10µM ND1R-FWBIV universal primer, 12.5µl of GoTaq 2X Master Mix, and 1µl of 1X DNA. Samples were amplified using a BioRad T100™ thermal cycler under the following conditions: initial denaturation at 94°C for 30s, followed by 38 cycles of 94°C for 1min, 48-60°C for 30s, 72°C for 1min, and a final step of 72°C for 10min, before being held at 4°C upon completion. Gradient PCRs were conducted over a range of annealing temperatures (48°C, 50°C, 54°C, and 59°C) to establish an optimal annealing temperature in which DNA would amplify the target Yellow Lampmussel and Tidewater Mucket samples only. Negative controls were run with each batch of DNA samples. To visualize the results of each amplified DNA sample, 5µl of each sample was mixed with 1.5µl of 6X loading dye and loaded into its respective well in a 1% TBE agarose gel stained with GelRed. Gel electrophoresis and imaging was carried out as described above.

Multiplex PCR testing on non-target species: To determine if our multiplex PCR assay would amplify non-target species found in the Canadian Maritimes, we conducted additional multiplex PCRs using genetically-confirmed DNA samples of the 8 non-target species currently present in the Maritimes. PCR protocols for non-target taxa and all subsequent multiplex assays were conducted using the Q5® High-Fidelity 2X Master Mix (New England BioLabs) due to limited availability of GoTaq 2X Master Mix for purchase. PCR reactions comprised 8.75µl of water, 1.25µl 10µM LC-NDI-F, 1.25µl

10µM AO-ND1-F, 1.25µl 10µM ND1R-FWBIV, 12.5µl of Q5 Hot Start High-Fidelity 2X Master Mix, and 1µl of 1/10X DNA. Samples were then placed in the thermocycler where they underwent initial denaturation at 98°C for 30s, followed by 30 cycles of 98°C for 10s, 59°C for 30s, 72°C for 30s, and a final step of 72°C for 2 min before being held at 4°C upon completion. After PCR, 5 µl of each sample underwent gel electrophoresis as previously described to determine if a PCR product(s) was evident for each species sampled and to gauge the approximate size.

Multiplex PCR on new Yellow Lampmussel and Tidewater Mucket samples: Once the primer sets had been validated, we applied this assay to DNA extracted from brush swab samples of Yellow Lampmussel and Tidewater Mucket collected from Blacketts Lake in 2023. DNA was amplified using protocols for the Q5® High-Fidelity 2X Master Mix before undergoing gel electrophoresis as described above. Species identifications (either Yellow Lampmussel or Tidewater Mucket) were then made for each sample based on the resulting amplification product size. Although not all samples successfully amplified on the first attempt, all recalcitrant samples eventually amplified using a 1/10X dilution of our original DNA extraction and Q5 Master Mix.

Mussel Identification Survey

Considering the potential challenges of differentiating between Yellow Lampmussel and Tidewater Mucket based on external shell features alone, we developed a Mussel Identification Survey to assess the ability of participants to discriminate between these two species correctly. Twenty photographs of mussel shells with lab-confirmed identifications based on our multiplex PCR assay were compiled into an online quiz via Google Forms and sent to more than 30 biology students/faculty (past and present) who ranged in experience identifying mussels (Fig 3). The survey was voluntary, and participants were asked to provide their level of experience working with freshwater mussels (no experience, some experience, very experienced), and then to identify each photograph as either a Yellow Lampmussel or Tidewater Mucket based on external shell characteristics. Participants were provided with a field guide (McAlpine *et al.* 2018) to help them make this distinction. Results were then compiled, and the percentage of correct and incorrect identifications was determined.

Statistical analyses of survey results were completed using Minitab V21.1.0 to assess the accuracy of identifications using external shell characteristics and to explore any association between the experience level of participants and the accuracy of their identifications. A one-sample t-test was used to determine if there was a significant difference between the mean quiz score and the expectation based on chance (50:50), if each participant was randomly selecting the identity of each photo. A one-way ANOVA was also used to determine if there was a significant difference between experience level in identifying freshwater mussels and accuracy of identifications.

RESULTS

Custom Multiplex Primers and Expected Fragment Sizes

Using an *in-silico* approach, we developed species-specific forward primers for the ND1 region of Yellow Lampmussel and Tidewater Mucket that worked in combination with the common reverse primer, ND1R-FWBIV, to amplify PCR products 460 bp and 758 bp, respectively (Table 2 & 3). *In silico* testing of these primers against non-target species indicated a minimum 4 base mismatch with our custom forward primers (Table 3). Amplification product sizes differed for some of these taxa, providing additional hallmarks of non-target binding (see Table 3).

Table 2 Primer sequences used in the multiplex PCR assay, including a forward primer specific to Yellow Lampmussel (LC-ND1-F), a forward primer specific to Tidewater Mucket (AO-ND1-F), and a universal reverse primer (ND1R-FWBIV). Primers were designed using Geneious Prime (v. 2023.1.1).

Name	Species	Sequence (5’-3’)	Size	Direction
LC-ND1-F	*Lampsilis cariosa*	ATT CGC CTA GTT AAC TTC TC	20bp	Forward
AO-ND1-F	*Atlanticoncha ochracea*	TTC CTA CCA TTC ATC CTT AC	20bp	Forward
ND1R-FWBIV	All species	TGC TTG GAA GGC AAY TGT ACT	21bp	Reverse

Table 3 **Minimum number of base pair mismatches associated with species-specific forward primer binding to the ND1 sequence of each of the 11 freshwater mussel species historically recorded in the Canadian Maritimes. Also shown is the predicted size of the amplified product(s) generated using each forward primer in combination with the ND1R-FWBIV primer. Product sizes with primer mismatches of 8bp or more are not shown. *In silico* analyses of primer binding and PCR amplifications were generated in Geneious Prime (2023.1.1).**

Species	Mismatches with LC-ND1-F	Product Size	Mismatches with AO-ND1-F	Product Size
Alasmidonta undulata	8	N/A	5	732bp
Alasmidonta varicosa	7	440bp	6	731bp, 380bp
Atlanticoncha ochracea	7	467bp	**0**	758bp
Elliptio complanata	6	453bp	4	744bp
Lampsilis cariosa	**0**	460bp	4	751bp
Lampsilis radiata	4	460bp	4	751bp
Margaritifera margaritifera	8	N/A	6	747bp, 684bp
Prolasmidonta heterodon	8	N/A	8	N/A
Pyganodon cataracta	9	N/A	6	98bp
Strophitus undulatus	8	N/A	5	731bp
Utterbackiana implicata	7	439bp	6	730bp

In vitro Validation of Multiplex PCR Assay

In vitro validation of our multiplex PCR assay confirmed the expected PCR product sizes when PCR mixes were spiked with DNA from either Yellow Lampmussel or Tidewater Mucket (Fig 4). Using GoTaq 2x Master Mix, the non-target species, Eastern Elliptio, generated a weak PCR product of ~ 750bp at annealing temperatures of 48°C, 50°C, and 54°C, but did not amplify at 60°C. The size of this band suggested that the custom forward primer for Tidewater Mucket, with 4 base differences from the *Elliptio* sequence, was binding to the *Elliptio* ND1 gene at low - moderate annealing temperatures (see Table 3). For this reason, annealing temperatures of 59-60°C were used for all samples moving forward. Further testing of our assay against the 8 non-target freshwater mussel species in the Canadian Maritimes using Q5 High Fidelity 2x Master Mix and an annealing temperature of 59°C did not result in any visible amplification products, except for positive controls.

Multiplex PCR sampling of Yellow Lampmussel and Tidewater Mucket DNA samples from across the Canadian Maritimes (Table 1) yielded successful amplifications for all locations sampled and generated the expected band sizes. Of the 54 specimens from Blacketts Lake, our Multiplex PCR test identified 35 Yellow Lampmussel and

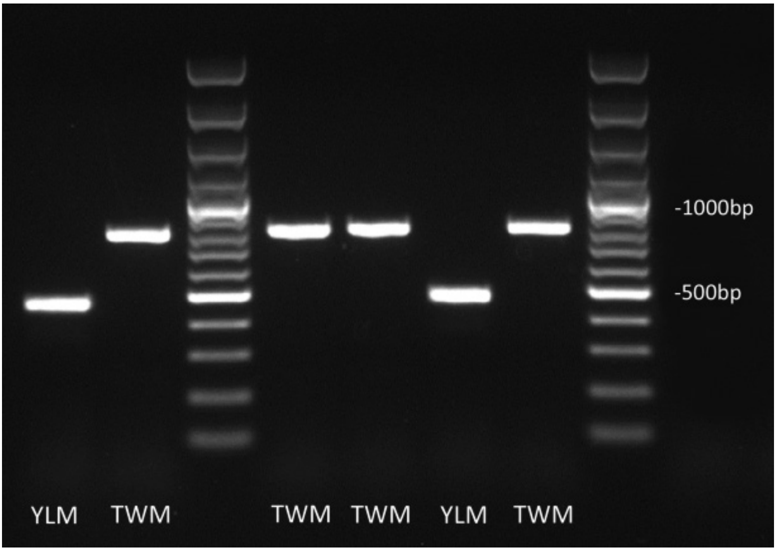


Fig 4 **PCR products resulting from the amplification of the ND1 gene region of Yellow Lampmussel (YLM: lanes 1 and 6) and Tidewater Mucket (TWM: lanes 2, 4, 5 & 7) using LC-ND1-F, AO-ND1-F, and ND1R-FWBIV primers in multiplex PCR. Lanes 3 and 8 include a 100 base pair size standard. As shown, band sizes of samples are a little larger than predicted since GelRed slows the migration of PCR products relative to the standard.**

19 Tidewater Mucket. Of these, 52 (96.3%) of the specimens matched their provisional field-based species identification (37 Yellow Lampmussel, 17 Tidewater Mucket). Of the 2 misidentified mussels, both were Tidewater Mucket specimens that were incorrectly labelled as Yellow Lampmussel.

Mussel Identification Survey

A total of 29 participants completed the Mussel Identification Survey with 15 (51.7%) having no experience in mussel identification, 10 (34.5%) having some experience, and 4 individuals (13.8%) rating themselves as very experienced. The mean quiz score across participants was 12.34/20 (*SD*= 2.6), indicating that on average, participants were only able to correctly identify Yellow Lampmussel and Tidewater Mucket 61.7% of the time based on external shell features alone. The average accuracy of Yellow Lampmussel identifications was 59.4%, while Tidewater Mucket was 66.0%, suggesting that Yellow Lampmussel was more likely to be misidentified than Tidewater Mucket. A one sample t-test conducted to determine if there was any significant difference between quiz participants' actual score and the expected score of 10/20 (50.0%) based on guessing correctly by chance alone indicated a significant difference from chance ($t_{(28)} = 4.82$, $p < .05$). This suggests that while not very accurate, external shell characteristics did provide some help in differentiating between Yellow Lampmussel and Tidewater Mucket.

In terms of the benefit of past experience with mussel identification, 15 participants with no experience in identifying freshwater mussels had an average score of 11.93/20 (59.7%) ($SD = 2.7$), 10 participants with some experience had an average score of 12.40/20 (62.0%) ($SD = 2.7$), and 4 experienced participants had an average score of 13.75/20 (68.8%) ($SD = 2.2$). Despite this small increase in score with experience, experience level did not significantly influence a participant's ability to differentiate between the two species of freshwater mussels (ANOVA: $F_{(2, 26)} = 0.75$, $p = 0.48$).

DISCUSSION

The multiplex PCR assay developed in this study provides a rapid, reliable, and non-lethal method for validating field-based species assignments, supporting the conservation and management of Yellow Lampmussel. By enabling the clear differentiation of Yellow Lampmussel and Tidewater Mucket, the assay addresses a key challenge in accurately estimating population sizes and distributions for conservation assessments. Our multiplex PCR assay also demonstrated high specificity, successfully amplifying only the target species even when tested against a range of non-target freshwater mussels from the Maritimes. In addition to its direct application in monitoring efforts, molecular confirmation opens new opportunities to develop improved field identification methods. For example, genetically-verified specimens could support the use of quantitative morphometric approaches to refine shell-based identifications (e.g., Willsie *et al.* 2020, Butler-Doucette 2024). Molecular truthing also enables the systematic evaluation of soft tissue features, such as mantle and siphon morphology, which may offer practical, non-destructive traits for distinguishing species in the field (Fishelson 2000, Martel *et al.* 2010). Although soft tissue characteristics have historically been underutilized in freshwater mussel taxonomy, their potential diagnostic value can now be explored with greater confidence (Fig 5).

Fig 5 **Underwater photographs of a Yellow Lampmussel (A) and Tidewater Mucket (B) *in situ* with soft tissue structures exposed including the mantle, inhalant siphon, exhalant siphon, and papillae. Photographs were taken at Cape Breton University in September, 2023, using an Olympus Tough TG-6 Waterproof Camera. Scale bars: 3mm.**

Misidentifications of freshwater mussels are surprisingly common, even when relying on external and internal shell characteristics and among experienced field biologists (Shea *et al.* 2011, Howells *et al.* 2017, Bolotov *et al.* 2024). In Shea *et al.* (2011), participants at a mussel identification workshop correctly identified only 73.5% of specimens overall, with success rates ranging from 33% to 100% across species, despite prior familiarity with the local fauna. Similarly, Howells *et al.* (2017) reported correct identification of only 24% of specimens among experienced participants in Texas, with particularly low accuracy for threatened species. Both studies found that identification success was positively associated with shell size, sculpture, and years of experience.

Our Mussel Identification Survey, while limited to two species and based solely on external shell photographs, further demonstrates the challenges of field-based mussel identification. Participants correctly identified Yellow Lampmussel and Tidewater Mucket only 61.7% of the time, a rate lower than that observed by Willsie *et al.* (2020) when differentiating Wabash Pigtoe and Round Pigtoe (77% accuracy). Although participants in our study had access to a field guide, most had limited or no prior experience with mussel identification. Notably, even among those self-reporting as "very experienced," success rates remained below 70%, reinforcing the insufficiency of external shell features alone for reliable species discrimination.

Patterns of misidentification in our survey revealed asymmetries: Yellow Lampmussel was more often misclassified as Tidewater Mucket than the reverse. This raises the possibility that, without molecular verification, Tidewater Mucket may be overrepresented in field surveys where the two species are sympatric. In contrast, provisional identifications of live specimens at Blacketts Lake conducted by experienced personnel aligned with genetic results 96.3% of the time, highlighting the value of extensive field experience. Nevertheless, the occurrence of misidentifications even among trained observers underscores the importance of supplementary molecular verification tools, particularly for species of conservation concern.

It is important to recognize that in typical field settings, biologists may sometimes have access to additional diagnostic features beyond external shell morphology. Empty shells exposing internal structures such as hinge teeth and muscle scars can improve identification accuracy (Nedeau *et al.* 2000, McAlpine *et al.* 2018). However, live surveys, often the only ethical method when working with at-risk species, rely predominantly on external characteristics, and access to internal features is inconsistent. Even when internal features are available, high rates of misidentification have still been documented (Shea *et al.* 2011, Howells *et al.* 2017).

Geographic variation and environmental influences on shell morphology (i.e., phenotypic plasticity) further complicate field identifications (Sheldon 2017). Diagnostic traits that distinguish Yellow Lampmussel and Tidewater Mucket in some regions may be less reliable elsewhere, such as in Cape Breton, where these species appear particularly similar. This highlights the importance of incorporating molecular tools into species identification efforts, especially for conservation-focused surveys.

In conclusion, our findings, combined with previous studies, highlight the persistent challenges of freshwater mussel identification based on morphology alone and reinforce the critical importance of developing complementary molecular approaches. Our multiplex PCR assay provides a practical, accessible tool that can support the conservation and management of Yellow Lampmussel and related species by substantially improving the accuracy and confidence of species-level identifications in the field.

Acknowledgements We would like to thank Courtney Trask and Sarah Smith for assistance with fieldwork, and Alicia Penney for providing helpful suggestions. Many thanks also to Mary Sollows, Amanda Bremner, and Donald McAlpine at the New Brunswick Museum for the loan of mussel specimens. Our Mussel Identification Survey was approved by the CBU Research Ethics Committee (REB #2024019) prior to implementation. This research was supported by an NSERC USRA to Sophia Butler-Doucette and funding through Fisheries and Oceans Canada (DFO) under the Species at Risk Act (SARA) program. We gratefully acknowledge DFO funding contributions across multiple grants that enabled this work.

LITERATURE CITED

Bolotov, I.N., Konopleva, E.S., Vikhrev, I.V. & Kondakov, A.V. (2024). An alarming tendency towards freshwater mussel misidentification in scientific works may bias endangered and invasive species management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 34(1): e4061.

Boyer, S.L., Howe, A.A., Juergens, N.W. & Hove, M.C. (2011). A DNA-barcoding approach to identifying juvenile freshwater mussels (Bivalvia: Unionidae) recovered from naturally infested fishes. *Journal of the North American Benthological Society* 30(1): 182-194.

Butler-Doucette, S.M. (2024). An Examination of Non-Destructive Methods for Differentiating Between Yellow Lampmussel (*Lampsilis cariosa*) and Tidewater Mucket (*Atlanticoncha ochracea*). Honours Thesis. Cape Breton University, 86 p.

COSEWIC. (2000). COSEWIC assessment and update status report on the Dwarf Wedgemussel *Alasmidonta heterodon* in Canada. Committee on the Status of Endangered Wildlife in Canada, 18 p.

COSEWIC. (2013). COSEWIC status appraisal summary on the Yellow Lampmussel *Lampsilis cariosa* in Canada. Committee on the Status of Endangered Wildlife in Canada, 23 p.

Fishelson, L. (2000). Comparative morphology and cytology of siphons and siphonal sensory organs in selected bivalve molluscs. *Marine Biology* 137: 497-509.

Fisheries and Oceans Canada. (2010). Management Plan for the Yellow Lampmussel (*Lampsilis cariosa*) in Canada [Final]. Species at Risk Act Management Plan Series. Fisheries and Oceans Canada, 44 p.

Gerke, N. & Tiedemann, R. (2001). A PCR-based molecular identification key to the glochidia of European freshwater mussels (Unionidae). *Conservation Genetics* 2: 287-289.

Government of Canada. (2010). Wild Species 2010: The General Status of Species in Canada (ch. 9). www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/publications/wild-species-2010/chapter-9.html (Accessed Nov. 3, 2023)

Government of Canada. (2024). Species at Risk Public Registry. www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html (Accessed Nov. 3, 2023)

Haag, W.R. (2012). North American Freshwater Mussels: Natural History, Ecology, and Conservation. Cambridge University Press, 1st. edition, 505 p.

Haag, W.R. & Williams, J.D. (2014). Biodiversity on the brink: an assessment of conservation strategies for North American freshwater mussels. *Hydrobiologia* 735: 45-60.

Howells, R.G., Randklev, C.R. & Ford, N.B. (2017). Accuracy of freshwater mussel identification: Results from a study in Texas. *American Conchologist* 45(3): 9-18.

IUCN. (2023). IUCN Red List of Threatened Species. International Union for Conservation of Nature. www.iucnredlist.org/ (Accessed Nov. 3, 2023)

Johnson, R.I. 1947. *Lampsilis cariosa* Say and *Lampsilis ochracea* Say. *Harvard University Museum of Comparative Zoology, Occasional Papers on Mollusks* 1(12): 145-156.

Karlsson, S., Larsen, B.M., Eriksen, L. & Hagen, M. (2013). Four methods of nondestructive DNA sampling from freshwater pearl mussels *Margaritifera margaritifera* L.(Bivalvia: Unionoida). *Freshwater Science* 32(2): 525-530.

Keogh, S.M. (2023). From individuals to species: How natural selection and phenotypic plasticity shape ecomorphological evolution in freshwater mussels. Doctoral Dissertation. University of Minnesota, 130 p.

Keogh, S.M. & Simons, A.M. (2019). Molecules and morphology reveal 'new'widespread North American freshwater mussel species (Bivalvia: Unionidae). *Molecular Phylogenetics and Evolution*, 138: 182-192.

Kneeland, S.C. & Rhymer, J.M. (2007). A molecular identification key for freshwater mussel glochidia encysted on naturally parasitized fish hosts in Maine, USA. *Journal of Molluscan Studies* 73(3): 279-282.

Lopes-Lima, M., Burlakova, L.E., Karatayev, A.Y., Mehler, K., Seddon, M. & Sousa, R. (2018). Conservation of freshwater bivalves at the global scale: diversity, threats and research needs. *Hydrobiologia* 810: 1-14.

Maine Department of Inland Fisheries and Wildlife. (2003). Tidewater Mucket 1990-1991 [pdf]. Maine Department of Inland Fisheries and Wildlife. www.maine.gov/fw/docs/endangered/tidewatermucket_90_91.pdf

Martel, A.L., McAlpine, D.F., Madill, J., Sabine, D.L., Paquet, A., Pulsifer, M. & Elderkin, M. (2010). Freshwater mussels (Bivalvia: Margaritiferidae, Unionidae) of the Atlantic Maritime Ecozone. In: McAlpine, D.F. (ed.). Assessment of Species Diversity in the Atlantic Maritime Ecozone. NRC Research Press, Ottawa, ON. p. 551-598.

Marshall, H.D., Johnstone, K.A. & Carr, S.M. (2007). Species-specific oligonucleotides and multiplex PCR for forensic discrimination of two species of scallops, *Placopecten magellanicus* and *Chlamys islandica*. *Forensic Science International* 167(1): 1-7.

Massachusetts Division of Fisheries and Wildlife. (n.d.). Tidewater Mucket (*Atlanticoncha ochracea*).
www.mass.gov/info-details/tidewater-mucket (Accessed May, 9, 2025)

Massault, C., Jeffrey, C., Jones, D.B., Barnard, R., Strugnell, J.M., Zenger, K.R. & Jerry, D.R. (2022). Non-invasive DNA collection for parentage analysis for bivalves: A case study from the silver-lipped pearl oyster (*Pinctada maxima*). *Aquaculture* 552: 738036.

McAlpine, D.F., Sollows, M.C., Madill, J.B. & Martel, A.L. (2018). Freshwater Mussels of Maritime Canada: A Flashcard Guide in Wolastoqey, Mi'kmaw, French and English. New Brunswick Museum and Canadian Museum of Nature, 1st. edition, 28 p.

Mehlhop, P. & Cifelli, R.L. (1997). A comparison of morphometric techniques to distinguish sympatric mussel species (Family Unionidae) with similar shell morphology. In: Yates, T.L., Gannon, W.L., & Wilson, D.E. (ed.). Life among the Muses: Papers in Honor of James S. Findley. The University of New Mexico Press, Albuquerque, USA. p. 249-258.

NatureServe. (2024). *Lampsilis cariosa*: Yellow Lampmussel. NatureServe Explorer.
explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.109623/Lampsilis_cariosa (Accessed Oct. 24, 2024)

Nedeau, E.J., McCollough, M.A. & Swartz, B.I. (2000). The Freshwater Mussels of Maine. Maine Department of Inland Fisheries and Wildlife, 1st. edition, 118 p.

Nova Scotia Department of Natural Resources and Renewables. (2022). Recovery Plan for the Yellow Lampmussel (*Lampsilis cariosa*) in Nova Scotia [Final]. Nova Scotia Endangered Species Act Recovery Plan Series, 75 p.

Rawlings, T.A. & White, K. (2022). Developing molecular tools for monitoring at-risk freshwater mussel populations in Atlantic Canada. DFO Report. Contract No. 4500010752.

Ryan, M. (2022). The Design and Implementation of a Molecular Identification Key for Freshwater Bivalves in the Maritime Provinces of Canada. Honour's Thesis. Cape Breton University, 47 p.

Sabine, D.L., Makepeace, S. & McAlpine, D.F. (2004). The Yellow Lampmussel (*Lampsilis cariosa*) in New Brunswick: a population of significant conservation value. *Northeastern Naturalist* 11: 407-420.

Serb, J.M., Buhay, J.E. & Lydeard, C. (2003). Molecular systematics of the North American freshwater bivalve genus *Quadrula* (Unionidae: Ambleminae) based on mitochondrial ND1 sequences. *Molecular Phylogenetics and Evolution* 28(1): 1-11.

Shea, C.P., Peterson, J.T., Wisniewski, J.M. & Johnson, N.A. (2011). Misidentification of freshwater mussel species (Bivalvia: Unionidae): Contributing factors, management implications, and potential solutions. *Journal of the North American Benthological Society* 30(2): 446-458.

Sheldon, F. (2017). Variable plasticity in shell morphology of some Australian freshwater mussels (Unionoida, Hyriidae). *Transactions of the Royal Society of South Australia* 141(2): 193-208.

Vaughn, C.C. (2018). Ecosystem services provided by freshwater mussels. *Hydrobiologia* 810: 15-27.

Willsie, J.A., Morris, T.J. & Zanatta, D.T. (2020). Morphometric analyses distinguish Wabash Pigtoe (*Fusconaia flava*) and Round Pigtoe (*Pleurobema sintoxia*) mussels. *Diversity* 12(9): 337.

Zanatta, D.T. & Murphy, R.W. (2006). Evolution of active host-attraction strategies in the freshwater mussel tribe Lampsilini (Bivalvia: Unionidae). *Molecular Phylogenetics and Evolution* 41(1): 195-208.

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 135-166

USING RAPID AND REPEATABLE SIDE SCAN SONAR METHODS FOR A SECOND ASSESSMENT OF THE SHORTNOSE STURGEON (*ACIPENSER BREVIROSTRUM*) POPULATION IN THE SAINT JOHN RIVER, NEW BRUNSWICK, CANADA

SAMUEL N. ANDREWS[1,2*], ANTÓIN M. O'SULLIVAN[3,5,6], TOMMI LINANNSAARI[4,5,6], R. ALLEN CURRY[4,5,6]

[1]*InStream Consulting, Kentville, NS B4P 1Z7*

[2]*Department of Biology, Acadia University,*
33 Westwood Avenue, Wolfville, NS B4P 2R6
samuel.andrews@acadiau.ca

[3]*O'Sullivan EcoHydraulics Inc. Fredericton, NB E3B 7G6*
antoin@osullivanecohydraulics.com

[4]*Department of Biology*

[5]*Faculty of Forestry and Environmental Management*

[6]*Canadian Rivers Institute, University of New Brunswick*
P.O. Box 4400, Fredericton, NB E3B 5A3
tommi.linnansaari@unb.ca, racurry@unb.ca

ABSTRACT

Population estimates are a key component of fisheries management, particularly when assessing species of concern. However, the time and effort required to conduct those estimates logistically limits their frequency. To facilitate assessment of Shortnose Sturgeon (*Acipenser brevirostrum*; SNS) which are a species of concern in the Saint John River, New Brunswick, Canada, a combined side-scan sonar and acoustic telemetry-based method was employed to enumerate SNS within high density winter aggregations. During this study 12,005 SNS were enumerated in one main winter aggregation and 2,186 SNS were counted within a second in the Kennebecasis Bay. Winter residency patterns determined from acoustic tracking of 18 tagged SNS over 8 years (2015/16-2022/23) indicated that these two aggregations represented on average 74.3% of the overall population suggesting that the total Saint John River population was ~19,100 SNS > 40 cm FL in winter 2022/23. Although the development of more in depth, robust, and repeated assessments are needed to verify this estimate of abundance and size classes, we conclude that the abundance of SNS in the Saint

* Author to whom correspondence should be addressed: samuel.andrews@acadiau.ca

John River has probably remained stable since the earliest population estimate completed in 1977.

Keywords: Winter Aggregation, Machine Learning, Acoustic Telemetry, Population Monitoring, Threatened Species

INTRODUCTION

Sturgeons (family *Acipenseridae*) are long-lived fishes (Sulak and Randall 2002) native to rivers, lakes, and coastlines across all continents of the Northern Hemisphere (Haxon and Cano 2016), but throughout this range nearly all populations are in decline (Lenhardt *et al.* 2006). The life history strategy of sturgeons which includes slow growth, late maturation, and high survival and fecundity (Tripp *et al.* 2009) has weathered millennia of natural environmental upheavals (Choudhury and Dick 1998). However, when faced with a world of rapidly evolving and compounding anthropogenic challenges, this strategy may no longer be advantageous. Globally, Sturgeons are threatened by dams which incur passage mortality and fragment habitats (Huang and Wang 2018), pollution that degrades water quality (Blevins 2011); affects reproduction (Feist *et al.* 2005); and reduces juvenile survival (Hummel *et al.* 2022), climate change that warms global waters (Lassalle *et al.* 2010), and overharvest which directly impacts spawner abundance (Quist *et al.* 2002, Chambers *et al.* 2012). As sturgeon populations worldwide trend towards low abundances, rates of decline become harder to measure as the species themselves become more difficult to observe. This challenge becomes particularly apparent when those species occur in large rivers and lakes. Without the ability to easily gather data, factors leading to population decline likewise become more difficult to mitigate and the time and costs associated with acquiring those necessary data can become a significant impediment to conservation.

The Saint John River (SJR), New Brunswick (NB), is the largest Canadian River east of the St. Lawrence, and the only river in Canada known to support a reproducing population of Shortnose Sturgeon (*Acipenser brevirostrum* Lesueur 1818; SNS). The occurrence of SNS in this system is likely due to the extensive, warm, mesohaline estuarine habitat enabling the amphidromous life history of this species (Miller 1972, Dadswell 1979, Fisheries and Oceans Canada 2016). In this system the habitats of Shortnose Sturgeon have been restricted by the construction of hydroelectric dams. The largest and most downstream of these barriers is the Mactaquac Dam which is located immediately upstream from an important spawning location (Usvyatsov *et al.* 2012) and forms a definitive barrier to upstream movement. Additional potential threats to the species in the SJR include industrial pollution (Dadswell 1979), residual dichlorodiphenyldichloroethylene (DDE) from past forest spraying with dichlorodiphenyltrichloroethane (DDT; Elson 1967), elevated total mercury (Dadswell 1975, Andrews *et al.* 2023), and possibly invasive species (Bruce *et al.* 2019, Zelman *et al.* 2023). Catch and release angling could also have an impact (Struthers *et al.* 2018), but those potential effects are unknown. In 1980, 2005, and 2015 the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the genetically distinct SJR SNS population (SSSRT 2010, Wirgin *et al.* 2010, King *et al.* 2014) as "Special Concern" (Dadswell 1980, Dadswell 1984, COSEWIC 2005, 2015). This designation was not based on current population trends which were unavailable. Rather, it was predicated upon the suspected occurrence of a single spawning location (Li *et al.* 2007, Usvyatsov *et al.* 2012) and the ensuing vulnerability imposed by the limited distribution of SNS in Canada. The COSEWIC designation was followed by an official listing under Schedule 1 of the Species at Risk Act (SARA) in 2009. This action prompted the creation of a management plan directing federal conservation, management, and monitoring efforts for the species (Fisheries and Oceans Canada 2015, 2016).

The most recent management plan for SNS in Canada lists "estimates of abundance" as a top priority for ongoing monitoring and management (Fisheries and Oceans Canada 2016). Several estimates of abundance for the SNS population (or components of the population) in the SJR have been attempted over past decades of which the most comprehensive reported ~18,000 ± 5,400 individuals >50 cm FL (fork length) following an intensive 5-year mark recapture study spanning 1973-1977 (Dadswell 1979). Subsequent assessments in 2005, 2009 and 2011 used video surveys of a localized winter aggregation in the Kennebecasis branch of SJR (Fig 1) over three months (January to March) and predicted a site-specific population of 4,836, 3,852 and 5,222 in each of those years respectively (Li *et al.* 2007, Usvyatsov *et al.* 2012). Mark recapture estimates were also conducted in the Kennebecasis between 1998-2004 using fish captured during an annual angling derby. That study produced an estimate of 2,068 individuals in the Kennebecasis, but the 95% confidence interval ranged widely (801-11,277; COSEWIC 2015). Most recently in 2018, population abundance was estimated using side imaging sonar coupled with a 4-year acoustic tracking data set (Andrews *et al.* 2020). That study directly enumerated 12,284 SNS on side imaging sonar during a 1-day survey, an estimated 61.1% of the SJR population. From this finding a whole river population was estimated as 20,101 > ~40 cm FL (Andrews *et al.* 2020). This estimate was comparable to the adult population of 18,000 ± 5,400 >50 cm FL estimated by Dadswell (1979) and was the first attempt at a full river population estimate in over 40 years.

Sonar systems, both simple and sophisticated are being more commonly employed to conduct fish population and habitat surveys (Kaeser 2010, 2012, Flowers and Hightower 2013, 2015). Advances in sonar technology have tightened gaps in image quality and post

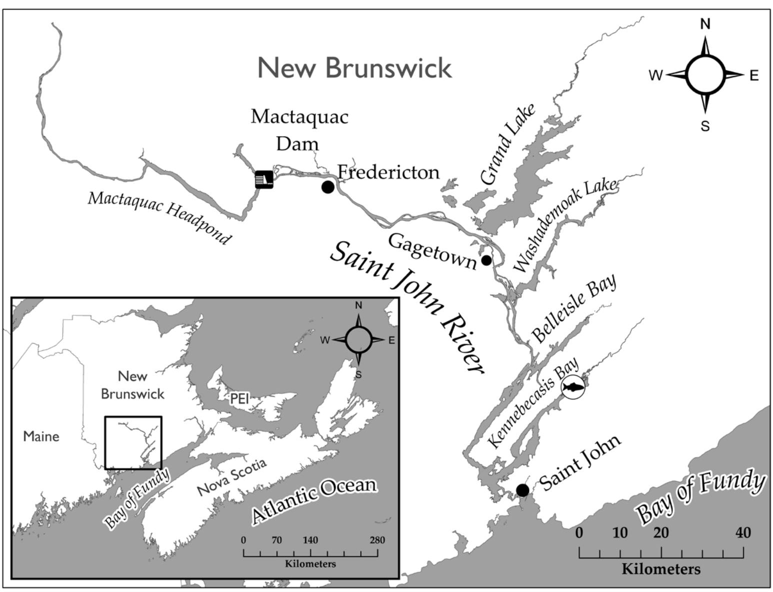


Fig 1 Saint John River, New Brunswick, extending from its confluence with the Bay of Fundy at the City of Saint John upstream past Kennebecasis Bay, Belleisle Bay, Washademoak Lake and Grand Lake until meeting the Mactaquac Dam upstream from the City of Fredericton at river km 150. An aggregation of Shortnose Sturgeon is described to form in late fall and winter in the upstream portion of Kennebecasis Bay near the confluence of the Kennebecasis and Hammond rivers and is indicated by the fish symbol. Image reproduced from Andrews *et al.* (2020) with permission.

processing capabilities between inexpensive consumer grade electronics (*e.g.,* Helminen *et al.* 2019) and professional commercial sonar systems (*e.g.,* Helminen and Linnansaari 2023). These advances have led to a transition from using inexpensive sonar systems as tools for depth and general fish habitat mapping (Buscombe 2017) to an effective means of surveying fish populations. While the most common sonar systems are dual beam and operated actively from a boat, some of the most effective fish sonar enumeration systems are situated such that the target species is guided past stationary multibeam sonars positioned in narrow rivers (Magowan *et al.* 2012, Helminen and Linnansaari 2023) or engineered fish passage structures (Grote *et al.* 2014). The most sophisticated of these systems incorporate artificial intelligence which can be trained to both identify species (Helminen *et al.* 2021) and rapidly enumerate targets in real time (Kandimalla *et al.* 2022, Connolly *et al.* 2022). Though broadly applicable, stationary sonar installments are most suited to monitoring anadromous species because spawning adults ascend rivers in large numbers within predictable seasons (Hughes & Hightower 2015), often passing both natural and man-made bottlenecks. The behaviour and migratory pathway of highly motivated anadromous species greatly facilitates this method.

Shortnose Sturgeon in the SJR, NB, conduct an upstream spawning migration to freshwater, but among individuals and sexes, these migrations have infrequent periodicity (Dadswell 1979, COSEWIC 2015). The size of the SJR itself (800 m-1 km wide) and lack of bottlenecks also make passive sonar monitoring for SNS impractical. Rather, exploration of winter habitats where SNS aggregate densely and remain in-situ for long periods of time provides a more practical solution (*e.g.,* Li *et al.* 2007). By surveying winter aggregations with boat mounted sonar, the limitations of fixed sonar can be mitigated, and its application reversed whereby a mobile sonar unit can be used to enumerate stationary fish (Andrews *et al.* 2020 see Flowers and Hightower 2013 and 2015 for a comparison to summer sonar surveys in a large river). This method has demonstrated potential in estimating river wide abundance when paired with telemetry-derived winter residency proportions of SJR SNS (Andrews *et al.* 2020). Given the recent applicability of sonar advances, the present study attempts to enumerate both the main winter aggregation (described by Andrews *et al.* 2020) and the Kennebecasis winter aggregation (described by Li *et al.* 2007 and Usvyatsov *et al.* 2012) of SNS in the SJR with consumer-grade side-scan sonar. The goal of this study is to provide a step forward in developing the necessary tools and methods for effective, rapid, and inexpensive monitoring of Canada's only population of SNS.

STUDY AREA

The Saint John River (Fig 1) is the largest river draining into the Bay of Fundy which it meets along the western shore of the bay at the City of Saint John, NB. Once free flowing for 673 km (Cunjak *et al.* 2011), the SJR is now obstructed by three large main-stem hydroelectric dams (Ruggles & Watt 1975). These barriers include 1) Grand Falls Dam located 350 km upstream from the river mouth constructed in 1931, 2) Beechwood Dam located 285 km upstream from the river mouth constructed in 1952, and 3) Mactaquac Dam constructed at river km 150 in 1968 (COSEWIC 2015). The Mactaquac Dam, which is the largest and most downstream passage barrier limits the upstream movements of most species including SNS. Downstream passage at Mactaquac Dam is facilitated only by transit through the turbines, spillways, or sluiceways when operational (Babin *et al.* 2020). Supervised upstream fish passage by means of a fish lift and trap and truck operation are facilitated for *Salmo salar* (Atlantic Salmon, L. 1758), limited quantities of Alewife (*Alosa pseudoharengus* Wilson, 1811), and Blueback Herring (*Alosa aestivalis* Mitchill, 1815), while all other species are manually filtered from the lift and returned downstream (Chateauvert *et al.* 2018). SNS have been captured during boat electrofishing surveys immediately downstream of Mactaquac Dam as recently as 2022 (R. Hill, Ph.D. student at UNB Fredericton pers. comm.). Though only a single Shortnose Sturgeon observed in 1968 (Smith 1979; the first year of operations at Mactaquac Dam) was ever recorded entering fish passage collection facilities (Meth 1972, Williamson 1974, Smith 1979, Ingram 1980, 1985, Jessop 1990, Hooper 1991, R. Beaumaster, Fisheries and Oceans Canada fish lift technician, pers. comm. 2016). Fish passage structures at Mactaquac Dam which were designed as a surface collection facility are inappropriate for the attraction and passage of SNS or other benthic species (*i.e.* American Eel; *Anguilla rostrata* Lesueur, 1821).

From the mouth of the SJR, tidal influence extends 130 km upstream to the city of Fredericton (Fig 1) with saltwater intrusion detectable ~70 km upriver to the village of Gagetown (Fig 1; Carter & Dadswell 1983). The lower reaches of the SJR are fed by four main-stem tributaries including Grand Lake, Washademoak Lake, Belleisle Bay, and Kennebecasis Bay which are subject to increasing degrees of tidal influence and proximity to the river mouth in that order. The upper portion of Kennebecasis Bay supports an extensive salt marsh (Hampton Marsh) at the mouth of the Kennebecasis River. This region contains a well documented winter aggregation of SNS (Li *et al.* 2007, Usvyatsov *et al.* 2012) that occupies a sandy thalweg 4.5-7 m deep near the confluence of the Kennebecasis and Hammond rivers. The Hampton Marsh itself is interspersed with tidal channels and pockets of various depth providing additional refugia for SNS in autumn and winter.

METHODS

Workflow

This study reproduced the methodology for a sonar-based population estimate of SNS in the SJR as described by Andrews *et al.* (2020) but expanded upon the number of surveyed areas to produce a more comprehensive estimate during winter 2022/2023. This updated study iteration surveyed the main aggregation described by Andrews *et al.* (2020) in addition a well-documented winter aggregation in the upper Kennebecasis Bay (Fig 1; Li *et al.* 2007, Usvyatsov *et al.* 2012). During surveys, parallel side-scan sonar transects were conducted with a Humminbird® (Johnson Outdoors, Racine, WI, United States) Helix 10 MEGA SI Gen 4 fish finder. These data were collated in Reefmaster® software (Reefmaster Software Ltd. Birdham, UK) to produce an image mosaic of each surveyed aggregation that were exported as mtbtiles for manipulation in QGIS and transfer to AcrPro. Within the GIS platform image pixels were classified either as “sturgeon” or “riverbed” using a supervised maximum likelihood model (*sMLC*) to produce an enumeration of “sturgeon” in each image mosaic. These estimates were further refined by calculating the minimum bounding geometry of each shape and applying an inclusion threshold based on size as per Andrews *et al.* (2020). The population counts across both surveyed locations were then compared to winter residency proportions determined from eight years of continuous acoustic tracking of 18 tagged SNS to create a population estimate for the entire SJR (Fig 2).

Side-scan data collection

Side-scan sonar surveys were conducted using a commercially available Humminbird® Helix fish finder and were recorded at a frequency of 1,275 kHz while scanning 30 m to either side of the survey vessel. Survey speed varied from ~3-9 km/h during transects depending on wind and current speed, and each survey was conducted as a series of parallel unidirectional tracks each saved as individual recorded files (Fig 3). Transects were started at one side and in parallel to the orientation of the sturgeon as observed on side-scan sonar to capture the fish in profile. Survey passes were then conducted in parallel, offset by ~25-30 m. This process was repeated until the entire aggregation had been covered and sturgeon ceased to appear on sonar. During surveys GPS (Global Positioning System) position, orientation and speed was continuously recorded by the fish finder. The positional difference between the head unit and the transducer, as well as the depth of the transducer below the water line were corrected prior to image mosaicking. Transects were driven manually and efforts were made to keep transects as straight and uniform as possible. Although wind and waves inevitably resulted in some yaw and sway in the trajectory of the vessel and thus movement of the transducer.

Side-scan sonar survey of winter aggregations

On Nov 24 and 25, 2022, the main aggregation was fully surveyed three times (two surveys on Nov 24, and one on Nov 25) with survey taking 4 to 5 hours of continuous scanning to complete. During scanning, wind speed ranged from 2 to 3.6 m/s though increased to >5 m/s in the afternoon of Nov 25th, removing the possibility to complete a 4th side-scan transect on that day. Surface water temperature during these surveys ranged from 1.2-1.4 °C, a temperature at which SNS form dense winter aggregations and remain relatively immobile (Andrews *et al.* 2020). Like the 2018 survey, side-scan passes over the main aggregation were completed during the outgoing tide as reversals in tide result in re-orientation and shuffling of the aggregation.

On Nov 27, 2022, three side-scan passes were conducted over the Kennebecasis aggregation during a single outgoing tide. Each of the three surveys took ~1 hour to complete. Wind speed at the time of

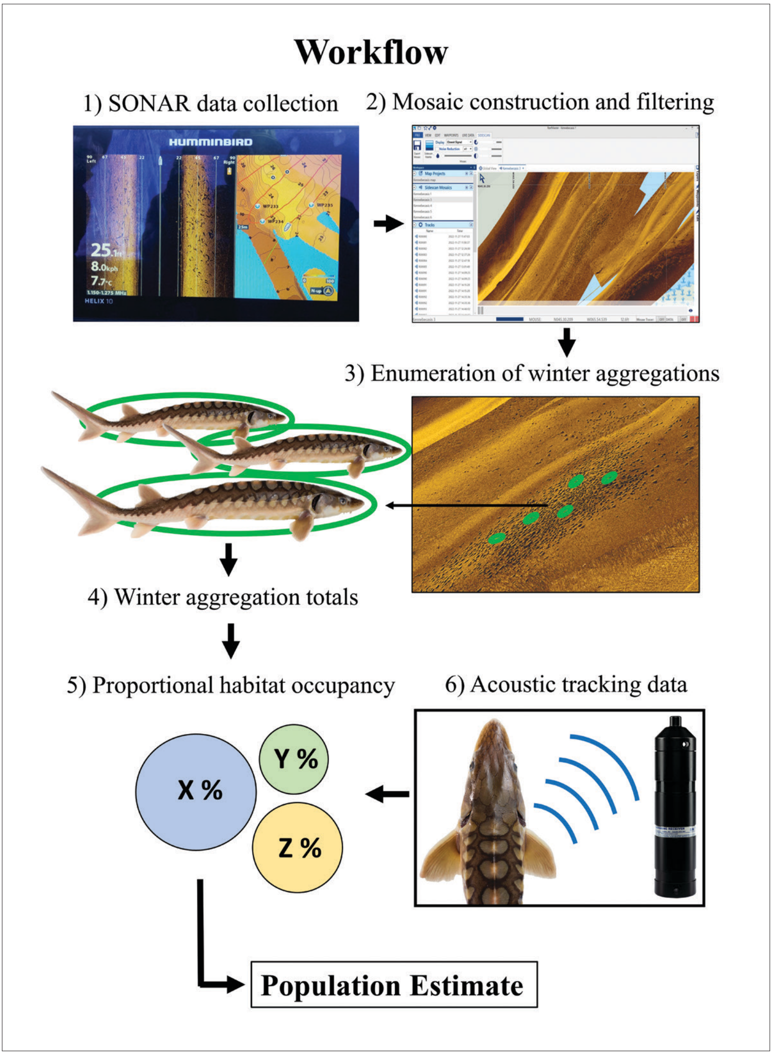


Fig 2 **Project workflow diagram following sequential steps including 1) collection of side-scan sonar data, 2) creation of side-scan mosaic mtbtiles file, 3) enumeration of scanned winter aggregations to create 4) totals within aggregations. These totals were then assessed in accordance to 5) winter habitat residency proportions derived from 6) an 8-year acoustic tracking data set from 18 tagged Shortnose Sturgeon (*Acipenser brevirostrum*) to calculate a final river-wide population estimate in the Saint John River, New Brunswick.**

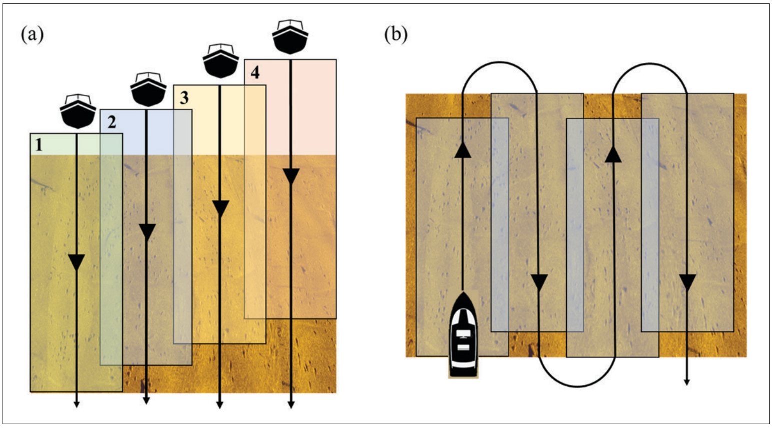


Fig 3 **Comparison of side-scan sonar track methods demonstrating (a) the method used in this study which involved separate evenly spaced parallel scans each saved as a separate sonar file, and (b) the method used by the prior study (Andrews *et al.* 2020) which involved a single continuous scan saved as a single sonar file where the scanned area was covered in two directions and later filtered to remove regions of maximum curvature.**

this survey ranged 1.5-2 m/s while surface water temperature was 0.8°C. At the time of the survey, SNS were observed to be very tightly aggregated, and this aggregation was scanned almost in its entirety in a single sonar pass. Additional surveys were also conducted along tidal channels adjacent to the Kennebecasis winter aggregation to count SNS not relating to the core group. These surveys were not comprehensive within the maze of available tidal channels of the Hampton Marsh, but three separate side-scan passes were completed for a small wintering assemblage located ~1.5 km away from the core group. No control summer surveys were conducted as part of this study because data for the main aggregation was collected by Andrews *et al.* (2020) and the Kennebecasis is a well documented winter aggregation (Li *et al.* 2007, Usvyatsov *et al.* 2012).

Side-scan sonar image mosaicking and filtering

During operation, the side-scan transducer produced multiple scan lines each second and simultaneously, the Humminbird® fish finder measured the GPS location, speed, and rotation of the boat which it records approximately 1-3 times per second. Using Reefmaster® software, the continuous scan lines recorded by the transducer were compiled to produce a 2D acoustic image or side-scan “mosaic”. This mosaic was corrected using the “Blend Closest Display” setting in Reefmaster® which prioritizes the signal closest to the center of the side-scan transect and blends the tracks at the margins of the swath for a more seamless overlap between recorded transects. The final mosaic was then processed though 1x noise reduction and 100% autogain to equalize brightness across the image. In some cases, boat movement resulted in image distortion and stretch. These instances were noted, and while the visualized fish could still be counted, some could have been filtered from the estimates. Removal of individuals from the estimates could have occurred if those stretched images resulted in SNS appearing to exceed pre-set target length restrictions defined during image post processing (see image classification). Filtration of stretched images would have resulted in lower overall counts. Following image mosaicking data were transfer to ArcGIS as a pixel resolution of 7.5 cm.

Image classification

Maximum likelihood classification (sMLC) was used to classify objects in the sonar images. These objects were characterized as “Riverbed” or “Sturgeon”. The initial training data were manually denoted by visually inspecting the sonar image and drawing polygons around objects that were either identified as riverbed or suspected sturgeon. These polygon features were then used to classify the images. All the data was processed in ArcMap 10.8 (ESRI, Redlands, CA, United States).

Following this classification, an additional filtering method was applied. This method is detailed in Andrews *et al.* (2020) and in brief entails calculating the “minimum bounding geometry” of the classified images meaning that an inclusion threshold was set using the length of the objects classified. Andrews *et al.* (2020) used an inclusion threshold for surgeon polygons of 20 cm < Potential SNS < 150 cm. The minimum limit served to remove bottom debris from classification as SNS, and the upper limit was the maximum length of SNS. During this survey we used a more conservative inclusion threshold of 40 cm < Potential Shortnose Sturgeon < 150 cm because 40 cm was the functional resolution of the sonar unit as described by Andrews *et al.* (2020).

A kappa coefficient (k) was calculated to assess the validity of the sMLC classification. Given the lack of actual observations, N = 105 manual classifications were demarked as riverbed (n = 40) and sturgeon (n = 65). We repeated this for each assessed site. These data were then used to calculate *k* and both analyses were completed in Excel (Microsoft 2023).

Our original goal was to classify and enumerate sturgeon captured within each collected sonar mosaic allowing for the reporting of variability and confidence limits between repeated estimates. However, some sonar passes were compromised by wind and wave action, and we elected to only analyse the cleanest mosaic taken at each study site for inclusion in our population estimate. Additional survey days were not possible in winter 2022 because both sites were accessed as late in the season as ice conditions would allow and wind conditions deteriorated during surveys and did not improve until shorelines became icebound and inaccessible. In future, the analysis of multiple mosaics for a single location should be considered to report on variability between sonar derived site-specific population estimates. Because these surveys are the only data available to describe the 2022/23 winter aggregations and the only data collected since 2018, analysis proceeded despite the known limitations.

Underwater camera survey

Andrews *et al.* (2020) conducted an underwater camera survey of SNS and bottom structure at the location of the main winter aggregation on Nov 27, 2019, the year after side-scan sonar data was collected on Dec 11, 2018. During that survey an underwater camera was affixed with underwater lights and towed near the river bottom for 2,681 m recording 109 min of video. During that survey 212 sturgeon were captured on camera of which every individual that could be clearly identified was confirmed as SNS. Since no other fish or sturgeon species were recorded, all side-scan sonar returns that had been recorded by Andrews *et al.* (2020) over the core aggregation in 2018 were counted as SNS. Following these results confirming single species occurrence, the underwater camera survey was not repeated for the main aggregation during this study.

The winter aggregation in Kennebecasis Bay was surveyed on 27 November 2022 during this study using an underwater camera to determine species composition. For this survey, a commercially available Vexillar® Scout camera with a DVR recording to a 32 GB microSD card was used with lights supplemented through the attachment of a scuba diving flashlight (bigblue $AL1200_{NP,}$ 1200 Lm, 10° beam). Each fish that appeared on camera was identified to species. The resulting ratio of SNS to other species was used as a correction factor for the side-scan sonar estimate. The bottom substrate was also described to make note of substrate type and character across the survey location.

Tagging and Winter Habitat Residency

To estimate percentages of the total SJR SNS population (fish ≥ 40 cm FL) aggregating in each identified winter habitat, we categorised the winter residency patterns of 18 SNS tagged with V16-4L 69 kHz acoustic transmitters (Innovasea Systems Inc.) in 2015 and described by Andrews *et al.* (2020). The tags used in the original study had an expected battery life of ten years and thus allowed those same tagged SNS to be continuously monitored in the SJR until this re-assessment (2022). This present study tabulated eight winters of data (2015/16-2022/23; 144 observations of winter location) for those individuals to calculate winter residency proportions in the SJR.

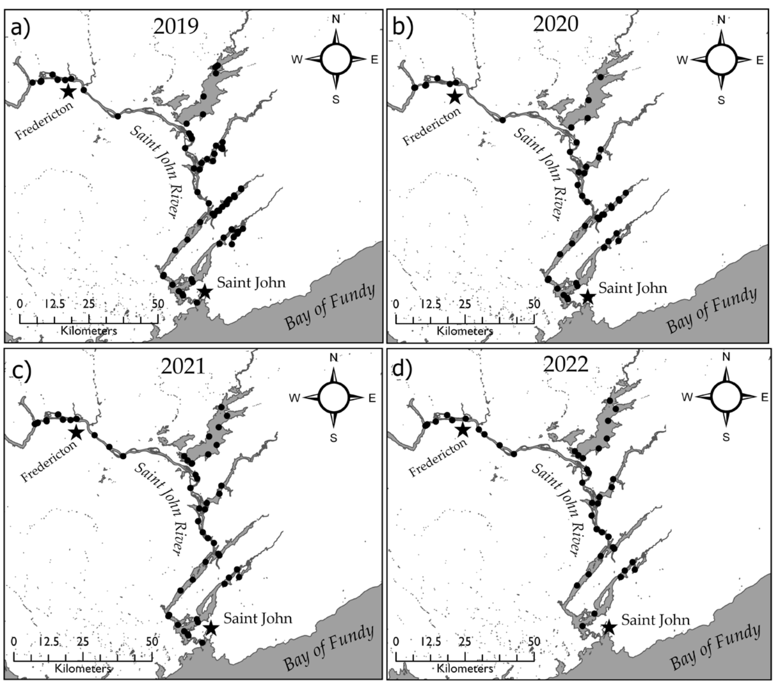


Fig 4 **Annual positions of project specific VR2W acoustic monitoring stations positioned in the Saint John River including 93 in 2019, 53 in 2020, 85 in 2021, 48 in 2022 that could detect the movements of Shortnose Sturgeon *(Acipenser brevirostrum)* and resolve the winter habitat residency proportions between occupied winter refuges.**

The tagging methodology in 2015 was as follows. Adult SNS (n=18, Total Length [TL] range = 100.5-128 cm) were captured by gill net in the SJR from 16-30 May 2015 (n=16 in Long Reach, n=2 in middle Kennebecasis Bay) and surgically implanted with V16-4L 69 kHz acoustic tags using an anesthetic of 40 mg/L solution of 10 parts ETOH: 1 part clove oil (eugenol). The sex of the tagged fish was not recorded. Tagged individuals were then tracked by a project-specific array of Innovasea® VR2W receivers (n=125 in 2015, n= 128 in 2016, n=135 in 2017 and n=60 in 2018; Andrews *et al.* 2020). Following this initial study period, the project specific receiver array numbered n=93 in 2019, n=53 in 2020, n=85 in 2021, and n=48 in 2022 (Fig 4) that were collectively able to identify annual winter habitat residency of all tagged individuals. The two SNS tagged in Kennebecasis Bay (~5 km from the overwintering location) were rarely observed to winter in the Kennebecasis. One individual occupied the Kennebecasis in two of eight years, the other was never observed in the Kennebecasis over winter.

Following eight years of continuous tracking, the mean proportional residency in each identified winter habitat was compiled. These relative proportions allowed for a projection of population abundance of SNS occupying un-surveyed habitats and to verify the accuracy of our abundance estimates when both prior estimates and side-scan derived enumeration became available for single locations (*i.e.* Kennebecasis). The number of SNS in each identified winter habitat within the SJR was calculated from these residency proportions as a mean percentage of the estimated total. When combined, these winter residency patterns allowed for a general estimation of the whole river population.

RESULTS

Side-scan Sonar

The survey of the main aggregation covered 342,392 m^2 where depths ranged from 4-9 m (mean = 6.5 m). Andrews *et al.* (2020) enumerated 12,284 SNS in 2018, with a kappa coefficient (k) = 0.98. Comparatively, 12,005 SNS polygons within the selection range of 40-150 cm were directly enumerated in the main aggregation on 24/25 November 2022. Our classification model produced a k = 0.975; almost identical to the 2018 assessment. These values for k demonstrate

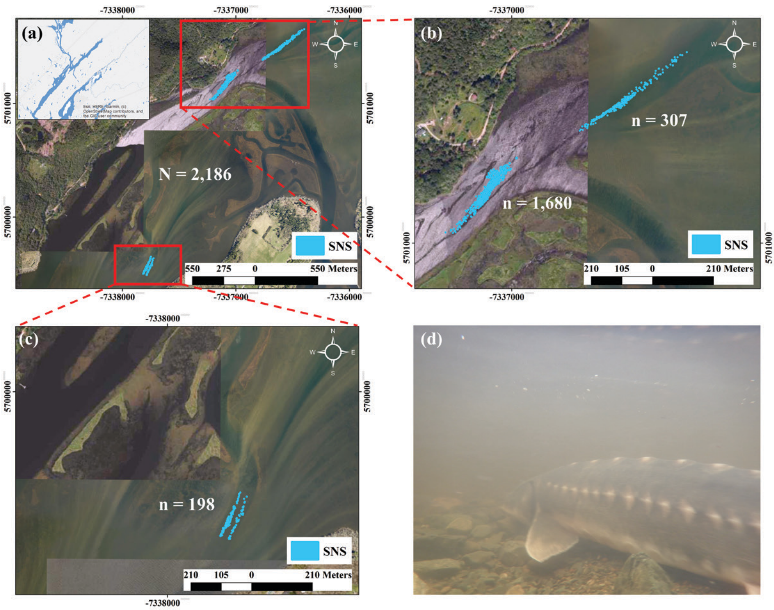


Fig 5 **An overview of the Kennebecasis study area along with the spatial distribution of the overwintering Shortnose Sturgeon (*Acipenser brevirostrum*)-SNS highlighted in blue (a). A fine-scale view of the core Kennebecasis aggregations is provided in (b) along with the number of SNS in each group. Similarly, a fine-scale view of the secondary channel grouping is shown in (c) along with an underwater image of a SNS in (d).**

strong agreement between the manually defined potential Shortnose Sturgeon and those selected by the sMLC.

Survey of the Kennebecasis aggregation covered an area of 85,510 m^2 (1/4 of the habitat extent of the main aggregation) where depths ranged from 2.5-7 m (mean = 4.5 m). Evaluation of side-scan sonar images resulted in the enumeration of 2,186 SNS polygons with the selection range of 40-150 cm that were spatially delimited within three distinct groups (see Fig 5a). Our supervised maximum likelihood classification (sMLC) rendered a $k = 0.979$, again nearly identical to that for the main aggregation in this study. The largest of the three defined groups contained 1,680 SNS polygons, the second largest group was located due northeast (directly upstream) of the largest group with 307 SNS polygons (Fig 5b). A third group was also present, located ~ 1.5 km (straight line measurement) due southwest from the other two groups in an adjacent side channel and contained 198 SNS polygons (Fig 5c). Of note is the river morphology characterizing the areas that aggregations occupied; each being denoted by the thalweg of a low gradient river.

Camera Survey

In total, the underwater camera survey in the Kennebecasis logged 58 minutes of video during which 229 sturgeon and two White Sucker (*Catostomus commersonii* Lacépède, 1803) were counted. All sturgeon detected in the camera survey were identified as SNS. Distance covered by the camera was not logged as the core winter aggregation in the Kennebecasis was confined to just 2,800 m^2 (0.6 sturgeon/m^2) and due to the lightweight camera, high current velocity, and low visibility, several passive drifts through the aggregation at different angles were repeated to collect the necessary footage. Surface water temperature at the time of the survey was 0.8°C.

Camera footage matched the side-scan sonar recordings which suggested very tight aggregation of SNS in this survey location (Fig 5). During several passes with the camera, the aggregation was observed to be so tightly associated that the camera became frequently

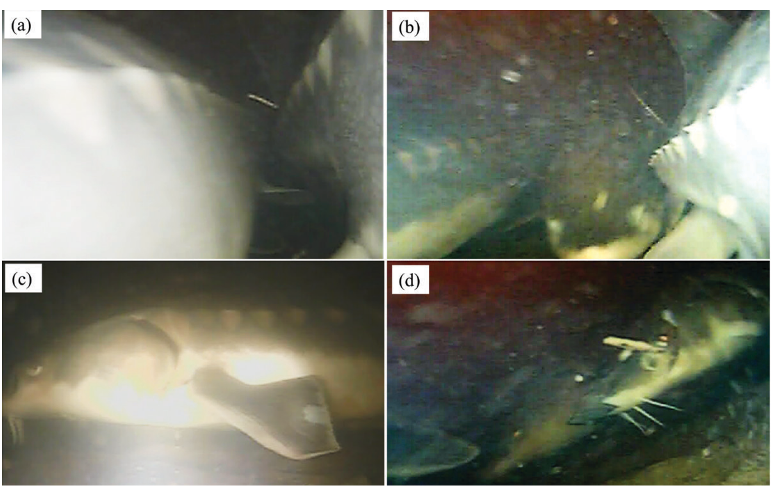


Fig 6 Still images extracted from underwater camera footage of the Shortnose Sturgeon (*Acipenser brevirostrum*) winter aggregation in the upper Kennebecasis Bay, Saint John River, New Brunswick taken on a Vexilar® Scout camera. Images provide an indication of the density of the aggregation and the stationary nature of the sturgeon under winter conditions. Panels include (a) camera stuck between two sturgeon, (b) camera caught between two sturgeon and blocked by a third, (c) sturgeon in profile in camera light, and (d) three sturgeon in profile showing close aggregation.

entrapped between fish (Fig 6a, b, d). Camera footage provided further evidence for the nearly immobile state of the SNS during the side-scan survey period. Observed SNS lay motionless on the bottom, no fin movement was observed, and they were undisturbed by the attached LED light (Fig 6c) or even physical contact from the camera itself. In several instances when the camera was inadvertently swept into the side of a sturgeon, no movement was observed, and sturgeon would eventually be either pushed sideways by the camera or the camera would need to be lifted over the fish to continue the survey. These observations provide further evidence that limited movement of SNS occurs during the side-scan survey transects described in this study. The substrate where SNS were observed in the Kennebecasis was clean sand; some rocks and plant debris were observed on bottom but only in areas where there was no sturgeon. No small/juvenile sturgeon appearing < 50 cm Fork Length (FL) were observed during this survey like observations made by Usvyatsov *et al.* (2012) in the same location.

Tracking and Population Estimate

Tagged SNS (n=18) were monitored by acoustic receivers over eight consecutive winters from 2015/16-2022/23 allowing for winter habitat residency proportions to be determined. In total, seven discrete overwintering locations were identified, increasing the number reported by Andrews *et al.* (2020) by two. These winter habitats included the main aggregation and the Kennebecasis aggregation, in addition to Grand Lake, Oromocto, Swan Creek, Washademoak Lake and an aggregation near Fredericton among those occupied by SNS (Table 1).

Following eight years of tracking, 144 winter positions were recorded for the 18 tagged SNS providing annual winter residency proportions within years for the duration of the tracking period (Table 1, 2). The eight-year mean proportional residency for the main aggregation was 64.6% while mean residency of the Kennebecasis was 9.7%. Occupancy of winter habitat near Fredericton also remained high as originally noted by Andrews *et al.* (2020) with an estimated 18.8% of Shortnose occupying that location. Over the eight-year monitoring period, nine of the tagged individuals (50%) were observed to switch from the winter habitat initially occupied in 2015. Four individuals (22%) occupied a different winter habitat from their main location of winter residency in one of the seven years of monitoring. Two sturgeon (11%) occupied a different location from their main

Table 1 **Winter locations of tagged Shortnose Sturgeon (*Acipenser brevirostrum*) in the Saint John River, New Brunswick, monitored over eight consecutive years spanning winter 2015-16 to 2022-23. Tag numbers match tag IDs of Shortnose Sturgeon tagged by the Canadian Rivers institute in 2015 in ascending order. Total length (TL; cm) is the length of each Shortnose Sturgeon at the time of tagging in 2015. Observed winter locations include the main aggregation (MA; grey boxes), the City of Fredericton (Fred; blue boxes), Kennebecasis (Ken; yellow boxes), Washademoak Lake (Wash; green boxes), the vicinity of Swan Creek (~Swan; pink boxes), a single observation in Grand Lake (Grand L; red box), and a single observation near Oromocto (orange box).**

		Winter							
Tag	TL (cm)	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23
1	102.1	MA	MA	MA	MA	MA	MA	MA	MA
2	102.9	Ken	MA	MA	MA	MA	MA	MA	MA
3	106.5	MA	Ken	MA	Ken	MA	MA	MA	MA
4	100.5	MA	Wash	MA	MA	MA	MA	MA	MA
5	128.5	MA	MA	MA	MA	MA	MA	MA	MA
6	116	MA	MA	MA	MA	MA	Grand L	MA	MA
7	106.6	MA	MA	MA	MA	MA	MA	MA	MA
8	104.1	Ken	MA	MA	MA	MA	MA	MA	MA
9	119.4	MA	Fred	Fred	Fred	Fred	Fred	MA	MA
10	108	MA	MA	MA	MA	MA	MA	MA	MA
11	109.2	MA	MA	MA	MA	MA	MA	MA	MA
12	116.8	Ken	Ken	Ken	Ken	Ken	Ken	Ken	Ken
13	106.7	MA	MA	MA	MA	MA	MA	MA	MA
14	106.7	MA	Wash	MA	Wash	MA	Wash	Wash	Wash
15	121.9	Fred	Fred	Fred	Fred	Fred	Fred	Fred	Fred
16	105.4	~Swan	~Swan	Ken	MA	MA	MA	Ken	Oromocto
17	109.2	Fred	Fred	Fred	Fred	Fred	Fred	Fred	Fred
18	111.8	Fred	MA	Fred	MA	Fred	Fred	Fred	Fred

location of winter residency in two of the eight years of monitoring. The remaining three individuals (17%) made more frequent switches between winter habitats across monitoring years (Table 1). Only one tagged sturgeon switched between more than two key winter locations. Habitat switching only occurred between winter periods and was never observed during winter.

Due to habitat switching, residency proportions in the main aggregation ranged from 55.6% in 2016 to 72.2% in 2019 (mean 64.6%) across eight years of monitoring (Table 2). At this site, the side-imaging sonar-based enumeration counted 12,005 individual SNS. Proportional residency at the Kennebecasis aggregation ranged from 5.6% observed in three of the monitoring years to 16.7% in 2015 (mean 9.7%) across eight years of monitoring (Table 2). In this location, side-imaging sonar provided an enumeration of 2,186 individuals across three spatially discrete aggregations. In combination, these two surveyed locations represent on average 74.3% of the SNS population occupying the SJR across years resulting in an estimated total adult population of 19,100 SNS (Table 2).

Table 2 **Winter residency observations of tagged Shortnose Sturgeon (*Acipenser brevirostrum*) monitored from winter 2015-16 to 2022-23 indicating the proportion of tagged sturgeon occupying each identified winter habitat location within and across years. The number of Shortnose Sturgeon in the main aggregation and Kennebecasis aggregations indicated by the * represent the enumeration from side-scan sonar surveys conducted in this study. In combination, these two aggregations which contained 14,191 sturgeon represent an estimated 74.3% of the total. This ratio was used to calculate the whole river (total) population of 19,100 from which estimates of the five other aggregations (Fredericton, Oromocto, Washademoak, Swan Creek, and Grand Lake) were back calculated. The back calculation was conducted using the average percentage of tagged Shortnose Sturgeon (in winter habitats) multiplied by the total.**

Overwintering Location	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Average percentage of tagged Shortnose Sturgeon**	**Mean local population calculated from average percentage or enumeration (*)**
Main Aggregation	61.1%	55.6%	66.7%	66.7%	72.2%	61.1%	66.7%	66.7%	64.6%	12,005*
Kennebecasis	16.7%	11.1%	11.1%	11.1%	5.6%	5.6%	11.1%	5.6%	9.7%	2,186*
Fredericton	16.7%	16.7%	22.2%	16.7%	22.2%	22.2%	16.7%	16.7%	18.8%	3,582
Oromocto	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.6%	0.7%	133
Washademoak	0.0%	11.1%	0.0%	5.6%	0.0%	5.6%	5.6%	5.6%	4.2%	797
Swan Creek	5.6%	5.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	265
Grand Lake	0.0%	0.0%	0.0%	0.0%	0.0%	5.6%	0.0%	0.0%	0.7%	133
Total Population	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**19,100**

From this total estimate, a back calculation of the proportional occupancy for each other winter habitat yields 3,582 SNS wintering near Fredericton, 797 in Washademoak, 265 in the vicinity of Swan Creek, and 133 in both Oromocto and Grand Lake (Table 2). Two White Suckers were observed among the Kennebecasis SNS aggregation, their small size < ~30-40 cm FL would have likely rendered them undetectable by the sonar at the survey depth. Fish of that length were further removed by the classification model and our estimates were therefore not corrected by the calculated 0.87% ratio (2 White Sucker among 231 observed fish of which 229 were SNS).

Using only the observed winter proportions from the study year of 66.7% of SNS in the main aggregation and 5.6% in the Kennebecasis (Table 2), the estimated total would be 19,628. While the 2018 estimate total was reported as 20,101 SNS >~40 cm FL. The lower total calculated during this study could be the result of error during image collection, processing, and filtration. Although winter residency proportions produced from a small group of 18 tagged sturgeon can also affect the calculation. During tracking efforts, no more than three and most often only two of the tagged SNS occurred in the Kennebecasis in any sampling year resulting in variability in the proportional occupancy of that location (ranging 5.6-16.7%). If a larger number of tagged SNS had been available for assessment these residency proportions could have been more refined.

DISCUSSION

Side-scan sonar has most commonly been used to map and assess benthic habitat (Switzer *et al.* 2020), although previously studies have already employed this technology to map, count, and even measure sturgeon (Flowers & Hightower 2013, Kazyak *et al.* 2020). When sonar is applied to create a population estimate of sturgeon such as SNS over a broad area, two significant challenges arise. First, SNS are active during the warmer months of the year (Dadswell 1979) and second, large areas cannot be efficiently surveyed without inevitably and inadvertently double counting some individuals and missing many others. These challenges are avoided by conducting surveys in winter when SNS are tightly aggregated and in a state of torpor. Winter is a particularly effective time for side-scan sonar surveys since SNS appear to maintain close bottom association, therefore sonar derived acoustic shadows are eliminated and the resulting sonar returns are easier to identify, count, and measure.

The enumeration produced in this study for the main SNS aggregation in SJR (n=12,005) is only 2% (n=279) different than the final count of 12,284 made in the same location in 2018. In consideration of the low occurrence of winter habitat switching between years (Table 1) and the omission of individuals within the enumeration process due to sonar pass overlap and length-based data filtering, these numbers appear to at least suggest a stable abundance within the annual aggregation. The 2018 side-scan enumeration of the main winter aggregation and proportion-based population estimate resulted in a predicted Kennebecasis aggregation size of 2,513 individuals (Andrews *et al.* 2020). Our 2022/2023 survey of the Kennebecasis aggregation (this study) enumerated 2,186, approximately 300 individuals different than what was estimated four years prior. Although we suspect that the count produced in the 2022/23 survey was an underestimate due to filtering of individuals following sonar data stretching, possible inaccuracies from counting tightly packed SNS, and the likely occurrence of other small aggregations in side-channels that were not located during this survey. Local fishing guides commonly reported one to two SNS aggregations in late autumn separate from the core Kennebecasis aggregation (S. Delaney, Saint John River fishing guide, pers comm). This phenomenon has previously been observed by the authors and was recorded in this study.

Following the 2018 survey and without direct sonar enumeration, Andrews *et al.* (2020) suggested that a sonar and acoustic telemetry-based estimate of 2,513 SNS occupying the Kennebecasis were comparable to the estimates of 4,836, 3,852 and 5,222 reported from winter video surveys in 2005, 2009, and 2011 (Li *et al.* 2007, Usvyatsov *et al.* 2012). Now having directly enumerated the Kennebecasis aggregation as n=2,186 individuals it is more likely that those prior studies reported overestimates, particularly because 198 (9%) of the SNS reported in this study were not associated with the core aggregation, and therefore would have been missed in 2005, 2009 and 2011. Since the video-based surveys described by Li *et al.* (2007) and Usvyatsov *et al.* (2012) were conducted over the span of months, sturgeon would have been able to redistribute themselves as they are observed to do during each tidal cycle, inevitably leading to repeated counts. Although, this study has shown that winter residency proportions can shift between assessment years.

The acoustic tracking component of this study estimates that the Kennebecasis supports only ~10% of the overall SNS population (>~40 cm FL) between years. Due to this low proportion and limited winter habitat switching, the recreational catch and release fishery conducted in this region from September to late-November and briefly at ice out in early March may have limited ability to impact on the overall SJR SNS population. Although stress related responses during an annual one-day angling derby are reported (Struthers *et al.* 2018). However, if the earlier population estimates (Li *et al.* 2007, Usvyatsov *et al.* 2012) and the current estimate (this study) are in fact accurate, unbiased, estimates of the SNS population at the Kennebecasis site independent of residency proportions, a potentially concerning alternative finding might be that the popular catch-and-release fishery in the Kennebecasis is either reducing sturgeon numbers through mortality or causing departure from this aggregation following disturbance. Only carefully conducted telemetry studies examining the effects of repeated capture in the recreational fishery could rule out the possible fisheries related impacts.

Across seasons, 3-4 of the tagged SNS (16.7-22.2 %) consistently wintered near Fredericton. Without a dedicated survey of the Fredericton location, it is not possible to determine if these individuals are a true indicator of a large aggregation near the city, or rather if the small sample size resulted in a few individuals being tagged that happened to occupy that location annually. If these estimates are accurate, the main aggregation, Kennebecasis, and Fredericton aggregations would total 93.1% of the adult population and in combination, could provide a very robust combination of survey sites.

During the 2019 survey of the main winter aggregation (Andrews *et al.* 2020), a length distribution curve was created for the enumerated SNS. These data approximated findings of Dadswell (1979), but these original measurements were collected after the completion of Mactaquac Dam in 1968 and may not have reflected the length frequency distribution of an unimpacted SNS population. Dadswell (1979) also described SNS reaching maturity in the SJR from 12-18 years at 50 cm FL (Bain 1997, Bain et al 2007), while Usvyatsov *et al.* 2012 documented the smallest SNS in the Kennebecasis winter aggregation as 54 cm FL. Following these findings and the suspected limitations of our applied sonar method in resolving accurate length (Andrews *et al.* 2020), it is likely that the identified winter habitats contain the known adult population of SNS in the SJR along with a small number of older but immature fish. No data exists on where juvenile SNS < 40 cm FL might occur in the SJR and their abundance is not included in our estimate.

The small sample size of monitored individuals resulted in shifting winter residency proportions across occupied habitats, but we suspect that larger more stable winter habitats consistently retain larger aggregations than smaller, less stable locations. Therefore, regardless of overall abundance, each winter habitat should support a consistent proportion of the overall adult population even if the overall population should vary. Monitoring of one or two large and easily surveyed locations may be sufficient to inform upon the status of the entire population even when estimating total abundance is not possible. Although, more detailed work will be required to determine if population demographics are changing despite an apparent stable abundance. Among the surveyed SNS, some individuals were never observed to switch between winter habitats while others switched frequently. No pattern in relation to spawning and non-spawning years was discernable. If more SNS are tagged in the future these data may refine estimates of proportional winter residency in the SJR.

LIMITATIONS

This study was subject to several limitations that should be considered and improved upon should these monitoring efforts continue in the future. Due to this small sample size of telemetered SNS, shifts of one or two individuals in winter could result in large changes in residency proportions and changes to the ensuing population estimate. This could be fixed by including a larger sample size of acoustically tagged SNS in the future, but considering the data at hand, greater confidence should be placed in the sonar enumerations than the projected proportions until a more robust tracking dataset can be included for analysis. Since the sonar transects were driven by hand, the boat speed, direction, and overlap of the side-scan sonar coverage between transects could not be precisely maintained which occasionally led to image distortion and stretching and could have affected the image filtration process. Movement of SNS could also have resulted in missed individuals or duplicate counts, but we know that movement by SNS is minimal within tidal cycles (Fig 6). As such, we must re-iterate the importance of completing passes during a single outgoing tide and at the coldest possible water temperature to ensure that sturgeon movement is kept to an absolute minimum during the survey.

Without multiple clear side imaging mosaics of each location, this study was unable to produce an estimate of variance around the reported population estimate. Three scans were collected for both the main aggregation and the Kennebecasis aggregation, but windy conditions resulted in only the single clearest scan being analysed. In the future, provisions should be made to gather multiple data sets to accurately describe error associated to the population estimate when weather conditions permit. Limitation are also apparent in the ability to resolve highly accurate length data, and while SNS abundance appears to have remained stable, further analysis must be made to determine if population demographics are changing over time. Finally, the accuracy of the sMLC classification could have been biased by the hand selection of "sturgeon" and "non-sturgeon" polygons that may have categorized the best examples of representative pixels from each group. Randomly selecting targets to delineate while training the sMLC might reduce bias in the selection and subsequent classification process.

CONCLUSIONS

Side-scan sonar enumeration of SNS is a rapid and effective method to quantify SNS occupying winter habitats. The estimate produced for the main aggregation during this study in winter 2022/23 was only 2% different than the number calculated for the same location in 2018. Predictions of abundance in the Kennebecasis in 2018 were only 327 fish greater than the count generated for that aggregation within this study. This difference may be accounted for by the potential removal of individuals within the automated data filtration process following sonar data distortion or shifting residency proportions. Despite such limitations, the rapid enumeration of SNS in winter aggregations by commercially available side-scan sonar appears to be a method which could be refined to produce a reliable and repeatable population estimates for SNS in the SJR in the future. Continued use and development of this method may therefore provide a viable solution to long-term monitoring to support management under the Fisheries and Oceans Canada (2016) management plan. Following these results and those of Andrews *et al.* (2020), there is growing evidence that the abundance of adult SNS in the SJR has likely remained stable since the initial surveys by Dadswell (1979) but more work is needed to determine if population demographics have also remained stable.

Acknowledgements We would like to thank Fisheries and Ocean Canada for funding the second iteration of this study and Jeremy Broome for providing project oversight. We thank Elizabeth Bateman for assisting with side-scan sonar mapping, underwater camera surveys, and survey organization. We would also like to thank Daniel Arluison for tagging the 18 Shortnose Sturgeon tracked in this study as part of the Mactaquac Aquatic Ecosystem Study (MAES) and the technicians at the Canadian Rivers Institute (CRI) at the University of New Brunswick, Fredericton, Canada for maintaining the Saint John River receiver array over the past eight years. The MAES program is largely funded by the New Brunswick Power Corporation and NSERC. We would also like to thank Steve Delaney for the generosity with which he has provided his hard-earned knowledge on the habitat and habits of Shortnose Sturgeon in the Kennebecasis and for his loan of the underwater camera that made this work possible.

Author contributions: S.N. Andrews planned the project and coordinated the boat and equipment required for data collection. S.N.A drove the side-scan transects of both the main Shortnose Sturgeon aggregation and the Kennebecasis aggregation and conducted the underwater camera surveys of the Kennebecasis aggregation. S.N.A compiled the side scan mosaics for export to GIS, analysed the video footage, and analysed an 8-year acoustic tracking data set to determine the proportional habitat occupancy and mixing rates between aggregations. A.M. O'Sullivan conducted the remote sensing statistical analysis to enumerate Shortnose Sturgeon in each surveyed aggregation and produced model derived Figs. R.A.C and T.L oversaw and acquired funding for the original tagging and monitoring effort in 2015 and have continue to oversee the acoustic river monitoring, receiver placement, and database management for the incurred detections.

S.N.A and A.M.O.S wrote the study results that were reviewed by all authors.

Conflict of Interest Statement: The authors declare there are no competing interests.

Data Availability Statement: To protect identified Shortnose Sturgeon winter aggregations from exploitation no shared data is available for this study.

Funding: This project including work by S.N. Andrews and A.M. O'Sullivan was funded by Fisheries and Ocean Canada, Maritimes Region, Species at Risk Program. The maintenance of the Saint John River Acoustic receiver array and the original tagging of the Shortnose Sturgeon tracking in this study was funded in part by the New Brunswick Power corporation with matched funding from NSERC-CRDPJ 462708-13.

Impact Statement: The use of side-scan sonar to enumerate winter aggregations of Shortnose Sturgeon provides a rapid, repeatable, and low-cost option for assessing this species of concern.

REFERENCES

Andrews, S.N., O'Sullivan, A.M., Helminen, J., Arluison, D.F., Samways, K.M., Linnansaari, T. & Curry, R.A. (2020). Development of active numerating side-scan for a high-density overwintering location of endemic Shortnose Sturgeon (*Acipenser brevirostrum*) in the Saint John River, NB. *Diversity* 12(1): 23. www.mdpi.com/1424-2818/12/1/23

Andrews, S.N., Roth, D.H., Kidd, K.A., Pavey, S.A., Reinhart, B., Hayden, B., Dadswell, M.J., Linnansaari, T. & Curry, R.A. (2023). Updated data on mercury and DDE in Striped Bass (*Morone saxatilis*) in relation to consumption advisories for the Saint John River, NB. *Northeastern Naturalist* 30(2): 226-243. bioone.org/journals/northeastern-naturalist/volume-30/issue-2/045.030.0208/Updated-Data-on-Mercury-and-DDE-in-Striped-Bass-Morone/10.1656/045.030.0208.short

Babin, A.B., Ndong, M., Haralampides, K., Peake, S., Jones, R.A., Curry R.A. & Linnansaari, T. (2020). Migration of Atlantic salmon (*Salmo salar*) smolts in a large hydropower reservoir. *Canadian Journal of Fisheries and Aquatic Sciences* 77(9): 1463-1476 cdnsciencepub.com/doi/abs/10.1139/cjfas-2019-0395

Bain, M.B. (1997). Atlantic and shortnose sturgeons of the Hudson River: common divergent life history attributes. *Environmental Biology of Fishes* 48: 347-358. link.springer.com/article/10.1023/A:1007325814893

Bain, M.B., Haley, N., Peterson, D.L., Arend, K.K., Mills, K.E. & Sullivan, P.J. (2007). Recovery of a US endangered fish. *PLOS One* 2(1): e168, 9 p. journals.plos.org/plosone/article?id=10.1371/journal.pone.0000168

Blevins, D.W. (2011). Water-quality requirements, tolerances, and preferences of pallid sturgeon (*Scaphirhynchus albus*) in the lower Missouri River: U.S. Geological Survey Scientific Investigations Report 2011-5186, 20 p. pubs.usgs.gov/publication/sir20115186

Bruce, M., Linnansaari, T. & Curry, R.A. (2019). First record of Eurasian Watermilfoil, *Myriophyllum spicatum*, for the Saint John River, New Brunswick. *The Canadian Field-Naturalist* 132(3): 231. www.canadianfieldnaturalist.ca/index.php/cfn/article/view/1943

Buscombe. D. (2017). Shallow water benthic imaging and substrate characterization using recreational-grade sidescan-sonar. *Environmental Modelling and Software* 89: 1-18. www.sciencedirect.com/science/article/abs/pii/S1364815216303899

Chambers, R.C., Davis, D.D., Habeck, E.A., Roy, N.K. & Wirgin, I. (2012). Toxic effects of PCB126 and TCDD on Shortnose Sturgeon and Atlantic sturgeon. *Environmental Toxicology and Chemistry* 31(10): 2324-2337. pubmed.ncbi.nlm.nih.gov/22825886/

Carter, J.C.H. & Dadswell, M.J. (1983). Seasonal and spatial distributions of planktonic crustacea in the lower Saint John River, a multi-basin estuary in New Brunswick, Canada. *Estuaries* 6(2): 142-153. link.springer.com/article/10.2307/1351704

Chateauvert, C.A., Linnansaari, T., Samways, K. & Curry, R.A. (2018). Fish passage at Tobique-Narrows, Beechwood, and Mactaquac hydropower generating facilities in the Saint John River system, New Brunswick. Mactaquac Aquatic Ecosystem Study Report Series 2018-024. Canadian Rivers Institute, University of New Brunswick, 52 p. unbscholar.lib.unb.ca/items/2450613d-7b66-46a5-92e2-f9fa51f910c8

Choudhury, A. & Dick, T.A. (1998). The historical biogeography of sturgeons (*Osteichthyes: Acipenseridae*): a synthesis of phylogenetics, palaeontology and palaeogeography. *Journal of Biogeography* 25(4): 623-640. onlinelibrary.wiley.com/doi/10.1046/j.1365-2699.1998.2540623.x

Connolly, R.M., Jinks, K.I., Shand, A., Taylor, M.D., Gatson, T.F., Becker, A. & Jinks, E.L. (2022). Out of the shadows: automatic fish detections from acoustic cameras. *Aquatic Ecology* 57: 833-844. link.springer.com/article/10.1007/s10452-022-09967-5

COSEWIC. (2005). COSEWIC assessment and update status report on the Shortnose Sturgeon *Acipenser brevirostrum* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. vi + 27 p. www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/cosewic-assessments-status-reports/shortnose-sturgeon-2005.html

COSEWIC. (2015). COSEWIC assessment and status report on the Shortnose Sturgeon *Acipenser brevirostrum* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. xii + 48 p. www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/cosewic-assessments-status-reports/shortnose-sturgeon-2015.html

Cunjak, R.A., Monk, W.A., Haralampides, K. & Baird, D.J. (2011). River habitats. p. 57-75 *In* S.D. Kidd, R.A. Curry, and K.R. Munkittrick (*Eds.*). The Saint John River: a state of the environment report. Canadian Rivers Institute, Fredericton, NB. 175 p. unbscholar.lib.unb.ca/items/74549e4a-42e3-48be-ae03-50ee71815c18

Dadswell, M.J. (1975). Mercury, DDT, and PCB content of certain fishes from the Saint John River estuary, New Brunswick. *In* Transactions of the Atlantic Chapter, Canadian Society of Environmental Biologists Annual Meeting; Huntsman Marine Laboratory: St. Andrews, NB. bioone.org/journals/northeastern-naturalist/volume-30/issue-2/045.030.0208/Updated-Data-on-Mercury-and-DDE-in-Striped-Bass-Morone/10.1656/045.030.0208.short

Dadswell, M.J. (1979). Biology and population characteristics of the Shortnose Sturgeon, *Acipenser brevirostrum* LeSueur 1818 (*Osteichyes: Acipenseridae*), in the Saint John River estuary, New Brunswick, Canada. *Canadian Journal of Zoology* 57(11): 2186-2210. cdnsciencepub.com/doi/10.1139/z79-287

Dadswell, M.J. (1980). COSEWIC status report on the Shortnose Sturgeon *Acipenser brevirostrum* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. 18 p.

Dadswell, M.J. (1984). Status of the Shortnose Sturgeon, *Acipenser brevirostrum*, in Canada. *Canadian Field Naturalist* 98: 75-79.

Elson, P.F. (1967). Effects on wild young salmon of spraying DDT over New Brunswick Forests. *Journal of the Fisheries Research Board of Canada* 24(4): 731-767.

Esri: GIS Mapping Software, Spatial data analytics; location platform. Available online: www.esri.com/en-us/home (Accessed on 17 October 2019)

Feist, G.W., Webb, M.A.H., Gundersen, D.T., Foster, E.P., Schreck, C.B., Maule, A.G. & Fitzpatrick, M.S. (2005). Evidence of detrimental effects of environmental contaminants on growth and reproductive physiology of White Sturgeon in impounded areas of the Columbia River. *Environmental Health Perspectives* 113(12): 1675-1682. pubmed.ncbi.nlm.nih.gov/16330346/

Fisheries and Oceans Canada. (2015). Management plan for the Shortnose Sturgeon (*Acipenser brevirostrum*) in Canada [Proposed]. Species at Risk Act Management Plan Series. Fisheries and Oceans Canada, Ottawa, ON. v + 55 p.

Fisheries and Oceans Canada. (2016). Management plan for the Shortnose Sturgeon (*Acipenser brevirostrum*) in Canada. Species at Risk Act Management Plan Series. Fisheries and Oceans Canada, Ottawa, ON v + 59 p. publications.gc.ca/site/eng/9.805581/publication.html

Flowers, H.J. & Hightower, J.E. (2013). A novel approach to surveying sturgeon using side-scan sonar and occupancy modeling. *Marine and Coastal Fisheries* 5(1): 211-223. pubs.usgs.gov/publication/70148138

Flowers, H.J. & Hightower, J.E. (2015). Estimating sturgeon abundance in the Carolinas Using Side-scan Sonar. *Marine and Coastal Fisheries* 7(1): 1-9. onlinelibrary.wiley.com/doi/10.1080/19425120.2014.982334

Grote, A.B., Bailey, M.M., Zydlewski, J.D. & Hightower, J.E. (2014). Multibeam sonar (DIDSON) assessment of American Shad (*Alosa sapidissima*) approaching a hydroelectric dam. *Canadian Journal of Fisheries and Aquatic Sciences* 71(4): 545-558. cdnsciencepub.com/doi/abs/10.1139/cjfas-2013-0308

Haxton, T. & Cano, T. (2016). A global perspective of fragmentation on a declining taxon – the sturgeon (*Acipenser formes*). *Endangered Species Research* 31(1): 203-210.

Helminen, J., Linnansaari. T., Bruce, M., Dolson-Edge, R. & Curry, R.A. (2019). Accuracy and precision of low-cost echosounder and automated data processing software for habitat mapping in a large river. *Diversity* 11(7): 116. www.mdpi.com/1424-2818/11/7/116

Helminen, J., O'Sullivan, A.M. & Linnansaari, T. (2021). Measuring tailbeat frequencies of three fish species from adaptive resolution imaging sonar data. *Transactions of the American Fisheries Society* 150(5): 627-636. academic.oup.com/tafs/article/150/5/627/7819277?login=false

Helminen, J. & Linnansaari, T. (2023). Combining imaging sonar counting and underwater camera species apportioning to estimate the number of Atlantic Salmon (*Salmo salar*) and Striped Bass (*Morone saxatilis*) in the Miramichi River, NB. onlinelibrary.wiley.com/doi/full/10.1002/nafm.10889

Hooper, W.C. (1991). Striped Bass management in New Brunswick, p. 29-40. *In* R.H. Peterson (*Eds.*) Proceedings of a workshop on biology and culture of Striped Bass (*Morone saxatilis*). Canadian Technical Report on Fisheries and Aquatic Sciences. vi + 66 p. New Brunswick Department of natural Resources & Energy, Fish and Wildlife Branch, Fredericton, NB. 11 p. publications.gc.ca/site/eng/460185/publication.html

Huang, Z. & Wang, L. (2018). Yangtze dams increasingly threaten the survival of the Chinese Sturgeon. *Current Biology* 28(22): 3640-3647. www.sciencedirect.com/science/article/pii/S0960982218312272

Hughes, J.B. & Hightower, J.E. (2015). Combining split-beam and dual-frequency identification sonars to estimate abundance of anadromous fishes in the Roanoke River, North Carolina. *North American Journal of Fisheries Management* 35: 229-240. onlinelibrary.wiley.com/doi/10.1080/02755947.2014.992558

Hummel, S.L., Bellamy, A. Tucker W.A. & Eckes, O.T. (2022). Exposure of juvenile Lake Sturgeon to contaminants of emerging concern (CECs), including Polybrominated Diphenyl Ethers (PBDEs): Location differences and effects on thyroid hormones. *North American Journal of Fisheries Management* 41(1): 123-139. academic.oup.com/najfm/article/42/1/123/7811473?login=false

Ingram, J.H. (1980). Capture and distribution of Atlantic Salmon and other species at Mactaquac Dam and Hatchery, Saint John River, N.B., 1972-76. Canadian Data Report of Fisheries and Aquatic Science No. 254. Department of Fisheries and Oceans, Halifax, NS. 33 p. publications.gc.ca/site/eng/440325/publication.html

Ingram, J.H. (1985). Capture and distribution of Atlantic Salmon in the Mactaquac area, Saint John River system, 1977-82. Canadian Data Report of Fisheries and Aquatic Science No. 508. Department of Fisheries and Oceans, Halifax, NS. 59 p. publications.gc.ca/site/eng/444520/publication.html

Jessop, B.M. (1990). The Status of Striped Bass in Scotia-Fundy Region. Canadian Atlantic Fisheries Scientific Advisory Committee Research Document 90/36. 23 p.

Kaeser, A.J. & Litts, T.L. (2010). A novel technique for mapping habitat in navigable streams using low-cost side scan sonar. *Fisheries* 35(4): 163-174. academic.oup.com/fisheries/article/35/4/163/7884767?login=false

Kaeser, A.J, Litts, T.L. & Tracy, T.W. (2012). Using low-cost side-scan sonar for benthic mapping throughout the lower Flint River, Georgia, USA. *River Research and Applications* 29(5): 634-644. onlinelibrary.wiley.com/doi/10.1002/rra.2556

Kandimalla, V., Richard, M., Smith, F., Quirion, J., Torgo, L. & Whidden, C. (2022). Automated detection, classification and counting of fish passages with deep learning. *Frontiers in Marine Science* 8: 823173. www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2021.823173/full

Kazyak, D.C., Flowers, A.M., Hostetter, N.J., Maden, J.A., Breece, M., Higgs, A., Brown, L.M., Royle, J.A. & Fox, D.A. (2020). Integrating side-scan sonar and acoustic telemetry to estimate the annual spawning run size of Atlantic Sturgeon in the Hudson River. *Canadian Journal of Fisheries and Aquatic Sciences* 77(6): 1038-1048. cdnsciencepub.com/doi/10.1139/cjfas-2019-0398

King, T.L., Henderson, A.P., Kynard, B.E., Kieffer, M.C., Peterson, D.L., Aunins, A.W. & Brown, B.L. (2014). A nuclear DNA perspective on delineating evolutionarily significant lineages in polyploids: the case of the endangered Shortnose Sturgeon (*Acipenser brevirostrum*). *PLoS ONE* 9:e102784. journals.plos.org/plosone/article?id=10.1371/journal.pone.0102784

Lassalle, G., Crouzet, P., Gessner, J. & Rochard, E. (2010). Global warming impacts and conservation responses for the critically endangered European Atlantic Sturgeon. *Biological Conservation* 143(11): 2441-2452. www.sciencedirect.com/science/article/abs/pii/S0006320710002740

Lenhardt, M., Jaric, I., Kalauzi, A. & Cvijanovic, G. (2006). Assessment of extinction risk and reasons for decline in sturgeon. *Biodiversity & Conservation* 15(6): 1967-1976. link.springer.com/article/10.1007/s10531-005-4317-0

Li, X.H., Litvak, M.K. & Clark, J.E.H. (2007). Overwintering habitat use of Shortnose Sturgeon (*Acipenser brevirostrum*): defining critical habitat using a novel underwater video survey and modeling approach. *Canadian Journal of Fisheries and Aquatic Sciences* 64(9): 1248-1257. https://cdnsciencepub.com/doi/10.1139/f07-093

Magowan. K., Reitsma, J. & Murphy, D. (2012). Use of dual-frequency identification sonar to monitor adult river herring in a small coastal stream. *Marine and Coastal Fisheries* 4(1): 651-659. academic.oup.com/mcf/article/4/1/651/7826860?login=false

Meth, F.F. (1972). Ecology of the Saint John River basin. V. Status of estuarial fisheries. Progress report prepared for the Saint John River Basin Board by the Canadian Department of Environment and Fisheries Services. Resource Development Branch, Halifax, Nova Scotia. viii + 105 p. science-catalogue.canada.ca/record=3623410~S6

Miller, R.R. (1972). Threatened freshwater fishes of the United States. *Transactions of the American Fisheries Society* 101(2): 239-252. onlinelibrary.wiley.com/doi/abs/10.1577/1548-8659%281972%29101%3C239%3ATFFOTU%3E2.0.CO%3B2

Quist, M.C., Guy, C.S., Pegg, M.A., Braaten, P.J., Pierce, C.L. & Travnichek, V.H. (2002). Potential influence of harvest on Shovelnose Sturgeon populations in the Missouri River System. *North American Journal of Fisheries Management* 22(2): 537-549. onlinelibrary.wiley.com/doi/abs/10.1577/1548-8675%282002%29022%3C0537%3APIOHOS%3E2.0.CO%3B2

Ruggles, C.P. & Watt, W.D. (1975). Ecological changes due to hydro-electric development on the Saint John River. *Journal of the Fisheries Research Board of Canada* 32(1): 161-170.

Smith, K.E.H. (1979). Capture and distribution of all fish species at Saint John River power dams, New Brunswick from construction years to 1971. Canadian Data Report of Fisheries and Aquatic Science No. 171. Department of Fisheries and Oceans, Halifax, NS. 55 p. publications.gc.ca/site/eng/440130/publication.html

SSSRT (Shortnose Sturgeon Status Review Team). (2010). Biological assessment of Shortnose Sturgeon (*Acipenser brevirostrum*). Report to National Marine Fisheries Service. National Oceanic and Atmospheric Administration. 417 p. www.fisheries.noaa.gov/resource/document/biological-assessment-shortnose-sturgeon-acipenser-brevirostrum

Struthers, D.P., Bower, S.D., Lennox, R.J., Gilroy, C.E., MacDonald, E.C., Cooke, S.J. & Litvak, M.K. (2018). Short-term physiological disruption and reflex impairment in Shortnose Sturgeon exposed to catch-and-release angling. *North American Journal of Fisheries Management* 38(5): 1075-1084.
academic.oup.com/najfm/article/38/5/1075/7817480?login=false

Sulak, K.J., & Randall. M. (2002). Understanding sturgeon life history: Enigmas, myths, and insights from scientific studies. *Journal of Applied Ichthyology* 18(4-6): 519-528.
onlinelibrary.wiley.com/doi/abs/10.1046/j.1439-0426.2002.00413.x

Switzer, T.S., Tyler-Jedlund, A.J., Keenan, S.F. & Weather, E.J. (2020). Benthic habitats, as derived from classification of side-scan-sonar mapping data, are important determinants of reef-fish assemblage structure in the eastern Gulf of Mexico. *Marine and Coastal Fisheries* 12(1): 21-32.
academic.oup.com/mcf/article/12/1/21/7819978?login=false

Tripp, S.J., Phelps, Q.E., Colombo, R.E., Garvey, J.E., Burr, B.M., Herzog, D.P. & Hrabik, R.A. (2009). Maturation and reproduction of Shovelnose Sturgeon in the middle Mississippi River. *North American Journal of Fisheries Management* 29(3): 730-738.
academic.oup.com/najfm/article/29/3/730/7847235?login=false

Usvyatsov, S., Watmough, J. & Litvak, M.K. (2012). Age and population size estimates of overwintering Shortnose Sturgeon in the Saint John River, New Brunswick. *Transactions of the American Fisheries Society* 141(4): 1126-1136.
academic.oup.com/tafs/article/141/4/1126/7877692?login=false

Williamson, F.A. (1974). Populations studies of Striped Bass *Morone saxatilis* in the Saint John and Annapolis rivers. Master’s thesis. Acadia University, Wolfville, NS. 74 p.
science-catalogue.canada.ca/record=3992619~S6

Wirgin, I., Grunwald, C., Stabile, J. & Waldman, J.R. (2010). Delineation of discrete population segments of Shortnose Sturgeon *Acipenser brevirostrum* based on mitochondrial DNA control region sequence analysis. *Conservation Genetics* 11: 689-708.
link.springer.com/article/10.1007/s10592-009-9840-1

Zelman, K., Harrison, P., O’Sullivan, A.M., Andrews, S.N., Peake, S., Linnansaari, T., Pavey, S.A. & Curry, R.A. (2023). Reproductive ecology of Muskellunge (*Esox masquinongy*), an introduced predator, in the lower Wolastoq/Saint John River, New Brunswick, Canada. *Journal of Fish Biology* 102(3): 643-654.
onlinelibrary.wiley.com/doi/10.1111/jfb.15302

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 167-271

HISTORY AND DISTRIBUTION OF LAKE WHITEFISH, *COREGONUS CLUPEAFORMIS* (MITCHILL, 1818), IN NOVA SCOTIA AND NEW BRUNSWICK, CANADA, WITH SUPPLEMENTARY NOTES ON REGIONAL COREGONIDS

SAMUEL N. ANDREWS[1,2*] COLIN F. BUHARIWALLA[3], MICHAEL J. DADSWELL[2], JEREMIAH WOOD[4], ELIZABETH M.T. BATEMAN[2], ELLIOT A. CEDERBERG[2], MATTHEW G. WARNER[2], JOHN L. MACMILLAN[3], KATHRYN COLLET[5], ABBEY GREER[5] AND MICHAEL J.W. STOKESBURY[2]

[1]Ducks Unlimited Canada, 64 Highway 6, Amherst, NS B4H 3Y4

[2]Acadia University, Acadia Center for Estuarine Research, Department of Biology, 33 Westwood Avenue, Wolfville, NS B4P 2R6
samuel.andrews@acadiau.ca, elizabethbateman@acadiau.ca, elliotcederberg6@gmail.com, matthewwarner@acadiau.ca, michael.stokesbury@acadiau.ca, mdadswell9@gmail.com

[3]Nova Scotia Department of Fisheries and Aquaculture: Inland Fisheries Division, 91 Beeches Rd., Pictou, NS B0K 1H0
colin.buhariwalla@novascotia.ca, john.macmillan@novascotia.ca

[4]Maine Department of Inland Fisheries and Wildlife, Ashland Regional Headquarters, 63 Station St, Ashland, Maine, USA 04732,
jeremiah.wood@maine.gov

[5]New Brunswick Department of Natural Resources and Energy Development, Hugh John Flemming Forestry Complex, 1350 Regent St, Fredericton, NB E3C 2G6
kathryn.collet@gnb.ca, abbey.greer@gnb.ca

ABSTRACT

Lake Whitefish (*Coregonus clupeaformis*) occur in the Canadian Maritime Provinces of New Brunswick and Nova Scotia and were first described regionally in the 1850s in the Saint John River. However, no early observations of the species were known in Nova Scotia prompting

* Author to whom correspondence should be addressed: samuel.andrews@acadiau.ca

extensive Lake Whitefish stocking through Canada's earliest federally run hatcheries. From 1878-1901, nearly 80 million Lake Whitefish fry were introduced to Nova Scotia and New Brunswick, but all attempted introductions were thought to have failed. From 1964 onward, Lake Whitefish discoveries were reported in Nova Scotia, but not until 1990 were these populations demonstrated to be native. Due to the distinct genetic lineage and eastern distribution of maritime Lake Whitefish populations, we argue that they originated from a distinct glacial refugium. The goal of this review is to provide baseline data on origin, distribution, and history of Lake Whitefish throughout the Maritimes that will facilitate continued research, help identify undocumented populations, and support the conservation of those so far known. As invasive species spread, climates warm, and new recreational fisheries develop, the resilience of Lake Whitefish populations should become a management consideration among the region's small yet distinct eastern assemblage of native cold-water fishes.

Keywords: Hatchery stocking, zoogeography, native species, continental shelf refugia, post-glacial dispersal

INTRODUCTION

The genus *Coregonus* is the most speciose within the family Salmonidae and has a northern circumpolar distribution (Bernatchez 1995) that includes freshwater, euryhaline, and anadromous ciscoes and whitefishes (Scott and Crossman 1973, Svårdson 1979, Bernatchez *et al.* 2010). This diverse group of fishes is highly adaptable with noted variations in diet, spawning habitat, and use of marine waters, even among conspecifics. In North America, 18 coregonid species are recognized of which the Lake Whitefish (*Coregonus clupeaformis* Mitchill, 1818) may be the most well known and widely distributed, ranging from the Lake Erie and Michigan basins in the south to the northern tributaries of Alaska (Scott and Crossman 1973). From this western point, the Lake Whitefish occurs as far east as the Atlantic coast of Nova Scotia (Bernatchez and Dodson 1991). Lake Whitefish is most common in deep, well oxygenated, oligotrophic lakes (Wood 2016), but it is also found in rivers, estuaries, and on occasion marine waters, particularly in the coastal tributaries of Hudson Bay and Arctic Ocean drainages (Scott and Crossman 1973). Among North American coregonids, the Lake Whitefish is one of three species native to the Canadian Maritime Provinces (MP; Fig 1). In northern New Brunswick (NB), Lake Whitefish occur alongside the Round Whitefish (*Prosopium cylindraceum* Pallas, 1784) while in Nova

Scotia (NS) the only other coregonid is the critically endangered and endemic Atlantic Whitefish (*Coregonus huntsmani*) (Scott 1967, Edge and Gilhen 2001). Due to the morphological plasticity and diversity of the genus *Coregonus* across the Holarctic, and difficulties in distinguishing member species (Scott and Scott 1988), the eastern-most natural distribution of Lake Whitefish has only recently been defined (Bernatchez and Dodson 1990, 1991, Edge and Gilhen 2001).

Lake Whitefish have been documented and described in NB since the 1850s, largely in the Saint John River Basin (Perley 1852). Although, the absence of early records in NS suggested that no Coregonids were known prior to 1919 (Vldykov and McKenzie 1935). This perceived absence of whitefish in NS and limited distribution in NB coupled with the high value of Lake Whitefish as a commercial food species elsewhere in Canada incentivised intensive stocking efforts across the MP (Pope 1879). These stocking efforts and the introduced fish were not successful, and Lake Whitefish supplementation programs in the MP were abandoned as early as the turn of the 20th century. Nearly 125 years after stocking was first attempted, native populations of Lake Whitefish were discovered in NS and its native ancestry in the MP has since been confirmed (Bernatchez and Dodson 1990, 1991). Despite this discovery, our knowledge of local distribution, basic ecology, and conservation status of Lake Whitefish is lacking. Furthermore, the persistence of several Lake Whitefish populations in NS has not been confirmed in over 20 years, and in many more locations far more time has elapsed since the most recent survey or report. In NB, documented Lake Whitefish disappearances have been left unexamined. These data gaps in both provinces have remained despite the known impacts of climate change and invasive species introduction that threaten native cold-water fishes region-wide (Curry and Gautreau 2010).

To inform future study of Lake Whitefish in the MP, this review compiles all available data on the Lake Whitefish including post glacial distribution, historical stocking efforts, population ancestry, and present occurrence in NS and NB. These data have been assembled into a series of tables and maps detailing the timing and magnitude of documented introductions while reporting the spatial distribution of stocked and native populations, the latter of which were identified both prior to and after the stocking occurred. Round Whitefish and Atlantic Whitefish are also described regionally when required to better understand Lake Whitefish history, distribution, and identification. While the presented data are comprehensive of what is known regarding Lake Whitefish and reported to date, a significant time gap exists between this writing (2025) and even the most recent partial surveys (Murray 2005, Nova Scotia Department of Fisheries and Aquaculture [NSDFA], unpubl. data). Therefore, modern persistence of identified populations in most locations and particularly in NS is almost entirely unknown. Though, in the absence of alternative data sources, these data must be considered accurate until updated assessments become available. The goal of this review is to provide baseline data to assist all future study and exploration of Lake Whitefish in the MP and we encourage future authors to confirm and update the species occurrence here presented alongside their findings.

Description of the Study Area

This review focuses on lakes of the Canadian MPs (including NS and NB) but omits Prince Edward Island (PEI; Fig 2, 3) due to its lack of suitable habitat and absence of Lake Whitefish occurrence or stocking. The MPs that support whitefishes occupy a temperate coastal ecozone characterized by mild winters and cool summers with mean annual monthly temperatures raging from -2 to 15.5°C in coastal regions (Webb and Marshall 1999) and with less seasonal temperature moderation as one travels inland. Lakes in Nova Scotia are usually small, shallow, and oligotrophic, often appearing darkly stained or tannic due to a high humic concentration drawn from organic material decay in wetland soils (Davis and Browne 1996). These darkly stained tannic waters are synonymous with low pH (Kerekes *et al.* 1982) resulting from the production of natural, dissolved organic acids. These conditions were in many regions exacerbated by the effects of acid rain in the 1970s (Clair *et al.* 2007) which eroded the natural buffering capacity of the soil. Darkly stained lakes subject to limited light penetration frequently establish shallow thermoclines that maintain cold-water refugia even within confined or shallow basins (Heiskanen *et al.* 2015).

In NS, the northwestern portion of the province, including much of Cape Breton, is composed of sedimentary rock such as limestone that is more easily weathered to provide a buffer against acidity (Davis and Browne 1996). In southwestern and eastern regions, shallow granite and shale bedrock covered with thin acidic soils provide little buffering capacity and low pH (≤ 4.5) is often reported in these regions susceptible to acidification (Shilts 1981, Clair *et al.* 2007, Curry and Gautreau 2010). Low pH is linked to impacts to aquatic ecosystems (Kerekes *et al.* 1982), including declines in native salmonids (Watt 1987), reductions in inland and anadromous fishes (White 1992) and loss of species diversity (Kelso *et al.* 1986), and thus it may also impact Lake Whitefish (Edge 1987, Goodchild 2001). Freshwater obligate and euryhaline fish diversity is low throughout NS (Curry 2007), resulting in limited interspecific competition amongst native species. This condition may have left native fishes of the MP vulnerable to predation and competition by aquatic invasive species such as Smallmouth Bass (*Micropterus dolomieu* Lacépède, 1802) and Chain Pickerel (*Esox niger* Lesueur, 1818), particularly in the south of the province where warm water invasives are most prevalent (LeBlanc 2010).

Similar environmental conditions exist in NB including low pH and the lack of natural buffering capacity in the southwest of the province (Clair *et al.* 2007). However, Lake Whitefish have much greater access to large rivers, deep basins, and interconnected lake systems in NB than are available in NS. In some of these larger systems such as the Saint John River, dams now block migration routes and fish passage. NB has a higher diversity of freshwater obligate fishes than NS (Curry 2007) but has also fostered more warm water invasive species of which many are regarded as key sportfish throughout inland lakes, the Saint John, and the Saint Croix rivers complicating management. The Saint John River where Lake Whitefish were first reported in the MP has a large estuary with saltwater measurable 70 km upstream from the river mouth (Carter and Dadswell 1983) and possibly offers refuge to Lake Whitefish away from freshwater obligate invasive species concentrated further upstream (Zelman *et al.* 2023).

Nomenclature

Hebda (2019) reported several names used to describe the Lake Whitefish, but across historical literature of the MP only a small number are repeated. Gizzard-fish is used by Perley (1851) and Smith (1969) in reference to the thick walled and gizzard-like stomach of the Lake Whitefish. The French name Poisson Pointu (English: sharp fish) is also reported by Perley (1851) and was used by early Acadian fishers that pursued the species in both Lake Témiscouata, Québec, and the Madawaska River, NB. This name likely describes the small, tapered head or pointed fins of the species because Lake Whitefish possess no rigid spines. The Sault Whitefish (*Coregonus labradoricus* Richardson, 1836) is used by Cox (1896a) and Piers (1924) and suggested a northern form or sub-species of the Lake Whitefish. Despite these differences in early naming conventions, Lake Whitefish in the MP are the same as those occurring throughout the rest of North America despite some meristic differences (Edge 1987, Edge *et al.* 1991, Hasselman 2003, Hasselman *et al.* 2009), and the identification of localized dwarf forms (Fenderson 1964). Following discoveries of phenotypic plasticity of the species relating to gill raker and lateral line scale counts, the species which occurs across North America was eventually consolidated into *Coregonus clupeaformis* and the suggestion of subspecies was abandoned (Gilhen 1974).

Modern vernacular in the MP often refers to the species simply as "whitefish", offering no distinction between the Lake Whitefish and the Round Whitefish that occupy an overlapping distribution in northern New Brunswick. Reference to the Round Whitefish within available records would likely be minimal because this planktivorous species is almost never caught by anglers, although, Maine once supported a recreational spring river fishery for the species (J. Wood, unpubl. data)." In contrast, the Atlantic Whitefish in Nova Scotia is commonly referred to specifically due to their conservation status (DFO 2006, 2018, COSEWIC 2010, COSEWIC 2022) and longstanding awareness campaigns. In French "Grand Corégone" is most common in and refers to the Lake Whitefish specifically.

Whitefish Morphology

Scott and Crossman (1973) state that the genus *Coregonus* is "*taxonomically, the most perplexing of all Canadian freshwater fishes*", a statement mostly relating to the difficulty of identifying cisco species due to high variability in gill raker counts and morphology, but the identification of whitefish in the MP has similarly resulted in considerable confusion (Edge and Gilhen 2001). Whitefish are subject to pronounced morphological variation (Fig 1; Svårdson 1979, Edge 1987, Edge *et al.* 1991) and diagnostic features such as gill raker number and length, and lateral line scale count can vary widely (Lindsey 1981, Edge 1987, Edge *et al.* 1991). Individual size and growth rate can also change based on environment, mode of feeding, and habitat that varies by individual lake (Scott and Crossman 1973, Goodchild 2001). In addition to broad intraspecies variation of the genus *Coregonus*, three species of whitefish are present in the MP that are of note for local identification purposes (Fig 1).

Lake Whitefish and Atlantic Whitefish are the only two coregonids found in NS (Edge 1987, Edge *et al.* 1991). At present, Atlantic Whitefish are only known to persist in Hebb Lake, Minamkeak Lake, and Millipsigate Lake at the head of the Petite Rivière watershed, Lunenburg County (DFO 2018). Following the likely extirpation of this species from the Tusket and Annis rivers, it no longer overlaps spatially with Lake Whitefish in NS (Edge 1984, 1987, Edge and Gilhen 2001). In the neighbouring province of NB, the Atlantic Whitefish is absent, but the Round Whitefish occupies an overlapping distribution with Lake Whitefish in the north of the province. There it is found in the Saint Croix River Basin, and upper Saint John River basin through Madawaska and Victoria Counties (Scott and Crossman 1959, Gautreau and Curry 2020, DNRED unpubl. data) in addition to Restigouche County in the Restigouche River basin (Gautreau and Curry 2020, DNRED unpubl. data). Characteristics for identifying the Lake Whitefish and distinguishing among the species pairs in each respective province are as follows.

Lake Whitefish (Fig 1) have large clearly defined cycloid scales and a straight and clearly visible lateral line expressing 70-85 scales in most populations of the MP (Edge 1987). However, lateral line scale counts may be as high as 90 among populations in the upper Saint John River basin (Hasselman 2003). The body is coloured greenish grey dorsally, changing to silver-grey on the sides, and fading to a white ventral surface (Kerekes 1975, Goodchild 2001). The body is deepest just before the dorsal fin (Scott and Crossman 1973) and is slightly laterally compressed (Scott 1967). The dorsal fin is small, pointed, and soft rayed, and an opaque adipose fin is present along with a deeply forked and dark grey caudal fin. The pectoral fins, the mid-ventral abdominal fins, and the anal fin can range in colour from dark grey to faded yellow and are also soft-rayed. Lake Whitefish have a pointed overhung snout with a slightly sub-terminal mouth. Small teeth are present in juveniles, but no teeth are expressed by adults (Goodchild 2001). The maxillary extends to the anterior edge of the eye/pupil (Scott and Crossman 1973). During spawning, nuptial tubercles develop in both sexes but are most pronounced in males (Goodchild 2001). Additional morphometric and meristic counts for Lake Whitefish in the MP have been reported in detail by Edge

(1987), Edge *et al.* (1991), and Hasselman (2003). While regionally the species can grow to 62 cm FL and 4.5 kg, as reported from the largest of 130 Lake Whitefish sampled in the Saint John River by Dadswell (1975), it generally maintains a relatively small average size in the MP (< 50 cm; Lanman 1874, Smith 1952, Dadswell 1975).

In contrast, the Atlantic Whitefish (Fig 1), which is only found in NS, has a terminal mouth with small well-developed teeth on the premaxillaries, vomer, palantines, dentary, and tongue that are expressed in juveniles and retained as adults (Scott and Crossman 1973, Edge and Gilhen 2001, Hasselman 2003). In comparison to the Lake Whitefish, the snout of the Atlantic Whitefish is rounded, but its inferior lower jaw renders this character hard to reliably distinguish from a true sub-terminal position (Hasselman 2003). The elongate body is slightly laterally compressed (Scott and Crossman 1973) and sports similar colouration to the Lake Whitefish with silvery sides and a dark back (Edge and Gilhen 2001). Lateral line scales counts are perhaps the most reliable external identifying feature because the Atlantic Whitefish never expresses fewer than 88 lateral line scales (typically 91-100) which separates it from all Nova Scotian populations of Lake Whitefish (Edge 1987, 1991, Edge and Gilhen 2001, Goodchild 2001, Hasselman 2003). While not observable in live specimens, Atlantic Whitefish also have 64-67 vertebrae as compared to the 58-64 of the Lake Whitefish (Edge 1987, Edge *et al.* 1991, Edge and Gilhen 2001) and these counts have been proven a reliable discriminatory character by taxonomists (Hasselman 2003).

The Round Whitefish by comparison (Fig 1) is generally small (20-30 cm total length) but can occasionally exceed 40 cm (J. Wood, observation), it has a long slender body that is cylindrical in cross section and is green to bronze along the back, silver laterally, and white along the ventral side (Scott and Crossman 1973). Scales are well defined with dark borders and 74-108 lateral line scales are present, thus overlapping with counts for Lake Whitefish (Scott and Crossman 1973). The fins are pale amber in colour, but the dorsal and caudal fin can take on a sooty black shade and the adipose may appear brown and spotted providing a useful identification character (Scott and Crossman 1973). When depressed, the tip of the dorsal fin does not extend past its posterior base as it does in Lake Whitefish (Gautreau and Curry 2020). Parr of the Round Whitefish are often spotted.

Dwarf forms of the Lake Whitefish were identified in at least 22 lakes in Maine by Fenderson (1964), 28 by Edge (1987, Edge *et al.* 1991), and updated to 29 by Wood (2016) who has since documented an additional population in Glazier Lake in 2017 for a total of 30 (J. Wood unpubl. data). Some of these populations occur as sympatric pairs of dwarf and normal populations. All occurrences of the dwarf form so far documented in Maine are reported in the Allagash, Aroostook, and St. Francis River drainages of the Saint John River basin and were thought to be exclusive to those systems. Though in the province of Québec, a dwarf population does exist in Lake Témiscouata (Edge 1987, Edge *et al.* 1991) where it occurs in sympatry with the standard form yet maintains reproductive isolation (Fenderson 1964, Kirkpatrick and Selander 1979, Bernatchez and Dodson 1990, 1991). An additional dwarf population likely exists in Scots Lake, Halifax County, Nova Scotia as described by Semple (1973, NSDFA unpubl. data; mean fork length 21.1 cm, mature at age 1-3). This finding might suggest that the purported distribution of dwarf whitefish supposedly occurring only in the upper reaches of the Saint John River basin could be a product of survey effort which is far greater in Maine than in the adjacent MPs. These dwarf Lake Whitefish are generally indistinguishable morphologically from a small Lake Whitefish apart from having more numerous and tightly packed gill rakers (Bernatchez *et al.* 2010) and an earlier age of spawning maturity (generally maturing at age 1-2; Edge 1987, Edge *et al.* 1991). Behaviorally, the two forms differ in swimming depth and burst acceleration (Rogers *et al.* 2002). In NB, Glazier Lake and Beau Lake (mostly encompassed in the Province of Québec) which border the northwest corner of the province both support the dwarf form, and a sympatric pair is confirmed to occur in Beau Lake (J. Wood unpubl. data updating Wood 2016). A lack of thorough assessment in other areas precludes the description of dwarf populations that might occur in the MP.

METHODS

Lake Whitefish in the MP have a disjointed history that includes naturalist accounts and stocking reports from the mid to late 1800s followed by modern surveys and literature from the late 1900s with sparse data available in between. As a result, available literature forms

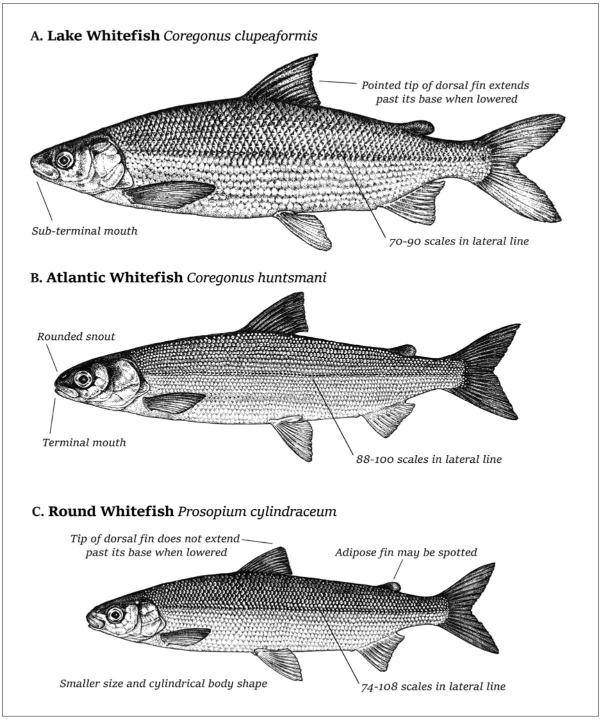


Fig 1 **Scientific illustration of the three whitefish species found in the Canadian Maritime Provinces including a) the Lake Whitefish (*Coregonus clupeaformis*) [dwarf and normal forms], b) the Atlantic Whitefish (*Coregonus huntsmani*), and c) the Round Whitefish (*Prosopium cylindraceum*). Illustrations by E.M.T Bateman.**

no clear link between introduced and native origin populations or past and present distribution critical for managers and ongoing research efforts (Mandrak *et al.* 2023). In this review, we 1) compiled reports of the early occurrence and distribution of Lake Whitefish in the MP reported prior to the onset of stocking, 2) provided a detailed account of the stocking efforts and all locations stocked throughout NS and NB, 3) summarized data for Lake Whitefish population ancestry and origin where available, and 4) identified the current distribution of Lake Whitefish populations in the MP inclusive of suspected locations. Where necessary for species identification and progression of the historical narrative, data from Round Whitefish and Atlantic Whitefish are included, but these data are not comprehensive for the region. The methods used to compile and display these data for this review are as follows.

Historical Distribution

Pre-stocking occurrence data for Lake Whitefish is only available for NB as the species was not discovered in NS until several decades after stocking concluded. To summarize Lake Whitefish presence in NB, early naturalist writings, fisheries observations, and distributional notes that pre-dated the first years of stocking (1879 in NS and 1886 in NB) were compiled. Within these documents, possible confusion exists between Lake Whitefish and Round Whitefish as the latter species was never identified overtly in historical literature. Fortunately, modern surveys demonstrate species overlap only in the northern portion of the province (Saint John River, Saint Croix River, and Restigouche River basins; Gautreau and Curry 2020, NBDNRED unpubl. data) and therefore, mistaken or unspecified Coregonid identity by early naturalists was deemed largely inconsequential. Furthermore, early accounts of "whitefish" occurring naturally in NB only overlapped with stocking that occurred in Grand Lake, Queens County, on the Saint John River which supports an irrefutable and formerly abundant native population (Perley 1851, Smith 1970), thereby simplifying our assessment of population ancestry. The Round Whitefish is not known from Grand Lake, Queens County, or elsewhere in the lower Saint John River.

Stocking History

Lake Whitefish stocking records were transcribed from the annual Department of Marine and Fisheries reports from 1878 (Pope 1879) to 1901 (Sutherland 1902) and crosschecked with summary tables that were similarly extracted by Bradford and Mahaney (2004). These records were first tabulated by year and stocking location (Table 1, 2) and then merged to form a stocking summary by lake detailing the range of years stocked, the total number of stocking years, and the total number of Lake Whitefish released (Table 3, 4). A second data frame was then created to provide details on each stocked location by province. These tables include county and watershed data extracted from provincial data layers on Google Earth Pro, latitude and longitude extracted from Google Earth Pro, lake depth extracted from provincial lake map databases when available, and lake area calculated using lake polygon layers for NS and NB in Arc GIS Pro

(ESRI 2024). Once summarised, stocked lakes were mapped using GIS and then compared with reconstructed maps of the Laurentide ice sheet to examine post glacial zoogeography (see supplementary data in Dalton *et al.* 2023).

In addition to the stocking history of Lake Whitefish, the recent history of provincially led hatchery introductions of trout (Brook Trout [*Salvelinus fontinalis* Mitchill, 1814], and Rainbow Trout [*Oncorhynchus mykiss* Walbaum, 1792]) within known whitefish lakes was also compiled. Comprehensive data for Brown Trout (*Salmo trutta* Linnaeus, 1758) stocking in the MP is tabulated in Andrews *et al.* (2025), but there is no overlap between provincially led introductions of this species and Lake Whitefish populations. Extensive stocking records for trout exist in federal reports going back to the mid 1800s (see Andrews *et al.* 2025), but for the purpose of this review only the more recent provincial stocking records were used (NSDFA, unpubl. data). These records extended back to 1976 in both NS and NB and provided a satisfactory though incomplete assessment of possible hatchery effects on native Lake Whitefish populations. Provincial hatchery stocking records were summarized by lake to detail the number of years stocked, the number of hatchery reared trout released, and the species. Concurrently, the presence of invasive species including Chain Pickerel or Smallmouth Bass in each lake was also noted from provincial databases in both NS and NB where available.

Lake Whitefish Ancestry and Origin

The ancestry and origin of Lake Whitefish in the MP has long been a topic of debate. This is particularly true in NS where the species was not identified in provincial waters until long after stocking efforts had concluded which initially implied an introduced origin. To report on Lake Whitefish ancestry and origin, we collected all available literature relating to morphometric and genetic analysis comparing Lake Whitefish populations within the MP to western Lake Whitefish populations that sourced regional hatcheries. Surveyed lakes, sampled fish, and reported ancestry from genetic analysis were cross referenced against reported stocking locations to assess possible origin and these data were entered into lake summary tables (Table 5, 6). Genetic data for Lake Whitefish populations in NB were sparse compared to NS, but accounts of occurrence pre-dating stocking coupled with limited stocking overlap served to confirm population ancestry in this region.

Table 1 **Complete summary of Lake Whitefish (*Coregonus clupeaformis*) fry stocking in Nova Scotia including annual stocking details for each lake by year and county, the number of fry released during each stocking event, and the source hatchery of the stocked fish. Lake Whitefish introduced to Nova Scotia were sent from either the Newcastle or Sandwich Hatcheries in Ontario. The Sandwich Hatchery sourced Lake Whitefish eggs from Lake Erie and the Detroit River and often sent stock to the Newcastle Hathery, though in early years it is possible that some whitefish eggs at the Newcastle Hatchery were sourced from Lake Ontario. All Lake Whitefish arriving from Ontario were received by the Bedford Hatchery in Halifax, Nova Scotia from which whitefish were stocked in local lakes or in some instances transferred to other hatcheries for distribution.**

Lake Name	County	Stocking Year	Number Released	Stocked Fish Origin	Source
Beeler's Lake	Annapolis	1892	300,000	Sandwich, ON	Tupper 1893
Beeler's Lake	Annapolis	1893	300,000	Sandwich, ON	Tupper 1894
George Lake	Annapolis	1891	250,000	Sandwich, ON	Tupper 1892
La Rose Lake	Annapolis	1896	500,000	Newcastle and Sandwich, ON	Davies 1897
Milford (Pits) Lake	Annapolis	1889	200,000	Sandwich, ON	Tupper 1890
Paradise Lake	Annapolis	1891	500,000	Sandwich, ON	Tupper 1892
Paradise Lake	Annapolis	1892	300,000	Sandwich, ON	Tupper 1893
Paradise Lake	Annapolis	1893	300,000	Sandwich, ON	Tupper 1894
Paradise Lake	Annapolis	1894	1,000,000	Sandwich, ON	Costigan 1895
Paradise Lake	Annapolis	1896	250,000	Newcastle and Sandwich, ON	Davies 1897
Paradise Lake	Annapolis	1897	1,200,000	Sandwich, ON	Davies 1898
Paradise/Round Hill Lakes (Upper/lower Wrights)	Annapolis	1898	700,000	Sandwich, ON	Davies 1899
Paradise Lake	Annapolis	1899	700,000	Sandwich, ON	Davies 1900
Paradise Lake	Annapolis	1900	500,000	Sandwich, ON	Davies 1901
Paradise Lake	Annapolis	1901	500,000	Sandwich, ON	Sutherland 1902
Round Hill Lake (Upper/Lower Wrights Lake)	Annapolis	1890	250,000	Sandwich, ON	Tupper 1891
Round Hill Lake (Upper/Lower Wrights Lake)	Annapolis	1893	300,000	Sandwich, ON	Tupper 1894
Round Hill Lake (Upper/Lower Wrights Lake)	Annapolis	1896	500,000	Newcastle and Sandwich, ON	Davies 1897
Lochaber Lake	Antigonish	1889	300,000	Sandwich, ON	Tupper 1890
Lochaber Lake	Antigonish	1894	700,000	Sandwich, ON	Costigan 1895

Table 1 Cont'd

Lake Name	County	Stocking Year	Number Released	Stocked Fish Origin	Source
Lochaber Lake	Antigonish	1901	500,000	Sandwich, ON	Sutherland 1902
St Joseph's Lake	Antigonish	1894	1,000,000	Sandwich, ON	Costigan 1895
St Joseph's Lake	Antigonish	1895	500,000	Sandwich, ON	Costigan 1896
Folly Lake	Colchester	1878	20,000	Newcastle, ON	Pope 1979
Haines & Porters Lake	Digby	1895	800,000	Sandwich, ON	Costigan 1896
Goshen Lake	Guysborough	1899	200,000	Sandwich, ON	Davies 1900
Goshen Lake	Guysborough	1900	500,000	Sandwich, ON	Davies 1901
Governor's Lake	Halifax	1887	150,000	Newcastle, ON	Foster 1888
Governor's Lake	Halifax	1889	200,000	Sandwich, ON	Tupper 1890
Grand Lake	Halifax	1878	120,000	Newcastle, ON	Pope 1979
Grand Lake	Halifax	1887	750,000	Newcastle, ON	Foster 1888
Grand Lake	Halifax	1888	1,400,000	Sandwich, ON	Tupper 1889
Grand Lake	Halifax	1889	500,000	Sandwich, ON	Tupper 1890
Grand Lake	Halifax	1890	500,000	Sandwich, ON	Tupper 1891
Grand Lake	Halifax	1891	500,000	Sandwich, ON	Tupper 1892
Grand Lake	Halifax	1892	300,000	Sandwich, ON	Tupper 1893
Grand Lake	Halifax	1893	300,000	Sandwich, ON	Tupper 1894
Hubley's Lake	Halifax	1887	150,000	Newcastle, ON	Foster 1888
Hubley's Lake	Halifax	1889	200,000	Sandwich, ON	Tupper 1890
Hubley's Lake	Halifax	1891	250,000	Sandwich, ON	Tupper 1892
Hubley's Lake	Halifax	1892	300,000	Sandwich, ON	Tupper 1893
Hubley's Lake	Halifax	1893	300,000	Sandwich, ON	Tupper 1894
Lake Thomas	Halifax	1893	300,000	Sandwich, ON	Tupper 1894
Lake William	Halifax	1893	300,000	Sandwich, ON	Tupper 1894

Lily Lake	Halifax	1878	10,000	Newcastle, ON	Pope 1979
Sandy Lake	Halifax	1878	10,000	Newcastle, ON	Pope 1979
Sandy Lake	Halifax	1886	50,000	Newcastle, ON	Foster 1887
Sandy Lake	Halifax	1887	750,000	Newcastle, ON	Foster 1888
Sandy Lake	Halifax	1888	700,000	Sandwich, ON	Tupper 1889
Sandy Lake	Halifax	1889	200,000	Sandwich, ON	Tupper 1890
Sandy Lake	Halifax	1890	500,000	Sandwich, ON	Tupper 1891
Sandy Lake	Halifax	1891	250,000	Sandwich, ON	Tupper 1892
Sandy Lake	Halifax	1894	300,000	Sandwich, ON	Costigan 1895
Sandy Lake	Halifax	1895	200,000	Sandwich, ON	Costigan 1896
Sandy Lake	Halifax	1896	250,000	Newcastle and Sandwich, ON	Davies 1897
Sandy Lake	Halifax	1897	1,400,000	Sandwich, ON	Davies 1898
Sandy Lake	Halifax	1900	200,000	Sandwich, ON	Davies 1901
Williams Lake	Halifax	1887	900,000	Newcastle, ON	Foster 1888
Williams Lake	Halifax	1888	700,000	Sandwich, ON	Tupper 1889
Williams Lake	Halifax	1889	200,000	Sandwich, ON	Tupper 1890
Williams Lake	Halifax	1890	500,000	Sandwich, ON	Tupper 1891
Williams Lake	Halifax	1891	250,000	Sandwich, ON	Tupper 1892
Williams Lake	Halifax	1892	300,000	Sandwich, ON	Tupper 1893
Williams Lake	Halifax	1897	1,400,000	Sandwich, ON	Davies 1898
Williams Lake	Halifax	1898	200,000	Sandwich, ON	Davies 1899
Williams Lake	Halifax	1901	200,000	Sandwich, ON	Sutherland 1902
Neal's/Neilson Lake	Halifax	1887	150,000	Newcastle, ON	Foster 1888
Lake Ainsley	Inverness	1895	1,000,000	Sandwich, ON	Costigan 1896
Lake Ainsley	Inverness	1896	500,000	Newcastle and Sandwich, ON	Davies 1897
Lake Ainsley	Inverness	1898	700,000	Sandwich, ON	Davies 1899
Lake O'Law (First Lake)	Inverness	1896	1,000,000	Newcastle and Sandwich, ON	Davies 1897
Lake O'Law (First Lake)	Inverness	1898	700,000	Sandwich, ON	Davies 1899
Lake O'Law (First Lake)	Inverness	1899	800,000	Sandwich, ON	Davies 1900
Lake O'Law (First Lake)	Inverness	1900	800,000	Sandwich, ON	Davies 1901

Table 1 Cont'd

Lake Name	County	Stocking Year	Number Released	Stocked Fish Origin	Source
Lake O'Law (First Lake)	Inverness	1901	1,000,000	Sandwich, ON	Sutherland 1902
Aylesford Lake	Kings	1890	250,000	Sandwich, ON	Tupper 1891
Gaspereau Lake	Kings	1889	200,000	Sandwich, ON	Tupper 1890
Gaspereau Lake	Kings	1892	300,000	Sandwich, ON	Tupper 1893
Lake George	Kings	1893	300,000	Sandwich, ON	Tupper 1894
Loon Lake	Kings	1893	300,000	Sandwich, ON	Tupper 1894
McPherson's Lake	Pictou	1899	50,000	Sandwich, ON	Davies 1900
McPherson's Lake	Pictou	1900	500,000	Sandwich, ON	Davies 1901
McPherson's Lake	Pictou	1901	500,000	Sandwich, ON	Sutherland 1902
Kejimkujik Lake*	Queens	~1900	-	-	Veilleux 1964
Minard Lake*	Queens	~1900	-	-	Kerekes 1975
Lake Rossignol	Queens	1889	500,000	Sandwich, ON	Tupper 1890, Veilleux 1964
Milton Lake (Lake Milo)	Yarmouth	1895	500,000	Sandwich, ON	Costigan 1896
Brazil Lake	Yarmouth	1899	800,000	Sandwich, ON	Davies 1900
Brazil Lake	Yarmouth	1900	500,000	Sandwich, ON	Davies 1901
Brazil Lake	Yarmouth	1901	500,000	Sandwich, ON	Sutherland 1902

* 500,000 Lake Whitefish eggs were sent to an auxiliary hatchery in the village of Kempt, Nova Scotia in 1889 (Tupper 1890) and likely released as fry in 1890. These were reported to have been released in Minard Lake and Kejimkujik Lake (Veilleux 1964, Kerekes 1975) but the numbers introduced and whether these two locations represent the full extent of the introductions from the Kempt Hatchery is unknown.

Note: In 1889 the Auxiliary hatchery in Lochaber, Nova Scotia was also sent a shipment of 120,000 Lake Whitefish eggs, but the destinations of the fry resulting from this transfer are unknown and therefore are not listed above.

Table 2 Detailed stocking history of New Brunswick lakes with Lake Whitefish (*Coregonus clupeaformis*) fry conducted by the Department of Marine and Fisheries from 1886 to 1901. Lake Whitefish eggs were sourced from the Newcastle and Sandwich hatcheries in Ontario that were primarily collected from Lake Erie and the Detroit River, though some broodstock could have originated from Lake Ontario in earlier years. Table includes the name of each stocked waterbody, county, stocking year, the number of fry released as well as hatchery origin and source document. The hatchery in Sandwich Ontario sourced its Lake Whitefish eggs from the Detroit River, but also sent whitefish eggs to the Newcastle Hatchery on the shores of Lake Ontario. All Lake Whitefish fry in New Brunswick were received and distributed by the Saint John River Hatchery located at Rapides des Femmes, Victoria County.

Lake Name	County	Year	Number Released	Origin	Source
German Town Lake	Albert	1896	320,000	Sandwich, ON	Davies 1897
Jones Lake	Carleton	1891	180,000	Sandwich, ON	Tupper 1892
Jones Lake	Carleton	1892	140,000	Sandwich, ON	Tupper 1893
Jones Lake	Carleton	1893	320,000	Sandwich, ON	Tupper 1894
Jones Lake	Carleton	1894	240,000	Sandwich, ON	Costigan 1895
Lakeville and Summerville Lakes (Williamstown Lake)	Carleton	1886	650,000	Newcastle, ON	Foster 1887
Lakeville Lake (Williamstown Lake)	Carleton	1888	466,662	Sandwich, ON	Tupper 1889
Lakeville Lake (Williamstown Lake)	Carleton	1889	350,000	Sandwich, ON	Tupper 1890
Lakeville Lake (Williamstown Lake)	Carleton	1890	300,000	Sandwich, ON	Tupper 1891
Lakeville Lake (Williamstown Lake)	Carleton	1893	320,000	Sandwich, ON	Tupper 1894
Lakeville Lake (Williamstown Lake)	Carleton	1894	240,000	Sandwich, ON	Costigan 1895
Lakeville Lake (Williamstown Lake)	Carleton	1896	240,000	Sandwich, ON	Davies 1897
Chamcook Lake	Charlotte	1887	400,000	Newcastle, ON	Foster 1888
Foster Lake	Charlotte	1889	350,000	Sandwich, ON	Tupper 1890
Foster Lake	Charlotte	1891	240,000	Sandwich, ON	Tupper 1892
Foster Lake	Charlotte	1892	220,000	Sandwich, ON	Tupper 1893
Foster Lake	Charlotte	1893	320,000	Sandwich, ON	Tupper 1894
Foster Lake	Charlotte	1898	640,000	Sandwich, ON	Davies 1899
Foster Lake	Charlotte	1899	240,000	Sandwich, ON	Davies 1900
Foster Lake	Charlotte	1897	320,000	Sandwich, ON	Davies 1898

Table 2 Cont'd

Lake Name	County	Year	Number Released	Origin	Source
Lake Utopia	Charlotte	1892	220,000	Sandwich, ON	Tupper 1893
Mohanneous River/Mohannes Stream	Charlotte	1900	320,000	Sandwich, ON	Davies 1901
Byran (Byram's) Pond	Madawaska	1893	120,000	Sandwich, ON	Tupper 1894
Byran (Byram's) Pond	Madawaska	1894	120,000	Sandwich, ON	Costigan 1895
Byran (Byram's) Pond	Madawaska	1896	240,000	Sandwich, ON	Davies 1897
Grand Lake	Queen's	1899	320,000	Sandwich, ON	Davies 1900
Washademoak Lake	Queen's	1899	320,000	Sandwich, ON	Davies 1900
Beaulieu (Baulieu/Bolieu's) Pond	Victoria	1899	240,000	Sandwich, ON	Davies 1900
Beaulieu (Baulieu/Bolieu's) Pond	Victoria	1900	240,000	Sandwich, ON	Davies 1901
Beaulieu (Baulieu/Bolieu's) Pond	Victoria	1901	240,000	Sandwich, ON	Sutherland 1902
Long Lake	Victoria	1887	300,000	Newcastle, ON	Foster 1888
Long Lake	Victoria	1889	300,000	Sandwich, ON	Tupper 1890
Long Lake	Victoria	1893	160,000	Sandwich, ON	Tupper 1894
Long Lake	Victoria	1894	240,000	Sandwich, ON	Costigan 1895
Long Lake	Victoria	1895	720,000	Sandwich, ON	Costigan 1896
Long Lake	Victoria	1896	560,000	Sandwich, ON	Davies 1897
Long Lake	Victoria	1897	320,000	Sandwich, ON	Davies 1898
Long Lake	Victoria	1901	240,000	Sandwich, ON	Sutherland 1902
Meadow Lake	Victoria	1887	300,000	Newcastle, ON	Foster 1888
Pond at Hatchery	Victoria	1899	320,000	Sandwich, ON	Davies 1900
Pond at Hatchery	Victoria	1900	120,000	Sandwich, ON	Davies 1901
Pond at Hatchery	Victoria	1901	400,000	Sandwich, ON	Sutherland 1902
Portage Lake	Victoria	1887	300,000	Newcastle, ON	Foster 1888
Portage Lake	Victoria	1889	200,900	Sandwich, ON	Tupper 1890

Portage Lake	Victoria	1891	180,000	Sandwich, ON	Tupper 1892
Portage Lake	Victoria	1892	140,000	Sandwich, ON	Tupper 1893
Rapids Des Femme	Victoria	1888	155,582	Sandwich, ON	Tupper 1889
Tomlinson Lake	Victoria	1888	155,554	Sandwich, ON	Tupper 1889
Baldhead Lake	York	1897	320,000	Sandwich, ON	Davies 1898
Baldhead Lake	York	1898	320,000	Sandwich, ON	Davies 1899
Baldhead Lake	York	1899	240,000	Sandwich, ON	Davies 1900
Baldhead Lake	York	1900	320,000	Sandwich, ON	Davies 1901
Baldhead Lake	York	1901	320,000	Sandwich, ON	Sutherland 1902
Forest Lake	York	1900	560,000	Sandwich, ON	Davies 1901
Foster Lake	York	1901	320,000	Sandwich, ON	Sutherland 1902
Harvey Lake	York	1888	466,662	Sandwich ON	Tupper 1889
Harvey Lake	York	1889	350,000	Sandwich, ON	Tupper 1890
Harvey Lake	York	1890	700,000	Sandwich, ON	Tupper 1891
Harvey Lake	York	1891	480,000	Sandwich, ON	Tupper 1892
Harvey Lake	York	1892	440,000	Sandwich, ON	Tupper 1893
Harvey Lake	York	1893	560,000	Sandwich, ON	Tupper 1894
Harvey Lake	York	1894	320,000	Sandwich, ON	Costigan 1895
Harvey Lake	York	1895	480,000	Sandwich, ON	Costigan 1896
Harvey Lake	York	1896	320,000	Sandwich, ON	Davies 1897
Harvey Lake	York	1897	320,000	Sandwich, ON	Davies 1898
Harvey Lake	York	1898	320,000	Sandwich, ON	Davies 1899
Harvey Lake	York	1899	320,000	Sandwich, ON	Davies 1900
Harvey Lake	York	1900	320,000	Sandwich, ON	Davies 1901
Harvey Lake	York	1901	320,000	Sandwich, ON	Sutherland 1902
Lake George	York	1892	220,000	Sandwich, ON	Tupper 1893
Lake George	York	1893	240,000	Sandwich, ON	Tupper 1894
Lake George	York	1894	320,000	Sandwich, ON	Costigan 1895
Lake George	York	1895	480,000	Sandwich, ON	Costigan 1896
Lake George	York	1896	320,000	Sandwich, ON	Davies 1897

Table 2 Cont'd

Lake Name	County	Year	Number Released	Origin	Source
Lake George	York	1897	320,000	Sandwich, ON	Davies 1898
Lake George	York	1898	640,000	Sandwich, ON	Davies 1899
Lake George	York	1899	240,000	Sandwich, ON	Davies 1900
Lake George	York	1900	320,000	Sandwich, ON	Davies 1901
Lake George	York	1901	320,000	Sandwich, ON	Sutherland 1902
Magaguadavic Lake	York	1887	400,000	Newcastle, ON	Foster 1888
Magaguadavic Lake	York	1888	933,324	Sandwich ON	Tupper 1889
Magaguadavic Lake	York	1889	350,000	Sandwich, ON	Tupper 1890
Magaguadavic Lake	York	1890	700,000	Sandwich, ON	Tupper 1891
Magaguadavic Lake	York	1891	240,000	Sandwich, ON	Tupper 1892
Oromocto Lake	York	1888	622,216	Sandwich ON	Tupper 1889
Oromocto Lake	York	1889	350,000	Sandwich, ON	Tupper 1890
Oromocto Lake	York	1890	300,000	Sandwich, ON	Tupper 1891
Oromocto Lake	York	1891	240,000	Sandwich, ON	Tupper 1892
Oromocto Lake	York	1892	220,000	Sandwich, ON	Tupper 1893
Oromocto Lake	York	1893	320,000	Sandwich, ON	Tupper 1894
Oromocto Lake	York	1894	320,000	Sandwich, ON	Costigan 1895
Oromocto Lake	York	1895	240,000	Sandwich, ON	Costigan 1896
Oromocto Lake	York	1896	320,000	Sandwich, ON	Davies 1897
Oromocto Lake	York	1897	320,000	Sandwich, ON	Davies 1898
Oromocto Lake	York	1898	320,000	Sandwich, ON	Davies 1899
Oromocto Lake	York	1899	240,000	Sandwich, ON	Davies 1900
Oromocto Lake	York	1900	320,000	Sandwich, ON	Davies 1901
Oromocto Lake	York	1901	320,000	Sandwich, ON	Sutherland 1902
Skiff Lake	York	1887	400,000	Newcastle, ON	Foster 1888

Skiff Lake	York	1889	350,000	Sandwich, ON	Tupper 1890
Yoho Lake	York	1892	220,000	Sandwich, ON	Tupper 1893
Yoho Lake	York	1893	240,000	Sandwich, ON	Tupper 1894
Yoho Lake	York	1894	320,000	Sandwich, ON	Costigan 1895
Yoho Lake	York	1895	240,000	Sandwich, ON	Costigan 1896
Yoho Lake	York	1896	320,000	Sandwich, ON	Davies 1897
Yoho Lake	York	1897	320,000	Sandwich, ON	Davies 1898
Yoho Lake	York	1898	320,000	Sandwich, ON	Davies 1899
Yoho Lake	York	1899	320,000	Sandwich, ON	Davies 1900
Yoho Lake	York	1900	320,000	Sandwich, ON	Davies 1901
Yoho Lake	York	1901	320,000	Sandwich, ON	Sutherland 1902
Pond at Hatchery (Grand Falls)	-	1895	240,000	Sandwich, ON	Costigan 1896
Private Waters	-	1897	240,000	Sandwich, ON	Davies 1898
Saint John River at Hatchery	-	1891	60,000	Sandwich, ON	Tupper 1892
Saint John River at Hatchery	-	1894	320,000	Sandwich, ON	Costigan 1895

Table 3 **Summary of lakes stocked with Lake Whitefish (*Coregonus clupeaformis*) fry in the Province of Nova Scotia including water body name, county, primary and secondary watershed, latitude, longitude, depth (m), and surface area (ha). Stocking details are also listed including the initial and final year of stocking, number of years stocked, and the total number of Lake Whitefish fry released during the stocking period.**

Water body Name	County	Primary Watershed	Secondary Watershed	Latitude	Longitude	Depth (m)	Surface Area (ha)	Initial Year of Stocking	Final Year of Stocking	# of Years Stocked	Number Stocked
Beeler's Lake	Annapolis	Annapolis River	Lequille River	44.652	-65.519	3	20.1	1892	1893	2	600,000
George Lake	Annapolis	Herring Cove/ Medway River	Medway River	44.578	-65.190	-	79	1891	1891	1	250,000
La Rose Lakes	Annapolis	Annapolis River	Annapolis River	44.713	-65.441	5	53.8	1896	1896	1	500,000
Milford (Pits/Pitts) Lake	Annapolis	Mersey River	Mersey River	44.588	-65.407	6	19.7	1889	1889	1	200,000
Paradise Lake*	Annapolis	Annapolis River	Annapolis River	44.764	-65.170	9	396.4	1891	1901	10	5,250,000*
Round Hill Lake* (Upper/Lower Wrights Lake)	Annapolis	Annapolis River	Annapolis River	44.727	-65.365	-	18.8/37	1890	1896	3	1,050,000*
Lochaber Lake	Antigonish	St Mary's River	St Mary's River	45.422	-62.029	52.4	307.2	1889	1901	3	1,500,000
St Joseph's Lake	Antigonish	South/West	West River	45.536	-62.080	6	19.9	1894	1895	2	1,500,000
Folly Lake	Cumberland	Salmon/ Debert Rivers	Folly River	45.540	-63.546	33.5	78.9	1878	1878	1	20,000
Haines Lake	Digby	Sissiboo/ Bear River	Sissiboo River	44.514	-65.807	7	66.7	1895	1895	1	800,000
Porters Lake	Digby	Sissiboo/ Bear River	Sissiboo River	44.493	-65.808	7	326.7	1895	1895	1	

Goshen Lake	Guysborough	Country Harbour	Country Harbour River	45.377	-61.978	8	12.1	1899	1900	2	700,000
Governor's Lake	Halifax	Sackville River	Nine Mile River	44.643	-63.701	11	105.2	1887	1889	2	350,000
Grand Lake (Shubenacadie Grand)	Halifax	Shubenacadie/ Stewiacke River	Shubenacadie River	44.910	-63.600	45	1841	1878	1893	8	4,370,000
Hubley's Lake (Hubley Big Lake)	Halifax	Sackville River	Woodens River	44.647	-63.829	14	255.3	1887	1893	5	1,200,000
Lake Thomas	Halifax	Shubenacadie/ Stewiacke River	Shubenacadie River	44.798	-63.609	14	111	1893	1893	1	300,000
Lake William	Halifax	Shubenacadie/ Stewiacke River	Shubenacadie River	44.767	-63.586	28	339	1893	1893	1	300,000
Lily Lake	Halifax	Sackville River	Shore Direct	44.743	-63.638	41.2	5	1878	1878	1	10,000
Neal's/ Neilson Lake	Halifax	-	-	-	-	-	-	1887	1887	1	150,000
Sandy Lake	Halifax	Sackville River	Sackville River	44.735	-63.701	19	74.5	1878	1900	12	4,810,000
Williams Lake	Halifax	Sackville River	Shore Direct	44.620	-63.593	20	34.1	1887	1901	9	4,650,000
Lake Ainsley	Inverness	Margaree River	Margaree River	46.127	-61.174	18	5,735.8	1895	1898	3	2,200,000
Lake O'Law (Frist Lake)	Inverness	Margaree River	Margaree River	46.277	-60.960	30	27.1	1896	1901	5	4,300,000
Aylesford Lake	Kings	Gaspereau River	Gaspereau/ Black River	44.947	-64.662	12	532	1890	1890	1	250,000
Gaspereau Lake	Kings	Gaspereau River	Gaspereau/ Black River	44.965	-64.548	-	2,202.9	1889	1892	2	500,000
Lake George	Kings	Gaspereau River	Gaspereau/ Black River	44.935	-64.699	9	153	1893	1893	1	300,000
Loon Lake	Kings	Gaspereau River	Gaspereau/ Black River	44.898	-64.669	6	69.6	1893	1893	1	300,000

Table 3 Cont'd

Water body Name	County	Primary Watershed	Secondary Watershed	Latitude	Longitude	Depth (m)	Surface Area (ha)	Initial Year of Stocking	Final Year of Stocking	# of Years Stocked	Number Stocked
McPherson's Lake	Pictou	East/Middle/ West River	East River Pictou	45.468	-62.545	13.4	13.4	1899	1901	3	1,050,000
Kejimkujik Lake**	Queens	Mersey River	Mersey River	44.383	-65.250	17	2,600	-	-	-	-
Minard Lake**	Queens	Mersey River	Mersey River	44.425	-65.168	6	121.3	-	-	-	-
Lake Rossignol	Queens	Mersey River	Mersey River	44.213	-65.148	-	15,105.2	1889	1889	1	500,000
Brazil Lake	Yarmouth	Tusket River	Annis River	44.008	-65.998	11	99.7	1898	1901	4	2,500,000
Milton Lake (Lake Milo)	Yarmouth	Tusket River	Ohio Millstream Brook	43.861	-66.115	10	58.7	1895	1895	1	500,000

* An additional 700,000 Lake Whitefish fry were reported stocked in Paradise/Round Hill Lakes that were not included within the presented totals.

** 500,000 Lake Whitefish eggs were sent to an auxiliary hatchery in the village of Kempt, Nova Scotia in 1889 (Tupper 1890) and likely released as fry in 1890. These were reported to have been distributed to Minard Lake and Kejimkujik Lake (Veilleux 1964, Kerekes 1975) but the numbers introduced and whether these two locations represent the extent of the introductions from the Kempt Hatchery is unknown.

Table 4 Summary of lakes stocked with Lake Whitefish (*Coregonus clupeaformis*) fry in the Province of New Brunswick including water body name, county, primary and secondary watershed, latitude, longitude, depth (m), and surface areas (ha). Stocking details are also listed including the initial and final year of stocking, number of years stocked, and the total number of Lake Whitefish fry released during the stocking period.

Water body Name	County	Primary Watershed	Secondary Watershed	Latitude	Longitude	Depth (m)	Surface Area (ha)	Initial Year of Stocking	Final Year of Stocking	# of Years Stocked	Number Stocked
Germantown Lake	Albert	Petitcodiac Composite	South Channel	45.674	-64.803	-	-	1896	1896	1	320,000
Jones Lake	Carleton	-	-	-	-	-	-	1891	1894	4	740,000
Lakeville/ Sommerville Lake (Williamstown Lake)	Carleton	Saint John River Basin Composite	Big Presque Isle Stream	46.315	-67.700	3.7	1733	1886	1896	6	2,566,662
Chamcook Lake	Charlotte	West Fundy Composite	Bocabec River Composite	45.145	-67.091	41.91	338.6	1887	1887	1	400,000
Foster Lake	Charlotte	St. Croix River Basin	Canoose Stream Composite	45.317	-67.231	-	48.5	1889	1901	7	1,870,000
Lake Utopia	Charlotte	West Fundy Composite	Magaguadavic River	45.176	-66.793	28.35	1387.9	1892	1892	1	220,000
Mohanneous River/ Mohanneous Stream	Charlotte	St. Croix River Basin	Canoose Stream Composite	45.151	-67.325	-	-	1900	1900	1	320,000
Byram's Pond	Madawaska	-	-	-	-	-	-	1893	1896	3	480,000
Grand Lake	Queens	Saint John River Basin	Jemseg River	45.957	-66.033	30.5	17067.2	1899	1899	1	320,000

Table 4 Cont'd

Water body Name	County	Primary Watershed	Secondary Watershed	Latitude	Longitude	Depth (m)	Surface Area (ha)	Initial Year of Stocking	Final Year of Stocking	# of Years Stocked	Number Stocked
Washademoak	Queens	Saint John River Basin	Washademoak Creek	45.794	-65.969	30	3122.8	1899	1899	1	320,000
Beaulieu Pond	Victoria	-	-	-	-	-	-	1899	1901	3	720,000
Long Lake	Victoria	Saint John River Basin	Tobique River	47.031	-66.895	27.4	989	1887	1901	8	2,840,000
Meadow Lake	Victoria	-	-	-	-	-	-	1887	1887	1	300,000
Pond at Hatchery (Grand Falls)	Victoria	Saint John River Basin	Boutot Brook Composite	47.007	-67.732	-	-	1899	1901	3	840,000
Portage Lake	Victoria	-	-	-	-	-	-	1887	1892	4	820,900
Rapids Des Femme Pond/ Creek	Victoria	Saint John River Basin	Boutot Brook Composite	47.007	-67.743	-	-	1888	1888	1	155,582
Tomlinson Lake	Victoria	Saint John River Basin	Aroostook River	46.711	-67.761	-	9.75	1888	1888	1	155,554
Baldhead Lake	York	-	-	-	-	-	-	1897	1901	5	1,520,000
Forest Lake	York	-	-	-	-	-	-	1900	1901	2	880,000
Harvey Lake	York	West Fundy Composite	Magaguadavic River	45.747	-67.028	13.6	695.6	1888	1901	14	5,716,662
Lake George	York	Saint John River Basin	Pokiok Stream	45.817	-67.047	5.15	691.5	1892	1901	10	3,420,000
Magaguadavic Lake	York	West Fundy Composite	Magaguadavic River	45.704	-67.200	10.69	2623.8	1887	1891	5	2,623,324

Oromocto Lake	York	Saint John River Basin	Oromocto River	45.586	-67.004	13.72	4047.3	1888	1901	14	4,452,216
Skiff Lake	York	St Croix River Basin	Spednic Lake	45.822	-67.527	17.68	627.26	1887	1889	2	750,000
Yoho Lake	York	Saint John River Basin	Oromocto River	45.781	-66.861	13.69	126	1892	1901	10	2,940,000

Note: Since the time of stocking Germantown Lake has been drained to restore wetland.

The classification of the Atlantic Whitefish as a separate species from the Lake Whitefish forms a key point of intersection in NS. Therefore, we also compiled all early observations of the Atlantic Whitefish, including those which occurred prior to its initial classification. These data include morphometric and meristic analyses to the point of distinction of the Atlantic Whitefish to more clearly outline and distinguish early Lake Whitefish discoveries.

Current Distribution

Based on available data, the assessment of Lake Whitefish distribution was approached differently in each province. In NS, several surveys conducted from the mid to late 1900s identified Lake Whitefish incidentally as the species was initially suspected to be absent from the province. Following recognition of the species in NS, surveys to procure samples for morphological studies often reported novel populations expanding evidence of occurrence. In a small number of locations, these historical reports were supplemented by modern surveys by the NSDFA and verified angler captures. Many locations where Lake Whitefish are reported in NS have been left un-surveyed since their first discovery. Without new data these locations must be considered current.

In NB, most available data on species distribution resulted from reports in the historical literature and records of occurrence spanning from 1958-1987 kept by the New Brunswick Department of Natural Resources and Energy Development (NBDNRED). Due to a lack of recent surveys in many locations outside of lakes bordering the State of Maine, these records must also be considered current. While reporting on the distributions of Lake Whitefish in both provinces using historical data, we acknowledge that inaccuracies are possible where un-surveyed populations may no longer persist following the impacts of invasive species, acidification, and dams in several locations.

Lake Whitefish Stocking in Canada

In 1865 Samuel Wilmot began his first experiments in fish culture, and one year later in 1866, he built what would become Ontario's first fish hatchery in Newcastle on the shores of Lake Ontario near its confluence with Wilmot Creek (Smith 1875, Lasenby *et al.* 2001, Morrison and Peiman 2021). The hatchery supported Wilmot's early attempts to restore Atlantic Salmon (*Salmo salar* Linnaeus, 1758) in Lake Ontario. Then after receiving federal support in 1867, the Newcastle Hatchery became Canada's first federal fish hatchery in 1868 (Prince 1906, note that Ontario, Québec, NS, and NB had only joined to form Canada through confederation in 1867 at which time the federal government gained jurisdiction over fisheries). Following confederation, Samuel Wilmot was given the title of fisheries overseer by the Minister of Marine and Fisheries in 1868 and was charged with operating the Newcastle Hatchery (McCullough 2003, Kight 2007, Morrison and Peiman 2021). The Newcastle Hatchery was born of Wilmot's efforts to recover Atlantic Salmon locally, but federal interests were to sustain commercial fisheries of which the Lake Trout (*Salvelinus namaycush,* Walbaum, 1792) and Lake Whitefish were the most valuable species (Evermann and Goldsborough 1907, Knight 2007). Wilmot successfully hatched Lake Whitefish in 1867 and 1868 (Prince 1906, Lasenby *et al.* 2001), and in accordance with federal interest he began propagating Lake Whitefish at the Newcastle hatchery in 1871 (Knight 2007). To support these efforts, Wilmot built a Lake Whitefish hatchery in Sandwich, Ontario on the shores of the Detroit River in 1875-76 (Whitcher 1876, Prince 1906, Lasenby *et al.* 2001, Knight 2007) and further enlarged the Newcastle Hatchery (Prince 1906). The Sandwich Hatchery sourced its eggs from wild spawning fish harvested by the Bois Blanc Island and Fighting Island Fisheries in the Detroit River (Prince 1906, Whitcher 1878). Using this nearby source, the Sandwich Hatchery became a prolific supplier of Lake Whitefish eggs and fry that were generally transferred from this location in February in the eyed stage for broader distribution and hatching (Prince 1906).

Whitefish Stocking in Nova Scotia

On 1 July 1876, Samuel Wilmot was appointed Superintendent of Fish Culture in Canada (McCullough 2003, Knight 2007, Morrison and Peiman 2021) and in that year he opened NS's first fish hatchery in Bedford along the Sackville River to support the propagation of Atlantic Salmon (Whitcher 1876). Despite the intended purpose of the Bedford Hatchery (Wilmot 1978), it immediately began to receive shipments of Lake Whitefish eggs from Ontario in 1877 (Pope 1879). The early shipments of Lake Whitefish eggs arrived from Newcastle by rail (likely via Sandwich), though later shipments often arrived directly from the Sandwich hatchery. From 1877 to 1901, the Bedford Hatchery received shipments totalling 42,230,000 Lake Whitefish eggs from both the Newcastle Hatchery and the Sandwich Hatchery. These eggs were then hatched and distributed by rail to accessible locations throughout the province (Bradford and Mahaney 2004). Many of these locations were near the City of Halifax, and along the western and northern shores of NS (Pope 1879, Bradford and Mahaney 2004; Fig 2).

At the onset of this intensive stocking effort, James. C. Pope, the Minister of Marine and Fisheries at the time, made his intentions in NS clear, stating that by "*extending the operations to the hatching of both whitefish and salmon trout* [Lake Trout]", "*the great number and extent of the inland lakes of this Province now useless and of no value whatever, as they contain few, if any, commercial fish, and it appears a very desirable object to stock, if possible, these lakes with those valuable fish. By doing so the value of the fisheries of Nova Scotia would largely increase, and an extensive inland fishery would be created which would afford remunerative employment and a partial means of subsistence to hundreds of people living at a distance from the seacoast.*" (Pope 1879, page 375-376). Lake Whitefish were of further interest in NS as the province was suspected to be devoid of the species (Evermann and Smith 1894, Perley 1852, Lanman 1874, Evermann and Smith 1896, Piers 1924) and Pope (1879) clearly saw Lake Whitefish as a desirable addition in the interest of supporting the local economy.

In the first year of stocking (1878), Lake Whitefish were only introduced to (Shubenacadie) Grand, Lily, and Sandy lakes, Halifax County, and Folly Lake, Colchester County (Pope 1879; Table 1). Stocking was again recorded in Sandy Lake in 1886 (Foster 1887; Table 1) after which the extent and number of introductions increased sharply. When Lake Whitefish stocking efforts increased, introductions were first reported in Halifax County near the Bedford Hatchery in 1887 and 1888 during which 2,850,000 (Foster 1888) and 2,800,000 (Tupper 1889) fry were released respectively. In 1889, 500,000 Lake Whitefish eggs were transferred to an auxiliary hatchery in Kempt, Queens County that was reported to have been owned by a local fishing club (Kerekes 1975, Edge 1987), and 120,000 eggs were sent to a second auxiliary hatchery in Lochaber, Antigonish County (Tupper 1890). These eggs were likely hatched as fry for distribution in 1890. The fate of those supplied to the Lochaber hatchery was unrecorded, but those sent to Kempt were reported stocked in Kejimkujik Lake

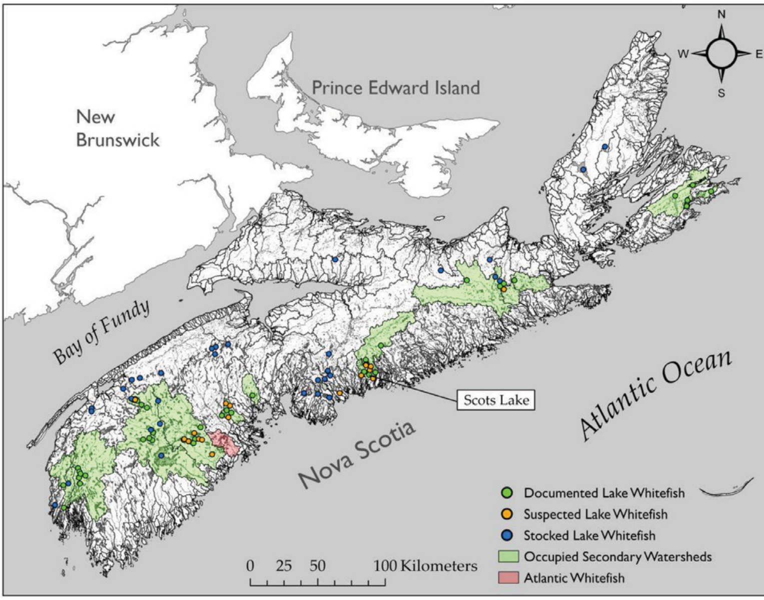


Fig 2 **Map of Lake Whitefish (*Coregonus clupeaformis*) stocking and present distribution in Nova Scotia, Canada. The watershed highlighted in red is the Petite Riviere and is currently (2025) the only region known to support Nova Scotia's endemic populations of Atlantic Whitefish (*Coregonus huntsmani*) within Hebb, Minamkeak, and Milipsigate lakes following their likely extirpation in the Tusket and Annis Rivers in the south of the province. Scots Lake, Halifax County, Nova Scotia supports a suspected dwarf Lake Whitefish population.**

and possibly Minard Lake (Veilleux 1964). Details regarding these releases are sparse and there is little information to suggest if other lakes were stocked near Kejimkujik or Lochaber or how many Lake Whitefish may have been released (Table 1, 3, 5). While Veilleux (1964) mentions stocking of Lake Whitefish in Lake Rossignol, possibly in reference to the Kempt hatchery, this lake was also reported stocked with 500,000 fry by the Bedford Hatchery in 1889 (Tupper 1890; Table 1, 3) and it is unclear whether these records represent two distinct stocking events or present duplicated information.

In subsequent years, introductions were recorded in the counties of Annapolis, Antigonish, Kings, and Queens until 1894; thereafter adding Digby, Yarmouth, and Inverness Counties in 1895, and Pictou County in 1900. Following 17 years of stocking in Nova Scotia (1878, 1886-1901), Lake Whitefish fry had been distributed to at least 33 lakes. Among these, Paradise Lake, Annapolis County, was the most heavily stocked, receiving >5,250,000 fry cumulatively over the course of ten consecutive years of stocking (1891-1901, Table 1, 3). Short-lived fisheries for Lake Whitefish were reported in some systems in years shortly after stocking (Murray 2005), but the excitement around the species and their potential to support the local economy faded as quickly as did the catches. All efforts to create self sustaining populations of Lake Whitefish in NS were reported to have "*utterly failed*" (Piers 1924, page 1; see also Murray 2005) and no further attempts were made to stock the species in NS after 1901.

Lasenby *et al.* (2001) remarks that at the time of stocking in the late 1800s that Lake Whitefish and Lake Herring (i.e. *Cisco* sp.) were not distinguished as separate species and both were given the name *Coregonus albus*. The Great Lakes hatcheries that shipped "Lake Whitefish" to the MP and beyond are home to five extant species of Cisco, though as many as eight species were historically described in the Great Lakes within this taxonomically complex group (Eshenroder *et al.* 2016). Any number of these species could have been introduced to the MP under the guise of "Whitefish". However, no subsequent captures have confirmed whether this species mixing occurred. Lake Whitefish and Cisco spawning runs known in the lower Detroit River near the Sandwich Hatchery collapsed by the early 1900s due to overfishing, pollution (Hartman 1972), and destruction of habitat following construction of the Livingstone Shipping Channel (Roseman *et al.* 2007). Following this collapse, 1910 was reported as the last year of Lake Whitefish propagation at the Sandwich hatchery during which time eggs were probably sourced from waters further afield (Lasenby *et al.* 2001). The Lake Whitefish which spawned in the Detroit River was reported as destroyed in 1900 due to siltation and smothering of their spawning shoals (Trautman 1957).

Nova Scotia Post-Stocking Whitefish Surveys and Observations

It was not until 1919, 18 years after Lake Whitefish stocking had ceased in NS, that the first whitefish was recorded in the province. At this time two coregonids were reported captured from the mouth of the Sissiboo River, Digby County, and were initially identified as Round Whitefish (Vladykov and Mckenzie 1935). But these were almost undoubtedly the first records of the Atlantic Whitefish, later known from the Tusket and Annis rivers to the south (Bradford *et al.* 2004). On 9 May 1923, Piers (1924) reported a whitefish angled at the spillway of the dam located at the outlet of Milipsigate Lake, near the town of Bridgewater, Lunenburg County. Piers (1924) first referred to the specimen as "*a variant of Coregonus labradoricus*" suggesting a purported northwestern form of Lake Whitefish, but the specimen possessed a high lateral line scale count and differences in form that separated it from other Coregonids. Following further assessment, that specimen was recognized as the first identified Atlantic Whitefish and not the Lake Whitefish, which was then only regionally known from the province of NB (Piers 1924, Gilhen 1974).

A subsequent account of *C. clupeaformis* (Lake Whitefish) captured from the Tusket River, Yarmouth County, on 10 April, 1951 (Smith 1952) was also revealed to be an Atlantic Whitefish as reported in Scott and Crossman (1973), Leim and Scott (1966), Scott (1967), and later confirmed by meristic and morphometric analysis by Edge (1987, Edge *et al.* 1991). As a result, the occurrence of Lake Whitefish in Yarmouth and Lunenburg Counties as described by Dymond (1947), Livingstone (1953), and Smith (1952) were incorrect due to misidentification, and all instances were similarly Atlantic Whitefish (Edge 1987, Edge *et al.* 1991). Leim and Day (1959) also report a Lake Whitefish that was likely a misidentified Atlantic Whitefish captured in saltwater from a wharf in Wedgeport, NS, on 8 July 1954, and another similar misidentification was reported in Halls Harbour, NS, on 31 May 1958 in fully marine water (Edge 1987, Edge *et al.* 1991).

The first true observations of Lake Whitefish in NS were reported from 8-11 July 1964 during a survey of Kejimkujik Lake (Veilleux 1964). Collected Lake Whitefish were captured using a 5 cm stretch mesh gill net set at depths ranging from 3-14 m (Veilleux 1964). At the time and still today (2025), it is unclear if these captures from Kejimkujik Lake represent a native population of Lake Whitefish, or rather if they resulted from a surviving stocked population (see Table 1). Edge (Edge 1987, Edge *et al.* 1991) notes that Lake Whitefish were stocked in Kejimkujik National Park by a fishing club, and Veilleux (1964) confirms that both Kejimkujik Lake, Lake Rossignol located downstream, and the nearby Minard Lake were stocked ~75 years prior to the 1964 surveys (stocking almost certainly occurred in 1890, Tupper 1890) with fish sourced from a small auxiliary hatchery in Kempt, NS (transferred from the Bedford hatchery, Tupper 1890, Veilleux 1964, Kerekes 1975, Table 1). During subsequent surveys of park waters from 1970-1972 (Note that Kejimkujik National Park was established in 1969), Lake Whitefish were confirmed in Mountain, Peskowesk, and Cobrielle lakes that were never reported stocked (Kerekes 1975; species confirmed by W.B. Scott; Table 1). Lake Whitefish were also reported in 1974 in Minard Lake just outside park boundaries (Gilhen 1974). Within the park, Kerekes (1975) notes that only Kejimkujik and Mountain Lake are deep enough to meet the cold-water habitat requirements of Lake Whitefish, and the species was suspected to move from deep waters in Mountain Lake to access Peskowesk and Cobrielle during cooler water periods. Spawning was noted in Mountain Lake in December and the maximum size of the species among fish captured in Kejimkujik National Park was reported as 30 cm (250 g; Veilleux 1964, Kerekes 1975).

The confirmation of Lake Whitefish in NS both in and around Kejimkujik National Park prior to its official designation (Veilleux 1964) was realized too late to be included in “The Freshwater Fishes of Canada” by Scott and Crossman (1973), as this seminal text on the freshwater fishes and their distribution in Canada only mentions observations of Atlantic Whitefish in NS. Perhaps ironically, that same year (1973) would begin a flurry of Lake Whitefish discoveries across the province. Semple (1973) reported Lake Whitefish in Scots Lake/ Scots Pond, Halifax County in that year which is located distant from any stocking location, and the identified population was documented in detail, including their spawning period, maturation, and size. Smith (1974) reported the occurrence of Lake Whitefish in Pringle Lake, Guysborough County, following surveys in 1973 (later confirmed by Ives 1975, Alexander *et al.* 1986), but the proximity of this lake to Goshen Lake (1.5 km) that was stocked in 1899 and 1890 (Davies 1900, 1901, Table 1) leaves questions regarding their origin. Subsequent lake surveys in 1973, also revealed Lake Whitefish in Narrow Lake (Ives 1975, confirmed by Alexander *et al.* 1986) which could still present a nearby transfer from Goshen Lake (9.5 km away) but is situated in a separate watershed. Lake surveys conducted from 1964-1981 by Alexander *et al.* (1986) also include 13 Lake Whitefish confirmations among 781 survey locations that were identified from 1964-1980 (which overlap with some previously described such as by Veilleux 1964). Further occurrence of Lake Whitefish in the Mira River (see also Goodchild 2001) was relayed to the author (D.R. Alexander) by J. Gilhen, a former curator of the Nova Scotia Museum of Natural History.

Due to frequent prior misidentifications of Lake Whitefish in the region (see Piers 1924, Smith 1952, Dymond 1947, Livingstone 1953, Leim and Day 1959), samples collected by Alexander *et al.* (1986) from Pringle Lake were sent to the Royal Ontario Museum for comparison to the Atlantic Whitefish (then referred to as the "Acadian Whitefish") which had been collected in 1973 (see Scott 1967, Edge 1987, Edge *et al.* 1991). In this instance, the species had not been misidentified, and the collected specimens were indeed Lake Whitefish, representing the easternmost occurrence of this species described at the time (Alexander *et al.* 1986). Alexander *et al.* (1986), however, wrote with uncertainty regarding whether the collected (and now confirmed) Lake Whitefish were native to NS or resulted from unreported hatchery introductions or subsequent private introductions (see also Edge 1987, Edge *et al.* 1991) because historical reports had made no prior indication of their natural occurrence in the province. Despite these concerns, several of the lakes sampled by Alexander *et al.* (1986) and reported to contain Lake Whitefish such as Chezzetcook Lake, Halifax County, Eden Lake, Pictou County, and Little Mushamush Lake, Lunenburg County, were all far removed from any documented stocking locations (Tables 1, 3).

Even following the discovery of several populations of Lake Whitefish by the late 1980s, the species remained largely unknown in NS. Scott and Crossman (1988) only stated that the Lake Whitefish occurs "*less commonly in some Nova Scotia lakes*", and a book published by J. Gourlay (1995) intending to highlight non-traditional freshwater sport fishes in NS makes no mention of the species at all. Evidently, Lake Whitefish never became a focal point of the NS fishery or economy as Pope (1879) had envisioned over a century prior, but scientific interest was growing regarding the origin of Lake Whitefish in NS. In years to follow, researchers began to study Lake Whitefish in more detail, first comparing their morphometrics and meristics to those of Atlantic Whitefish (Edge 1987, Edge *et al.* 1991, Hasselman 2003, Hasselman *et al.* 2009), and later by assessing population ancestry using genetic methods (Bernatchez and Dodson 1990, Bernatchez *et al.* 1996). Through these studies, additional lakes in NS were surveyed to collect samples of the two Coregonid species for comparison (Bradford *et al.* 2004).

The most interesting lakes documented to support Lake Whitefish are perhaps those at the headwaters of the Tusket River. Lake Whitefish were confirmed in Ogden, Parr, Petes, Mink, and Kempt Back lakes by Bradford *et al.* (2004) and are suspected to have remained in those lakes separate from the river-dwelling Atlantic Whitefish until the extirpation of the latter species in ~1982 (Bradford *et al.* 2004). Bradford *et al.* (2004) also suggests that some unverified local reports of Lake Whitefish in the Annis and Tusket rivers may have been Atlantic Whitefish. The status of Lake Whitefish in any part of the Tusket River is currently unknown (last reported during surveys in 2002) following the introduction of Chain Pickerel (first reported in Snare Lake in 1948; NSDFA unpubl. data) and acidification of surface waters in NS (Watt 1987, White 1992). Recently in 2017, a Lake Whitefish was captured for the first time during a routine survey of Conrod Lake, Halifax County (Table 5; NSDFA unpubl. data). Conrod Lake lies adjacent to Chezzetcook Lake where the species was found in 1974 (Alexander *et al.* 1986) and near Scots Lake where Lake Whitefish were described in 1973 (Semple 1973) and re-confirmed by NSFDA in 2008 (NSFDA unpubl. data). A Lake Whitefish was also confirmed in Big Lake Mushamush, Lunenburg County, NS for the first time in 2025 (Table 5).

Following survey efforts spanning 60 years from 1964 to present (2025), Lake Whitefish have so far been identified in 42 lakes in NS spanning 16 secondary watersheds (Fig 2; Table 5). Collection of these data revealed populations distributed from Porcupine Lake, Yarmouth County to Salmon River, Cape Breton County (Table 5). Known Lake Whitefish populations have a clustered distribution exclusive to Atlantic facing watersheds of NS (Fig 2) and Lanman (1874) noted that Lake Whitefish are not observed in any systems draining into the Gulf of St Lawrence. This is likely a product of their glacial refuges and post-glacial colonization routes (Edge 1987, Schmidt 1986, Dalton *et al.* 2023) and closely mirrors the distribution of Lake Trout in the MP described by Warner *et al.* (2023), although this species regionally is found in far fewer confirmed locations. The continued existence of Lake Whitefish in the south of NS is uncertain as this region remains the epicenter of invasive species spread and acidification of surface waters, along with being one of the least studied regions of the province. White (1992) suggested that Lake Whitefish inhabit too few lakes to determine their pH tolerance in NS based on surveys conducted in 1983 and 1987, but following the loss of salmonids from southern NS due in part to acidification (Watt *et al.* 1983, Watt 1987), impacts to both Lake Whitefish and Atlantic Whitefish are possible. Lake Whitefish typically spawn in late fall and winter in streams or over cobble/gravel lake shoals (Whitaker and Wood 2021), a time of year when pH levels are most alkaline (Watt *et al.* 1983, Edge and Gilhen 2001). At this time early developmental stages may be most sensitive to acidification both during incubation and immediately post-hatch (Edge 1987), but the emergence of larvae in spring (Whitaker and Wood 2021) may provide some temporal ecological buffer to low pH.

Whitefish Stocking in New Brunswick

Bradford and Mahaney (2004) report that 196 million Lake Whitefish fry hatched from eggs sourced from "*federal hatcheries on the lower Great Lakes*" were reared and released in waters across Canada from 1878-1914. Of these, 37,470,900 eggs (nearly 20% of the total produced) were sent to NB to hatch and be released over a period of 16 years spanning 1886-1901 (Table 2). Lake Whitefish were the only Coregonid stocked in NB (apart from possibly mistaken Ciscoes; Lasenby *et al.* 2001), and Lake Whitefish eggs sent to NB were received by the "Saint John River hatchery" located at Rapide des Femmes 5 km downstream from Grand Falls. The hatchery building and associated dam had been constructed in the summer of 1879 and was opened by Samuel Wilmot in October 1879 (Pope 1879). This site was ideal for receiving and distributing Lake Whitefish eggs and fry as Samuel Wilmot described that "*the railway runs through the property only a few yards from the hatchery*" and from this point, eggs and fry could be transported along the Saint John River by means of boat, rail, or road (Pope 1879). Like the Bedford hatchery in NS, the Saint John River hatchery at Grand Falls was constructed with the intention of producing Atlantic Salmon for release directly into the Saint John River. Within nine years of establishment and only one year into the whitefish stocking program, the output of Lake Whitefish at this establishment would greatly outnumber all other species including Atlantic Salmon.

The first point of introduction of hatchery reared Lake Whitefish to NB was in Lakeville/Sommerville Lake (Williamstown Lake), Carleton County, where 650,000 Lake Whitefish fry were released in 1886 (Table 2; Fig 3), but in the following year stocking quickly expanded to include lakes in Charlotte, Victoria, and York counties in regions south of the Saint John River. Stocking was recorded in Madawaska County in 1893, adding Albert County in 1896.

Table 5 **Observations of Lake Whitefish (*Coregonus clupeaformis*) in the Province of Nova Scotia including lake name, county, primary and secondary watershed, latitude, longitude, depth (m), surface area (ha), years of observation, ancestry (stocked or native) and data source. When lakes are indicated as stocked it does not rule out the possibility of a pre-existing native population. Lakes with a native ancestry marked as "?" are native populations that could have received unreported introductions of Lake Whitefish from nearby stocked lakes. Shallow lakes may be occupied during cold water periods by populations residing in deeper connected waters.**

Lake Name	County	Primary Watershed	Secondary Watershed	Lat	Long	Depth (m)	Surface area (ha)	Whitefish Observations	Stocked	Native	Source
Boot Lake	Annapolis	Mersey River	Mersey River	44.570	-65.383	6.0	102.8	2001-2002	No*	-	Hasselman 2003
Eleven Mile Lake	Annapolis	Mersey River	Mersey River	44.530	-65.292	2.1	226.3	1975	No*	-	Alexander *et al.* 1986 1986
Fisher Lake*	Annapolis	Mersey River	Mersey River	44.548	-65.344	6.0	394.8	-	No*	-	Located between Boot and Eleven Mile Lake
Geier Lake*	Annapolis	Mersey River	Mersey River	44.577	-65.396	-	20.0	-	No*	-	Located between Liverpool Head and Boot Lake
Liverpool Head Lake	Annapolis	Mersey River	Mersey River	44.581	-65.404	6.9	13.2	1975	No*	-	Alexander *et al.* 1986
Milford (Pits/Pitts) Lake	Annapolis	Mersey River	Mersey River	44.586	-65.405	6.3	20.0	1975	Yes	-	Alexander *et al.* 1986
Grand Lake	Cape Breton	Salmon/ Mira River	Gerratt Brook	45.957	-59.956	-	148.6	1980	No	Yes	Alexander *et al.* 1986
Hardy Lake	Cape Breton	Salmon/ Mira River	Shore Direct	45.864	-60.195	-	24.9	1956	No	Yes	NSDFA, Unpublished data
MacIntyres Lake	Cape Breton	Salmon/ Mira River	Shore Direct	45.902	-60.185	12.8	71.7	1973, 2000-2002	No	Yes	Hasselman 2003; Murray 2005; Hasselman *et al.* 2009

MacLeods Lake	Cape Breton	Salmon/ Mira River	Shore Direct	45.886	-60.181	-	73.9	2000-2002	No	Yes	Hasselman 2003; Murray 2005; Hasselman *et al.* 2009
Mira River	Cape Breton	Salmon/Mira River	Mira River	46.003	-60.129	-	3,237.6	1983, 2000-2002	No	Yes	John Gilhen observation in Alexander *et al.* 1986; Edge 1987; Bernatchez and Dodson 1990; Edge *et al.* 1991; Hasselman 2003; Bradford *et al.* 2004b; Hasselman *et al.* 2009
Salmon River	Cape Breton	Salmon River and Mira	Mira River	45.935	-60.302	-	-	1982	No	Yes	Edge 1987; Edge *et al.* 1991, connected to Mira River
Eight Island Lake*	Guys-borough	Country Harbour	Country Harbour River	45.351	-61.962	10.1	91.3	-	No	-	Connected to Pringle Lake
G Lake	Guys-borough	Country Harbour	Country Harbour	45.357	-61.974	10.0	18.7	1985	No	?	NS Dept of Inland Fisheries
Narrow Lake	Guys-borough	New Harbour / Salmon River	Salmon River	45.397	-61.849	11.0	24.4	1973	No	?	Ives 1975, Alexander *et al.* 1986
Pringle Lake	Guys-borough	Country Harbour	Country Harbour River	45.377	-61.949	26.0	58.3	1973	No	?	Smith 1974; Ives 1975; Alexander *et al* 1986; Edge 1987, 1991
Big Shaw Lake	Halifax	Musquodoboit River	Musquodoboit River	44.968	-63.112	10.0	82.0	2000-2004	No	Yes	Murray 2005
Chezzetcook Lake	Halifax	Musquodoboit River	Chezzetcook River	44.773	-63.222	18.3	296.0	1974	No	-	Alexander *et al* 1986; Bradford *et al.* 2004b

Table 5 Cont'd

Lake Name	County	Primary Watershed	Secondary Watershed	Lat	Long	Depth (m)	Surface area (ha)	Whitefish Observations	Stocked	Native	Source
Conrod Lake	Halifax	Musquodoboit River	Chezzetcook River	44.776	-63.258	29.6	134.9	2017	No	-	NS Dept of Inland Fisheries
Gibraltar Lake	Halifax	Musquodoboit River	Musquodoboit River	44.862	-63.252	16.0	85.4	2000-2004	No	Yes	Hasselman 2003; Murray 2005; Hasselman *et al.* 2009
Long Bridge Lake*	Halifax	Musquodoboit River	Chezzetcook River	44.787	-63.208	-	85.	-	No	-	Connected to Chezzetcook Lake
Moose Lake*	Halifax	Musquodoboit River	Musquodoboit River	44.843	-63.251	7.6	15.4	-	No	-	Connected to Gibraltar Lake
Morris Lake**	Halifax	Sackville River	Cow Bay River	44.650	-63.496	12.8	175.9	1999	No	-	Unconfirmed angler report in Bradford *et al.* 2004b
Petepeswick Lake*	Halifax	Musquodoboit River	Chezzetcook River	44.770	-63.193	-	297.5	-	No	-	Connected to Chezzetcook Lake
Pace(s) Lake*	Halifax	Musquodoboit River	Little River, Petepeswick Inlet	44.815	-63.212	51.2	302.7	-	No	-	Connected to Scots Lake
Scots Lake/ Scots Pond	Halifax	Musquodoboit River	Little River, Petepeswick Inlet	44.791	-63.180	18.0	15.0	1973	No	Yes	Semple 1973, Murray 2005
Thompson Lake*	Halifax	Musquodoboit River	Chezzetcook River	44.768	-63.295	-	48.8	-	No	-	Connected to Conrod Lake

Big Mushamush Lake	Lunenburg	Gold River	Mushamush River	44.492	-64.554	25.0	1,078	2025	No	Yes	Dr. A. Spares pers comm and photo
Caribou Lake	Lunenburg	Gold River	Mushamush River	44.526	-64.549	50.0	268.5	1982, 2000-2002	No	-	Edge 1987; Hasselman 2003; Hasselman *et al.* 2009
Little Mushamush Lake	Lunenburg	Gold River	Mushamush River	44.510	-64.505	13.0	438.7	1980	No	Yes	Alexander *et al.* 1986; Edge 1987; Edge *et al.* 1991; Hasselman 2003; Murray 2005; Hasselman *et al.* 2009
Millet Lake	Lunenburg	Gold River	Middle River (Lunen Co.)	44.627	-64.309	26.0	66.9	1983, 2000	No	Yes	NSDFA, unpublished data
Shingle Lake	Lunenburg	Herring Cove/ Medway	Medway River	44.408	-64.789	14.0	468.2	2000	No	Yes	Hasselman 2003; Bradford *et al.* 2004b; Murray 2005; Hasselman *et al.* 2009
Sucker Lake	Lunenburg	Gold River	Mushamush River	44.489	-64.593	9.0	30.3	2013	No	-	Verified Angler Report
West Whale Lake*	Lunenburg	Gold River	Mushamush River	44.571	-64.557	-	159.6	-	No	-	Connected to Little Mushamush Lake
Whale Lake*	Lunenburg	Gold River	Mushamush River	44.569	-64.541	-	395.8	-	No	-	Connected to Little Mushamush Lake
Eden Lake	Pictou	St. Mary's River	St. Marys River	45.401	-62.299	16.5	223.4	1975, 2000-2002	No	Yes	Alexander *et al.* 1986; Hasselman 2003; Murray 2005; Hasselman *et al.*2009

Table 5 Cont'd

Lake Name	County	Primary Watershed	Secondary Watershed	Lat	Long	Depth (m)	Surface area (ha)	Whitefish Observations	Stocked	Native	Source
Annis Lake	Queens	Herring Cove/ Medway	Medway River	44.329	-64.839	18.0	80	-	No	-	Edge 1987; Edge *et al.* 1991
Beavertail Basin*	Queens	Herring Cove/ Medway	Medway River	44.329	-64.803	13.3	220.0	-	No	-	Part of Molega Lake
Beavertail Lake*	Queens	Herring Cove/ Medway	Medway River	44.329	-64.785	3.0	71.6	-	No	-	Part of Molega Lake (Note: Winter only)
Cameron / Beartrap Lakes*	Queens	Herring Cove/ Medway	Medway River	44.320	-64.945	-	121.2	-	-	-	Connected to Little Ponhook Lake
Cobrielle (Coblielle) 1986 Lake	Queens	Mersey River	Mersey River	44.310	-65.230	6.3	131.8	1971-72	No	?	Kerekes 1975; Alexander *et al.* (Note: winter only)
Kejimkujik Lake	Queens	Mersey River	Mersey River	44.383	-65.250	19.2	2,435.0	1964	Yes	?	Veilleux 1964; Alexander *et al.* 1986
Little Ponhook Lake	Queens	Herring Cove/ Medway	Medway River	44.301	-64.851	14.0	79.2	2001-2004	No	Yes	Hasselman 2003, Bradford *et al.* 2004b; Murray 2005; Hasselman *et al.* 2003
Minard Lake	Queens	Mersey River	Mersey River	44.425	-65.168	5.8	111.9	1974	Yes	?	Kerekes 1975; Alexander *et al.* 1986
Mountain Lake	Queens	Mersey River	Mersey River	44.316	-65.260	14.3	136.6	1971-72	No	?	Kerekes 1975; Alexander *et al.* 1986
Molega Lake*	Queens	Herring Cove/ Medway	Medway River	44.367	-64.843	15.0	2085	-	No	-	Connected to Shingle Lake

Peskowesk Lake	Queens	Mersey River	Mersey River	44.316	-65.283	13.0	685.0	1972	No	-	Kerekes 1975; Alexander *et al.* 1986 (Note: winter only)
Ponhook Lake*	Queens	Herring Cove/ Medway	Medway River	44.313	-64.898	-	1729.2	-	No	-	Connected to Little Ponhook Lake
Salters Lake**	Queens	Herring Cove/ Medway	Medway River	44.229	-64.676	-	50.5	~2000	No	-	Angler report in Bradford *et al.* 2004b
St. Mary Bay (Ponhook Lake)*	Queens	Herring Cove/ Medway	Medway River	44.328	-64.938	-	115.0	-	No	-	Connected to Little Ponhook Lake
Carleton River	Yarmouth	Tusket River	Tusket River	44.113	-65.914	-	-	~2003	No	-	Hasselman 2003
Kempt Back Lake	Yarmouth	Tusket River	Tusket River	44.064	-65.844	18.0	278.5	1986, 2002	No	Yes	Bradford *et al.* 2004b; Hasselman 2003; Murray 2005; Hasselman *et al.* 2009
Lake George	Yarmouth	Tusket River	Salmon River	43.995	-66.044	-	1161.2	1982-1983	No	-	Edge 1987; Edge *et al.* 1991
Mink Lake	Yarmouth	Tusket River	Tusket River	44.010	-65.891	16.0	145.0	1952, 1983, 1999, 2001-2002	No	Yes	Bradford *et al.* 2004b; Hasselman 2003; Murray 2005; Hasselman *et al.* 2009
Ogden Lake	Yarmouth	Tusket River	Tusket River	44.049	-65.902	19.9	297.3	2002	No	-	Bradford *et al.* 2004b
Parr Lake	Yarmouth	Tusket River	Tusket River	44.089	-65.900	9.4	257.8	1986	No	-	Bradford *et al.* 2004b
Petes Lake	Yarmouth	Tusket River	Tusket River	44.076	-65.890	-	108.0	2002	No	-	Bradford *et al.* 2004b

Table 5 Cont'd

Lake Name	County	Primary Watershed	Secondary Watershed	Lat	Long	Depth (m)	Surface area (ha)	Whitefish Observations	Stocked	Native	Source
Porcupine Lake	Yarmouth	Tusket River	Annis River	43.845	-66.032	12.2	147.0	2002	No	-	Bradford *et al.* 2004b

Lake Name* Lakes directly connected to water where Lake Whitefish are verified, having a high likelihood of also containing Lake Whitefish
Lake Name** Lakes where Lake Whitefish have been reported by unverified sources.
Stocked* Lakes directly connected to waters where Lake Whitefish were stocked.

Table 6 Observation of Lake Whitefish (*Coregonus clupeaformis*) in the Province of New Brunswick including lake name, county, primary and secondary watershed, latitude, longitude, depth (m), surface area (ha), year of observation, ancestry (stocked or native) and data source. All major water bodies connected to the lower Saint John River are assumed to have native Lake Whitefish populations." It is unknown whether the Lake Whitefish population in most lakes persist following their last year of observation.

Lake Name	County	Primary Watershed	Secondary Watershed	Lat	Long	Depth (m)	Surface area (ha)	Whitefish Observations	Stocked	Native	Source
Beechwood Dam	Carleton	Saint John River Basin	Muniac Stream Composite	46.543	-67.668	-	-	1958	No*	Yes	Smith 1979
Beechwood Headpond	Carleton	Saint John River Basin	Muniac Stream Composite	46.615	-67.712	-	-	1958	No*	Yes	NB Power
Black's Harbour	Charlotte	West Fundy Composite	Pocologan River Composite	45.054	-66.800	-	-	1958	No	-	Edge 1987
Digdeguash Lake	Charlotte	West Fundy Composite	Magaguadavic River	45.219	-66.917	19.8	407.5	1993	No	Yes	Saia 1995
Kerr(s) Lake	Charlotte	West Fundy Composite	Bocabec River	45.217	-67.023	12.0	73.0	1945-1950	No	Yes	Smith 1952, Edge 1987
Darling's Lake	Kings	Saint John River Basin	Kennebecasis River	45.501	-65.864	5	400.0	1851	No*	Yes	Perley 1852
Nerepis River	Kings	Saint John River Basin	Nerepis River	45.378	-66.259	-	-	Pre-1852	No*	Yes	Perley 1852
Saint John River	Kings	Saint John River Basin	Black Brook Composite	45.451	-66.131	-	-	Pre-1874	No*	Yes	Lanman 1874

Table 6 Cont'd

Lake Name	County	Primary Watershed	Secondary Watershed	Lat	Long	Depth (m)	Surface area (ha)	Whitefish Observations	Stocked	Native	Source
Sherwood Lake	Kings	West Fundy Composite	Musquash River	45.307	-66.396	-	226.4	1973, 1998	No	Yes	Atlantic Canada Conservation Data Center
Beau Lake	Madawaska/ Québec	Saint John River Basin	Riviere Baker-Brook Composite	47.299	-69.050	-	668.0	Pre-1914, 2024	No	Yes	Kendall 1914, Author observation
First (Green) Lake	Madawaska	Saint John River Basin	Green River	47.638	-68.276	16.8	466.0	1972	No	Yes	Meth 1973
Glazier Lake	Madawaska	Saint John River Basin	Riviere Baker-Brook Composite	47.233	-69.011	35.9	453.2	Pre-1907	No	Yes	Evermann & Goldsborough 1907
Green River (Davis Mill)	Madawaska	Saint John River Basin	Green River	47.350	-68.136	-	-	Pre-1969	No	Yes	Smith 1969
Lac Baker (Baker Lake)	Madawaska	Saint John River Basin	Rivière Baker-Brook Composite	47.368	-68.699	35.7	564.1	1942	No	-	Meth 1973, Edge 1987
Madawaska River	Madawaska	Saint John River Basin	Madawaska River	47.365	-68.324	-	-	Pre-1851	No	Yes	Perley 1851, Lanman 1874
Second Falls Head Pond (Green River Reservoir)	Madawaska	Saint John River Basin	Green River	47.467	-68.231	-	61.7	Pre-1969, 1973	No	Yes	Smith 1969; NBDNRED unpubl. data; Environment Canada 2002

Third (Green) Lake	Madawaska	Saint John River Basin	Green River	47.772	-68.373	17.7	100.0	1939, 1983	No	-	Meth 1973, Edge 1987, NBDNRED unpubl .data
Logan Lake	Northum-berland	Miramichi River Basin	Northwest Miramichi	47.093	-66.706	-	85.5	-	No	Yes	NBDNRED unpubl. data
Serpentine Lake	Northum-berland	Saint John River Basin	Tobique River	47.130	-66.863	24.4	495.3	Pre-1973	No	-	Meth 1973
Belleisle Bay Bay	Queens	Saint John River Basin	Belleisle Creek	45.592	-65.931	33.5	2,337.6	Pre-1972	No*	Yes	Meth 1972
Grand Lake (Saint John River)	Queens	Saint John River Basin	Jemseg River	45.957	-66.033	30.5	17,067.0	Pre-1851, 2017	Yes	Yes	Perley 1851; Bernatchez and Dodson 1990, Author observation
Maquapit Lake	Queens	Saint John River Basin	Jemseg River	45.907	-66.194	-	1843.2	-	No*	Yes	Atlantic Canada Conservation Data Center
Saint John River	Queens	Saint John River Basin	Swan Creek Composite	45.811	-66.126	-	-	Pre-1851	No*	Yes	Perley 1851, Adams 1873
Salmon River	Queens	Saint John River Basin	Jemseg river	46.251	-65.834	-	-	1969	No*	Yes	Smith 1970
Washademoak Lake	Queens	Saint John River Basin	Washademoak	45.776	-65.994	-	3,349.8	1987	No	Yes	NBDNRED. unpubl. data
McDougall Lake	Restigouche	Restigouche River Basin	Kedgwick River	47.907	-67.726	-	298.2	1969, 2014	No	-	NBDNRED. unpubl. data
Saint John River	Saint John	Saint John River Basin	Grand Bay Composite	45.268	-66.068	-	-	Pre-1874	No*	Yes	Lanman 1874
West Branch Reservoir (Halls Lake)*	Saint John	West Fundy Composite	Musquash River	45.216	-66.376	-	437.9	-	No	-	Connected to West Branch (Musquash) Reservoir (South)

Table 6 Cont'd

Lake Name	County	Primary Watershed	Secondary Watershed	Lat	Long	Depth (m)	Surface area (ha)	Whitefish Observations	Stocked	Native	Source
West Branch (Musquash) Reservoir (South)	Saint John	West Fundy Composite	Musquash River	45.190	-66.366	-	110.9	1972, 1973	No	-	NBDNRED unpubl.data
Saint John River	Sunbury	Saint John River Basin	Swan Creek Composite	45.881	-66.523	-	-	Pre-1851	No*	Yes	Perley 1851, Meth 1872
Long Lake	Victoria	Saint John River	Tobique River	47.031	-66.895	27.4	989.0	1973	Yes	-	NBDNRED unpubl. data
Tobique River Lakes (undefined)	Victoria	Saint John River Basin	Tobique River	-	-	-	-	Pre-1873	No*	Yes	Adams 1873
Tobique River Reservoir	Victoria	Saint John River Basin	Tobique River	46.795	-67.677	-	421.1	1979	Yes	Yes	NBDNRED unpubl. data
Trousers Lake	Victoria	Saint John River Basin	Tobique River	47.011	-66.959	18.3	1008.5	1964, 1972, 1983	No	Yes	Meth 1973, Edge 1987, NBDNRED unpubl. data
East Grand Lake	York	St Croix River Basin	Forest City Stream	45.737	-67.798	36.6	6,503.3	1969, 1984, 2010	No	Yes	Edge 1987; Bernatchez and Dodson 1990; Wood 2016
Mactaquac Dam	York	Saint John River Basin	Indian Brook Composite	45.955	-66.865	-	-	1969	No*	Yes	Smith 1970, Murray 2005

Mactaquac Headpond	York	Saint John River Basin	Baker Brook Composite	45.926	-67.072	-	5,483.4	Pre-1851, 1977	No*	Yes	Perley 1851; NBDNRED publ. data
Oromocto Lake	York	Saint John River Basin	Oromocto River	45.585	-67.010	-	4047.3	1997	No	Yes	NBDNRED unpubl. data
Oromocto River Mouth	York	Saint John River Basin	Oromocto River	45.851	-66.481	-	-	1971	No*	Yes	Meth 1972
Palfrey Lake*	York	St Croix River Basin	Spednic Lake	45.650	-67.480	-	726.4	-	No	Yes	Connected to Spednic Lake
Spednic Lake	York	St. Croix River Basin	Spednic Lake	45.597	-67.529	16.5	6,968.3	1972, 2007	No	Yes	NBDNRED unpubl. data, Wood 2016
Wauklahegan Lake	York	St. Croix River Basin	Spednic Lake	45.606	-67.369	-	353.4	-	No	Yes	Atlantic Canada Conservation Data Center

Lake Name* Lakes directly connected to water where Lake Whitefish are verified, having a high likelihood of also containing Lake Whitefish

Note:

Tobique River Lakes are not defined, but likely include Trousers Lake and Long Lake, Victoria County and Serpentine Lake, Northumberland County, but could include other attached basins.

McDougall Lake and the possible occurrence in Logan Lake (NBDNRED unpubl. data) in the River Basin of the Northwest Miramichi are the only locations to support Lake Whitefish in NB that do not drain to the Atlantic Ocean.

Stocking was generally focused on large lakes in the southwest of the province with Lake George, Oromocto Lake, and Harvey Lake receiving over 3 million Lake Whitefish fry each before the whitefish stocking program ended in 1901 (Table 2).

New Brunswick Post-Stocking Whitefish Surveys

Lake Whitefish were first noted in NB by Perley (1851) in the Madawaska River at the falls near this tributary's confluence with the Saint John River. In this location, Perley (1851) reported that Lake Whitefish could be captured in summer but were commonly harvested in autumn and served as a winter staple for both the First Nations and French colonists (Perley 1851,1852, Adams 1873, Lanman 1874, Piers 1924, Meth 1973). In this region of the upper Saint John River, the species was pursued nearly to the point of its destruction (Cox 1896b). Lake Whitefish were also documented in the Tobique Lakes connected to the Saint John River by Adams (1873), but no mention of specific lakes was made. The species was captured in spring in Grand Lake of the Saint John River and in the river's main stem between Grand Lake (Jemseg River) and the City of Fredericton (Perley 1851, Evermann and Goldsborough 1907). In these systems, Lake Whitefish appeared in shallow lake margins during cooler water periods, though were reported to occupy deeper water in summer (Perley 1851, Adams 1873). While Perley (1851) makes passing mention of Lake Whitefish in the downstream reaches of the Saint John River, Lanman (1874) describes its occurrence through the "*whole extent*" of that system. Perley (1852) and Lanman (1874) even describe the capture of Lake Whitefish in the Saint John Harbour in spring. Here, Lake Whitefish occurrence was likely supported by high volumes of freshwater causing a local reduction in surface salinity during the annual freshet for which that system is known (Newton and Burrell 2015). Cox (1893) and Meth (1972) also mention Lake Whitefish occurrence downstream in autumn, though not necessarily to the harbour mouth. Further collections of Lake Whitefish from the lower Saint John River are held by the Royal Ontario Museum, the Canadian Museum of Nature, and the New Brunswick Museum of Natural History archived within the collection of fishes (NB Museum of Natural History, online data portal). These observations are also supported by Dadswell (1975) who reported that the entire population occupies the inshore estuary in autumn and spends the summer in

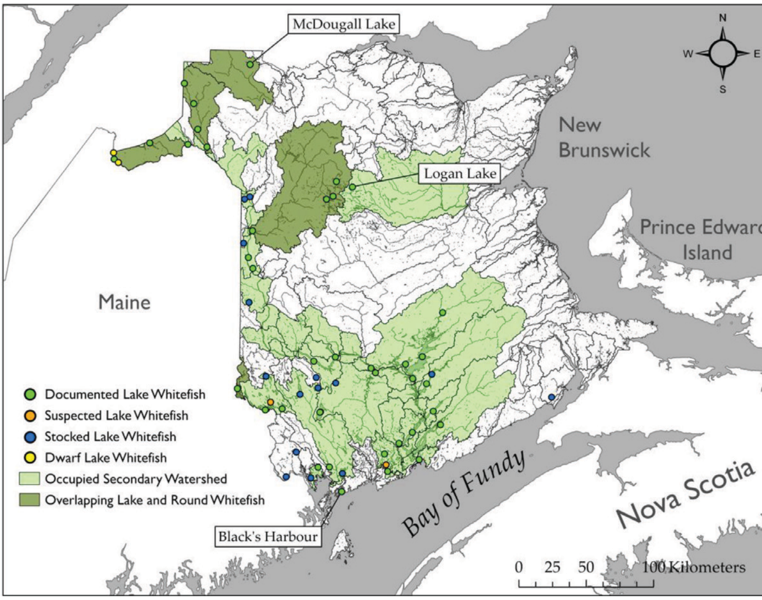


Fig 3 **Map of Lake Whitefish (*Coregonus clupeaformis*) stocking and present distribution in New Brunswick, Canada. The overlapping range of Round Whitefish (*Prosopium cylindraceum*) is indicated but is not comprehensive of their distribution. Lake Whitefish and Round Whitefish co-occur in McDougall Lake and together with Logan Lake are the only Lake Whitefish populations outside of an Atlantic-draining watershed. Black's Harbour marks the occurrence of a Lake Whitefish observation in non-estuarine marine waters.**

Belleisle Bay which has a salinity ranging 2.5-4.6 ppt through much of its 33 m deep basin (Andrews *et al.* 2020).

Lake Whitefish were also reported in both Darlings' Lake in Kennebecasis Bay and the Nerepis River branching from the main stem of the Saint John River at Grand Bay (Fig 3). The Nerepis River likely supported a spawning migration based on the descriptions made by Perley (1852). Adams (1873) suggested that the Saint John River may host both a freshwater obligate form of the Lake Whitefish and another which inhabited the estuary, though subsequent reports and analysis by Adams (1873) suggest no difference between these types other than colouration. Despite this conclusion, Edge (1987) confirms the capture of a Lake Whitefish in Black's Harbour, NB in 1958 in fully marine waters (see also Leim and Day 1959, Scott and Crossman 1957, Edge 1987; Fig 3). Scott and Crossman (1959) also report a Lake Whitefish captured between 18-27 m depth in the lower Saint John River by Dadswell (1975), a region below the halocline with salinities measuring ~20 ppt (Carter and Dadswell 1983). Lake Whitefish are known to form anadromous populations (Dadswell 1975, Morin *et al.* 1981) and there is high likelihood that this behaviour is also present in the estuary of the Saint John River that receives significant tidal exchange from the Bay of Fundy. As surface temperatures cooled in Saint John River in autumn (mid September-October), Lake Whitefish were observed to seek tributary streams to spawn, an activity primarily conducted at night (Perley 1851,1852, Lanman 1874).

In later years, Lake Whitefish were also reported from Beau Lake (Kendall 1914) in the upper reaches of the Saint John River (most of which occurs in Québec), and while Lake Whitefish presence in the adjoining Glazier Lake was falsely reported by Evermann and Goldsborough (1907) in reference to Kendall (1903), it was later confirmed in 1972 by Meth (1973); DDT levels in Lake Whitefish were simultaneously reported as 0.220-0.252 ppm in that location in 1972. Smith (1969) mentions the occurrence of Lake Whitefish in the Green River, and it was later confirmed upstream in the First and Third Green River lakes (Keachie and Cote 1973). Lac Baker was also reported to support the species (Meth 1973, Hyatt 1970 in Meth 1973). When the Saint John River began to be developed for hydropower, Lake Whitefish were observed at both the Beechwood Generating Station and the Mactaquac Generating Station following their respective completion dates in 1957 and 1968 (Smith 1979; Table 7, 8). By 1990, catches of Lake Whitefish in the bypass facility at Beechwood Dam had dwindled to zero (Beaumaster *et al.* 2020), while catches declined even more precipitously at Mactaquac (Smith 1979, Ingram 1980; Table 7, 8). At that location, the number of observed Lake Whitefish dropped from 2,440 fish in 1968 (Smith 1970; he states 2,351 fish) to just 15 in 1971 (Meth 1973, Smith 1979, Ingram 1980), and from 2005-present (2025), not a single Lake Whitefish has been captured or observed at the dam.

Smith (1970) reports that Lake Whitefish arriving to the Mactaquac facility did so in late October and November, consistent with an upstream spawning migration that was "*usually still in progress when collection facilities were closed for the season*". This observation simultaneously explained the lack of consistent fish lift captures of Lake Whitefish in autumn and the most likely reason for their disappearance (Smith 1970, 1979; Table 8). When present, Lake Whitefish were observed in the fish lift starting in October and this pattern of autumn captures was consistent through later years (Table 7, 8). Initially it was suspected that Lake Whitefish blocked by the Mactaquac Dam re-routed to the Keswick River (Meth 1974). Gravid fish were also captured near the mouth of Oromocto River located 35 km downstream (Meth 1972), but this location possibly supported a separate population which has not been observed since and was never verified. A similarly timed spawning migration was also intercepted in Salmon River, a tributary at the upstream end of Grand Lake, Queens County in 1969 (Smith 1970), that was also first and last reported in 1971 and 1972 respectively (Meth 1972, 1974).

Most early accounts of Lake Whitefish originated from the Saint John River basin which undoubtedly supported the region's largest population, but Lake Whitefish in NB were not exclusive to that watershed. Kendall (1903) described the Lake Whitefish broadly from the St. Croix River but provided no specifics on inhabited lakes. In 1950, specimens of Lake Whitefish were collected in a 5.1 cm stretched mesh gill net set at the bottom of Kerr Lake, Charlotte County, at a depth of 7.5 m (Smith 1952), suggesting for the first time in regional literature that the species might also occur outside of the Saint John and St. Croix River basins.

Among records of Lake Whitefish in NB, two reports are of note. The first being reports of Lake Whitefish in the Restigouche River (see Cox 1893, Scott and Crossman 1959) and in McDougall Lake, Restigouche County (NBDNRED unpubl. data; Fig 3). These observations could have been misidentified Round Whitefish known to occupy the region or might represent Lake Whitefish originating from a different glacial refugium than those elsewhere in the MP (i.e., the Mississippian glacial refuge; Curry 2007, Curry and Gautreau 2010). The second report is that of the occurrence of Lake Whitefish in Logan Lake in the headwaters of the Miramichi River basin (NBDNRED unpubl. data; Fig 3). Logan Lake similarly does not match the post-glacial distribution of the species in the MP that typically occur only in Atlantic-facing watersheds. However, Lake Whitefish in this location may have been separated from populations in the Tobique River watershed (Huntsman 1953) during post-glacial isostatic rebound. If the record from Logan Lake is correct, this populations may provide important clues regarding regional zoogeography and post-glacial dispersal of the inland fishes of NB.

Table 7 **Lake Whitefish (*Coregonus clupeaformis*) captured in the fish lift of the Beechwood Dam on the Saint John River, New Brunswick. The Beechwood Dam was completed in 1957 following which a small number of Lake Whitefish were reported annually until the year 2000 when catches declined to zero. Catches are listed by month within the operational period of the fish lift each year alongside a catch per unit effort of fish/day and the information source when data is available.**

Year	Start of Operation	May	June	July	Aug	Sept	Oct	Nov	End of Operation	Total Days	Total Whitefish	CPUE	Source
1957	14-Jun	-	0	0	0	0	0	0	30-Nov	153	0	0.00	Smith 1979
1958	01-Jun	-	0	0	0	0	1	0	21-Nov	173	1	0.01	Smith 1979
1959	20-May	2	0	0	0	0	0	0	23-Nov	187	2	0.01	Smith 1979
1960	20-May	0	0	0	0	0	1	2	22-Nov	186	3	0.02	Smith 1979, Ingram 1960
1961	12-Jun	-	0	0	0	0	2	1	21-Nov	162	3	0.02	Smith 1979, Ingram 1961
1962	02-Jun	-	1	0	0	0	10	0	12-Nov	163	11	0.07	Smith 1979, Ingram 1962
1963	30-May	0	2	0	0	0	2	0	19-Nov	173	4	0.02	Smith 1979, Ingram 1963
1964	21-May	0	3	0	0	8	6	0	25-Nov	188	17	0.09	Smith 1979
1965	17-May	0	1	0	0	0	1	0	17-Nov	184	2	0.01	Smith 1979
1966	26-May	0	2	0	0	0	0	0	14-Nov	172	2	0.01	Smith 1979
1967	02-Jun	-	0	0	0	0	0	0	20-Nov	171	0	0.00	Smith 1979
1968	15-May	1	1	0	0	0	0	0	18-Nov	187	2	0.01	Smith 1979
1969	05-Jun	0	0	0	0	0	0	0	04-Nov	152	0	0.00	Smith 1979
1970	02-Jun	-	0	0	0	0	0	0	12-Nov	163	0	0.00	Smith 1979
1971	01-Jun	-	0	0	1	2	0	0	08-Nov	160	3	0.02	Smith 1979
1972	16-May	0	1	0	0	0	0	0	31-Oct	168	1	0.01	Ingram 1981
1973	16-May	0	0	0	0	0	0	0	31-Oct	168	0	0.00	Ingram 1981
1974	16-May	0	0	0	0	0	0	0	31-Oct	168	0	0.00	Ingram 1981
1975	No Data									-	-	-	Ingram 1981

1976	16-May	0	4	0	0	0	0	0	31-Oct	168	4	0.02	Ingram 1981
1977	20-Jun	-	0	0	1	1	0	0	03-Nov	136	2	0.01	Ingram 1987
1978	12-Jun	-	0	2	0	2	0	-	31-Oct	141	5	0.04	Ingram 1987
1979	14-Jun	-	2	1	0	1	0	0	01-Nov	140	4	0.03	Ingram 1987
1980	10-Jun	-	1	0	1	1	0	0	04-Nov	147	3	0.02	Ingram 1987
1981	10-Jun	-	0	0	0	0	1	0	11-Nov	154	1	0.01	Ingram 1987
1982	14-Jun	-	0	0	0	0	3	0	03-Nov	142	3	0.02	Ingram 1987
1983	30-Jun	No Whitefish Data							27-Oct	119	-	-	-
1984	03-Jul								29-Oct	118	-	-	-
1985	25-Jun								30-Oct	127	-	-	-
1986	30-Jun								16-Oct	108	-	-	-
1987	02-Jun								30-Oct	150	-	-	-
1988	28-Jun								31-Oct	125	-	-	-
1989	28-Jun								30-Oct	124	-	-	-
1990	21-Jun	-	0	0	0	0	0	-	09-Oct	110	0	0.00	Beaumaster *et al.* 2020
1991	24-Jun	-	0	0	0	0	0	-	17-Oct	115	0	0.00	Beaumaster *et al.* 2020
1992	06-Jul	-	-	0	0	0	0	-	07-Oct	93	0	0.00	Beaumaster *et al.* 2020
1993	12-Jul	-	-	0	0	0	0	-	18-Oct	98	0	0.00	Beaumaster *et al.* 2020
1994	18-Jul	-	-	0	0	0	0	0	10-Nov	115	0	0.00	Beaumaster *et al.* 20200
1995	26-Jul	-	-	5	0	0	0	-	27-Oct	93	5	0.05	Beaumaster *et al.* 2020
1996	24-Jul	-	-	0	0	0	0	0	05-Nov	104	0	0.00	Beaumaster *et al.* 2020
1997	24-Jul	-	-	0	0	0	0	-	30-Oct	98	0	0.00	Beaumaster *et al.* 2020

Table 7 Cont'd

Year	Start of Operation	May	June	July	Aug	Sept	Oct	Nov	End of Operation	Total Days	Total Whitefish	CPUE	Source
1998	30-Jun	-	0	0	0	2	0	-	30-Oct	122	2	0.02	Beaumaster *et al*. 2020
1999	22-Jun	-	0	1	0	0	0	0	03-Nov	134	1	0.01	Beaumaster *et al*. 2020
2000	15-Jul	-	-	0	0	0	0	0	14-Nov	122	0	0.00	Beaumaster *et al*. 2020
2001	28-Jun	-	0	0	0	0	0	0	07-Nov	132	0	0.00	Beaumaster *et al*. 2020
2002	16-Jul	-	-	0	0	0	0	0	06-Nov	113	0	0.00	Beaumaster *et al*. 2020
2003	11-Jul	-	-	0	0	0	0	0	13-Nov	125	0	0.00	Beaumaster *et al*. 2020
2004	30-Jun	-	0	0	0	0	0	0	10-Nov	133	0	0.00	Beaumaster *et al*. 2020
2005	08-Jul	-	-	0	0	0	0	-	08-Oct	92	0	0.00	Beaumaster *et al*. 2020
2006	05-Jul	-	-	0	0	0	0	0	06-Nov	124	0	0.00	Beaumaster *et al*. 2020
2007	05-Jul	-	-	0	0	0	0	0	01-Nov	119	0	0.00	Beaumaster *et al*. 2020
2008	09-Jul	-	-	0	0	0	0	-	27-Oct	110	0	0.00	Beaumaster *et al*. 2020
2009	23-Jun	-	0	0	0	0	0	0	06-Nov	136	0	0.00	Beaumaster *et al*. 2020
2010	23-Sep	-	-	-	-	0	0	0	03-Nov	41	0	0.00	Beaumaster *et al*. 2020

2011	13-Jun	-	0	0	0	0	0	-	31-Oct	140	0	0.00	Beaumaster *et al*. 2020
2012	10-Jul	-	-	0	0	0	0	0	05-Nov	118	0	0.00	Beaumaster *et al*. 2020
2013	17-Jul	-	-	0	0	0	0	-	24-Oct	99	0	0.00	Beaumaster *et al*. 2020
2014	21-Jul	-	-	0	0	0	0	-	30-Oct	101	0	0.00	Beaumaster *et al*. 2020
2015	09-Jul	-	-	0	0	0	0	0	15-Nov	129	0	0.00	Beaumaster *et al*. 2020
2016	04-Jul	-	-	0	0	0	0	0	15-Nov	134	0	0.00	Beaumaster *et al*. 2020
2017	28-Jun	-	0	0	0	0	0	0	29-Nov	154	0	0.00	Beaumaster *et al*. 2020
2018	15-Jun	-	0	0	0	0	0	0	19-Nov	157	0	0.00	Beaumaster *et al*. 2020
2019	09-Jul	-	-	0	0	0	0	-	28-Oct	111	0	0.00	Beaumaster *et al*. 2020
2020	-	-	-	-	-	-	-	-	-	-	-	-	-
2021	-	-	-	-	-	-	-	-	-	-	-	-	-
2022	-	-	-	-	-	-	-	-	-	-	-	-	-
2023	-	-	-	-	-	-	-	-	-	-	-	-	-
2024	-	-	-	-	-	-	-	-	-	-	-	-	-
2025	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 8 **Lake Whitefish (*Coregonus clupeaformis*) recorded in the fish lift of the Mactaquac Dam on the Saint John River, New Brunswick. The Mactaquac Dam was completed in 1968 following which catches of Lake Whitefish that arrived during their upstream spawning migration in October and November rapidly declined. While the arrival of this species was noted in the fish lift, there are no accounts that the captured whitefish were transported upstream of the dam by the fish lift. Spawning tributaries that likely occurred upstream were almost certainly impacted from flooding of the Mactaquac Headpond where the water level was increased by 40 m.**

Year	Start of Operation	May	June	July	Aug	Sept	Oct	Nov	End of Operation	Total Days	Total Whitefish	CPUE	Source
1968	14-May	0	0	0	2	16	1,264	1,158	21-Nov	191	2440	12.77	Smith 1979
1969	16-May	0	0	0	0	1	319	842	25-Nov	193	1162	6.02	Smith 1979
1970	20-May	0	0	0	0	0	439	136	18-Nov	182	575	3.16	Smith 1979
1971	22-May	0	0	0	0	0	5	10	16-Nov	178	15	0.08	Smith 1979
1972	21-May	0	0	0	0	0	15	2	17-Nov	180	17	0.09	Ingram 1980
1973	17-May	0	0	0	0	0	3	0	15-Nov	182	3	0.02	Ingram 1980
1974	21-May	0	0	0	0	1	44	25	13-Nov	176	70	0.40	Ingram 1980
1975	20-May	0	0	0	0	0	74	39	14-Nov	178	113	0.63	Ingram 1980
1976	13-May	0	0	0	3	0	2	0	29-Nov	200	5	0.03	Ingram 1980
1977	16-May	0	0	0	0	0	18	-	31-Oct	168	18	0.11	Ingram 1985
1978	16-May	0	0	0	0	0	90	-	31-Oct	168	90	0.54	Ingram 1985
1979	16-May	0	0	0	0	0	184	-	31-Oct	168	184	1.10	Ingram 1985
1980	16-May	0	0	0	0	0	17	-	31-Oct	168	17	0.10	Ingram 1985
1981	16-May	0	0	0	0	0	5	-	31-Oct	168	5	0.03	Ingram 1985
1982	16-May	0	0	0	0	0	49	-	31-Oct	168	49	0.29	Ingram 1985
1983	16-May	0	0	0	0	0	0	-	30-Oct	167	0	0.00	Ingram 1990
1984	16-May	0	0	0	0	5	12	-	30-Oct	167	17	0.10	Ingram 1990
1985	16-May	0	0	0	0	0	17	-	30-Oct	167	17	0.10	Ingram 1990
1986	01-May	0	0	0	0	0	67	-	30-Oct	182	67	0.37	Ingram 1990
1987	01-May	0	0	0	0	0	68	-	30-Oct	182	68	0.37	Ingram 1990
1988	01-May	0	0	0	0	0	14	-	30-Oct	182	14	0.08	Ingram 1990

1989	04-Jun	-	0	0	0	1	6	-	18-Oct	136	7	0.05	MGS Fishway unpubl data
1990	14-May	0	0	0	0	0	3	-	25-Oct	164	3	0.02	MGS Fishway unpubl data
1991	01-Jun	-	0	0	1	0	16	-	28-Oct	149	17	0.11	MGS Fishway unpubl data
1992	24-May	0	0	0	0	0	64	-	26-Oct	135	64	0.47	MGS Fishway unpubl data
1993	10-May	0	0	0	0	0	-	-	29-Sep	142	0	0.00	MGS Fishway unpubl data
1994	03-Jun	-	0	0	0	0	613	-	25-Oct	144	613	4.26	MGS Fishway unpubl data
1995	29-May	0	0	0	0	0	16	-	26-Oct	150	16	0.11	MGS Fishway unpubl data
1996	27-May	0	0	0	0	0	1	-	11-Oct	137	1	0.01	MGS Fishway unpubl data
1997	18-Jun	-	0	0	0	0	0	-	23-Oct	127	0	0.00	MGS Fishway unpubl data
1998	19-May	0	0	0	0	0	2	-	26-Oct	160	2	0.01	MGS Fishway unpubl data

Table 8 Cont'd

Year	Start of Operation	May	June	July	Aug	Sept	Oct	Nov	End of Operation	Total Days	Total Whitefish	CPUE	Source
1999	10-May	0	0	0	0	0	14	-	25-Oct	168	14	0.08	MGS Fishway unpubl data
2000	20-May	0	0	0	0	0	12	-	26-Oct	159	12	0.08	MGS Fishway unpubl data
2001	18-May	0	0	0	0	0	3	-	31-Oct	166	3	0.02	MGS Fishway unpubl data
2002	18-May	0	0	0	0	0	5	-	31-Oct	166	5	0.03	MGS Fishway unpubl data
2003	22-May	0	0	0	0	0	0	-	20-Oct	151	0	0.00	MGS Fishway unpubl data
2004	21-Jun	-	0	0	0	0	1	-	21-Oct	122	1	0.01	MGS Fishway unpubl data
2005	20-May	0	0	0	0	0	0	-	13-Oct	146	0	0.00	MGS Fishway unpubl data
2006	16-May	0	0	0	0	0	0	-	26-Oct	163	0	0.00	MGS Fishway unpubl data

2007	23-May	0	0	0	0	0	0	-	19-Oct	149	0	0.00	MGS Fishway unpubl data
2008	No Data										-	-	MGS Fishway unpubl data
2009	16-May	0	0	0	0	0	0	-	09-Oct	146	0	0.00	MGS Fishway unpubl data
2010	04-May	0	0	0	0	0	0	-	04-Oct	153	0	0.00	MGS Fishway unpubl data
2011	25-May	0	0	0	-	-	-	-	26-Jul	62	0	0.00	MGS Fishway unpubl data
2012	14-May	0	0	0	0	0	0	-	16-Oct	155	0	0.00	MGS Fishway unpubl data
2013	10-May	0	0	0	0	0	0	-	09-Oct	152	0	0.00	MGS Fishway unpubl data
2014	17-May	0	0	0	0	0	0	-	24-Oct	160	0	0.00	MGS Fishway unpubl data
2015	11-May	0	0	0	0	0	0	-	22-Oct	164	0	0.00	MGS Fishway unpubl data
2016	13-May	0	0	0	0	0	0	0	07-Nov	178	0	0.00	MGS Fishway unpubl data

Table 8 Cont'd

Year	Start of Operation	May	June	July	Aug	Sept	Oct	Nov	End of Operation	Total Days	Total Whitefish	CPUE	Source
2017	18-May	0	0	0	0	0	0	-	27-Oct	162	0	0.00	MGS Fishway unpubl data
2018	19-May	0	0	0	0	0	0	-	29-Oct	163	0	0.00	MGS Fishway unpubl data
2019	16-May	0	0	0	0	0	0	-	15-Oct	152	0	0.00	MGS Fishway unpubl data
2020	15-May	0	0	0	0	0	0	-	20-Oct	158	0	0.00	MGS Fishway unpubl data
2021	17-May	0	0	0	0	0	0	-	20-Oct	156	0	0.00	MGS Fishway unpubl data
2022	19-May	0	0	0	0	0	0	-	28-Oct	162	0	0.00	MGS Fishway unpubl data
2023	12-May	-	-	-	-	-	-	-	20-Oct	161	0	0.00	MGS Fishway unpubl data
2024	-	-	-	-	-	-	-	-	-	-	-	-	-
2025	-	-	-	-	-	-	-	-	-	-	-	-	-

Morphometrics and Meristics of Whitefish in the Maritime Provinces

Edge (1987, Edge *et al.* 1991) was the first author to produce a detailed morphometric comparison between the Atlantic Whitefish and the Lake Whitefish in NS (n=6 populations), NB (n=5 populations), Québec, and Maine, and to further document intraspecific variation amongst the latter species. This analysis of meristic characters by Edge (1987, Edge *et al.* 1991) within NS and NB identified specimens from Mira River (Salmon River branch), NS and Kerr Lake, NB as distinct based on low lateral line scale counts. Edge (1987) also noted high gill rakers counts in Lake Whitefish collected from Pringle Lake, NS (mean 30.9), possibly due to a planktivorous diet, but observed that Lake Whitefish from the Mira River had low gill raker counts that may indicate benthic feeding. Following this assessment, Edge (1987) suggested that based on gill raker counts most population from NS and NB seemed to group separately. Lake Whitefish from the Mira River were also suggested as "*sufficiently distinct to be described as a subspecies*" due to lower lateral line scale (64-75, mean 70.1) and gill raker counts (20-24, mean 22.6) when compared to other assessed populations (Edge 1987, Edge *et al.* 1991, Goodchild 2001). The genus *Coregonus*, however, is known for its phenotypic plasticity, particularly in gill raker number and form (Loch 1974, Svårdson 1979, Lindsey 1981) that, while hereditary, can be strongly influenced by habitat type and foraging strategy within a few generations (Lindsey 1981). Therefore, these characters have been considered unreliable for differentiating populations (Goodchild 2001). Upon further assessment, the Mira River population of Lake Whitefish has demonstrated no genetic difference from other NS populations (Bernatchez and Dodson 2001, Goodchild 2001) despite apparent morphological differences.

When describing all three Maritime Coregonids, Hasselman (2003) reports that a combination of the length of the longest gill rakers, the lateral line scale count, and the pectoral fin length was able to correctly distinguish among the various species. Detailed morphometrics and meristics for the three species examined are found in Hasselman (2003). Morphometric analysis by Hasselman (2003, Hasselman *et al.* 2009) also identified distinctive phenotypic variation in Lake Whitefish populations between Kerr Lake, NB and three other populations that included Lake George, Mira River in NS, and Saint John River in NB. Murray (2005) noted high Fst values between Lake Whitefish populations in Maritime drainages. Conversely, Lake Whitefish in the Saint John River, NB (sampled at Mactaquac Dam) and the Mira River, NS were found to have the least genotypic differentiation but the greatest phenotypic differences (Murray 2005).

Ancestry of Whitefish in the Maritime Provinces

Atlantic Whitefish and Round Whitefish have always been considered native to NS and NB respectively due to a lack of historical stocking and the endemic nature of the former species, but the ancestry of Lake Whitefish was not so clear. Following detailed meristic analysis of multiple Lake Whitefish populations by Edge (1987, Edge *et al.* 1991, Hasselman 2003, Hasselman *et al.* 2009), questions remained about whether the Lake Whitefish observed in NS were native to the province or remnants of past stocking efforts (see also Curry and Gautreau 2010). As recently as 1996, Davis and Browne (1996) wrote without evidence that the Lake Whitefish was an introduced species in NS, and to a degree it was, but these statements disregarded several studies already addressing the local origin and ancestry of this species.

Bernatchez and Dodson (1990) used restriction-fragment length polymorphism in mitochondrial DNA to study several populations of Lake Whitefish in Maine, NS, and NB. Their findings first made a distinction between western Lake Whitefish that dispersed from a Mississippian glacial refuge following glacial retreat at the end of the Pleistocene epoch and those arriving from a probable, isolated Atlantic refugium. They suspected that those populations from the Atlantic refugium now occupy waters ranging from Maine's Allagash Basin through to Cape Breton, NS. The Atlantic glacial refugium likely encompassed an unglaciated plain around the present-day Hudson and Susquehanna River basins (Schmidt 1986; Fig 4). Initial hypotheses perceived that the only region of overlap between these two clonal groups (Atlantic and Mississipian) was the Allagash Basin of the Saint John River drainage in Maine where sympatric populations from two glacial refuges exist (Bernatchez and Dodson 1990, Bernatchez *et al.* 1996; Fig 4). In this overlapping region, Lake Whitefish suspected to have originated from the western (Mississippian) assemblage appeared to exhibit only a normal size phenotype, while those thought to originate from the eastern (Atlantic) assemblage appeared to exhibit either a normal or a dwarf phenotype that occasionally formed a sympatric pair. Bernatchez and Dodson (1990) theorised that these dwarf and normal phenotype pairs (see also Fenderson 1964) developed through sympatric speciation in the Allagash Basin while remaining reproductively isolated within individual lakes. In NB, these dwarf/normal pairs are only known in Beau Lake in the upper Saint John River on the Maine/NB/Québec border, but they may also occur in Glazier Lake where only the dwarf form is identified (Wood 2016; J. Wood unpubl data). Based on the degree of sequence divergence, it was suggested as a conservative estimate that Lake Whitefish in the MP suspected to have originated from an Atlantic refugium last shared a common ancestor with Lake Whitefish from the Mississippian (western) group 150,000 years ago (Bernatchez and Dodson 1990). This timespan is considered a relatively recent divergence among Lake Whitefish clades (Bernatchez and Dodson 1991).

Bernatchez and Dodson (1991) corrected their previous findings for the MP after characterising four distinct assemblages of Lake Whitefish identifiable across North America which they described as the Beringian (i.e., Yukon/Alaska origin), Mississippian, Atlantic, and Acadian lineages. Among these, Lake Whitefish in NS, NB, some parts of southern Québec, and the northeastern USA through to New England (Bodaly *et al.* 1992) comprised a unique clade based on the analysis of mitochondrial DNA. This group of Lake Whitefish was deemed to be the "Acadian" lineage by Bernatchez and Dodson (1991; to avoid confusion with the Atlantic Whitefish [*Coregonus huntsmani*] once known as the "Acadian Whitefish" we will use the term "Scotian" or "Scotian lineage" to describe this eastern group of Lake Whitefish [*Coregonus clupeaformis*] occurring in the MP throughout the remainder of this article). Within this re-evaluation, Bernatchez and Dodson (1991) found no evidence of the "Scotian" haplotype identified in the MP in other lakes known to have been sourced from the Atlantic refugium (e.g. Lake Champlain, New York State; Bernatchez and Dodson 1994). Furthermore, these new data suggested that Lake Whitefish from the Mississipian refugium only overlapped with those from the Atlantic refugium in the lower St. Lawrence River and Eastern Québec (Fig 4) but Bernatchez and Dodson (1991) reported no overlap between the Mississipian and the "Scotian" lineages. Previous reports of overlapping clades in the Allagash Basin were thus more likely the intersection of the Atlantic and "Scotian" groups that only meet in Northern Maine and Québec (Bernatchez and Dodson 1991, Pigeon *et al.* 1997, Mee *et al.* 2015). The "Scotian" assemblage of Lake Whitefish thus constitutes a distinct group native to the MP and neighbouring eastern regions (Bernatchez and Dodson 1991, 1994, Bernatchez and Wilson 1998) which has maintained reproductive isolation from other Lake Whitefish groups from discrete glacial origins even when found in sympatry in eastern lakes (Lu and Bernatchez 1998, 1999, COSEWIC 2008).

Identifying a distinct "Scotian" group of Lake Whitefish was an important first step in re-defining the origin of Lake Whitefish in the MP, but Bernatchez and Dodson (1990, 1991) only examined Grand Lake, in Queens County, NB, and Mira River, in Cape Breton, NS during their analysis. Murray (2005), however, was the first to consider the possible implications of historical stocking and to discuss the introduction of Ontario-origin (Detroit River) Lake Whitefish to the MP. Murray (2005) assayed 13 Lake Whitefish populations (12 in NS and 1 in NB; Fig 2, Table 5, 6) using 11 microsatellite loci and included samples from Lake Ontario (a possible stocking source) and MacAlpine Lake, Nunavut, as two representatives of the Mississippian lineage. This study demonstrated that Lake Whitefish sampled from the MP were more closely related to each other within the range of the proposed "Scotian" lineage than to the Mississippian group, mirroring findings by Bernatchez and Dodson (1990, 1991). Based on these results, Murray (2005) concluded that stocking had been unsuccessful (see also Piers 1924), but apart from Grand Lake, Queens County, NB, which supported a significant native population prior to being stocked, population ancestry had not actually been assessed in stocked waters. Lakes within and adjacent to Kejimkujik National Park (likely stocked in 1890) and those near Goshen Lake in Guysborough County (stocked in 1899 and 1900) that could retain stocked genetics were missed (Davies 1900, 1901; Table 1). Though possibly apart from a slim possibility in these regions, there is little chance that any stocked whitefish remained in NS to be sampled (Fig 2).

Glacial Refuges and Origin of the "Scotian" Lineage of Lake Whitefish

Following on the findings of (Bernatchez and Dodson 1991) it was hypothesised that the "Scotian" lineage of Lake Whitefish found in the MP and Maine arrived from eastern continental shelf areas that remained above sea level and ice free during the last glacial maxima (Fulton and Andrews 1987, Bodaly *et al.* 1992). Evidence for this hypothesised eastern origin is robust in part because the known distribution of the "Scotian" Lake Whitefish (Fig 2, 3, 4) is concentrated in and nearly exclusive to eastern draining watersheds of the MP. Three possible eastern refugia are described by Curry (2007) and include: 1) a southern Georges Banks Refugium (Whitmore *et al.* 1967, Shaw 2006), 2) a Sable Island Banks or "Scotian" Refugium (Catling *et al.* 1985, Davis and Browne 1996, 1998, Mandrak *et al.* 2023), and 3) a Northeastern Grand Banks Refugium east of Newfoundland (NFLD; Schmidt 1986, Curry and Gautreau 2010; Fig 4). Among these regions, the Northeastern Grand Banks of NFLD is often suggested as being the most likely origin for many eastern fishes (Schmidt 1986, Bernatchez and Dodson 1991, Curry 2007, Curry and Gautreau 2010; Fig 4), but the precise post-glacial origin for some species is still subject to some debate and we believe it is incorrect for the whitefish occurring in the MP. A fourth region, the Atlantic Glacial Coastal refugium (i.e., Atlantic Refugium) which overlapped with present day Cape Cod and occurred next to Georges Bank (Curry 2007; Fig 4) is not included here because Lake Whitefish distinct from the "Scotian" lineage have been identified separately as having originated from this refugium and occur sparsely in central Maine but not as far as the MPs (Bernatchez and Dodson 1991).

Tangential to the three regions described, it has also been postulated that a glacially de-watered continental shelf could have presented a near continuous land mass as a possible refuge (Wright 1989). However, modern assessment has led to the hypothesis that ice extending to and even past the continental shelf edge was possible (Dalton *et al.* 2020, 2023). For simplicity of argument, we will assume three discrete refugia as potential Lake Whitefish sources for the MP. Dalton *et al.* (2020, 2023) provides extensive and robust geochronological data sets regarding ice cover of modern landforms, but little data is presented describing ice extent beyond those coastlines. Furthermore, the presence of significant ice streams along the Laurentian and Fundian channels (Piper and MacDonald 2001, Shaw 2006, Shaw *et al.* 2006; Fig 4) would have roughly split a continuous land mass into the three isolated refuges (Georges Bank, Sable Island "Scotian", and Grand Banks) as previously described.

Beginning in the south, clear evidence suggests that Georges Bank remained ice free during the Wisconsin glacial maximum. This evidence includes fine lacustrine sediments characteristic of freshwater habitats and glacial moraines which provide evidence of ice margin contact on the western edge of the bank (Pratt and Schlee 1969). These data complement the discovery of numerous fossils teeth of both Mastodon and Mammoth (*M. americanum, and Mammuthus sp*; Whitmore *et al.* 1967) dredged from the sea floor indicating the presence of numerous large herbivores. The existence of such large mammals at sufficient abundance to leave discoverable fossils suggest that forests and grasslands once covered Georges Bank. Therefore, sufficient freshwater was available to support vegetation growth and probably freshwater obligate fishes until Georges Bank became inundated by rising sea levels. To the north, the Northeastern Banks of NFLD also remained ice free based on evidence from geochronological data (Dalton *et al.* 2023) and probably provided refuge to some salt tolerant and anadromous fishes that dispersed widely from this location (Bernatchez and Dodson 1991, Curry 2007, Curry and Gautreau 2010). However, the occurrence of Lake Whitefish from the "Scotian" lineage or Atlantic Whitefish seems unlikely in either of these refugia.

During glacial retreat beginning 18,000 years before present (BP; Curry 2007), both the Northeastern Grand Banks of NFLD and Georges Bank would have been isolated from NS (Fig 4). Both regions were separated from the MP by significant expanses of cold and seasonally stratified marine waters (de Vernal *et al.* 2000) and partially blocked by significant streams of calving glacial ice (Shaw 2006). Calving glaciers formed ice streams that flowed rapidly seaward from the North American continent during glacial retreat (Shaw 2006). These glaciers extended to the ocean floor in a then shallow sea, and their seaward displacement carved both the Laurentian Channel to the north of NS and the Fundian Channel to the south, sending huge plumes of sediment and ice into continental shelf waters (Shaw 2006, Dalton *et al.* 2020, 2023). To the south of NS, Georges Bank was flooded between 11,000-8,000 years BP during which a shallow sea in the Gulf of Maine began to widen (Grant 1970). Thus, any freshwater obligate fishes on Georges Bank would have had to navigate low salinity surface waters of an otherwise hypersaline ocean to reach the mainland (Curry 2007). The closest landmass would have been the northeastern United States. At this point, and if successful, whitefish would most likely overlap with fishes of the Atlantic Coastal Refugium, but fishes from that refugium probably did not disperse as far as the MP (Curry 2007). Lake Whitefish and in particular the anadromous Atlantic Whitefish are tolerant to salt water (Scott and Crossman 1973), but dispersal from Georges Bank fails to explain why neither is found in the Northeastern United States that would have been far closer and more easily accessible.

The Northeastern Grand Banks most often provides the favoured hypothesis for an eastern Lake Whitefish refugium (Bernatchez and Dodson 1991, Curry 2007, Curry and Gautreau 2010), but is subject to similarly puzzling disjunctions in fish distribution. No whitefish species or freshwater obligate fishes of any type are native to the island of NFLD (Curry 2007), which was not only the closest colonizable landmass, but one with an enormous abundance of suitable lakes. Atlantic Whitefish by comparison only occupy southern NS where Lake Whitefish populations are also numerous. This distribution begs explaining how these species (particularly the Atlantic Whitefish) could have bypassed so much available habitat in both NFLD and NS only to take up residence further south while avoiding lakes draining to the Southern Gulf of St Lawrence. In contrast, Arctic Char (*Salvelinus alpinus,* Linnaeus, 1758) that did originate from the Northeastern Grand Banks refugium occur on NFLD but have not been found in NS (Bernatchez and Dodson 1991, Brunner *et al.* 2001, Salisbury *et al.* 2019). This absence occurs even though Arctic Char would have been the most well adapted to disperse through cold marine waters that abounded during glacial retreat (Scott and Crossman 1973). Notably, some assessments of the Northeastern Banks as a suitable refuge for Lake Whitefish had assumed that the species was introduced to NS and therefore not native to the province (Curry and Gautreau 2010) or had uncertain distribution (Mandrak *et al.* 2023), a conclusion that may have led to overlooked distributional clues.

Following this assessment, a "Scotian" group of Lake Whitefish is perhaps more likely to have survived in proglacial lakes in a Scotian Shelf refugium ahead of the ice front (Shaw 2006; Fig 4). Upon glacial retreat, these lakes would have been transported onto the eastern Maritime coast following the forebulge and topography over which the retreating ice front passed (Dadswell 1974), probably avoiding the need for marine migration. This avenue of colonization would support the exclusive occurrence of Lake Whitefish in the eastern facing watersheds of NS, and the distribution of endemic populations of Atlantic Whitefish on that shore (DFO 2018). The distribution of "Scotian" Lake Whitefish is also identical to that of genetically distinct Lake Trout which occur exclusively in the MP and northern Maine (Warner *et al.* 2023, 2024). Since Lake Trout have the lowest salinity tolerance of the genus Salvelinus (Scott and Crossman 1973), marine colonization routes would have been extremely unlikely for this species, suggesting that it probably also shared the Scotian Shelf refugium with the two NS Coregonid species which would have served as suitable prey in fresh water.

In NB, the "Scotian" lineage of Lake Whitefish also reached river basins spanning from the Saint John River to the St. Croix River (Fig 4). To arrive at these locations, Lake Whitefish likely passed over NS and through the Bay of Fundy as glacial melt water transgressed in proglacial lakes over the land that was depressed approximately 200 m from its present elevation upon glacial retreat (Quinlan and Beaumont 1982, Dalton *et al.* 2023). The Bay of Fundy, which had cleared of ice between 13,000 -12,500 years BP (Fader 2005), initially posed a marine barrier to Lake Whitefish movement. Isostatic rebound then outpaced sea level rise causing the bay to drain between 13,000-9,500 years BP (Grant 1971, Fader *et al.* 1977, Fader 2005), probably initially the bay became a freshwater lake fed by melting ice on the western Fundy shore (Stea and Mott 1998, Shaw *et al.* 2002). Near 11,000 years BP, sea level rise caused the gradual return of marine waters to the bay which would soon provide a pathway for whitefish to enter NB through a rising but still brackish Bay of Fundy (Grant 1970, Shaw 2006). Migrating whitefish would have then met the Saint John River along the NB coastline which formed its present-day southern connection to the Bay of Fundy near 8,000 years BP (Curry 2007).

Near 9,500 years BP, eustatic sea level rise started to rapidly outpace isostatic rebound, and by 7,000 years BP the Bay of Fundy was once again flooded with cold sea water (Fader 2005). Rising sea levels re-established the marine barrier to whitefish migration, once again separating NS and NB while widening of the Gulf of Maine (Grant 1970). Under this timeline, Lake Whitefish which dispersed into the Saint John River near 8,000 years BP would have had approximately 3,000-4,000 years to follow on the heels of the retreating glacial ice in proglacial lakes to arrive in headwater lakes of the upper Saint John River. Proglacial lakes were one of the most effective means of widespread post-glacial dispersal of fishes during the Wisconsin glacial retreat throughout the Holarctic (Segerstråle 1957, Dadswell 1972, Dadswell 1974). Isostatic rebound and dewatering of the land mass from 6,000 years BP to present (Curry 2007) would have provided the mechanism to transport Lake Whitefish to the upper Saint John River and Maine's Allagash Basin (deglaciated between 14,500-11,000 years BP; Borns *et al.* 2004) where they are now found isolated in deep lake basins.

Reflecting further, Atlantic Whitefish were found exclusively in watersheds draining to the Atlantic Ocean but survive only in the Petite Rivière, Lunenburg County (Bradford *et al.* 2004). This restricted distribution is surprising, because the anadromous life cycle and greater adaptation of this species to salt water should have provided more opportunity for it to disperse. Some authors have suggested that the Atlantic Whitefish may have sought refuge in a small deglaciated corner of southern NS (Edge 1987), but there is no data that suggests this hypothesized refuge existed (Dalton *et al.* 2023). Conversely, Atlantic Whitefish probably originated from a similar "Scotian" refugium as did the Lake Whitefish (Curry and Gautreau 2010). In contrast to the eastern origin of other coregonids of the MP, the Round Whitefish in NB arrived from the Mississipian glacial refugium (Morgan *et al.* 2018), once situated in the upper Mississippi valley where most of the freshwater obligate fishes in the MP and central North America originated (Dadswell 1972, Curry 2007, Curry and Gautreau 2010).

Diet

Lake Whitefish diet can vary considerably by lake and in NS has been reported to include Cladocera plankton (Pringle Lake, Guysborough County, NS; Edge 1987), benthic organisms including amphipods, diptera larvae, isopods, sphaeriid clams (Lake George, Annapolis County, and Mira River Cape Breton County NS; Edge 1987), and gastropods (Saint John River; Dadswell 1975). Gilhen (1974) reported that Lake Whitefish are bottom feeders that graze on insect larvae and gastropods while occasionally capturing small fishes, including small Rainbow Smelt (*Osmerus mordax* Mitchill, 1814) when present (J. Wood unpubl. data). All Lake Whitefish captured during winter sampling in East Grand Lake on the Maine/NB border in 2024/25

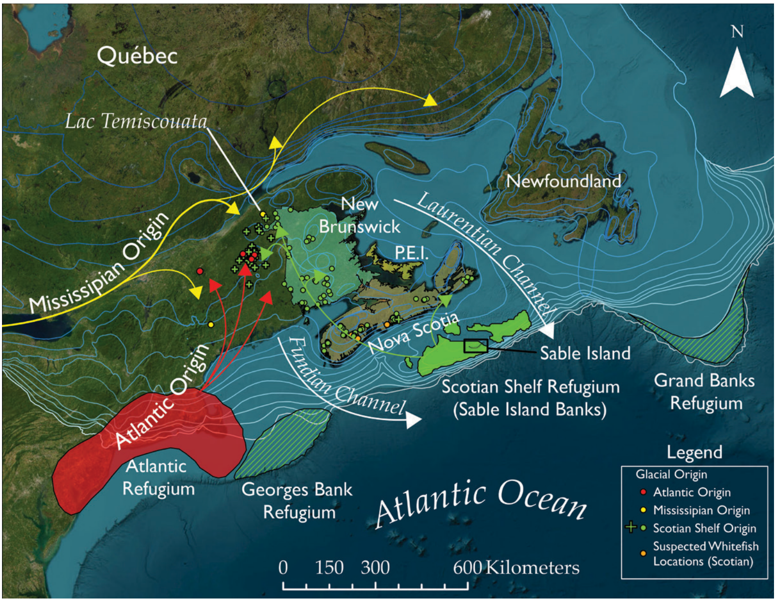


Fig 4 **Map of the optimal 25,000-year (calibrated age before present) ice margin extracted from supplementary files in Dalton** ***et al.*** **(2023) showing the hypothesised ice edge in 1,000-year increments during retreat and the possible glacial refuges hypothesised to have existed in eastern North America during Wisconsin Glaciation. These locations include the Grand Banks and Georges Banks refugia (green hatched polygon), the Scotian Shelf Refugium (Sable Island Banks; solid green polygon) and the Atlantic refugium (red polygon) which was located near modern day Cape Cod and the mouth of the Hudson River. Arrows emanating from the Mississipian Refuge (yellow), Atlantic Refuge (red), and the Scotian Refugium (green) show the hypothesised colonization routes of Lake Whitefish so far identified in the Canadian Maritime Provinces and State of Maine. Round points matching the colours of source refugia indicate documented Lake Whitefish populations with likely or known origin, while suspected populations are marked as orange circles. Dwarf Lake Whitefish likely originating from the Scotian Shelf Refugium are marked as a green "+".**

had juvenile Alewife ~4.5 cm in their stomachs (M. Warner unpubl. data). In NB, Dadswell (1975) reported that adult Lake Whitefish in the Saint John River were benthic carnivores preying largely on gastropods while juveniles are planktivorous until a size of 20 cm. Dadswell (1975) observed the most feeding and highest gut fullness from October-June, suggesting greater feeding in the colder months and found other food items to include amphipods, insect larvae, and fish eggs at this time. Differences in diet and food resource competition are thought to be responsible for divergence in gill raker counts observed across circumpolar Lake Whitefish populations (Loch 1974, Svårdson 1979, Lindsey 1981) and diet evidently varies with prey availability and lake.

Recreational Fishing Regulations

Nova Scotia

Goodchild (2001) reported that there was no catch or retention limit for Lake Whitefish in NS for the 1998 season. From 2002 to present (2025), there appears to be no targeted fishery, yet recreational angling regulations in NS allow a daily bag and possession limit of 8 Lake Whitefish with seasons corresponding to open seasons for recognized sportfish that span from April 1 to Sept 30 (Nova Scotia Anglers Handbook 2025). All lakes are open to summer angling, but Sucker Lake, Lunenburg County, and Pringle Lake, Guysborough County, are the only lakes reported to sustain Lake Whitefish that are open to winter fishing. There is no length restriction applied for retaining Lake Whitefish in NS and the species has been reported as only a minor recreational species in the province (Goodchild 2001). This lack of angler interest combined with limited winter fishing opportunities in NS may have in-part reduced the ability to determine regional Lake Whitefish distribution.

Atlantic Whitefish

Following a federal Species at Risk Act (SARA) listing as endangered in 2003 (Bradford *et al.* 2004; the first species listing under SARA), the Atlantic Whitefish found exclusively in NS has become highly protected within its remaining native range. As a result, no fishing is permitted in Hebb, Minamkeak, or Milipsigate lakes, Lunenburg County. Furthermore, Atlantic Whitefish cannot be targeted or retained by recreational anglers and must be released immediately if captured accidentally (Nova Scotia Anglers Handbook 2025).

New Brunswick

In NB regulations pertaining to "whitefish" do not distinguish between Lake Whitefish and Round Whitefish, and neither species is considered a sportfish. As a result, the recreational fishing season opens in accordance with the designated sportfish seasons in both inland and tidal waters across all recreational fishing areas and closes on Sept 15th. Anglers in NB have a daily bag and possession limit of 8 "whitefish", but within a slot size ranging from 10-70 cm total length. This length limit encompasses the entire adult size range for both whitefish species in the province. The sole exception to these regulations is on boundary waters shared with the State of Maine where fishing is permitted for "whitefish" during both the summer and winter sportfishing seasons during which the daily bag and possession limit is three without length restrictions. NB also supports a recreational fishery for whitefish in waters designated as tidal (i.e., lakes, bays, and portions of tidally influenced inland waters where no sportfishing licence is required). These tidally influenced waters supporting Lake Whitefish are exclusive to the downstream reaches and tributary lakes of the Saint John River. The daily bag and possession limit for whitefish in these designated waters is five whitefish without length limitations (New Brunswick Regulations Summary 2025).

Round Whitefish

No distinction is made between Round Whitefish and Lake Whitefish in NB and this species is included within daily limits and length restrictions of the latter species. There appears to be no fishery for this species anywhere in NB and there are no reports of accidental captures by anglers.

Overlap with Introduced Species

Bolstering Atlantic Salmon (landlocked and anadromous populations) and Brook Trout (*Salvelinus fontinalis* Mitchill, 1815) populations in provincial waters has been the central goal of federal and provincial run hatcheries since their initial establishment in the MP (Whitcher 1876). As interest in the potential of new species introductions to the MP developed, stocking efforts quickly expanded to include the Lake Whitefish (Pope 1879), Lake Trout (Warner *et al.* 2023), Brown Trout (*Salmo trutta* Linnaeus, 1758; Andrews *et al.* 2025), Rainbow Trout (*Oncorhynchus mykiss* Richardson, 1836), Smallmouth Bass (*Micropterus dolomieu* Lacepède, 1802; Leblanc 2010), Chain Pickerel (*Esox niger* Lesueur, 1818; Adams 1873, Mitchell *et al.* 2012), Muskellunge (*Esox musquinongy* Mitchill, 1824; Zelman *et al.* 2023) and, on rare occasions, Rainbow Smelt. Directed releases were conducted in many accessible waters with little information on the ecosystems to which they were introduced or impacts that may result (Warner *et al.* 2023, Andrews *et al.* 2025). It is unlikely that pre-occurrence of any native fishes, particularly the little-known and widely undocumented Coregonids, was considered by hatcheries in early years. Stocking efforts were politically driven by seeking to win public favour by satiating demand for stocked trout and salmon while attempting to create exciting new fisheries or bolster existing ones (Andrew *et al.* 2025). The continued deficit of information on native species distributions and interaction persists across the MP to the present day while stocking efforts continue.

The impacts of stocked trout over Lake Whitefish populations are unknown, but both Lake Whitefish and Atlantic Whitefish have seemingly thrived in systems with low fish diversity and low trout abundance (Edge 1987, Edge and Gilhen 2001, Bradford *et al.* 2015). When surveyed by Edge (1987), Brook Trout were not captured in the lakes of the Petite Rivière with Atlantic Whitefish, nor were they found in any lake of the Mushamush River watershed in NS that seem to support a high number of Lake Whitefish lakes. However, Brook Trout do exist in both the Mushamush and Petite Riviere watershed at low abundance and have been stocked in Fancy Lake in the latter (Edge and Gilhen 2001). An examination of provincial stocking records in NS from 1976-2021 reveals that 25 of the 40 confirmed Lake Whitefish lakes and 14 of the 18 suspected Lake Whitefish lakes (62.5% and 77.7% respectively) have been stocked with at least one species of trout (Brook Trout or Rainbow Trout). Brown Trout may have also arrived naturally to some locations (Andrews *et al.* 2025). Eleven of these whitefish lakes (6 known and 5 suspected) were stocked with Brook Trout as recently as 2021 (Table 9). Among recently stocked locations, Eden Lake, a 223-hectare lake in Pictou County, was stocked with 174,672 Brook Trout from 1976-2021 with unknown effect (Table 9). There is no recent account of Lake Whitefish from this lake, nor were they located in Pringle Lake or Narrow Lake following surveys by NSDFA in 2024. These two locations were planted with 23,941 and 89,426 Brook Trout respectively within the assessed period.

In NB, provincial stocking records maintained from 1976-2023 document similar introductions of Brook Trout in 10 of 40 known and one of two suspected Lake Whitefish habitats (counting the main Saint John River as one location and omitting marine observations; Table 10). Among these locations, Lac Baker was stocked with 185,500 Brook Trout over 28 years with the most recent introduction occurring in 2023 (Table 10). Across reported Lake Whitefish locations, Lake Trout, Brown Trout, landlocked Atlantic Salmon, and Splake (Brook Trout x Lake Trout hybrid) were also introduced. Again, an examination of historic stocking records would likely reveal a much greater number of introductions. The impacts or effects of these introductions are unknown due to a lack of survey in Lake Whitefish supporting waters.

In Maine, the introduction of landlocked Rainbow Smelt has been linked to the broadscale collapse of Lake Whitefish populations (Wood 2016). Where Lake Whitefish population declines have occurred, Wood (2016) notes that recruitment failure can go unnoticed because adults continue to appear common due to their long lifespan (30-45 years). Feeding pelagically, Rainbow Smelt may prey on larval whitefish with the greatest effects reported in small lakes with low habitat complexity (Evans and Loftus 1987, Loftus and Huntsman 1986). Some lines of thought suggest that complex habitats such as those available in East Grand Lake on the border of Maine and NB may serve to protect young whitefish amidst its deep basins and boulder-strewn substrate. Similarly in the Mira River in Cape Breton, NS, Lake Whitefish do not appear to be affected by co-occurrence with smelt (Edge 1987, Goodchild 2001) but smelt in this system may tend towards anadromy rather than remaining in freshwater. Although in some systems food competition between Rainbow Smelt and larval Lake Whitefish may be more impactful than direct predation because introduced smelt are known to transform zooplankton communities (Evans and Loftus 1987). Resilient Lake Whitefish populations may benefit from habitat complexity that offers cover and greater food resources for juvenile whitefish or support more diverse fish communities maintaining possible predator controls on smelt (Whitaker and Wood 2021).

The detrimental effects of Rainbow Smelt on Atlantic Whitefish were apparently learned during an attempt to safeguard the endangered and endemic coregonid in Anderson Lake near Halifax, NS. Here Atlantic Whitefish was introduced to a small and highly protected lake within the confines of a Canadian Forces Base (CFB-Halifax) between 2005-2012 (Bradford *et al.* 2015). Landlocked Rainbow Smelt were identified within the lake prior to stocking Atlantic Whitefish, but at the time young Rainbow Smelt were deemed a beneficial pelagic food source (Bradford *et al.* 2015). After extensive efforts to monitor the introduced population failed, piscivorous Brook Trout and Rainbow Smelt were suggested to have had a negative effect on survival and reproduction (Bradford *et al.* 2015). Efforts to rear Atlantic Whitefish in Anderson Lake were abandoned in 2012 (Bradford *et al.* 2015) and no subsequent attempts have yet been made to introduce the species outside of their remaining native distribution in the Petite Rivière watershed.

Invasive Chain Pickerel and Smallmouth Bass are most prevalent in the lakes of southern NS (Nova Scotia Anglers Handbook 2024; Leblanc 2010, Mitchell *et al.* 2012) and are reported in 21 of the confirmed and nine of the suspected Lake Whitefish lakes in that province (Table 9). These invasives also overlap with the SARA listed Atlantic Whitefish. Smallmouth Bass were first confirmed in Milipsigate Lake in 2000 (LeBlanc 2010) and are now found in all three lakes containing the species (DFO 2024). Chain Pickerel were identified in both Hebb and Milipsigate Lakes in May 2013 (DFO 2018). Because of the overlap of these invasives within the world's last remaining habitats of the Atlantic Whitefish, eradication options such as rotenone application cannot be attempted, and electrofishing must be used to regulate predator populations (DFO 2018).

In NB, Smallmouth Bass are found in 23 of the 40 confirmed Lake Whitefish waters while Chain Pickerel are found in 22 (Table 10). The two suspected whitefish locations are invaded by both species (Table 10). Lake Whitefish in the Saint John River are faced with additional threats from Muskellunge (*Esox masquinongy* Mitchill, 1824) introduced in a headwater lake in the 1970s (Zelman *et al.* 2023) and more recently Largemouth Bass (*Micropterus salmoides* Cuvier, 1828) (Culberson *et al.* in press) which are also found in St. Croix River watershed on the Maine/NB border.

DISCUSSION

The occurrence of Lake Whitefish in the MP is exclusive to watersheds draining to the Atlantic Ocean (Goodchild 2001) apart from single occurrences in Restigouche and Miramichi counties that drain into the Gulf of St. Lawrence. While several authors describe genetically distinct "Scotian" whitefish as originating from a Northeastern Grand Banks Refugium, a more likely origin was perhaps nearer to Sable Island (see Shaw 2006) where numerous endemic terrestrial species persist today (e.g. COSWIC 2014). This pattern of distribution contrasts with many other freshwater obligate species occurring in the MP that likely survived Wisconsin glaciation in either an Atlantic or Mississipian glacial refugium and arrived from the southwest (Fig 4).

Table 9 Summary of Brook Trout (*Salvelinus fontinalis*; BT) and Rainbow Trout (*Oncorhynchus mykiss*; RT) stocking in water bodies where Lake Whitefish (*Coregonus clupeaformis*) are confirmed or suspected in the province of Nova Scotia. Suspected lakes are those directly connected to lakes supporting confirmed population of Lake Whitefish. Provincial stocking years extend from 1976 until present as recorded by the Nova Scotia Department of Inland Fisheries and Aquaculture and correspond to when stocking was taken over by the province of Nova Scotia from the Federal Government, though stocking in many locations occurred long prior to this time and in some locations may have involved other species such as Brown Trout (*Salmo trutta*; see Andrews et al. 2025). Data displayed includes water body name, county, first and last year stocked, number of years stocked, total number stocked and species. The presence of invasive Smallmouth Bass (*Micropterus dolomieu*) and Chain Pickerel (*Esox niger*) in listed lakes is also reported from provincial records.

Water Body Name	County	Status	First Year Stocked	Last Year Stocked	# of Years Stocked	Total Stocked	Species	Smallmouth Bass	Year Reported	Chain Pickerel	Year Reported
Boot Lake	Annapolis	Confirmed	1976	2020	25	53,964	BT	-	-	-	-
Eleven Mile Lake	Annapolis	Confirmed	-	-	-	-	-	-	-	-	-
Fisher Lake	Annapolis	Suspected	1976	1978	3	3,263	BT	-	-	-	-
Geier Lake	Annapolis	Suspected	-	-	-	-	-	-	-	-	-
Liverpool Head Lake	Annapolis	Confirmed	-	-	-	-	-	-	-	-	-
Milford (Pits/Pitts) Lake	Annapolis	Confirmed	1977	2012	3	2,801	BT	-	-	-	-
Grand Lake	Cape Breton	Confirmed	1977	2021	19	50,500	BT, RT	-	-	-	-
Hardy Lake	Cape Breton	Confirmed	1976	1976	1	996	BT	-	-	-	-
MacIntyres Lake	Cape Breton	Confirmed	1983	2018	12	29,031	BT	-	-	-	-
MacLeods Lake	Cape Breton	Confirmed	2013	2013	1	900	BT	-	-	-	-
Mira River	Cape Breton	Confirmed	-	-	-	-	-	-	-	-	-
Salmon River	Cape Breton	Confirmed	2009	2009	1	3,840	BT	-	-	-	-
Eight Island Lake	Guysborough	Suspected	2018	2018	1	2,333	BT	-	-	-	-
G Lake	Guysborough	Confirmed	-	-	-	-	-	-	-	-	-

Narrow Lake	Guysborough	Confirmed	1977	2021	25	89,426	BT	-	-	-	-
Pringle Lake	Guysborough	Confirmed	1976	2021	11	23,941	BT	-	-	-	-
Big Shaw Lake	Halifax	Confirmed	-	-	-	-	-	-	-	-	-
Chezzetcook Lake	Halifax	Confirmed	1981	2008	6	11,672	BT	Present	2012	-	-
Conrod Lake	Halifax	Confirmed	1979	2017	33	146,933	BT	Present	2012	-	-
Gibraltar Lake	Halifax	Confirmed	-	-	-	-	-	-	-	-	-
Long Bridge Lake	Halifax	Suspected	1979	2017	29	101,513	BT	Present	2012	-	-
Moose Lake	Halifax	Suspected	-	-	-	-	-	-	-	-	-
Morris Lake	Halifax	Suspected	1987	2021	18	31,491	BT	Present	1975	Present	2000
Petepeswick Lake	Halifax	Suspected	1981	2017	26	78,855	BT	Present	2012	-	-
Paces Lake	Halifax	Suspected	1984	2019	27	103,208	BT	-	-	-	-
Scots Lake/ Scots Pond	Halifax	Confirmed	1998	2019	15	39,877	BT	-	-	-	-
Thompson Lake	Halifax	Suspected	1993	1996	3	1,483	BT	-	-	-	-
Big Mushamush Lake	Lunenburg	Confirmed	1976	1977	2	1,199	BT	Present	1994	-	-
Caribou Lake	Lunenburg	Confirmed	1976	2013	23	130,611	BT	Present	2005	-	-
Little Mushamush Lake	Lunenburg	Confirmed	1976	2012	20	83,887	BT	Present	1999	-	-
Millet Lake	Lunenburg	Confirmed	1976	2021	9	6.950	BT	-	-	-	-
Shingle Lake	Lunenburg	Confirmed	-	-	-	-	-	Present	1995	-	-
Sucker Lake	Lunenburg	Confirmed	1990	2021	31	132,528	BT, RT	Present	1996	-	-
West Whale Lake	Lunenburg	Suspected	-	-	-	-	-	-	-	-	-
Whale Lake*	Lunenburg	Suspected	-	-	-	-	-	-	-	-	-
Eden Lake	Pictou	Confirmed	1976	2021	42	174,672	BT	-	-	-	-
Annis Lake	Queens	Confirmed	1976	2001	19	82,842	BT	Present	2001	-	-
Beavertail Basin	Queens	Suspected	1984	1999	8	43,101	BT	Present	2001	-	-

Table 9 Cont'd

Water Body Name	County	Status	First Year Stocked	Last Year Stocked	# of Years Stocked	Total Stocked	Species	Smallmouth Bass	Year Reported	Chain Pickerel	Year Reported
Beavertail Lake	Queens	Suspected	1984	1999	8	See Beavertail Basin	BT	Present	2001	-	-
Cameron / Beartrap lakes	Queens	Suspected	1976	2021	12	See Ponhook	BT	Present	1995	-	-
Cobrielle (Cobrielle) Lake	Queens	Confirmed (Winter)	-	-	-	-	-	-	-	Present	2023
Kejimkujik Lake	Queens	Confirmed	-	-	-	-	-	-	-	Present	2018
Little Ponhook Lake	Queens	Confirmed	1977	2016	19	38,144	BT	Present	2001	-	-
Minard Lake	Queens	Confirmed	1976	1977	2	883	BT	-	-	-	-
Mountain Lake	Queens	Confirmed	-	-	-	-	-	-	-	Present	2023
Molega Lake	Queens	Suspected (Winter)	1976	2021	14	75,335	BT	Yes	2001	-	-
Peskowesk Lake	Queens	Confirmed	-	-	-	-	-	-	-	Present	2018
Ponhook Lake	Queens	Suspected	1976	2021	12	20,320	BT	Yes	1995	-	-
Salters Lake	Queens	Suspected	1984	1984	1	1,001	BT	-	-	-	-
St. Mary Bay (Ponhook Lake)	Queens	Suspected	1976	2021	12	See Ponhook	BT	Yes	1995	-	-
Carleton River	Yarmouth	Confirmed	-	-	-	-	-	Yes	1994	-	-
Kempt Back Lake	Yarmouth	Confirmed	1976	1998	9	49,225	BT	Yes	1998	-	-
Lake George	Yarmouth	Confirmed	-	-	-	-	-	Yes	2001	-	-
Mink Lake	Yarmouth	Confirmed	1976	2009	22	48,993	BT	Yes	1994	-	-
Ogden Lake	Yarmouth	Confirmed	1976	1995	9	9,999	BT	Yes	1989	-	-
Parr Lake	Yarmouth	Confirmed	1976	1977	2	1,853	BT	Yes	1989	-	-

Petes Lake	Yarmouth	Confirmed	-	-	-	-	-	Yes	1989	-	-
Porcupine Lake	Yarmouth	Confirmed	-	-	-	-	-	-	-	Present	1977

MacIntyres Lake: Rainbow Trout stocking constitutes 2,544 of the total number of trout introduced.
Sucker Lake: Rainbow Trout stocking constitutes 117,804 of the total number of trout introduced.

Table 10 **Summary of Brook Trout (*Salvelinus fontinalis*; BT) stocking in water bodies where Lake Whitefish (*Coregonus clupeaformis*) are confirmed or suspected in the province of New Brunswick. Brook Trout stocking in many locations was initiated by the Department of Marine and Fisheries in the late 1800s, but only stocking conducted by the province from 1976 – 2024 and recoded by the New Brunswick Department of Natural Resources and Energy Development is reported. Stocking in many locations occurred long prior to this time and in some locations may have involved other species such as Brown Trout (*Salmo trutta*; see Andrews et al. 2025). Displayed data includes water body name, county, first and last year stocked, number of years stocked, total number stocked and species. No Rainbow Trout (*Oncorhynchus mykiss*) were documented to have been stocked in these waterbodies during the listed period, however, escaped Rainbow Trout now occur and reproduce in the Mactaquac and Beechwood headpond. Splake, a hybrid between a Brook Trout and Lake Trout (*Salvelinus namaycush*) and Brook Trout x Arctic Char (*Salvelinus alpinus*) were stocked in Grand Lake, Queens County and both Oromocto Lake and Grand Lake Queens County have also been supplemented with Landlocked Salmon.**

Lake Name	County	Status	First Year Stocked	Last Year Stocked	# of Years Stocked	Total Stocked	Species	Chain Pickerel	Smallmouth Bass
Beechwood Dam	Carleton	Confirmed	-	-	-	-	-	Present	Present
Beechwood Headpond	Carleton	Confirmed	-	-	-	-	-	Present	Present
Black's Harbour	Charlotte	Confirmed	-	-	-	-	-	-	-
Digdeguash Lake	Charlotte	Confirmed	-	-	-	-	-	Present	Present
Kerr(s) Lake	Charlotte	Confirmed	-	-	-	-	-	-	-
Darling's Lake	Kings	Confirmed	-	-	-	-	-	Present	Present
Nerepis River	Kings	Confirmed	-	-	-	-	-	Present	Present
Saint John River	Kings	Confirmed	-	-	-	-	-	Present	Present
Sherwood Lake	Kings	Confirmed	-	-	-	-	-	-	-
Beau Lake	Madawaska/ Province of Québec	Confirmed	-	-	-	-	-	-	-
First (Green) Lake	Madawaska	Confirmed	1976	2001	15	50,648	Brook Trout	-	-
Glazier Lake	Madawaska	Confirmed	1987	2007	4	8,850	Brook Trout	-	In watershed

Green River (Davis Mill)	Madawaska	Confirmed	-	-	-	-	-	-	In watershed
Lac Baker (Baker Lake)	Madawaska	Confirmed	1979	2024	29	188,400	Brook Trout	-	In watershed
Madawaska River	Madawaska	Confirmed	-	-	-	-	-	-	-
Second Falls Head Pond (Green River Reservoir)	Madawaska	Confirmed	-	-	-	-	-	-	-
Third (Green) Lake	Madawaska	Confirmed	1987	2003	6	13,836	Brook Trout	-	-
Logan Lake	Northumberland	Confirmed	-	-	-	-	-	-	-
Serpentine Lake	Northumberland	Confirmed	1980	2015	19	133,866	Brook Trout	-	-
Belleisle Bay	Queens	Confirmed	-	-	-	-	-	Present	Present
Grand Lake (Saint John River)	Queens	Confirmed	1977	1989	4	37,113	Brook Trout	Present	Present
Maquapit Lake	Queens	Confirmed	-	-	-	-	-	Present	Present
Saint John River	Queens	Confirmed	-	-	-	-	-	Present	Present
Salmon River	Queens	Confirmed	-	-	-	-	-	Present	Present
Washademoak Lake	Queens	Confirmed	-	-	-	-	-	Present	Present
McDougall Lake	Restigouche	Confirmed	2000	2024	19	40,835	Brook Trout	-	-
Saint John River	Saint John	Confirmed	-	-	-	-	-	Present	Present
West Branch Reservoir (Halls Lake)*	Saint John	Suspected	1976	1980	5	21,351	Brook Trout	Present	Present
West Branch (Musquash) Reservoir (South)	Saint John	Confirmed	-	-	-	-	-	Present	Present
Saint John River	Sunbury	Confirmed	-	-	-	-	-	Present	Present
Long Lake	Victoria	Confirmed	-	-	-	-	-	-	-

Table 10 Cont'd

Lake Name	County	Status	First Year Stocked	Last Year Stocked	# of Years Stocked	Total Stocked	Species	Chain Pickerel	Smallmouth Bass
Tobique River Lakes (undefined)	Victoria	Confirmed	-	-	-	-	-	-	-
Tobique River Reservoir	Victoria	Confirmed	-	-		-	-	-	Present
Trousers Lake	Victoria	Confirmed	1976	2000	12	32,323	Brook Trout	-	-
East Grand Lake	York	Confirmed	-	-	-	-	-	Present	Present
Mactaquac Dam	York	Confirmed	-	-	-	-	-	Present	Present
Mactaquac Headpond	York	Confirmed	1978	1990	10	53,068	Brook Trout	Present	Present
Oromocto Lake	York	Confirmed	1976	1978	3	24,755	Brook Trout	Present	Present
Oromocto River Mouth	York	Confirmed	-	-	-	-	-	Present	Present
Palfrey Lake*	York	Suspected	-	-	-	-	-	Present	Present
Spednic Lake	York	Confirmed	-	-	-	-	-	Present	Present
Wauklahegan Lake	York	Confirmed	-	-	-	-	-	Present	Present

The precise identity of the "Tobique River Lakes" is not defined but likely include Trousers Lake, Long Lake, and Serpentine Lake
Lake Name* Lakes directly connected to water where Lake Whitefish are verified, having a high likelihood of also containing Lake Whitefish

Within the distinctly eastern distribution of the "Scotian" Lake Whitefish, populations have been steadily discovered since initial observations were made in Kejimkujik Lake by Veilleux (1964), and several more populations are likely to exist regionally. This is particularly true in NS where Lake Whitefish have never been a priority species for sport fisheries or research. Lakes supporting known Lake Whitefish populations are often nestled in un-surveyed and interconnected lake chains that could easily host several additional populations (Table 5). For example, Lake Whitefish were only discovered in Conrod Lake, Halifax County by the NSDFA in 2017 (Fig 5), but this lake is directly connected to Chezzetcook Lake where Whitefish were confirmed in 1974 (Alexander *et al.* 1986; Table 5). Lake Whitefish presence in adjacent waters including Thompson, Petepeswick, and Long Bridge lakes is likely (Table 5), as are several more in the unsurveyed lakes of Guysborough County. Even though many of these lakes are developed, it is not uncommon for Lake Whitefish to evade detection (Edge and Gilhen 2001) due to their adherence to deep lake basins, a brief winter spawning period, and a diet of plankton and benthic macroinvertebrates minimizing the chance for incidental capture by anglers. In Kerr Lake, NB, Smith (1952) noted that Lake Whitefish had avoided detection by local anglers for years, and it was not until a suitably sized gill net was deployed at appropriate lake depths that individuals of the species were captured. The lesser extent of eastern facing watersheds in NB may leave fewer regions to investigate, though lakes between the Saint John and Saint Croix River watersheds, particularly the Lepreau and Magaguadavic drainages are potential candidates for future sampling.

The repeated discovery of new Lake Whitefish populations, particularly in NS, has not resulted in the species becoming more well studied. Since distinctions were made between the Lake Whitefish and the Atlantic Whitefish by Scott (1967) and the general question of Lake Whitefish origin in the MP was addressed, research interest has stagnated. Anglers in NS are generally unaware of the occurrence of Lake Whitefish in the province, and both research and public interest in NB (apart from lakes along the Maine border) remains similarly sparse. Once abundant populations in the Saint John River appear to have declined dramatically as evidenced by plummeting captures at the Mactaquac and Beechwood dams (Table 7). Lake Whitefish could also be extirpated from the Mactaquac Headpond following

Fig 5 **Photo of a Lake Whitefish (36.2 cm Fork Length) captured in Conrod Lake, Halifax County, Nova Scotia on 23 August 2017. The photographed specimen was the only individual captured and was taken in a 5 cm square mesh gill net set on the bottom along a slope extending from 9-15 m deep during an overnight set. Bottom temperature along this depth range was 6.4-11.0°C. A thermocline was measured at 14 m and dissolved oxygen below the thermocline was 9.46-8.79 mg/l from 14-29.5 m; pH ranged from 4.90-5.0. The maximum depth of Conrod Lake was 29.6 m where water temperature was recorded as 5.4°C (NSDFA, unpubl. data).**

obstruction of upstream passage by the Mactaquac Dam and flooding of potential spawning habitat, but this was never assessed prior to or following construction of the Mactaquac Dam. Spawning runs by Lake Whitefish in the lower Saint John River may also be highly reduced, but the extent of any declines or even their continued occurrence have not been investigated. Following initial surveys in the MP, no Lake Whitefish-specific assessments have been completed, perhaps with the sole exception of border lakes which include East Grand Lake of the St. Croix River drainage and Beau and Glazier lakes of the Saint John River that have received periodic assessment by the State of Maine (Whitaker and Wood 2021).

At present, data regarding the persistence or abundance of Lake Whitefish in the MP is unavailable in nearly all locations. While retention limits have generally remained high, angler interest in Lake Whitefish is low, and perhaps due to lack of interest alone retention could be deemed inconsequential. Low angler retention in the MP might only provide superficial relief to Lake Whitefish populations while threats unrelated to harvest could be more critical to long term population survival. Introductions of native and non-native fishes have re-shuffled species distributions and unknowingly superimposed new competitors and predators over pre-existing Lake Whitefish populations with unknown consequences. Edge (1984) relates that the effects of Brook Trout introductions on Atlantic Whitefish populations are also unknown, but the former could be a detrimental competitor throughout the MP due to the magnitude and scope of the stocking effort.

Similarly, Warner (1965) reported that in the NB-adjacent waters of Maine, Lake Whitefish suffered from the introduction of landlocked Atlantic Salmon and Rainbow Smelt. The State of Maine has raised serious concerns regarding the decline and disappearance of many of its Lake Whitefish populations, drawing links to the re-distribution of otherwise native fishes such as Rainbow Smelt (Whitaker and Wood 2021). Until competitive interactions between native Lake Whitefish and introduced but otherwise native species are confirmed and quantified, stocking any species over known Lake Whitefish populations should be considered with utmost caution or avoided entirely. Simultaneously, warmwater invasive species continue to spread through waters of the MP. Lake Whitefish are susceptible to predation like other soft rayed Maritime species, but the tendency for Lake Whitefish to occupy cold bathypelagic waters and potentially reach an adult size refuge (Whitaker and Wood 2001) may somewhat prolong their persistence in invaded systems. As warmwater invaders spread, Lake Whitefish may someday remain as Nova Scotia's only native cold-water lacustrine species.

Dams have been noted as an impediment to the recovery of the anadromous Atlantic Whitefish in the Petite Rivière watershed, NS (DFO 2006, 2018, COSEWIC 2010). Regarding Lake Whitefish, impoundments could provide a trade-off by increasing the volume of available cold-water refuge in exchange for impacting the integrity of shallow spawning habitat. Lake Whitefish persist in Conrod Lake, NS despite the presence of a small dam and fishway that inevitably increased water levels within the lake. However, there is no documented need for passage by Lake Whitefish at this location. Large runs of Lake Whitefish seemingly vanished along with their spawning habitats in the Saint John River, but it is unreported if other dams such as the Madawaska Dam or the Tobique Narrows Dam (Huntsman 1953) had similar effect upstream. Spawning runs in unimpeded tributaries of the Saint John River such as Salmon and Nerepis Rivers must now bypass lumber processing and historical mining operations, but no recent surveys indicate if these spawning migrations persist.

Much study is needed to determine not only the state and conservation status of Lake Whitefish in all MP waters, but first and foremost, to determine simply whether many of the populations described in this review can still be found at all.

This is the first review to compile a complete list of historical Lake Whitefish stocking locations, known and suspected Lake Whitefish lakes, and provide details on overlap between Lake Whitefish, stocked trout, and other prevalent invasive species in the MP. Following this compilation of data and identification of the gaps therein, we can conclude that examinations of Lake Whitefish populations and their continued occurrence region wide are greatly needed. Lake Whitefish populations are disappearing across Maine adjacent to our study area, prompting actions outlined in a 2001 management plan and updated in a 2016 status assessment (Wood 2016). Such actions are not possible in the MP where data on Lake Whitefish populations are not available. Many locations such as Kejimkujik Lake, NS are now on the invasion front for Chain Pickerel, and while all other native species have been carefully monitored by park staff and university researchers during an ensuing and precipitous post-invasion decline (Boyachek 2024), Lake Whitefish in Kejimkujik National Park have remained completely unassessed since the formation of the park. Once Lake Whitefish are gone from park waters, no data will be available apart from perhaps scales remaining in lake sediment cores that could be used to genetically determine whether the species was native to the park to inform restocking if such an option exists in the future. The intent of this review is to provide baseline data and background information necessary to inform future studies of Lake Whitefish in NS and NB. Nationally, this species is identified as a distinct group in the MP found nowhere else in North America, while regionally this species is worth studying and protecting as it forms a distinct component of the region's small but unique cold-water fish assemblage.

Future Questions

1. Do undescribed Lake Whitefish populations still occur in Nova Scotia and/or New Brunswick? Several un-surveyed lakes exist that have direct connections with those supporting confirmed populations. Some of these suspected lakes are listed in Table 5, but this list is unlikely exhaustive. Other populations may exist in lakes of Atlantic-facing watersheds in both provinces, particularly in Guysborough County, NS.

2. What is the origin of Lake Whitefish in Kejimkujik National Park? Stocking in this location was noted by Kerekes (1975) and Edge (1987), but no explanation exists as to why introductions may have been successful in this region and nowhere else in the MP. If Lake Whitefish within the park are native, they will be important to describe before these populations are potentially lost to invasive Chain Pickerel.
3. Do Lake Whitefish persist in all lakes identified in this review (Table 2, 5)? Invasive species, stocking of native species, hydroelectric dams, reduced water quality, warming and acidification of surface waters have broadly impacted lakes and rivers of the MP with unknown consequences for Lake Whitefish.
4. Do any stocked Lake Whitefish populations with genetics from the Detroit River persist in NS? Minard Lake near Kejimkujik National Park might be a key candidate for investigation.
5. How has the introduction of hatchery-reared Brook Trout, Brown Trout, and Rainbow Trout impacted Lake Whitefish populations in the Maritime Provinces?
6. Apart from border waters where retention limits have been amended, is a daily bag and possession limit of 8 whitefish sustainable now or if fisheries develop in NS and NB?
7. How do Lake Whitefish in the lower Saint John River use the estuary? And are they a truly anadromous population as suggested by captures in both the Saint John Harbour and at Black's Harbour, New Brunswick?
8. How do Lake Whitefish in the Mira River, NS, use the estuary? And like those in the Saint John River, are they a salt-tolerant anadromous population?
9. Where do Lake Whitefish in any Maritime population spawn, and what considerations must be met to protect those spawning habitats if needed?
10. Do the Lake Whitefish which occur in McDougall and Logan Lakes of the Restigouche and Miramichi River watersheds, NB, originate from the Atlantic glacial refugium?

REFERENCES

Adams, A.L. (1873). Field and forest rambles, with notes and observations of the natural history of eastern Canada. Henry S. King and Co., London, UK. 333 p. archive.org/details/fieldforestrambl00adam_0

Alexander, D.R., Kerekes, J.J. & Sabean, B.C. (1986). Description of selected lake characteristics and occurrence of fish species in 781 Nova Scotia lakes. *Proceedings of the Nova Scotian Institute of Science* 36(2): 63-106. dalspace.library.dal.ca/items/2c95cfab-69cf-4a87-98d6-292c43324495

Andrews, S.N., Linnansaari, T., Curry, R.A., LeBlanc, N.M & Pavey, S.A. (2020). Winter ecology of striped Bass (Morone saxatilis) near its northern limit of distribution in the Saint John River, NB. *Environmental Biology of Fishes* 103: 1343-1358. link.springer.com/article/10.1007/s10641-020-01027-x

Andrews, S.N., Colton, K.J., Bateman, E.M.T., MacMillan, J.L., Buhariwalla, C.F., Collet, K., Greer, A., McFarlane, R. & Stokesbury, M.J.W. (2025). The history and distribution of Brown Trout Salmo *trutta Linnaeus*, 1758 in Nova Scotia, New Brunswick, and Prince Edward Island. *Northeastern Naturalist* 32(Monograph 26): 1-90. www.eaglehill.us/NENAonline/articles/NENA-mon-26/mon-26-Andrews.shtml

Beaumaster, R., Chateauvert, A., Anderson, L., Linnansaari, T. & Jones, R.A. (2020). Counts of fish captured from upstream fish passage facilities at Beechwood and Tobique Dams, New Brunswick, 1990-2019. Canadian Data Report of Fisheries and Aquatic Science 1328: iii + 23 p. publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2020/mpo-dfo/Fs97-13-1328-eng.pdf

Bernatchez, L. (1995). A role for molecular systematics in defining evolutionary significant units in fishes. In Evolution and the aquatic ecosystem: defining unique units in population conservation. Edited by J.L. Nielsen and D.A. Powers. *American Fisheries Society Symposium* 17: 114-132. fisheries.org/bookstore/all-titles/afs-symposia/x54017xm/

Bernatchez, L. & Dodson, J.J. (1990). Allopatric origin of sympatric populations of Lake Whitefish (*Coregonus clupeaformis*) as revealed by mitochondrial-DNA restriction analysis. *Evolution* 44(5): 1263-1271. www.jstor.org/stable/2409287

Bernatchez, L. & Dodson, J.J. (1991). Phylogeographic structure in mitochondrial DNA of the Lake Whitefish (*Coregonus clupeaformis*) and its relation to pleistocene glaciations. *Evolution* 45(4): 1016-1033. www.jstor.org/stable/2409706

Bernatchez, L. & Dodson, J.J. (1994). Phylogenetic relationships among palearctic and nearctic whitefish (*Coregonus* sp.) populations as revealed by mitochondrial DNA variation. *Canadian Journal of Fisheries and Aquatic Sciences* 51(Suppl. 1): 240-251. cdnsciencepub.com/doi/10.1139/f94-310

Bernatchez, L., Vuorinen, J.A., Bodaly, R.A Dodson, J.J. (1996). Genetic evidence for reproductive isolation and multiple origins of sympatric trophic ecotypes of whitefish (*Coregonus*). *Evolution* 50(2): 624-636. academic.oup.com/evolut/article-abstract/50/2/624/6870801?redirectedFrom=fulltext&login=false

Bernatchez, L., Renault, S., Whiteley, A.R., Derome, N., Jeukens, J., Landry, L., Lu, G., Nolte, A.W., Østbye, K., Rogers, S.M. & St-Cyr, J. (2010). On the origin of species: insights from the ecological genomics of Lake Whitefish. *Philosophical Transactions of the Royal Society of London*. Series B, *Biological Sciences* 365(1547): 1783-1800. pmc.ncbi.nlm.nih.gov/articles/PMC2871888/

Bernatchez, l. & Wilson, C.C. (1998). Comparative phylogeography of Nearctic and Palearctic fishes. *Molecular Ecology* 7(4): 431-452. www2.bio.ulaval.ca/louisbernatchez/pdf/(046)%20Bernatchez_Molecular_Ecology_98.pdf

Bodaly, R.A., Clayton, J.W., Lindsey, C.C. & Vuorinen, J. (1992). Evolution of Lake Whitefish (*Coregonus clupeaformis*) in North America during the Pleiostocene: genetic differentiation between sympatric populations. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 769-779. cdnsciencepub.com/doi/10.1139/f92-086

Borns, H.W, Jr., Doner, L.A., Dorion, C.C., Jacobson, J.L, Jr., Kaplan, M.R., Kreutz, K.J., Lowell, T.V., Thompson, W.B. & Weddle, T.K. (2004). The Deglaciation of Maine, USA. Earth Science Faculty Scholarship. 276. digitalcommons.library.umaine.edu/ers_facpub/276/

Boyachek, S. (2024). Invasive Chain Pickerel in Kejimkujik National Park and National Historic Site: population description, effects on native fish assemblages, and spawning timing. M.Sc. Thesis, Acadia University, Wolfville, NS. 150 p. scholar.acadiau.ca/node/4388

Bradford, R.G. & Mahaney, C.M.B. (2004). Distribution of Lake Whitefish (*Coregonus clupeaformis*) fry from the lower Great Lakes Federal Hatcheries to elsewhere in Canada and beyond (Years 1878-1914). Canadian Data Report of Fisheries and Aquatic Sciences No. 1149. Department of fisheries and Oceans, Bedford Institute of Oceanography, Dartmouth, NS. publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2007/dfo-mpo/Fs97-13-1149E.pdf

Bradford, R.G., Longard, D.A. & Longue, P. (2004). Status, trend, and recovery considerations in support of an allowable harm assessment for Atlantic Whitefish (*Coregonus huntsmani*). Canadian Science Advisory Secretariat Research Document 2004/109. www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/2004/2004_109-eng.htm

Bradford, R.G., Themelis, D., LeBlanc, P., Campbell, D.M., O'Neil, S.F. & Whitelaw, J. (2015). Atlantic Whitefish (*Coregonus hunstmani*) stocking in Anderson Lake, Nova Scotia. Canadian Technical Report of Fisheries and Aquatic Sciences 3142. publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2015/mpo-dfo/Fs97-6-3142-eng.pdf

Brunner, P.C., Douglas, M.R., Osinov, A., Wilson, C.C. & Bernatchez, L. (2001). Holarctic phylogeography of Arctic Charr (*Salvelinus Alpinus* L.) inferred from mitochondrial DNA sequences. *Evolution* 55(3): 573-586. onlinelibrary.wiley.com/doi/abs/10.1111/j.0014-3820.2001.tb00790.x

Carter, J.C.H. & Dadswell, M.J. (1983). Seasonal and spatial distribution of planktonic crustacea in the lower Saint John River, a multibasin estuary in New Brunswick, Canada. *Estuaries* 6(2): 142-153. www.jstor.org/stable/1351704

Catling, P.M., Freedman, B. & Lucas, Z. (1985). Vegetation and phytogeography of Sable Island, Nova Scotia. *Proceedings of the Nova Scotian Institute of Science* 24: 181-248. www.biodiversitylibrary.org/part/356581

Clair, T.A., Dennis, I.F., Scruton, D.A. & Gilliss, M. (2007). Freshwater acidification research in Atlantic Canada: a review of results and predictions for the future. *Environmental Reviews* 15: 153-167. cdnsciencepub.com/doi/abs/10.1139/A07-004

COSEWIC. (2008). Designatable units at an appropriate scale for the Lake Whitefish *Coregonus clupeaformis* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. X + 64 p. cosewic.ca/images/cosewic/pdf/Lake_Whitefish_Special_Report_2008_e.pdf

COSEWIC. (2010). COSEWIC assessment and status report on the Atlantic Whitefish *Coregonus huntsmani* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. X +31 p. publications.gc.ca/site/eng/392011/publication.html

COSEWIC. (2014). COSEWIC assessment and status report on the Sable Island Sweat Bee *Lasioglossum sablense* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON. ix + 38 p. publications.gc.ca/site/eng/9.557220/publication.html

COSEWIC. (2022). COSEWIC Rapid review of classification on the Atlantic Whitefish *Coregonus huntsmani* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, ON. xiii p. www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/cosewic-assessments-status-reports/rroc-atlantic-whitefish-2022.html

Costigan, J. (1895). Twenty-Seventh Annual Report of the Department of Marine and Fisheries 1894. Printed by Order of Parliament by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Costigan, J. (1896). Twenty-Eight Annual Report of the Department of Marine and Fisheries 1895. Printed by Order of Parliament by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Cox, P. (1893). Observations on the distribution and habits of some New Brunswick fishes. *Bulletin of the Natural History Association of New Brunswick* 11: 33-42.

Cox, P. (1896a). Catalogue of the marine and freshwater fishes of New Brunswick. *Bulletin of the Natural History Society of New Brunswick* 13: 62-75.

Cox, P. (1896b). History and present state of ichthyology of New Brunswick. *Bulletin of the Natural History Society of New Brunswick* 13: 62-75.

Culberson, A.E., Nakamoto, B., Lento, J., Curry, R.A. & Harrison, P.M. (2024). New bass on the block: Trophic interactions among invasive largemouth bass *Micropterus salmoides* and local sportfish. *Journal of Fish Biology* 106(3): 784-796.
onlinelibrary.wiley.com/doi/10.1111/jfb.15997

Curry, R.A. (2007). Late glacial impacts on dispersal and colonization of Atlantic Canada and Maine by Freshwater fishes. *Quaternary Research* 67: 225-233.
www.sciencedirect.com/science/article/abs/pii/S0033589406001530

Curry, R.A. & Gautreau, M.D. (2010). Freshwater fishes of the Atlantic Maritime Ecozone. *In* Assessment of Species Diversity in the Atlantic Maritime Ecozone. Edited by D.F. McAlpine and I.M. Smith. NRC Research Press, Ottawa, ON. p. 599-612.

Dadswell, M.J. (1972). Postglacial dispersal of four deepwater fishes on the basis of new distribution records in eastern Ontario and Western Quebec. *Journal of the Fisheries Research Board of Canada* 29: 545-553.
cdnsciencepub.com/doi/10.1139/f72-091

Dadswell, M.J. (1974). Distribution, ecology, and postglacial dispersal of certain crustaceans and fishes in eastern North America. National Museum of Natural Sciences Publications in Zoology, No. 11. National Museum of Canada, Ottawa, ON. 117 p.
www.collectionscanada.gc.ca/obj/s4/f2/dsk3/ftp04/MQ58330.pdf

Dadswell, M.J. (1976). Notes on the biology and resource potential of whitefish in the St. John estuary. In: Baseline Survey and Living Resource Potential Study of the Saint John River Estuary, Volume III Fish and Fisheries. The Huntsman Marine Laboratory, St. Andrews, NB.

Dalton, A.S., Margold, M., Stokes, C.R., Tarasov, L., Dyke, A.S., Adams, R.S., Allard, S., Arends, H.E., Atkinson, N., Attig, J.W., Barnett, P.J., Barnett, R.L., Batterson, M., Bernatchez, P., Borns, H.W., Breckenridge, A., Briner, J.P., Brouard, E., Campbell, J.E., Carlson, A.E., Clague, J.J., Curry, B.B., Daigneault, R.A., Dubé-Loubert, H., Easterbrook, D.J., Franzi, D.A., Friedrich, H.G., Funder, S., Gauthier, M.S., Gowan, A.S., Harris, K.L., Hétu, B., Hooyer, T.S., Jennings, C.E., Johnson, M.D., Kehew, A.E., Kelley, S.E., Kerr, D., King, E.l., Kjeldsen, K.K., Knaeble, A.R., Lajeunesse, P., Lakeman, T.R., Lamothe, M., Larson, P., Lavoie, M., Loope, H.M., Lowell, T.V., Lusardi, B.A., Manz, L., McMartin, I., Nixon, F.C., Occhietti, S., Parkhill, M.A., Piper, D.J.W., Pronk, A.G., Richard, P.J.H., Ridge, J.C., Ross, M., Roy, M., Seaman, A., Shaw, J., Stea, R.R., Teller,

J.T., Thompson, W.B., Thorleifson, L.H., Utting, D.J., Veillette, J.J., Ward, B.C., Weddle, T.K. & Wright, H.E. & 70 co-authors. (2020). An updated radiocarbon-based ice margin chronology for the last deglaciation of the North American ice sheet complex. *Quaternary Science Reviews* 234: 106223.
www.sciencedirect.com/science/article/abs/pii/S0277379119307619

Dalton, A.S., Dulfer, H.E., Margold, M., Heyman, J., Clague, J.J., Froese, D.G., Gautier, M.S., Hughes, A.L.C., Jennings, C.E., Norris, S.L. & Stoker, B.J. (2023). Deglaciation of the North American ice sheet complex in calendar years based on a comprehensive database of chronological data: NADI-1. *Quaternary Science Reviews* 321 (2023). 108345. www.scopus.com/record/display.uri?eid=2-s2.0-85176235571&origin=inward&txGid=a04e3205f0e4bc6751c4d54e808e8dbe

Davies, L.H. (1896). Twenty-Ninth Annual Report of the Department of Marine and Fisheries 1896. Printed by Order of Parliament by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Davies, L.H. (1897). Thirtieth Annual Report of the Department of Marine and Fisheries 1897. Printed by Order of Parliament, by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Davies, L.H. (1898). Thirty-First Annual Report of the Department of Marine and Fisheries 1898. Printed by Order of Parliament, by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Davies, L.H. (1900). Thirty-Second Annual Report of the Department of Marine and Fisheries 1899. Printed by Order of Parliament by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Davies, L.H. (1901). Thirty-Third Annual Report of the Department of Marine and Fisheries 1900. Printed by Order of Parliament by S.E. Dawson, printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Davis, D.S. & Browne, S. (1996). The Natural History of Nova Scotia, Volume One, Topics and Habitats. Revised Edition Nova Scotia Museum of Natural History, Halifax, NS.
ojs.library.dal.ca/nsm/issue/view/349

Davis, D.S. & Browne, S. (1998). The Natural History of Nova Scotia. Revised Edition Nova Scotia Museum of Natural History, Halifax, NS.

De Vernal, A., Hillaire-Marcel, C., Turon, J. & Matthiessen, J. (2000). Reconstruction of sea-surface temperature, salinity, and sea-ice cover in the northerns North Atlantic during the last glacial maximum based on dinocyst assemblages. *Canadian Journal of Earth Sciences* 37: 725-750. cdnsciencepub.com/doi/10.1139/e99-091

DFO. (2006). Recovery Strategy for the Atlantic Whitefish (Coregonus huntsmani) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series. Ottawa: Fisheries and Oceans Canada. 42 p.
www.registrelep.gc.ca/virtual_sara/files/plans/rs_Atlantic_Whitefish_0906_e.pdf

DFO. (2018). Amended Recovery Strategy for the Atlantic Whitefish (*Coregonus huntsmani*) in Canada. Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa, ON. xiii + 62 p. publications.gc.ca/site/eng/9.826221/publication.html

DFO. (2024). Optimal strategy for invasive species control to ensure survival and recovery of Atlantic Whitefish in the Petite Rivière Lakes. DFO Canadian Science Advisory Secretariat Science Advisory Report. 2024/045. publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2025/mpo-dfo/fs70-6/Fs70-6-2024-045-eng.pdf

Dymond, J.R. (1947). A list of the freshwater fishes of Canada east of the Rocky Mountains. Royal Ontario Museum of Zoology, Misc. Publ., No. 1, 1-36 p.

Edge, T.A. (1984). Preliminary status of the Acadian Whitefish, *Coregonus canadensis*, in southern Nova Scotia. *Canadian Field Naturalist.* 98(1): 86-90. www.biodiversitylibrary.org/part/355097

Edge, T.A. (1987). The systematics, distribution, ecology and zoogeography of the endangered Acadian Whitefish, *Coregonus canadensis* Scott, 1967, in Nova Scotia, Canada. M.Sc. thesis, University of Ottawa, Ottawa, ON. 175 p. ruor.uottawa.ca/items/9091e99f-a7bf-4a33-aea4-1e9b6cb4f780

Edge, T.A. & Gilhen, J. (2001). Updated status report on the endangered Atlantic Whitefish, *Coregonus huntsman*. *Canadian Field Naturalist* 115: 635-651.

Edge, T.A., MacAllister, D.E. & Qadri, S.U. (1991). Meristic and morphometric variation between the endangered Acadian Whitefish, *Coregonus huntsmani*, and the Lake Whitefish, *Coregonus clupeaformis*, in the Canadian maritime Provinces and the State of Maine. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2140-2151.

Eshenroder, R.L., Vecsei, P., Gorman, O.T., Yule, D.L., Pratt, T.C., Mandrak, N.E., Bunnell, D.B. & Muir, A.M. (2016). Ciscoes (*Coregonus*, subgenus *Leucichthys*) of the Laurentian Great Lakes and Lake Nipigon [online]. www.glfc.org/pubs/misc/Ciscoes_of_the_Laurentian_Great_Lakes_and_Lake_Nipigon.pdf (Accessed 20 December 2024)

Esri. (2024). ArcGIS Pro 3.3.1. Redlands, CA: Environmental Systems Research Institute.

Evans, D.O. & Loftus, D.H. (1987). Colonization of inland lakes in the Great Lakes Region by Rainbow Smelt, *Osmerus mordax*: their freshwater niche and effects on indigenous fishes. *Canadian Journal of Fisheries and Aquatic Science* 44(Suppl. 2): 249-266. jvzlab.limnology.wisc.edu/wp-content/uploads/sites/1902/2022/11/Evans_Loftus_1987_Colonization_CJFAS.pdf

Evermann, B.W. & Goldsborough, E.L. (1907). A checklist of the freshwater fishes of Canada. *Proceedings of the Biological Society of Washington, U.S. Bureau of Fisheries* 20: 89-120. archive.org/details/biostor-3904

Evermann, B.W. & Smith, H.M. (1894). The Whitefishes of North America. In: Report of the U.S. Commissioner of Fish and Fisheries for 1896. p. 283-324.

Fader, G. (2005). Glacial, post glacial, present and projected sea levels, Bay of Fundy. Atlantic Marine Geological Consulting ltd. Halifax, NS. 20 p. files.pca-cpa.org/pcadocs/bi-c/1.%20Investors/3.%20Exhibits/C0408.pdf

Fader, G.B.J., King, L.H. & MacLean, B. (1977). Surficial geology of the eastern Gulf of Maine and the Bay of Fundy. Geological Survey of Canada Paper 76-17, 23 p.

Fenderson, C.O. (1964). Evidence of subpopulations of Lake Whitefish, *Coregonus clupeaformis*, involving a dwarfed form. Maine Department of Inland Fisheries and Game, Orono, Maine, USA.

Foster, G.E. (1887). Third annual report of the Deputy Minister of Fisheries for the year 1886. Printed by Order of Parliament by MacLean, Roger & Co., Wellington Street, Ottawa, ON.

Foster, G.E. (1888). Fourth annual report of the Deputy Minister of Fisheries for the Year 1887. Printed by Order of Parliament by MacLean, Roger & Co., Wellington Street, Ottawa, ON.

Fulton, R.J. & Andrews, J.T. (1987). Inception, growth and decay of the Laurentide Ice Sheet. *Géographie Physique et Quaternaire* 41(2): 179-180. www.episodes.org/journal/view.html?doi=10.18814/epiiugs/1987/v10i1/006

Gautreau, M. & Curry, R.A. (2020). Inland Fishes of New Brunswick. Canadian Rivers Institute. 208 p.

Gilhen, J. (1974). Fishes of Nova Scotia's Lakes and Streams. Nova Scotia Museum, Halifax, NS v+40 p.

Goodchild. C.D. (2001). Status of the Mira River population of Lake Whitefish, *Coregonus clupeaformis*, in Canada. *The Canadian Field-Naturalist* 115(4): 623-634. www.biodiversitylibrary.org/part/363861

Gourlay, J.I. (1995). Missed opportunities, The angler's guide to non-traditional sport fishes in Nova Scotia. Land & Sea Limited, Dartmouth, NS.

Grant, D.R. (1970). Recent coastal submergence of the Maritime provinces, Canada. *Canadian Journal of Earth Sciences* 7(2): 676-689. cdnsciencepub.com/doi/10.1139/e70-067

Grant, D.R. (1971). Glacial deposits, sea level changes and pre-Wisconsinan deposits in southwest Nova Scotia. Geological Survey of Canada Paper 71-B: 110-113.

Hartman, W.L. (1972). Lake Erie: effects of exploitation, environmental changes, and new species on the fishery resources. *Journal of the Fisheries Research Board of Canada* 29: 931-936. www.glfc.org/pubs/TechReports/Tr22.pdf

Hasselman, D.J. (2004). Discrimination of adult and early life history stage Coregonid fishes in Maritime Canada. M.Sc. Thesis. Acadia University. publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2013/mpo-dfo/Fs97-6-2993-eng.pdf

Hasselman, D.J., Edge, T.A. & Bradford, R.G. (2009). Discrimination of the endangered Atlantic Whitefish from Lake Whitefish and Round Whitefish by use of external characters. *North American Journal of Fisheries Management* 29: 1046-1057. onlinelibrary.wiley.com/doi/10.1577/M08-217.1

Hebda, A.J. (2019). List of the fish found in the freshwaters of Nova Scotia: A review of the taxonomy applied to these species with synonyms used in the literature relating to Nova Scotia including Mi'kmaw names for fish, Curatorial Report No. 108, Nova Scotia Museum, Halifax, 100 p. ojs.library.dal.ca/NSM/article/view/8849

Heiskanen, J.J., Mammarella, I., Ojala, A., Stepanenko, V., Erkkilä, K., Miettinen, H., Sandström, H., Eugster, W., Leppäranta, M., Järvinen, H., Vesala, T. & Nordbo, A. (2015). Effects of water clarity on lake stratification and lake-atmosphere heat exchange. *Journal of Geophysical Research: Atmospheres* 120(15): 7412-7428. agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014JD022938

Huntsman. A.G. (1922). The Fishes of the Bay of Fundy. *Contributions to Canadian Biology* 3: 49-72.

Huntsman, A.G. (1953). Mortality of fish in the Tobique River, N.B. In: reports of the Consulting Director (1953), Fisheries Research Board of Canada Manuscript Report. 38-39 p.

Hyatt, R.A. (1970). A biological survey of Baker Lake, N.B. Canadian Department of Fisheries and Forestry, Fisheries Services, Resource Development Branch, Halifax, N.S. MS Report. 13 p. & figs. (Referenced in Meth 1973, not found).

Ingram, J.H. (1960). Atlantic Salmon investigation Beechwood Dam-Saint John River, N.B. Fishway and Area. Manuscript report (Canada. Fisheries Service. Maritimes Region. Resource Development Branch). 60-1.

Ingram, J.H. (1961). Atlantic Salmon investigation Beechwood Power Dam-Saint John River, N.B. fishway and area 1961. Manuscript report (Canada. Fisheries Service. Maritimes Region. Resource Development Branch). 61-1.

Ingram, J.H. (1962). Summary of salmon investigation in upper Saint John River (Beechwood and Tobique fishways). Manuscript report (Canada. Fisheries Service. Maritimes Region. Resource Development Branch). 62-1.

Ingram, J.H. (1963). Atlantic Salmon investigation Beechwood and Tobique Power dam fishways Saint John River-New Brunswick. Manuscript report (Canada. Fisheries Service. Maritimes Region. Resource Development Branch). 63-3.

Ingram, J.H. (1980). Capture and distribution of Atlantic Salmon and other species at Mactaquac Dam and Hatchery, Saint John River, N.B., 1972-76. Canadian Data Report on Fisheries and Aquatic Sciences. No. 181. 74 p.

Ingram, J.H. (1981). Fish-count data at Beechwood Dam, fish-collection facilities, 1972-76. Canadian Data Report on Fisheries and Aquatic Sciences. No. 254. vii + 33 p.

Ingram, J.H. (1985). Capture and distribution of Atlantic Salmon in the Mactaquac area, Saint John River system, 1977-82. Canadian Data Report on Fisheries and Aquatic Sciences. No. 508. 508. vii + 59 p.

Ingram, J.H. (1987). Atlantic Salmon counts at Beechwood Dam fish-collection facilities, 1977-82. Canadian Data Report on Fisheries and Aquatic Sciences. No. 664. viii + 34 p.

Ingram, J.H. & Ensor, B.V. (1990). Capture and distribution of Atlantic Salmon in the Mactaquac area, Saint John River system 1983-1988. Canadian Data Report on Fisheries and Aquatic Sciences. No. 791: 55 p.

Ives, B.H. (1975). 1973 Surveys of eleven lakes in Antigonish and Guysborough Counties, Nova Scotia. Data Record Series No. MAR/D-75-10. Resource Development Branch, Fisheries and Marine Service, Department of the Environment, Halifax, NS.
waves-vagues.dfo-mpo.gc.ca/Library/15238.pdf

Keachie, P.M. & Côté, R.P. (1973). Toxic pollutants in the Saint John River Basin. A report prepared for the Saint John River Basin Board. Surveillance and Analysis Division Environmental Protection Service Halifax, NS. waves-vagues.dfo-mpo.gc.ca/Library/40596333.pdf

Kelso, J.R.M., Minnis, C.K., Gray, J.E. & Jones, M.L. (1986). Acidification of surface waters in eastern Canada and its relationship to aquatic biota. Canadian Special Publication of Fisheries and Aquatic Sciences. 87: 42 p.
publications.gc.ca/site/archivee-archived.html?url=https://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs41-31-87-eng.pdf

Kendall, W.C. (1903). Notes on some fresh-water fishes from Maine. Bulletin U.S. Fish Commission, Vol XXII, 1902-1903, 353-368 p.

Kendall, W.C. (1914). An annotated catalogue of the fishes of Maine. *Proceedings of the Portland Society of Natural History* 4(1): 1-198.
ia601305.us.archive.org/16/items/annotatedcatalog00kend/annotatedcatalog00kend.pdf

Kerekes, J. (1975). Distribution of fishes. Kejimkujik national Park, Aquatic resources inventory. Canadian Wildlife service. MS. Rep. 97 p.

Kerekes, J., Howell, G., Beauchamps, S. & Pollock, T.L. (1982). Characterization of three lake basins sensitive to acid precipitation in Central Nova Scotia. *International Review of Hydrobiology* 67: 679-694.

Kirkpatrick, M. & Selander, R.K. (1979). Genetics of speciation in Lake Whitefishes in the Allegash Basin. *Evolution* 33: 478-483.
academic.oup.com/evolut/article-abstract/33/1Part2/478/6871192?redirectedFrom=fulltext&login=false

Knight, W. (2007). Samuel Wilmot, fish culture, and recreational fisheries in late 19th century Ontario. *Scientia Canadensis* 30(1): 75-90.
www.erudit.org/en/journals/scientia/2007-v30-n1-scientia2569/800527ar.pdf

Lanman, C. (1874). The Whitefish of Eastern Maine and New Brunswick. Report of the Commissioner of Fish and Fisheries. p. 84-86.

Lasenby, T.A., Kerr, S.J. & Hooper, G.W. (2001). Lake whitefish culture and stocking: an annotated bibliography and literature review. Fish and Wildlife Branch, Ontario Ministry of Natural Resources. Peterborough, Ontario. 72 p. + appendices.

LeBlanc, J.E. (2010). Geographic distribution of Smallmouth Bass, *Micropterus dolomieu*, In Nova Scotia: history of early introductions and factors affecting current range. DFO Canadian Science Advisory Secretariat Research Document 2010/028. Iv + 25 p. publications.gc.ca/site/eng/394346/publication.html

Leim, A.H. & Day, K.R. (1959). Records of uncommon and unusual fishes from eastern Canadian waters, 1950-1958. *Journal of the Fisheries Research Board of Canada* 16: 503-514.

Leim, A.H. & Scott, W.B. (1966). Fishes of the Atlantic Coast of Canada. Fisheries Research Board of Canada. Ottawa, ON. 485 p.

Lindsey, C.C. (1981). Stocks are chameleons: plasticity in gill-rakers of coregonid fishes. *Canadian Journal of Fisheries and Aquatic Sciences* 38: 1497-1506. cdnsciencepub.com/doi/10.1139/f81-202

Livingstone, D.A. (1953). The freshwater fishes of Nova Scotia. *Proceedings of the Nova Scotian Institute of Science* 1950-1951, 23: 1-90.

Loch, J.S. (1974). Phenotypic variation in the Lake whitefish, *Coregonus clupeaformis*, induced by introduction into a new environment. *Journal of the Fisheries Research Board of Canada* 31: 55-62. cdnsciencepub.com/doi/10.1139/f74-008

Loftus, D.H. & Hulsman, P.F. (1986). Predation on larval lake whitefish (*Coregonus clupeaformis*) and lake herring (*C. artedii*) by adult rainbow smelt (*Osmerus mordax*). *Canadian Journal of Fisheries and Aquatic Science* 43: 812-818. cdnsciencepub.com/doi/10.1139/f86-100

Lu, G. & Bernatchez, L. (1998). Experimental evidence for reduced hybrid viability between limnetic and benthic ecotypes of Lake Whitefish (*Coregonus clupeaformis* Mitchill). *Proceedings of the Royal Society of London B-Biological Sciences* 265: 1025-1030. royalsocietypublishing.org/doi/10.1098/rspb.1998.0394

Lu, G. & Bernatchez, L. (1999). Correlated trophic specialization and genetic divergence in sympatric Lake Whitefish ecotypes (*Coregonus clupeaformis*): Support for the ecological speciation hypothesis. *Evolution* 53: 1491-1505. www.jstor.org/stable/2640895

Mandrak, N.E., Curry, R.A., Dumont, P., Reist, J.D., Taylor, E.B. & Watkinson, D.A. (2023). Zoogeography of the Freshwater Fishes of Canada. In C.T. Hasler, Inhoft, J.G., Mandrack, N.E. & Cooke, S.J [Eds.] Freshwater Fisheries in Canada: Historical and Contemporary Perspectives on the Resources and Their Management. American Fisheries Society. fisheries.org/doi/9781934874707-ch1/

McCullough, A.B. (2003). "WILMOT, SAMUEL," in *Dictionary of Canadian Biography*, vol. 12, University of Toronto/Université Laval. www.biographi.ca/en/bio/wilmot_samuel_12E.html (Accessed March 20, 2024)

Mee, J.A., Bernatchez, L., Reist, J.D., Rogers, S.M. & Taylor, E.B. (2015). Identifying designatable units for intraspecific conservation prioritization: a hierarchical approach applied to the lake whitefish species complex (Coregonus spp.). *Evolutionary Applications* 8(2015): 423-441. onlinelibrary.wiley.com/doi/10.1111/eva.12247

Meth. F.F. (1972). Ecology and the Saint John River Basin V. Status of the Estuary. Dept of the Environment, Fisheries service, Resource Development Branch, Halifax, NS.

Meth, F.F. (1973). Fishes of the upper and middle Saint John River. A report to the Saint John River Basin Board. Resource Development Branch, Fisheries and Marine Service, Canada Department of the Environment, Halifax, NS.

Meth. F.F. (1974). Sport and commercial fisheries of the Saint John Estuary. The Saint John River Basin Board, Report No. 7b.

Mitchell, S.C., LeBlanc, J.E. & Heggelin, A.J. (2012). Impact of introduced Chain Pickerel (*Esox niger*) on lake fish communities in Nova Scotia, Canada. Report. Nova Scotia Department of Inland Fisheries and Aquaculture. 18 p. novascotia.ca/fish/documents/special-management-areas-reports/impact-chain-pickerel.pdf

Morgan, T.D., Graham, C.F., McArthur, A.G., Raphenya, A.R., Boreham, D.R., Manzon, R.G., Wilson, J.Y., Lance, S.L., Howland, K.L., Patrick, P.H. & Somers, C.M. (2018). Genetic population structure of the round whitefish (*Prosopium cylindraceum*) in North America: multiple markers reveal glacial refugia and regional subdivision. *Canadian Journal of Fisheries and Aquatic Sciences* 75(6): 836-849. cdnsciencepub.com/doi/abs/10.1139/cjfas-2016-0528?src=recsys

Morin, R., Dodson, J.J. & Power, G. (1981). The migrations of anadromous cisco (*Coregonus artedii*) and lake whitefish (*C. clupeaformis*) in estuaries of eastern James Bay. *Canadian Journal of Zoology* 59: 1600-1607. www2.bio.ulaval.ca/labdodson/Papers%20Julian/10.Morin%20et%20al.1981.pdf

Morrison, B.P. & Peiman, K.S. (2022). The role of hatcheries in the decline of Lake Ontario Atlantic Salmon. *Canadian Journal of Fisheries and Aquatic Sciences* 79(6): 994-1002. utoronto.scholaris.ca/server/api/core/bitstreams/7fd75d8a-ab00-4d20-8ff9-97ebb2dc1060/content

Murray, K. (2005). Population genetic assessment of the endangered Atlantic whitefish, *Coregonus huntsmani*, and the lake whitefish, *C. clupeaformis*, in Atlantic Canada. Master's thesis. Dalhousie University, Halifax, NS.

Newton, B. & Burrell, B.C. (2015). The April-May 2008 flood event in the Saint John River basin: causes, assessment and damages. *Canadian Waters Resources Journal / Revue Canadienne des Ressources Hydriques* 41(1-2): 118-128. www.tandfonline.com/doi/pdf/10.1080/07011784.2015.1009950

Nova Scotia Department of Inland Fisheries and Aquaculture. (2024). Nova Scotia Anglers' Handbook and 2024 Summary of Regulations. 71 p.

Perley, M.H. (1851). Catalogue (in part) of the fishes of New Brunswick and Nova Scotia. Government Emigration Office, Saint John, NB.

Perley, M.H. (1852). Reports on the sea and river fisheries of New Brunswick. J. Simpson, Printer to the Queen's most excellent majesty, Fredericton, NB.

Piers, H. (1924). *Coregonus labradorius*, The Sault Whitefish, an interesting addition to the freshwater fish fauna of Nova Scotia. Provincial Museum, Halifax, NS. 4 p. dalspace.library.dal.ca/items/2949d2a2-8aca-4fa8-ad91-9f71b0a0941a

Pigeon, D., Chouinard, A. & Bernatchez, L. (1997). Multiple modes of speciation involved in the parallel evolution of sympatric morphotypes of Lake Whitefish (*Coregonus clupeaformis*, Salmonidae). *Evolution* 51: 196-205. academic.oup.com/evolut/article-abstract/51/1/196/6757124?redirectedFrom=fulltext&login=false

Piper, J.W. & MacDonald, A. (2001). Timing and position of late Wisconsinan ice-margins on the upper slope seaward of Laurentian Channel. *Géographie Physique et Quaternaire* 55(2): 131-140. www.erudit.org/en/journals/gpq/2001-v55-n2-gpq480/008298ar/

Pope, J.C. (1879). Eleventh annual report of the Department of Marine and Fisheries being for the fiscal year ended 30th June 1878. Printed by Order of Parliament by MacLean, Roger & Co., Wellington Street, Ottawa, ON.

Pratt, R.M. & Schlee, J. (1969). Glaciation of the continental margin off New England. *Geological Society of America Bulletin* 80: 2335-2342. pubs.geoscienceworld.org/gsa/gsabulletin/article-abstract/80/11/2335/6479/Glaciation-on-the-Continental-Margin-off-New?redirectedFrom=fulltext

Prince, E.E. (1906). The progress of fish culture in Canada 1905. Special Reports, Government Printing Bureau, Ottawa, ON.

Rogers, S.M., Gagnon, V. & Bernatchez, L. (2002). Genetically based phenotype-environment association for swimming behaviour in Lake Whitefish ecotypes (*Coregonus clupeaformis* Mitchill). *Evolution* 56(11): 2322-2329. From=fulltext&login=false

Roseman, E.F., Kennedy, G.W., Boase, J., Manny, B.A., Todd, T.N. & Stott, W. (2007). Evidence of Lake Whitefish spawning in the Detroit River: implications for habitat and population recovery. *Journal of Great Lakes Research* 33(2): 397-406. www.sciencedirect.com/science/article/abs/pii/S0380133007700643

Quinlan, G. & Beaumont, C. (1982). The deglaciation of Atlantic Canada as reconstructed from the postglacial relative sea-level record. *Canadian Journal of Earth Sciences* 19(12): 2232-2246
cdnsciencepub.com/doi/10.1139/e82-197

Saia, M. (1995). Fishing Guide and Depth Maps to New Brunswick Lakes and Ponds. Smart Fisherman Publications, Saint John, NB. 10 p.

Salisbury, S., McCracken, G.R., Keefe, D., Perry, R. & Ruzzante, D.E. (2019). Extensive secondary contact among three glacial lineages of Arctic Char (*Salvelinus alpinus*) in Labrador and Newfoundland. *Ecology and Evolution* 9: 2031-2045.
onlinelibrary.wiley.com/doi/10.1002/ece3.4893

Schmidt, R.E. (1986). Zoogeography of the Northern Appalachians. In Charles, H. and C.O. Hocutt [Eds]. Zoogeography of North American Freshwater Fishes. p. 137-159.

Scott, W.B. (1967). Freshwater fishes of eastern Canada. Second Edition. University of Toronto Press, Toronto, ON. 137 p.

Scott, W.B. & Crossman, E.J. (1959). The Freshwater Fishes of New Brunswick: A checklist with distributional notes. Royal Ontario Museum of Zoology and Paleontology Contributions 51. Toronto, ON. 45 p.

Scott, W.B. & Crossman, E.J. (1973). The freshwaters fishes of Canada. Bulletin 184. Fisheries Research Board of Canada, Ottawa, ON. 966 p.

Scott, W.B. & Scott, M.G. (1988). The Atlantic Fishes of Canada. Canadian Bulletin of the Fisheries and Aquatic Sciences, 219: 731.

Segerstråle, S.G. (1957). The immigration of the glacial relicts of Northern Europe, with remarks on their prehistory. *Societas Scientiarum Fennica, Commentationes Biologicae* 16(16): 1-117.

Semple, J.R. (1973). The Lake Whitefish, (*Coregonus clupeaformis* Mitchill), of Scotch Pond, Petpeswick River, Nova Scotia. *Transactions of the Canadian Society of Environmental Biologists*, Dec. 1973, 21 p.

Shaw, J. (2006). Palaeogeography of Atlantic Canadian continental shelves from the last glacial maximum to the present, with an emphasis on Flemish Cap. *Journal of Northwest Atlantic Fisheries Science* 37: 119-126.
journal.nafo.int/Portals/0/2005-2007/10-shaw.pdf

Shaw, J., Piper, D.J.W., Fader, G.B.J., King, E.L., Todd, B.J., Bell, T., Batterson, M.J. & Liverman, D.G.E. (2006). A conceptual model of the deglaciation of Atlantic Canada. *Quaternary Science Reviews* 25: 2059-2081.
www.sciencedirect.com/science/article/abs/pii/S0277379106001326?via%3Dihub

Shilts, W.W. (1981). Sensitivity of bedrock to acid precipitation: modification by glacial processes. Paper 81-14. Geological Survey of Canada, Ottawa, ON.
ostrnrcan-dostrncan.canada.ca/entities/publication/ec9036ab-2cd0-4eda-9a09-7d164f583e3f

Smith, A.J. (1875). Seventh Annual Report of the Department of Marine and Fisheries being for the Fiscal Year ended 30th June 1874. Printed by order of Parliament by MacLean, Roger & Co., Wellington Street, Ottawa, ON.

Smith, M.W. (1952). The Lake Whitefish in Kerr Lake, New Brunswick. Atlantic Biological Station, St. Andrews, N.B. *Journal of the Fisheries Research Board of Canada* 8(5): 340-346.

Smith. K.E.H. (1969). Compendium Saint John River System, N.B. Resource Development Branch Manuscript Report No. 69-6. Environment Canada. 253 p.

Smith, K.E.H. (1970). Summary Report, Atlantic salmon investigation, Saint John River System, New Brunswick, 1969. Canada Dept. Fish. and Forestry, Fisheries Service, Resource Development Branch, Halifax, NS. MS Report 70-12.

Smith, K.E.H. (1974). 1973 report. Resource Development Branch, Maritime Region, Halifax, NS.

Smith, K.E.H. (1979). Capture and Distribution of all Fish Species at Saint John River Power Dams, New Brunswick, From Construction Years to 1971. Canadian Data Report of Fisheries and Aquatic Sciences No. 171. Department of Fisheries and Oceans, Halifax, NS.

Stea, R.R. & Mott, R.J. (1998). Deglaciation of Nova Scotia: Stratigraphy and chronology of lake sediment cores and buried organic sections. *Géographie Physique et Quaternaire* 52(1): 3-21. www.erudit.org/en/journals/gpq/1998-v52-n1-gpq155/004871ar.pdf

Sutherland, J. (1902). Thirty-Fourth annual report of the Department of Marine and Fisheries 1901, Printed by Order of Parliament by S.E. Dawson, Printer to the Kings Most Excellent Majesty, Ottawa, ON.

Svårdson, G. (1979). Speciation of Scandinavian *Coregonus. Report of the Institute of Freshwater Research* 57: 3-95. www.scirp.org/reference/referencespapers?referenceid=1551387

Trautman, M.B. (1957). The Fishes of Ohio. Ohio State University. Press, Columbus, Ohio, USA. xviii + 683 p.

Tupper, C.H. (1889). Fifth annual report of the Department of Fisheries, Dominion of Canada for the Year 1888. Printed by Order of Parliament for the Queen's Printer and Controller of Stationary, A. Senecal, Superintendent of Printing, Ottawa, ON.

Tupper, C.H. (1890). Sixth Annual Report of the Department of Fisheries, Dominion of Canada, for the Calendar Year 1889. Printed by Order of Parliament by Brown Chamberlin, printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Tupper, C.H. (1891). Supplement No. 1 to the Annual Report of the Department of Fisheries, Fisheries Statements, and Inspector's Reports for the Year 1890. Printed by Order of Parliament by Brown Chamberlin, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Tupper, C.H. (1892). Annual Report of the Department of Fisheries of the Dominion of Canada 1891. Printed by Order of Parliament by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Tupper, C.H. (1893). Supplement No. 4 to the Annual Report of the Department of Marine and Fisheries. Fisheries Statements and Inspector's Reports for the Year 1892. Printed by Order of Parliament by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Tupper, C.H. (1894). Twenty-Sixth Annual Report of the Department of Marine and Fisheries 1893. Printed by Order of Parliament by S.E. Dawson, Printer to the Queen's Most Excellent Majesty, Ottawa, ON.

Veilleux, C. (1964). Limnological Surveys in Kejimkujik National Park. Canadian Wildlife Service, MS Reports, 38 p.

Vladykov, V.D. & McKenzie, R.A. (1935). The marine fishes of Nova Scotia. *Proceedings of the Nova Scotian Institute of Science* 19(1): 17-113. dalspace.library.dal.ca/items/658f1ef6-c34a-4465-802d-9df3aef3b4b0

Warner, K. (1965). Fishery management in the fish river drainage. Maine Department of Inland Fisheries and Game. Augusta, Maine, USA. 59 p. catalog.hathitrust.org/Record/010364514

Warner, M.G., Andrews, S.N., MacMillan, J.L, Lowles, A.G., Collet, K., Curry, R.A., Linnansaari, T. & Stokesbury, M.J.W. (2023). Past and present distribution and identification of extant native Lake Trout (*Salvelinus namaycush*) populations in the Canadian Maritime Provinces. *Northeastern Naturalist* 30(Monograph 23): 1-59. www.eaglehill.us/NENAonline/articles/NENA-mon-23/mon-23-Warner.shtml

Warner, M.G., Andrews, S.N., Marcy-Quay, B., Solda, C.C., Lowles, A.G. & Stokesbury, M.J.W. (2024). Lake Trout (*Salvelinus namaycush*) origin, behaviour, and habitat residency in Sherbrooke Lake, NS. *Environmental Biology of Fishes* 10: 1067-1088. link.springer.com/article/10.1007/s10641-024-01603-5

Watt, W.D. (1987). A summary of the impact of acid rain on Atlantic Salmon (*Salmo salar*) in Canada. *Water, Air, Soil Pollution* 35: 27-35. link.springer.com/article/10.1007/BF00183841

Watt, W.D., Scott, C.D. & White, W.J. (1983). Evidence of acidification of some Nova Scotian rivers and its impact on Atlantic Salmon, *Salmo salar*. *Canadian Journal of Fisheries and Aquatic Science* 40: 462-473. cdnsciencepub.com/doi/10.1139/f83-065

Webb, K.T. & Marshall, L.B. (1999). Ecoregions and ecodistricts of Nova Scotia. Crops and Livestock Research Centre, Research Branch, Agriculture and Agri-Food Canada, Truro, Nova Scotia; Indicators and Assessment Office, Environmental Quality Branch, Environment Canada, Hull, Quebec. 39 p. and 1 map. sis.agr.gc.ca/cansis/publications/surveys/ns/nsee/nsee_report.pdf

Whitaker, D.S. & Wood J. (2021). An investigation of Lake Whitefish recruitment, spawning, and early life history in Northern Maine: Final Report. Maine Department of Inland Fisheries & Wildlife, Fisheries and Hatcheries Division. 57 p. www.maine.gov/ifw/docs/An-Investigation-of-Lake-Whitefish-

Recruitment-Spawning-and-Early-Life-History-in-Northern-Maine-Final-Report.pdf

Whitcher, W.F. (1876). Eighth Annual Report of the Minister of Marine and Fisheries, for the Year 1875. Printed by MacLean, Roger & Co., Wellington Street, Ottawa, ON.

Whitcher, W.F. (1878). Tenth Annual Report of the Department of Marine and Fisheries being for the Fiscal Year Ending 31st December 1877. Printed by MacLean, Roger & Co., Wellington Street, Ottawa, ON.

White, W.J. (1992). Effects of pH on the zoogeographical distribution of freshwater fish in Nova Scotia. in B.L. Beattie [ed]. The Atlantic Region LRTAP Monitoring and Effects Working Group Report for 1991. Biological Sciences Branch, Department of Fisheries and Oceans, Halifax, NS. 108-138 p.

Whitmore F.C, Jr., Emery, K.O., Cooke, H.B.S. & Swift, D.J.P. (1967). Elephant teeth from the Atlantic continental shelf. USGS Staff-Published Research. 236 p.
digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1245&context=usgsstaffpub

Wilmot, S. (1877). Report on fish-breeding in the Dominion of Canada, 1877. Ottawa: Maclean, Roger & Co., 1878. 78 p.

Wood. J. (2001). Current Status of Lake Whitefish in Maine; an Update to the MDIFW's 2001 Whitefish Assessment. Fisheries Final report Series No. 16-01. Maine Department of Inland Fisheries & Wildlife Fisheries and Hatcheries Division.
www.maine.gov/ifw/docs/fisheries-reports/2016/lakewhitefish_currentstatus.pdf

Wood. J. (2016). Current Status of Lake Whitefish in Maine; an Update to MDIFW's 2001 whitefish assessment. fishery final report Series No. 16-01 Maine Department of Inland Fisheries & Wildlife Fisheries and Hatcheries Division.
www.maine.gov/ifw/docs/fisheries-reports/2016/lakewhitefish_currentstatus.pdf

Wright, B. (1989). The Fauna of Sable Island. Curatorial Report Number 68, Nova Scotia Museum, Halifax, NS. 93 p.
ojs.library.dal.ca/NSM/article/view/4051

Zelman, K., Harrison, P., O'Sullivan, A.M., Andrews, S.N., Peake, S., Linnansaari, T., Pavey, S.A. & Curry, R.A. (2023). Reproductive ecology of muskellunge (*Esox masquinongy*), an introduced predator, in the lower Wolastoq/Saint John River, NB. *Journal of Fish Biology* 102: 643-654. onlinelibrary.wiley.com/doi/pdf/10.1111/jfb.15302

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 273-304

CONSIDERATION OF CLIMATE CHANGE IN NOVA SCOTIAN ENVIRONMENTAL ASSESSMENTS: A CRITICAL REVIEW AND RECOMMENDATIONS FOR IMPROVEMENT

LENA FINE[1*] AND SEAN R. HAUGHIAN[1,2]

[1]Biology Department, Dalhousie University, Life Sciences Centre, 6287 Alumni Crescent Halifax, NS B3H 4R2

[2]Biology Department, Saint Mary's University 923 Robie Street, Halifax, NS B3H 3C3

ABSTRACT

This study evaluates how climate change (CC) is considered in recent environmental assessments (EA) in Nova Scotia, Canada. We assessed 38 EA reports covering six project types: wind farms, road expansions/utility corridors, quarries, mines, green hydrogen plants, and waste treatment facilities. Reports were scored based on 4 or 5 questions in each of four categories: coverage of basic CC science, greenhouse gas (GHG) accounting, greenhouse gas mitigation, and CC adaptation. Wind farms and road expansion/utility corridor projects scored the highest across most categories, particularly in GHG accounting and mitigation. Quarry expansions and waste treatment facilities scored poorly, with quarry projects receiving the lowest scores in GHG accounting and adaptation. Common weaknesses included inadequate enforcement of mitigation measures and a lack of consideration for carbon sequestration in GHG accounting. Green hydrogen production plants demonstrated strengths in renewable energy sourcing but lacked comprehensive GHG accounting and basic CC science. Mines, though reporting well on basic climate-change science and CC adaptation, had inadequate GHG accounting and mitigation. Environmental assessment practices have improved slightly but can be better aligned with Nova Scotia's climate action goals. Planners need better integration of sequestration, more consistent accounting, and more consistent enforcement of mitigation strategies.

Keywords: Greenhouse gas accounting; climate mitigation; climate adaptation; carbon sequestration

* Author to whom correspondence should be addressed: sean.haughian@smu.ca

INTRODUCTION

Environmental assessment (EA) is an important prerequisite for development in much of the modern world. In its ideal form, it ensures that developers are appropriately accounting for and planning to mitigate the potential harms that their project could do to communities and ecosystems within the project's area of influence. It also offers governments a considerable amount of evidence upon which they may subsequently base legally defensible decisions to manage development in an optimal way, or prevent "reckless or inadequately informed actions", when such work is not in the best interests of its citizens (Barrow 1997). Specific regulations concerning EA vary among jurisdictions, but in Nova Scotia, proponents are usually required to provide information on (1) baseline geology, water and air quality, biodiversity (usually focused on rare, at-risk, or culturally significant species), and culturally significant uses of the landscape, (2) expected changes to the baseline that are inferred, estimated, or projected based on the proposed development, (3) whether the expected changes are "significant", and (4) proposed mitigation or compensation measures that address any harmful impacts from the proposed development (Province of Nova Scotia 1995).

Although it has not historically been addressed by EA processes, Climate Change (CC) is among the most urgent and important environmental harms caused by human activity in the 21st century, and our response to it could benefit from being integrated into the EA process (MacKinnon *et al.* 2018). The effects of CC are increasingly apparent and harmful in Canada and around the world. Compared to historic conditions mean annual temperatures, frost-free periods, and prolonged summer weather have all increased significantly (Garbary & Hill 2021, Vincent *et al.* 2018). These changes have driven shifts in the distribution of plant and animal populations (Pecl *et al.* 2017, Rubenstein *et al.* 2023, Schumacher *et al.* 2022) and of the pathogens and pathogen-vectors that affect them (Gilbert 2021). Moreover, CC has increased the frequency and intensity of natural disturbances such as wildfires, droughts, floods, hurricanes, and tropical storms, leading to substantial damage to human infrastructure and losses of life (Insurance Bureau of Canada 2024, Jain *et al.* 2024, Mekis *et al.* 2015, Ollerhead 2023). Given the prominent place of the EA process in determining whether or how projects should proceed while considering environmental and human harms, CC should be explicitly addressed as part of the EA process (MacKinnon *et al.* 2018). Indeed, Nova Scotia adopted mandatory reporting of greenhouse gases for projects with emissions over 50,000 t CO_2 equivalents per year in 2018, for consistency with federal changes to EA regulations (Quantification, Reporting and Verification Regulations Made under Section 112Q of the Environment Act, 2018). Climate-change consideration in the EA process appears to have improved since 2019, but is inconsistent, and so a more empirical approach was needed to determine how well EA writers are doing, and whether their work can be further improved.

Earlier Nova Scotian EA regulations conferred no legal responsibility on proponents to consider CC (Nova Scotia, 2001). Attempts to encourage developers to consider CC in EAs (Nova Scotia Environment 2011, The Federal-Provincial-Territorial Committee on CC and Environmental Assessment 2003) met with little uptake, being based almost entirely on voluntary guidelines and recommendations. Moreover, much uncertainty likely still exists among EA professionals as to how and when to incorporate CC considerations into the EA process (Jiricka *et al.* 2016), particularly when projects are too small to require GHG reporting for large emitters.

The goals of this study are two-fold: (1) to examine Nova Scotian EAs published after legislative changes in 2018 to assess how effectively they have incorporated CC considerations into the EA process; and (2) to provide recommendations as to how regulators and industry can improve. The review of these EAs is approached through the consideration of four main categories: (1) the basic science of CC, (2) accounting for GHG emissions, (3) mitigation of GHG emissions, and (4) adaptation planning.

METHODS

To assess the consideration of CC in Nova Scotian EAs, 38 EA reports from the period 2018-2023 were studied and scored using standardized criteria. EA reports were obtained from the Nova Scotia government's web page of recent environment and CC projects, where all EAs are posted as public documents (Nova Scotia Department of Environment and Climate Change 2024). To improve representativeness within sectors, and to minimize bias across sectors, we sought to include either (a) all EAs of that project type from 2022 and 2023, or (b) as many EAs of a given class as were available from between 2018 and 2023. For project types with adequate representation (≥ 5) in the 2018-2023 period, we additionally reviewed at least two EA reports from prior to 2018, to evaluate changes in report quality since legal changes in GHG reporting requirements were enacted.

As EA reports typically are hundreds of pages in length, we focused our review on specific sections of each individual EA that might contain significant information pertinent to the scoring criteria we applied. Generally, sections highlighting project impacts on airborne pollution, emissions, or air quality were studied in all reports. To ensure that atypical report structure did not cause important information to be overlooked, keyword searches were also used to find relevant information in each report, including such terms as "greenhouse gas", "GHG", "climate change", "carbon", and "CO_2".

Reports were scored based on four categories: CC basics, GHG accounting, GHG mitigation, and CC adaptation (Table 1). Within each category, a suite of 4 or 5 questions were scored, and the sum of these scores was used to generate an overall score for that category. A score system was created for this study where questions were given scores ranging from 0 to 1 on questions that yielded a binary (yes/no) answer and -1 to 1 on questions that required some judgement, with 1 denoting unbiased assessment based on published standards, 0 being unbiased but haphazard or neglected, and -1 being self-serving.

In all categories, we first asked whether the category was mentioned or acknowledged at some place in the report. The bar for a point on this question was intentionally low to contextualize other responses within those categories; reports that failed to include more detailed information on GHG accounting or mitigation because the report writers failed to consider CC entirely could be discriminated from those that made erroneous assumptions, for example.

For the category "CC basics", we additionally asked: (1) is CC acknowledged as a problem, (2) were obfuscating or misleading statements absent, (3) were federal or provincial guides to considering CC cited (Nova Scotia Environment 2011, Province of Nova Scotia 2020, The Federal-Provincial-Territorial Committee on CC and Environmental Assessment 2003), and (4) was other pertinent literature cited? The answers to these questions helped us to understand whether the report writers and proponents were relying on current and accurate information or perhaps had outdated and/or ideologically motivated understandings of CC.

The GHG accounting category included four additional questions: (1) are GHG accounting estimates reasonable, (2) are GHG accounting assumptions appropriate, (3) is GHG sequestration considered, and (4) is significance determination appropriate? Because our expertise is not in life-cycle analysis for determining GHG footprints, determining whether estimates were reasonable depended upon whether obvious aspects of the project were considered by accounting practices, rather than critiquing specific accounting values. For example, we did not critique the specific GHG-equivalent values applied to each tonne of steel or concrete but rather noted whether such values were present and appeared to be based on literature or international standards. Similarly, in determining whether assumptions were appropriate, we looked for evidence that the writers scaled up materials and operating impacts using reference projects of a similar size or using previous experience as a guide to making such calculations. Consideration of GHG sequestration on the landscape prior to project development was self-evident, and we simply looked for the presence of such values in the report. For significance determination, we examined whether projects were comparing themselves to objective, published criteria based on literature or industry standards (e.g., Murphy and Gillam 2013).

The GHG mitigation category asked four additional questions: (1) whether there were expected behavioral changes for project staff or operations to improve GHG mitigation, (2) whether there were technological-based solutions for GHG mitigation included in project design, (3) whether offsets and/or compensations with regard to GHG mitigation were planned, and (4) whether enforcement of GHG mitigation activities was present. Behavioural reductions in GHGs could include, for example, company policies against unnecessary vehicle idling or efficiency improvements through 2-way hauling. Technological mitigations could include, for example, upgrading of equipment to high-efficiency standards, or supplying power from renewable sources. Offsets or compensations could include such activities as financially supporting tree planting initiatives or research on climate solutions or donating land with a high GHG sequestration or storage value for protection. Enforcement of mitigation activities included providing evidence of company policies and practices that ensured staff would be compliant and that goals would be tracked and met, such as integrating compliance with said policies into performance reviews for staff.

The final category was CC adaptation. Within it, we asked three additional questions: (1) whether any behavioural adaptations were planned, (2) whether any technological adaptations were included in the project design, and (3) whether any projections or tools were used to determine the need for adaptations. Behavioural adaptations included explicit articulation of modified work practices related to environmental health and safety concerns for staff that stemmed from CC impacts, such as taking more frequent breaks and having access to water during extreme heat or ensuring that staff were trained in emergency protocols to respond to severe weather. Hypothetically, behavioural adaptations could also include initiatives to promote employee mental health and cope with climate anxiety, but based on the experience of the authors, such adaptations were extremely unlikely to be articulated in an EA report and therefore were not explicitly searched for. Technological adaptations included specific technologies that solved climate-related environmental health and safety problems for staff and project infrastructure, such as improved heating and cooling systems in buildings. Finally, we looked for evidence that the writers used climate projections or other tools (e.g., flood risk maps, fire-smart assessments) to develop a nuanced understanding of what specific behavioural or technological adaptations may be required.

In addition to the categories and questions upon which we focused our critique of EA reports, our initial workplan included a fifth category of CC consideration, which was "how does CC interact with the project to impact other valued environmental components within the study area?" After conducting our review, we decided to exclude this category because it was data deficient, not having been mentioned in a single report.

After EAs were examined and scored based on these criteria, common strengths, weaknesses, and opportunities were highlighted using descriptive statistics, and these were used to inform recommendations regarding potential areas of improvement.

Table 1 The four categories being scored and the criteria that make up each category

Criteria	CC basics	Greenhouse Gas Accounting	Greenhouse Gas Mitigation	CC adaptation
1	CC was mentioned	Some form of greenhouse gas accounting was shown	Some form of GHG mitigation is planned	Some form of adaptation to future climates planned
2	CC was acknowledged as a problem	Accounting estimates were reasonable	Behavioral reductions present	There were specific behavioural (including geospatial) changes
3	Obfuscating/ misleading statements were absent	Accounting assumptions were appropriate	Technological-based reductions present	Technological CC adaptation was present/considered
4	Nova Scotia's guide to considering CC & reporting standards was used	Sequestration was considered	There were any offsets/ compensations	Projections/tools were used
5	Other literature was used and cited	Significance determination was appropriate	There was any enforcement of greenhouse gas mitigation	-

RESULTS

We reviewed 38 EA reports of six project types: green hydrogen & ammonia production plants (n=2), mines (n=3), quarries (n=7), road expansions/ utility corridors (n=7), wind farms (n=12), and waste treatment facilities (n=7). Modal scores for all questions within each CC category are reported in Appendix A, and a list of the projects we reviewed is provided in Appendix B.

Road expansion and utility corridor projects performed better than most other project types, except for on CC adaptation, where they tied wind farms and mines for the lowest overall scores. Citing more provincial EA documentation, accounting for changes to the carbon sequestration capacity of the landscape, and proposing carbon offset activities to mitigate emissions helped these reports to stand out amongst other project types. Modal scores ranging from 3 to 5 in different categories for combined scores of 16/19 overall (Fig 1). Although there was considerable variability among projects, one report stood out for its high scores on GHG mitigation and CC adaptation, the “Highway 101 Cambridge Interchange and Connector Road Project” (WSP Consulting 2023). On GHG accounting and CC basics, the “Highway 101 Digby to Marshalltown Corridor Project” (Stantec Consulting Ltd. 2017) scored the best.

Wind farms received some of the best overall scores of all project types. Not only were wind farm projects found to be highly considerate of CC, including extensive GHG accounting sections, but they also had the advantage of claiming the production of renewable energy during the operational phase to mitigate any GHG emissions created during the construction phase. Most wind farm projects performed well in all categories except for CC adaptation, where there was a consistent lack of stated technological adaptation (specifically) to CC. Although this adaptation may have been included in wind-turbine design, it was not stated in the reports. On the CC basics and adaptation, the Ellershouse 3 Wind Project (Strum Consulting Ltd. 2023a) performed best, while the Mersey River Wind Farm (Strum Consulting Ltd. 2023b) performed best on GHG Accounting and Mitigation.

Green hydrogen and ammonia production plants were found to have room for improvement in their EAs about reporting on CC basics and GHG accounting. They scored the lowest in the “CC basics” category, obtaining total scores of 2 in that category. They tied roads and corridors for the highest median scores (3) for both the GHG mitigation and CC adaptation categories (Fig 1), due in large part to such aspects as relying on renewable power sources and applying behavioural mitigations and adaptations.

In terms of how they reported on both the basic science of CC and how they proposed to adapt to future climates, mines were comparable to the highest-scoring projects: they referred to relevant provincial literature and avoided obfuscation. Mine EA reports also included technological or behavioural adaptations in their plans that showed adaptation to climate impacts such as greater flood potential around roads or higher peak temperatures.

However, mines, quarries, and waste treatment facilities had the lowest scores for GHG accounting and mitigation, where points were lost for self-serving significance determinations, a total absence of relevant information, or a lack of technological mitigations or offsets

(Fig 1). In the case of mines, these low scores primarily resulted from inappropriate assumptions or self-serving significance determination for accounting, and from a lack of technological or offset-based mitigations. For example, the significance of GHG emissions for all mines was determined to be "negligible", based on minimum thresholds for significance determination that varied across projects from 1-8% of provincial emissions. These thresholds appeared to have been chosen either haphazardly or based on the amount that would individually threaten the province's GHG reduction goals. Proposed GHG mitigations were limited to low-effort behavioural modifications of staff, such as preventing idling and maintaining equipment in good working order. No enforcement of such behaviours was proposed, and no commitments were made to technological enhancements that would further reduce GHG emissions.

Quarry expansion projects had the lowest modal scores of all project types, in fact receiving a negative median or modal score in the GHG accounting category and not achieving a combined score higher than 4 in any category (Fig 1). Most of the quarry EAs failed even to mention anything related to GHG accounting. Quarry EAs also received lower scores than all other project types for CC adaptation. Waste treatment projects scored similar to quarries as a group for GHG accounting and CC adaptation, but were more consistent in omitting GHG accounting information entirely. Waste treatment projects performed slightly better than quarries in articulating the basic science of CC, but were highly variable across projects, with scores ranging from 0-5. Waste treatment projects fared slightly worse in mitigation efforts than quarry expansions. The best scoring waste treatment project on CC Basics was the Arlington Heights Asbestos Disposal Facility (East Coast Aquatics Inc. 2017).

Wind farms, waste treatment facilities, and road or utility corridor expansions had sufficient numbers of reports from the 2018-2023 period, and so two additional reports were reviewed from prior to 2018 for each of these project types, spanning the years 2016-2017. From these comparisons across time periods, only wind farm EA reports showed a change in how effectively they considered CC. Between pre- and post-2018 periods, wind farm climate consideration scores in EA reports improved by 9 points, or 47%. Prior to 2018, there was almost no mention of GHG accounting or adaptation for wind farm projects, and very little mention of mitigation.

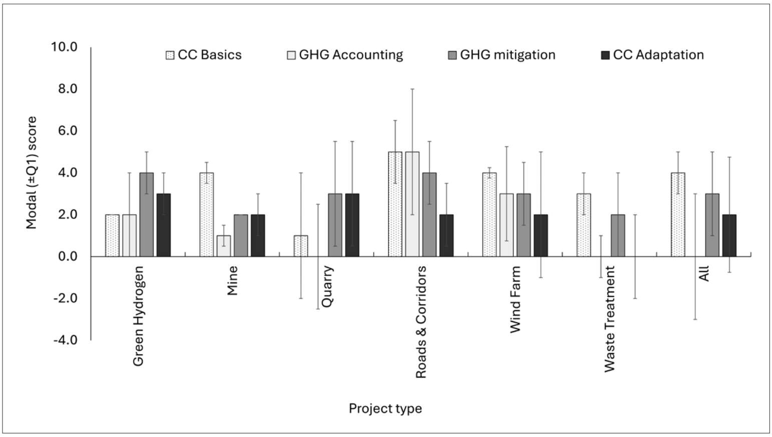


Fig 1 **Modal scores of different EA types out of four or five (environmental effect factor-dependent) regarding four categories: CC basics, GHG accounting, GHG mitigation, and CC adaptation.**

DISCUSSION

Of the 38 reports we assessed, wind farms and road expansion/ utility corridor projects tended to have the highest scores, followed closely by green hydrogen and ammonia production plants. The least consideration for CC was in reports for waste treatment sites and quarry expansion projects; mines were intermediate. Wind farms, but not other project types, showed improvements between pre and post- 2018 periods in how much consideration was given to CC in EA reports. Nevertheless, all project types still had both strengths and weaknesses after 2018. Going forward, proponents and consulting firms can learn much from the literature and from each other about how to improve their consideration of CC in future EAs. We highlight some of these opportunities below.

General criticisms

In assessing the EAs of all project types, two specific scoring criteria stood out as weaknesses throughout all project types. The first of these was the "enforcement" criterion within the GHG mitigation category. Not a single assessed EA from any project type scored above zero on this question. The absence of proposed enforcement policies for any climate-change related mitigations or adaptations is concerning, because it suggests that the proposals contained within EA reports may not be reliable. The other criterion in which most project types performed poorly was the “sequestration considered?” question within the GHG accounting category. Only five out of the 38 assessed EAs scored above zero in this subcategory. This lack of recognition that the pre-existing landscape could have a carbon-sequestering function was surprising, given the emphasis placed on baseline values in most other sections of EA reports (e.g., water & air quality, presence of at-risk species, etc.). Development of standardized carbon flux models for Nova Scotian ecosystems, in collaboration with industry and government, may improve such reporting in the future, but in the interim, consultants are encouraged to examine the many published sources from which estimates of pre-existing carbon sequestration could be obtained (Gallant *et al.* 2020, Kendall *et al.* 2021, Smyth *et al.* 2024).

Specific criticisms by project type

Road expansion/utility corridors

Road expansion projects have one of the highest GHG emission factors of the six evaluated project types due to the quantity of emissions released by asphalt production (Ma *et al.* 2016), and by the high emissions associated with heavy construction equipment. Nevertheless, some additional strategies could be used to reduce projected emissions. The heavy equipment and vehicles that are used in the construction of roadways and utility corridors can be chosen based on their efficiency or ability to generate as few GHG emissions as possible (Avetisyan *et al.* 2012). Moreover, the raw materials that are used to produce asphalt are not equal in terms of carbon emissions (Anthonissen *et al.* 2016), and where possible, material sources should be optimized to reduce GHGs through the construction phases of the projects. In addition, EA report writers should more consistently consider projected changes in transportation efficiency, such as anticipated reductions in vehicle idling, when evaluating projected CO2 emissions through the life-cycle of the infrastructure created (WSP Consulting 2023).

Wind farms

Wind farms performed consistently well in most categories, but were variable in others, and still have room for improvement. Although the small amounts of GHG emissions generated by wind turbine maintenance (Padey *et al.* 2012) are mostly negligible when compared against comparable emissions from fossil-fuel generated energy, they must nevertheless be reported as part of the carbon accounting for a project. In addition, wind farm proponents should consider reporting on whether their designs are adapted to projected changes in the frequency of severe wind and weather events with CC, such as increased frequency of hurricanes.

Green hydrogen and ammonia production

Green hydrogen & ammonia production plants are a relatively new type of renewable energy development that is being introduced in Nova Scotia. Production of green hydrogen can be carried out through "cracking" or hydrolysis of ammonia; this is a carbon-free way of producing energy that does not generate greenhouse gases if the initial energy source is from renewable power, such as wind turbines or photovoltaic generators (Rizi and Shin 2022).

Some additional coverage of the state of the climate in NS or Canada, with recent references to IPCC or federal and provincial reports on the attribution and impacts of CC, are likely needed to improve report rigour for Green Hydrogen projects. In addition, more in-depth consideration of pre-existing GHG sequestration on the landscape, as well as detailed GHG accounting through a combination of life-cycle analysis, projected energy use, literature review, or comparison to similar projects, could significantly improve the proponents' ability to account for (and therefore mitigate) GHGs over the lifetime of the project. Some additional consideration of what constitutes "significant" in the context of a project of this size is also likely needed. Although green power projects such as these may have a large up-front GHG footprint, they are often favourable overall by reducing long-term emissions relative to those generated by conventional energy sources for the same amount of energy. Nevertheless, this expectation should not exempt a project from providing an unbiased assessment of its significance in the context of provincial energy needs and emissions projections.

Mines

In recent years, a renewed interest in gold mining along the eastern shore region of Nova Scotia has led to several EAs for proposed gold mines. Nova Scotia has a long history of mining for precious metals, coal, and other resources, but the industry has waxed and waned over time due to shifting prices and technology (Nova Scotia Department of Mines 1976, Parsons *et al.* 2012). The toxic legacy of historical mining operations (Sivarajah *et al.* 2024, Walker *et al.* 2015, Bowes and Walker 2024) and potential CC impacts of these resource-intensive projects have, understandably, led to renewed criticism in the public domain (Jones 2023). Consequently, the analysis presented here is both timely and important for public discourse and improving sustainable development practices in the province.

The long lifespan and high investment requirements of mining projects probably contributed to their high scores in CC basics and adaptation, because such considerations are important to the economic viability of the project, resulting in a high standard of coverage. On the other hand, mine projects were scored lower than most other project types on their GHG accounting and mitigation, due to the self-serving significance determination and lack of mitigations. While the context of the province's GHG reduction goals is important to consider, it would be extremely unlikely for any single project to cause an annual increase of 1-8% in provincial GHG emissions. Such provincial or national thresholds are inappropriately high for significance determination (Hetmanchuk 2020). Given the current and predicted future availability of sustainable electricity sources in Nova Scotia (Department of Natural Resources and Renewables 2020), both concrete actions (e.g., rooftop solar generation over structures) and aspirational targets (e.g., future shifts to green hydrogen-powered haul vehicles; Figueiredo *et al.* 2023) could reasonably be included in mining EA reports. For those emissions that cannot be eliminated through behavioural or technological improvements, carbon offsets should be required, such as investments in restoration of local peatlands, salt marshes, or forests on degraded lands. Any such offsets must, however, be accompanied by locally-calibrated carbon accounting and monitoring to ensure unbiased estimation of carbon stocks or flux (Haya *et al.* 2023), and consider the time-scales associated with expected emissions, expected offsets, and provincial GHG-reduction goals to avoid problems such as "multi-gas transactions" (Allen *et al.* 2021).

Quarries

Quarry projects have considerable room for improvement when it comes to their EA reports. This low level of CC consideration was surprising given the almost unanimous consideration of it in other project types, and the fact that several EA consulting firms contributed to both quarry EAs and other project types that scored well on this category. On the other hand, the relatively small size of quarry expansion projects may bias such EA reports towards minimalist coverage of anything that is not strictly required by law, as the cost of expansive coverage for such impacts may threaten the financial viability of a small project itself.

Going forward, consultants and proponents should look for additional guidance from publications released by the province of Nova Scotia as to how to properly quantify and report GHG emissions expected to be released by a project (Province of Nova Scotia 2020). When multiple aggregate sources are available near an intended building project, planners should consult published resources to determine which types of materials have the smallest impact on the environment, and preferentially develop those over others. Quarry developers could then cite these decisions as evidence of GHG mitigation. For example, Qamhia *et al.* (2023) found that different types of aggregate, and the efficiency with which quarry by-products could be used, impacted the GHG footprint of the cement it was used to create. At a minimum, proponents of quarries should be able to estimate GHGs from the lifetime of the project and annual vehicular activity and the emissions that were produced from off-road construction vehicles, which appear to be the main source of emissions for these projects (Jassim *et al.* 2018). Like mines, plans for reducing emissions from fossil fuels via technological and behavioural changes to operations should be expected within the EAs for quarries, with both near-term plans and aspirational targets for clean power use.

Quarry proponents are also missing opportunities to contextualize their projects as an essential part of the province's Climate Action Plan (Province of Nova Scotia 2022), or as part of larger projects. Quarries typically are accessed for aggregate for most construction projects and therefore contribute to the Climate Action Plan by improving the efficiency of transportation infrastructure through improved road networks (concerns mitigation; Zhang *et al.* 2023), by enhancing protections against sea-level rise and severe storms through provision of locally sourced construction and stabilization materials (concerns adaptation; Anfuso *et al.* 2021), and more. Such values may be difficult to quantify on a quarry-by-quarry basis; a consortium- or province-led effort to quantify these values in broader terms would assist quarry developers with improving their

EA reports in the future, as would integration of quarry EAs into the projects for which they will be the primary source of aggregate material.

Waste treatment and disposal facilities

The lack of consistency on CC basics for waste treatment facilities is likely due, in part, to the diverse nature of the projects within this category; proposed projects ranged from waste oil or tire recycling to asbestos disposal to a dangerous waste storage facility, all of which have very different land- and water-use requirements and very different goals. Nevertheless, it will be important for such projects to improve on this category going forward, as it ensures that CC is at least being considered during project design phases. In addition, these projects were very closely aligned on scores for GHG accounting and mitigation and likely share much in common with respect to climate adaptation, suggesting that the group designation remained reasonable.

Concerning GHG accounting and mitigation, proponents may have neglected to consider the potential impacts and improvements their work could have on GHGs because the projects are primarily concerned with limiting environmental damage from waste products. As such, most are likely necessary to human health and the operation of other industries in the province, and likely to be approved regardless of their impact on GHGs. Nevertheless, as with mining and quarrying, many choices must be made in the design and operation of waste management facilities that can impact GHG emissions, and as such a full accounting of the anticipated impacts of a waste management facility on GHGs is a useful decision aid when considering opportunities to mitigate environmental harms.

Waste management facilities performed poorly on CC adaptation, a category which is arguably more important for such facilities than most. Facilities that store or dispose of hazardous waste could cause considerable harm if they are not built to a sufficient standard to endure the expected increases in frequency or severity of severe weather events. In this context, climate projections and tools, as well as technological and behavioural adaptations, are critical to protecting both infrastructure and human health.

General guidance for future EAs

The process of establishing a baseline for greenhouse gases (GHGs) in a study area can be challenging but may be approached in several ways. In the broad sense, baseline conditions are what exists in the absence of the project on the landscape, quantified in such a way that the potential impacts of the project can be predicted, and any subsequent changes resulting from the project can be measured (Hirsch 1980). In the context of CC, these include the GHGs stored by soil, vegetation, ice, water, or geological formations, and the greenhouse gases that are sequestered or emitted on an annual basis by those features. Many forms of land use change can reduce carbon storage and sequestration, particularly when deforestation is part of the change. Direct measurement of such features is possible but would likely be cost-prohibitive in many cases for an EA study. Nevertheless, several metrics can be inferred using pre-existing data that are freely available via government sources (e.g., GIS data on forest inventory and soil or ecosystem classification) in combination with empirical studies of greenhouse gases in similar landscapes. The forest industry has produced hundreds of studies on carbon storage and dynamics associated with forests of different compositions, ages, and sizes (Smyth *et al.* 2024). Studies of carbon storage and dynamics in wetlands and other habitats are fewer, but likely sufficient for the purpose of estimating baseline conditions within a reasonable range (Gallant *et al.* 2020, Kendall *et al.* 2021). For rare ecosystems or those not well represented by studies of greenhouse gas dynamics in the literature, industry should be encouraged to initiate and publish such a study as a form of compensation for expected damages, or governments could fund such work proactively to ensure industry has the required tools to produce high quality baseline studies in the future.

GHG accounting is, from an EA standpoint, relatively straightforward, given the plethora of published information that is now available. Depending on the intended operational life of the project, it may be most appropriate to account for GHGs in two or three phases: construction, operation, and, for projects of limited duration, decommissioning (Wu *et al.* 2014). GHG emissions during construction and decommissioning phases are dominated by emissions from manufacturing and transportation of building materials (Sizirici *et al.* 2021), and from generators or heavy equipment used during on-site activities (Province of Nova Scotia 2020). International standards for estimated greenhouse gas footprints of many classes of building materials are now supplied with the materials themselves on an emissions per kg or per tonne basis (I.S.O. 2006, 2013) or have been published in academic literature (Sizirici *et al.* 2021). These values can easily be extrapolated based on the combination of materials that will be used in a project. Emissions from transportation and construction equipment can be estimated based on the GHG footprint of the equipment or materials being used, the fraction of the equipment's lifetime that it will be used for, and the fuel required to operate the equipment (Province of Nova Scotia 2020). The operations phase GHGs stem primarily from power or fuel requirements for running equipment or heating buildings on an ongoing basis, and from the building materials used during the construction phase, as well as the proportion of the lifespan of the equipment for which it will be used.

Significance determination for the impacts of a project on greenhouse gases should be based on clear, legally binding standards, because without such standards proponents may apply variable standards of their own design to make projects appear less detrimental (Murray *et al.* 2018), or portray limited consultation with community stakeholders, who lack the expertise to fully represent their interests to the same extent as proponents, as tacit designation of nonsignificance (Singh *et al.* 2020). Many aspects of EAs (e.g., air and water-borne pollutants) are assessed relative to thresholds at which negative impacts become detectable on human or environmental health, referred to by some as "technical" thresholds (Murray *et al.* 2018). With the changes made to the Nova Scotia Environmental Assessment Act in 2018, projects with GHG emissions above 50,000 t CO_2 equivalents per year are required to report emissions to the government; the size at which this requirement is activated may constitute an appropriate threshold for "significance" in the case of certain large projects. Nevertheless, this standard would not apply to many small and mid-sized projects and therefore leaves far too much leeway for proponents to misrepresent GHG impacts as negligible in comparison to a reference point of their choosing (Murray *et al.* 2018). Some scholars have proposed their own strategies for significance determination with GHGs that hold some promise (Murphy and Gillam 2013). Nova Scotia Department of Environment itself suggested that, given the importance and urgency of reducing global GHGs, any emissions that result from development are significant, and should be reported and mitigated to as high a degree as possible (Nova Scotia Environment 2011).

As currently practiced, the EIA process in many jurisdictions is biased against finding significant negative impacts, or towards assumed effectiveness of poorly supported mitigation measures (Singh *et al.* 2020). However, as with determination of significance for impacts on human health from air or water-borne pollutants, an effective significance determination system should be set proactively by the government with the advice of scientists and CC experts and should be considered relative to the pre-existing baseline conditions on the landscape (Murray *et al.* 2018, Singh *et al.* 2020). Failure to adequately consider baseline conditions in determining the significance of projected changes in GHG emissions post development is equivalent to assuming a "zero baseline" (Soimakallio *et al.* 2015), which both implicitly undervalues ecosystem services and reduces projected impacts relative to a landscape with significant carbon sequestration potential.

Mitigation of GHG emissions is also relatively straightforward, albeit still limited in scope when it comes to heavy industry. Limiting the footprint of the project to the smallest area necessary, and progressively reclaiming sections of the footprint that are no longer used, should be a starting point. By preserving or restoring woody plants and active soils to the project area, the developer maintains more carbon sequestration and storage potential than would otherwise be the case. Behavioural adjustments are also relatively easy to implement and can have significant impacts on resulting emissions. All staff should be required to adhere to energy-conserving actions such as turning off vehicles rather than idling them (to the extent that engine maintenance practices permit) when not in transit, coordinating across sites to increase two-way hauling instead of moving empty trucks, using high-efficiency fuels, and maintaining equipment to the manufacturer's specifications for optimal efficiency (Lewis *et al.* 2009, 2011). Renewable energy sources should be used to power equipment, buildings, and vehicles whenever possible. Although replacements for heavy diesel-powered vehicles and equipment are not yet commercially available, more sustainable options are available for many other applications. For example, office, residential, and commercial buildings could have rooftop photovoltaic power generation incorporated into designs from the start, and smaller classes of vehicles used by the proponent could be powered by electric or hybrid electric engines. Finally, all companies taking on projects large enough to require an EA should be required to have long-term plans for replacing outdated and inefficient equipment with more sustainable versions at the equipment's end of life.

A final component of the EA process in Nova Scotia is to consider the impacts of the environment on the project. In the broad sense, this consideration is to ensure that proponents plan and carry out development activities with a clear sense of what building standards may be necessary to ensure the safety of staff, the soundness of critical infrastructure, and the health of nearby communities in case of extreme weather or natural disasters. Proponents typically evaluate such impacts by having engineers and planners consult maps, data, and risk assessments on the probability of floods, seismic activity, forest fires, coastal storm surge, and other potentially catastrophic disturbances for the study area, and by adjusting plans to ensure that infrastructure can withstand them. In recent years, the compounding impacts of CC on the frequency and severity of such events has been brought into sharp focus for many parts of Canada (Insurance Bureau of Canada 2024), emphasizing the need to consider large-scale events that would have been too unlikely to warrant consideration even 20 years ago. The simplest approach for adapting to a changing climate is to choose a more robust standard to build towards. For example, instead of ensuring that roads can withstand a 1 in 20-year flood, proponents could ensure that roads can withstand a 1 in 100-year flood. On the other hand, this approach may be more costly than is necessary and could make decommissioning more difficult. A more nuanced approach, where climate projections are explicitly incorporated into the planning process, is likely to yield a more realistic and efficient set of scenarios to which the plans can be adapted. Although incorporating climate projections into the planning process may seem intimidating to those who have not used them, there are many simple and accessible tools that are now available through government and nonprofit organizations to examine such expected effects as increased temperatures and fire activity, increased rainfall and flood risk, and expected sea level rise (Canadian Centre for Climate Services 2024, The Prairie Climate Centre 2019, Wang *et al.* 2016).

Finally, for larger or longer-lived projects, there may be considerable value in cumulative effects analysis, wherein the effects of both

CC and the project, as well as any interactions between them, on valued environmental components within the study area are simultaneously considered (Sinclair *et al.* 2017). No EA reports that we read had such analyses included, despite the potential value in doing so. For example, for projects that are expected to alter wetlands and watercourses, thereby impacting water temperatures and sediment loads, they would additionally need to consider the additive effects of CC-driven increases in water temperatures while the effects of the project persist, when determining whether their proposed alterations could negatively impact fish. Although such analyses may seem complex, the suite of modeling tools that are now available to consulting firms should simplify the process, particularly where such models are already regularly used to predict project impacts. Moreover, guidance on cumulative effects assessment is readily available for Canadian practitioners (IAAC 2018). This lack of cumulative effects assessment in Nova Scotian EAs appears to be primarily a legal and policy gap that could be addressed through regulatory changes (Northrup 2022).

To avoid damaging increases in global temperatures, massive reductions in carbon emissions are needed over the coming decades (IPCC 2018). As such, Nova Scotia has committed to 53% lower GHG emissions than levels in 2005 by 2030 and net zero GHG emissions by 2050 (Province of Nova Scotia 2022). Achieving these reductions will require significant actions by large industrial emitters, and likely significant changes to the legal frameworks within which these emitters operate. The EA process is well positioned to become a standardized planning tool for developers to transparently consider and plan reductions in their GHG emissions, as well as to plan for and adapt to emerging risks associated with CC. We hope that the data, analysis, and perspectives shared in this report have improved awareness of the many tools, resources, and approaches that planners can use to immediately improve their EA reports. Moreover, we hope that we have clarified some of the regulatory and research gaps that currently inhibit more effective consideration of CC in the EA process, such that these gaps can be appropriately addressed in the coming years.

Acknowledgements We wish to thank Dr. Peter Duinker for several helpful discussions, reviews of draft manuscripts, and recommendations on study design. We also thank Tony Walker, Ian Stewart, and an anonymous referee for their constructive and insightful reviews, which greatly improved the manuscript. We thank Dalhousie University and the Nova Scotia Museum for supporting this work via course credit for LF and salaried time for SRH, respectively.

REFERENCES

Allen, M., Tanaka, K., Macey, A., Cain, M., Jenkins, S., Lynch, J. & Smith, M. (2021). Ensuring that offsets and other internationally transferred mitigation outcomes contribute effectively to limiting global warming. *Environmental Research Letters* 16(7): 1-9. 074009. doi.org/10.1088/1748-9326/abfcf9

Anfuso, G., Postacchini, M., di Luccio, D. & Benassai, G. (2021). Coastal sensitivity/vulnerability characterization and adaptation strategies: A review. In *Journal of Marine Science and Engineering* 9(1): 1-29. doi.org/10.3390/jmse9010072

Anthonissen, J., Van den bergh, W. & Braet, J. (2016). Review and environmental impact assessment of green technologies for base courses in bituminous pavements. *Environmental Impact Assessment Review* 60: 139-147. doi.org/10.1016/j.eiar.2016.04.005

Avetisyan, H.G., Miller-Hooks, E. & Melanta, S. (2012). Decision Models to Support Greenhouse Gas Emissions Reduction from Transportation Construction Projects. *Journal of Construction Engineering and Management* 138(5): 631-641. doi.org/10.1061/(asce)co.1943-7862.0000477

Barrow, C.J. (1997). Introduction. In: Environmental and Social Impact Assessment: An Introduction. Oxford University Press, New York, NY, USA. p. 1-14.

Bowes, B.L. & Walker, T.R. (2024). Effective management of endangered Blanding's Turtle (*Emydoidea blandingii*) populations in Nova Scotia, Canada, requires consideration of threats posed by legacy gold mine contamination. *Proceedings of the Nova Scotian Institute of Science* 53(2): 289-304.

Canadian Centre for Climate Services. (2024). ClimateData.ca: Climate Data for a Resilient Canada. Available from: climatedata.ca/ (Accessed 3 December 2024)

Department of Natural Resources and Renewables. (2020). Nova Scotia's 2030 Clean Power Plan Nova Scotia. Halifax, NS.

East Coast Aquatics Inc. (2017). Arlington Heights Waste Disposal Facility. Bridgetown, NS.

Figueiredo, R.L., da Silva, J.M. & Ortiz, C.E.A. (2023). Green hydrogen: Decarbonization in mining – Review. *Cleaner Energy Systems* 5: 100075. doi.org/10.1016/j.cles.2023.100075

Gallant, K., Withey, P., Risk, D., van Kooten, G.C. & Spafford, L. (2020). Measurement and economic valuation of carbon sequestration in Nova Scotian wetlands. *Ecological Economics* 171 (February): 106619. doi.org/10.1016/j.ecolecon.2020.106619

Garbary, D.J. & Hill, N.M. (2021). Climate change in Nova Scotia: temperature increases from 1961 to 2020. *Proceedings of the Nova Scotian Institute of Science* 51(2): 411-442.

Gilbert, L. (2021). The Impacts of Climate Change on Ticks and Tick-Borne Disease Risk. *Annual Review of Entomology* 66(1): 373-388. doi.org/10.1146/annurev-ento-052720-094533

Haya, B.K., Evans, S., Brown, L., Bukoski, J., Butsic, V., Cabiyo, B., Jacobson, R., Kerr, A., Potts, M. & Sanchez, D.L. (2023). Comprehensive review of carbon quantification by improved forest management offset protocols. *Frontiers in Forests and Global Change* 6: 958879. doi.org/10.3389/ffgc.2023.958879

Hetmanchuk, K. (2020). Consideration of climate change mitigation in Canadian environmental assessment: intention and implementation. *Impact Assessment and Project Appraisal* 38(3): 181-193. doi.org/10.1080/14615517.2019.1625252

Hirsch, A. (1980). The baseline study as a tool in environmental impact assessment. In: Speth, G. (Ed). Biological evaluation of environmental impacts: Proceedings of a symposium at the 1976 meeting of the Ecological Society of America. Council on Environmental Quality and the U.S. Fish and Wildlife Service, Washington, D.C., USA. p. 84.

Northrup, T. (2022). Cumulative Effects FAQ Materials for the Website of the Confederacy of Mainland Mi'kmaq. Confederacy of Mainland Mi'kmaq, Millbrook, NS. cmmns.com/wp-content/uploads/2023/06/Cumulative-Effects-FAQ-Materials-for-CMM-Website_Draft-2_24-March-2022-003.pdf

Rizi, H.A.Y. & Shin, D. (2022). Green Hydrogen Production Technologies from Ammonia Cracking. *Energies* 15(21).

IAAC. (2018). Technical Guidance for Assessing Cumulative Environmental Effects under the *Canadian Environmental Assessment Act, 2012*, Version 2. Impact Assessment Agency of Canada, Environment and Climate Change Canada, Ottawa, ON. www.canada.ca/en/impact-assessment-agency/services/policy-guidance/assessing-cumulative-environmental-effects-ceaa2012.html

Insurance Bureau of Canada. (2024). One-Year Update Following 2023 Nova Scotia Wildfires and Flooding. Halifax, NS.

IPCC. (2018). Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. & Waterfield, T. (Eds). Intergovernmental Panel on Climate Change, World Meteorological Organization, Geneva, Switzerland. 616 p.

I.S.O. (2006). I.S.O. 14044, Environmental Management – Life Cycle Assessment – Requirements and Guidelines. Geneva, Switzerland.

I.S.O. (2013). I.S.O. 14067, Greenhouse Gases – Carbon footprint of products – Requirements and Guidelines for Quantification and Communication. Geneva, Switzerland.

Jain, P., Barber, Q.E., Taylor, S.W., Whitman, E., Castellanos Acuna, D., Boulanger, Y., Chavardès, R.D., Chen, J., Englefield, P., Flannigan, M., Girardin, M.P., Hanes, C.C., Little, J., Morrison, K., Skakun, R.S., Thompson, D.K., Wang, X. & Parisien, M.A. (2024). Drivers and Impacts of the Record-Breaking 2023 Wildfire Season in Canada. *Nature Communications* 15(1): 6764. doi.org/10.1038/s41467-024-51154-7

Jassim, H.S.H., Lu, W. & Olofsson, T. (2018). Assessing energy consumption and carbon dioxide emissions of off-highway trucks in earthwork operations: An artificial neural network model. *Journal of Cleaner Production* 198: 364-380. doi.org/10.1016/j.jclepro.2018.07.002

Jiricka, A., Formayer, H., Schmidt, A., Völler, S., Leitner, M., Fischer, T.B. & Wachter, T.F. (2016). Consideration of climate change impacts and adaptation in EIA practice - Perspectives of actors in Austria and Germany. *Environmental Impact Assessment Review* 57: 78-88. doi.org/10.1016/j.eiar.2015.11.010

Jones, A.M. (2023). Nova Scotia's modern 'gold rush' poses huge risk to climate, expert warns. *CTV News (website)*. www.ctvnews.ca/

Kendall, R.A., Harper, K.A., Burton, D. & Hamdan, K. (2021). The role of temperate treed swamps as a carbon sink in southwestern Nova Scotia. *Canadian Journal of Forest Research* 51(1): 78-88. doi.org/10.1139/cjfr-2019-0311

Lewis, P., Frey, H.C. & Rasdorf, W. (2009). Development and use of emissions inventories for construction vehicles. *Transportation Research Record* 2123: 46-53. doi.org/10.3141/2123-06

Lewis, P., Leming, M. & Rasdorf, W. (2011). Impact of Engine Idling on Fuel Use and CO_2 Emissions of Nonroad Diesel Construction Equipment. *Journal of Management in Engineering* 28(1): 31-38.

Ma, F., Sha, A., Lin, R., Huang, Y. & Wang, C. (2016). Greenhouse gas emissions from asphalt pavement construction: A case study in China. *International Journal of Environmental Research and Public Health* 13(3): 351-365. doi.org/10.3390/ijerph13030351

MacKinnon, A.J., Duinker, P.N. & Walker, T.R. (2018). Emerging Concepts for Science in EIA. Chapter 6 from The Application of Science in Environmental Impact Assessment. MacKinnon, A.J., Duinker, P.N., & Walker, T.R., eds. Routledge Focus, London, UK. doi.org/10.4324/9781351173445

Mekis, É., Vincent, L.A., Shephard, M.W. & Zhang, X. (2015). Observed Trends in Severe Weather Conditions Based on Humidex, Wind Chill, and Heavy Rainfall Events in Canada for 1953-2012. *Atmosphere - Ocean* 53(4): 383-397. doi.org/10.1080/07055900.2015.1086970

Murphy, M.R. & Gillam, K.M. (2013). Greenhouse Gases and Climate in Environmental Impact Assessment – Practical Guidance. In: 33rd Annual Conference of the International Association for Impact Assessment. International Association for Impact Assessment, Calgary, AB.

Murray, C.C., Wong, J., Singh, G.G., Mach, M., Lerner, J., Ranieri, B., Peterson St-Laurent, G., Guimaraes, A. & Chan, K.M.A. (2018). The Insignificance of Thresholds in Environmental Impact Assessment: An Illustrative Case Study in Canada. *Environmental Management* 61(6): 1062-1071. doi.org/10.1007/s00267-018-1025-6

Nova Scotia Environmental Assessment Branch. (2001). A Proponents Guide to Environmental Assessment. Nova Scotia Department of the Environment, Halifax, NS.

Nova Scotia Department of Environment and Climate Change. (2024). Environmental Assessment: Projects. Available from: novascotia.ca/nse/ea/projects.asp (Accessed 25 February 2024)

Nova Scotia Department of Mines. (1976). A brief history of mining and geology in Nova Scotia, Halifax, NS.

Nova Scotia Environment. (2011). Guide to Considering Climate Change in Environmental Assessments in Nova Scotia. Nova Scotia Department of Environment, Halifax, NS.

Ollerhead, J. (2023). Climate change and the coasts of Maritime Canada: expect the previously unexpected. *Proceedings of the Nova Scotian Institute of Science* 53: 19-27. doi.org/doi.org/10.15273/pnsis.v53i1.11808

Padey, P., Blanc, I., Le Boulch, D. & Xiusheng, Z. (2012). A Simplified Life Cycle Approach for Assessing Greenhouse Gas Emissions of Wind Electricity. *Journal of Industrial Ecology* 16 (suppl.1). doi.org/10.1111/j.1530-9290.2012.00466.x

Parsons, M.B., LeBlanc, K.W.G., Hall, G.E.M., Sangster, A.L., Vaive, J.E. & Pelchat, P. (2012). Environmental geochemistry of tailings, sediments and surface waters collected from 14 historical gold mining districts in Nova Scotia; Geological Survey of Canada, Ottawa, ON. Open File 7150. doi:10.4095/291923.

Pecl, G.T., Araújo, M.B., Bell, J.D., Blanchard, J., Bonebrake, T.C., Chen, I.C., Clark, T.D., Colwell, R.K., Danielsen, F., Evengård, B., Falconi, L., Ferrier, S., Frusher, S., Garcia, R.A., Griffis, R.B., Hobday, A.J., Janion-Scheepers, C., Jarzyna, M.A., Jennings, S., Lenoir, J., Linnetved, H.I., Martin, V.Y., McCormack, P.C., McDonald, J., Mitchell, N.J., Mustonen, T., Pandolfi, J.M., Pettorelli, N., Popova, E., Robinson, S.A., Scheffers, B.R., Shaw, J.D., Sorte, C.J.B., Strugnell, J.M., Sunday, J.M., Tuanmu, M.N., Vergés, A., Villanueva, C., Wernberg, T., Wapstra, E. & Williams, S.E. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science* 355(6332): 1389. March 31, 2017.

Province of Nova Scotia. (1995). Nova Scotia Royal Gazette Part II Environmental Assessment Regulations made under Section 49 of the Environment Act. Canada.

Province of Nova Scotia. (2018). Quantification, Reporting and Verification Regulations made under Section 112Q of the Environment Act. Nova Scotia Provincial Legislature, Halifax, NS.

Province of Nova Scotia. (2020). Standards for Quantification, Reporting, and Verification of Greenhouse Gas Emissions. Nova Scotia Department of Environment, Halifax, NS.

Province of Nova Scotia. (2022). Our climate, our future: Nova Scotia's climate change plan for clean growth. Halifax, NS.

Qamhia, I.I.A., Tutumluer, E. & Ozer, H. (2023). Life Cycle Assessment of Aggregate Quarry By-Product Fines in Pavement Applications. *Sustainability (Switzerland)* 15(13): 10705. doi.org/10.3390/su151310705

Rubenstein, M.A., Weiskopf, S.R., Bertrand, R., Carter, S.L., Comte, L., Eaton, M.J., Johnson, C.G., Lenoir, J., Lynch, A.J., Miller, B.W., Morelli, T.L., Rodriguez, M.A., Terando, A. & Thompson, L.M. (2023). Climate change and the global redistribution of biodiversity: substantial variation in empirical support for expected range shifts. *Environmental Evidence* 12(1): 7. doi.org/10.1186/s13750-023-00296-0

Schumacher, E., Brown, A., Williams, M., Romero-Severson, J., Beardmore, T. & Hoban, S. (2022). Range shifts in butternut, a rare, endangered tree, in response to past climate and modern conditions. *Journal of Biogeography* 49(5): 866-878.

Sinclair, A.J., Doelle, M. & Duinker, P.N. (2017). Looking up, down, and sideways: Reconceiving cumulative effects assessment as a mindset. *Environmental Impact Assessment Review* 62: 183-194. doi.org/10.1016/j.eiar.2016.04.007

Singh, G.G., Lerner, J., Mach, M., Murray, C.C., Ranieri, B., St-Laurent, G.P., Wong, J., Guimaraes, A., Yunda-Guarin, G., Satterfield, T. & Chan, K.M.A. (2020). Scientific shortcomings in environmental impact statements internationally. *People and Nature* 2(2): 369-379. doi.org/10.1002/pan3.10081

Sivarajah, B., Campbell, L.M., Smol, J.P., Vermaire, J.C. & Kurek, J. (2024). Historical gold mining increased metal(loid) concentrations in lake sediments from Nova Scotia, Canada. *Facets* 9: 1-14. doi.org/10.1139/facets-2023-0063

Sizirici, B., Fseha, Y., Cho, C.S., Yildiz, I. & Byon, Y.J. (2021). A review of carbon footprint reduction in construction industry, from design to operation. *Materials* 14(20): 6094. doi.org/10.3390/ma14206094

Smyth, C., Metsaranta, J., Tompalski, P., Hararuk, O. & Le Noble, S. (2024). 10-year progress on Forest Carbon Research in Canada. *Environmental Reviews* 32: 611-637. doi.org/10.1139/er-2024-0001

Soimakallio, S., Cowie, A., Brandão, M., Finnveden, G., Ekvall, T., Erlandsson, M., Koponen, K. & Karlsson, P.E. (2015). Attributional life cycle assessment: is a land-use baseline necessary? *International Journal of Life Cycle Assessment* 20(10): 1364-1375.

Stantec Consulting Ltd. (2017). Highway 101 Digby to Marshalltown Corridor: environmental assessment registration. Dartmouth, NS.

Strum Consulting Ltd. (2023a). Ellershouse 3 Wind Project. Halifax, NS.

Strum Consulting Ltd. (2023b). Mersey River wind farm: environmental assessment registration. Bedford, NS.

The Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment. (2003). Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners. Ottawa, ON.

The Prairie Climate Centre. (2019). Climate Atlas of Canada, version 2 using BCCAQv2 climate model data. Available from: climateatlas.ca/ (Accessed 3 December 2024)

Vincent, L.A., Zhang, X., Mekis, É., Wan, H. & Bush, E.J. (2018). Changes in Canada's Climate: Trends in Indices Based on Daily Temperature and Precipitation Data. *Atmosphere - Ocean* 56(5): 332-349. doi.org/10.1080/07055900.2018.1514579

Walker, T.R. & Grant, J. (2015). Metal(loid)s in sediment, lobster and mussel tissues near historical gold mine sites. *Marine Pollution Bulletin* 101(1): 404-408. doi.org/10.1016/j.marpolbul.2015.10.010

Wang, T., Hamann, A., Spittlehouse, D. & Carroll., C. (2016). Locally downscaled and spatially customizable climate data for historical and future periods for North America. *PLoS ONE* 11(6): e0156720.

WSP Consulting. (2023). Highway 101 Cambridge Interchange and connector roads EA registration document. Dartmouth, NS.

Wu, P., Xia, B. & Zhao, X. (2014). The importance of use and end-of-life phases to the life cycle greenhouse gas (GHG) emissions of concrete - A review. *Renewable and Sustainable Energy Reviews* 37: 360-369.

Zhang, L., Chen, H., Li, S. & Liu, Y. (2023). How road network transformation may be associated with reduced carbon emissions: An exploratory analysis of 19 major Chinese cities. *Sustainable Cities and Society* 95: 104575. doi.org/10.1016/j.scs.2023.104575

APPENDIX A: MEAN SCORES WITHIN EACH CATEGORY ACROSS PROJECT TYPES

Appendix Table 1

Modal scores of 38 different EAs on five questions about Climate Change basics. For categories with no true mode, the median values are presented.

Project type	Mentioned?	Acknowledged as problem?	Obfuscating statements absent?	NS guides & reporting standards cited?	Other literature used?	All
Green Hydrogen	1	0	-0.5	0.5	1	2
Mine	1	1	1	1	0	4
Quarry	1	1	0	0	1	1
Roads & Corridors	1	1	1	1	1	5
Wind Farm	1	1	1	0	1	4
Waste Treatment	1	1	1	0	1	3
All	1	1	1	0	1	4

Appendix Table 2

Modal scores of 38 different EAs for five questions about GHG accounting. For categories with no true mode, the median values are presented.

Project type	Present?	Estimates reasonable?	Assumptions appropriate?	Sequestration considered?	Significance determination appropriate?	All
Green Hydrogen	1	0.5	0.5	0	0	2
Mine	1	1	1	0	-1	2
Quarry	0	0	0	0	0	0
Road / Corridor	1	1	1	1	1	5
Wind Farm	1	1	1	0	1	4
Waste Treatment	0	0	0	0	0	0
All	1	0	0	0	1	0

Appendix Table 3

Modal scores of 38 different EAs for five questions about GHG mitigation. For categories with no true mode, the median values are presented.

Project type	Present?	Behavioural reductions?	Tech-based reductions?	Offsets / compensation	Enforcement?	All
Green Hydrogen	1	1	1	0.5	0.5	4
Mine	1	1	0	0	0	2
Quarry	1	1	0	0	0	3
Road / Corridor	1	1	0	1	1	4
Wind Farm	1	1	1	0	0	3
Waste Treatment	1	0	0	0	0	2
All	1	1	0	0	0	3

Appendix Table 4

Modal scores of 38 different EAs for five questions about Climate Change adaptation. For categories with no true mode, the median values are presented.

Project type	Present?	Behavioural (incl. geospatial)	Technological	Projections/ tools used?	All
Green Hydrogen	1	1	0.5	0.5	3
Mine	1	0	1	0	2
Quarry	1	1	0	0	2
Roads & Corridors	1	1	0	1	3
Wind Farm	1	1	0	0	2
Waste Treatment	1	1	0	0	2
All	1	1	0	0	2

APPENDIX B: LIST OF EA PROJECTS REVIEWED FOR THIS REPORT

Project name	Proponent	Project type	Consulting firm	Year
Bear Head Energy Green Hydrogen and Ammonia Production, Storage and Loading Facility	Bear Head Energy Inc.	Green Hydrogen & Ammonia Production Plant	Stantec Consulting Ltd.	2023
EverWind Point Tupper Green Hydrogen/ Ammonia Project - Phase 1	EverWind Fuels Company	Green Hydrogen & Ammonia Production Plant	Strum	2023
Beaver Dam Mine	Atlantic Gold	Mine	GHD & McCallum	2019
Goldboro Gold Mine	Signal Gold Inc.	Mine	GHD & McCallum	2022
Fifteen Mile Stream Gold Project	Atlantic Gold	Mine	MER	2021
Walden Quarry Expansion Project	Municipal Enterprises Ltd	Quarry	McCallum Environmental Ltd.	2023
Middle River Pit Expansion Project, Victoria County	Municipal Enterprises Ltd	Quarry	Envirosphere	2023
Blair Road Pit Expansion Project	The Shaw Group Limited	Quarry	Englobe	2023
Granite Village Quarry Expansion Project	Municipal Enterprises Ltd	Quarry	Municipal Enterprises Ltd.	2023
Spicer North Mountain Quarry Expansion Project	B. Spicer Construction Ltd.	Quarry	East Cost Aquatics Inc.	2020

Appendix B cont'd

Project Name	Proponent	Project Type	Consulting firm	Year
Sheet Harbour Aggregate Quarry Project	Dexter Construction Company Limited	Quarry	GHD	2019
Money Point Quarry Expansion Project	Dexter Construction Company Limited	Quarry	Dexter Construction Company Limited	2018
Highway 101 Digby to Marshalltown Corridor Project	Nova Scotia Department of Transportation and Infrastructure Renewal	Roads & Corridors	Stantec Consulting Ltd.	2017
Highway 101 Twinning Three Mile Plains to Falmouth Project	Nova Scotia Department of Transportation and Infrastructure Renewal	Roads & Corridors	Stantec Consulting Ltd.	2017
Highway 107 Burnside to Bedford Project	Nova Scotia Department of Transportation and Infrastructure Renewal	Roads & Corridors	Dillon	2018
Highway 102 Aerotech Connector Road project	Nova Scotia Department of Transportation and Infrastructure Renewal	Roads & Corridors	Wood	2021
Highway 104 Twinning Sutherlands River to Antigonish Project	Nova Scotia Department of Transportation and Infrastructure Renewal	Roads & Corridors	CBCL	2019
Highway 101 Cambridge Interchange and Connector Road Project	Department of Public Works	Roads & Corridors	WSP Canada Inc.	2023
NS-NB Reliability Inertie Project	Nova Scotia Power Inc	Roads & Corridors	Nova Scotia Power Inc	2023

Kmtnuk Wind Power Project	Kmtnuk Wind Ltd.	Wind Farm	Strum	2023
Weavers Mountain Wind Energy Project	WEB Weavers Mountain Wind Limited Partnership	Wind Farm	Strum	2023
Ellershouse 3 Wind Project	Ellershouse 3 GP Inc, Annapolis Valley First Nation and Potentia Renewables Canada Holdings LP (i.e., Ellershouse 3 Wind Limited Partnership)	Wind Farm	Strum	2023
Wedgeport Wind Farm Project	Wedgeport Wind Farm GP Inc, Elemental Energy Renewables Inc, Stevens Wind Ltd and Sipekne'katik First Nation, (i.e., Wedgeport Wind Farm Limited Partnership)	Wind Farm	McCallum Environmental Ltd.	2023
Higgins Mountain Wind Farm Project	Higgins Mountain Wind Farm General Partner Inc, Sipekne'katik First Nation, Elemental Energy Renewables Inc and Stevens Wind Ltd (i.e., Higgins Mountain Wind Farm Limited Partnership)	Wind Farm	Strum	2023
Mersey River Wind Farm	Mersey River Wind Inc.	Wind Farm	Strum	2023
Goose Harbour Lake Wind Farm Project	PHP Wind GP Inc and PHP Wind LP Inc, (i.e., Port Hawkesbury Paper Wind Ltd Partnership)	Wind Farm	Strum	2023
Westchester Wind Project	Natural Forces Developments LP	Wind Farm	Natural Forces Developments LP	2023

Appendix B cont'd

Project Name	Proponent	Project Type	Consulting firm	Year
Goose Harbour Lake Wind Farm	Port Hawkesbury Paper Wind	Wind Farm	Strum	2023
Bear Lake Wind Power Project	Bear Lake Wind Ltd	Wind Farm	Strum	2023
Ellershouse Windfarm Expansion Project	Alternative Resource Energy Authority	Wind Farm	Strum	2017
New Victoria Community Wind Power Project	Celtic Current Limited Partnership	Wind Farm	Celctic Current LP.	2016
Envirosoil Limited - Waste Oil Recycling and Water Treatment Facility Project	Envirosoil Limited	Waste Treatment	Wind Farm+D22+D34+ D34:D40	2023
Waste Dangerous and Non-Dangerous Goods Temporary Storage Facility	Envirosystems Incorporated	Waste Treatment	GHD	2020
Asbestos Waste Disposal Cell Project	Colchester Containers Limited	Waste Treatment	Englobe	2019
Pyrolysis Plant Project	Sustane Chester Incorporated	Waste Treatment	Strum	2018
Asbestos Disposal Facility	Yarmouth County Solid Waste Management Authority	Waste Treatment	Fracflow Consultants Inc.	2019
Asbestos Waste Disposal Facility Project	Arlington Heights C&D Limited	Waste Treatment	East Cost Aquatics Inc.	2017
Lower Carbon Fuel: Tire Derived Fuel (TDF) System	Lafarge Canada Inc.	Waste Treatment	Lafarge	2017

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 305-335

WHO HAS SEEN THE WIND? A NATURAL HISTORY OF STORM WINDS IN NOVA SCOTIA, 1957-2024

DAVID J. GARBARY[1*] AND NICHOLAS M. HILL[2]

[1]*Department of Biology, St. Francis Xavier University*
Antigonish, NS B2G 2W5

[2]*Coordinator, Southwest Biosphere Reserve Association*
424 Bentley Road, Berwick, NS B0P 1E0

ABSTRACT

The natural history of storm winds is described for Nova Scotia from the late 1950s to 2024. The overall pattern was a decline from greater storm frequency and intensity in the 1960s to minimal levels 2000-2011, and a subsequent return to levels experienced in the 1970s and 1980s. Patterns were consistent in five wind metrics: (1) maximum provincial wind gust; (2) mean of annual wind maximum from the five sites; (3) annual mean of monthly maxima; (4) number of storm days (i.e., wind $\geq$ 75 km h^{-1}); and (5) number of months per year with maximum wind $\geq$ 75 km h^{-1}). Linear regression equations were significant in both the declining and increasing years. These results are consistent with continent-wide wind stilling and recovery. Despite significant temperature increases since 1998 and an increase in wind metrics since the early 2000s, the overall relationship between wind and temperature since the 1950s has been negative. These results are discussed in light of oceanographic events including periods of La Niña, Atlantic Multidecadal Oscillation, and the development of ocean hotspots. Increasing winter temperatures and winds are predicted to have a negative effect on plant communities along the Atlantic coast of Nova Scotia.

Keywords: Atlantic Multidecadal Oscillation, climate change, ocean hotspots, storms, wind stilling

INTRODUCTION

Studies of climate change have focussed primarily on temperature and precipitation, and the effects of global warming on both terrestrial and aquatic realms (IPCC 2013, 2022). Wind has received less attention, yet the importance of its consequences for the biota and human

* Author to whom correspondence should be addressed: dgarbary@gmail.com

infrastructure is undeniable. While the causes of wind in terms of major air circulation patterns is understood to result from changes in air pressure and temperature, long-term patterns of change in wind intensity and their causes are not well understood, nor do they fit neatly into the context of human-induced climate change. An exception is the increase in ocean water temperature and its association with the increasing intensity of tropical cyclones (Goldenberg *et al.* 2001, Young *et al.* 2011, Walsh *et al.* 2019).

Long-term changes in storm frequency and intensity are important components of understanding weather as a component of overall climate change. In addition, wind impacts the physiology of plants and selects among growth forms based on height, elasticity, and strength. In eastern North America, wind sculpts the ericaceous balds of the Appalachians (Cain 1930, Bliss 1963), as it does the tuckamore (stunted trees, mainly spruce and fir) of coastal Nova Scotia and Newfoundland and Labrador. The stress of wind on tree physiology, particularly in concert with other stresses, such as soil infertility, means that changes in wind strength and timing can have major economic and ecological impacts on forestry and plant communities (e.g., Robichaud and Bégin 1997, Steenberg *et al.* 2011, Mitchell 2012, Taylor *et al.* 2020, Gardiner 2021). In addition, as Nova Scotia converts from coal and petroleum to more wind (and solar) to generate electricity, trends in wind become economically significant (Murthy and Rahi 2017).

Given the significance of changes in wind and the lack of understanding of this aspect of climate in Nova Scotia, we take two approaches to wind. First, we test the logical connection between climate change in the form of increasing heat in the system and climate change represented by shifting patterns in the wind regime. If differences in heat make wind, we should expect a relationship between these two elements of weather. We evaluate this hypothesis for Nova Scotia over the last 65 years using the temperature record where an increase in temperature of about a 1°C has occurred over this period (Garbary and Hill 2021, 2025). Second, we explore the patterns of change in 'wind' as viewed primarily from the perspective of storm winds and their change over time and with season. Long-term declines in wind velocity have been described associated with continental land masses; this phenomenon is termed 'wind stilling' and has been characterized from the late 1950s to the early 2000s (e.g., Klink 1999, Smits *et al.* 2005, Xu *et al.* 2006, Roderick *et al.* 2007, McVicar *et al.* 2008, 2012, Vautard *et al.* 2010, Azorin-Molina 2021). More recent accounts describe a reversal of the stilling process (Pirazzoli and Tomasin 2003, Azorin-Molina *et al.* 2016, Yang *et al.* 2021, Ultrabo-Carazo *et al.* 2022). Wind stilling and its reversal may be part of inherent climate variability rather than human-induced climate change (Wohland *et al.* 2021). Regardless of its cause, the wind record from Nova Scotia allows us to assess wind stilling and its reversal on a local scale. Our approach to understanding wind is to describe the pattern of change in a context that could be understood by non-climatologists. Our focus is on natural history (e.g., De Villiers 2006), especially of the terrestrial vegetation, rather than the underlying climatic mechanisms (e.g., Bichet *et al.* 2012, Lucio-Eceiza *et al.* 2020, Wohland *et al.* 2021).

We address the following questions with respect to climate in Nova Scotia over the past 65 years:

1. Is there a relationship between changing patterns of temperature and wind?
2. Have storm winds changed in frequency and intensity over this period?
3. Have there been seasonal changes in storm frequency and intensity?
4. To what extent has the phenomenon of wind stilling occurred regionally, and has the reversal of this process occurred?
5. Will changes in wind impact terrestrial plant communities in Nova Scotia?

MATERIAL AND METHODS

Selection of climate data

Data reflecting strong winds (i.e., gale force and higher) and monthly maxima were selected to avoid the complications raised in previous studies associated with much larger geographic areas and with average wind velocity (Klink 1999, Wan *et al.* 2010, Dunn *et al.* 2022). Maximum monthly gust strength throughout the year and number days per month and year with gusts ≥ 75 km h^{-1} were selected to evaluate changes in storm variables from the late 1950s to 2024. Wind data were extracted manually from the Government of Canada webpage titled Historical Climate Data (2025). Five Nova Scotia sites

(Table 1) were used that had relatively complete datasets from the late 1950s to 2024. Whereas instrumentation height for monitoring wind speed has changed at some Canadian weather stations, none of those used here were impacted by these changes (Richards and Abuamer 2007).

Table 1 **Weather stations in Nova Scotia used for analysis of storm intensity and frequency. These are domestic or military airports. Abbreviation: A, airport. climate.weather.gc.ca/historical_data/search_historic_data_e.html**

Site (weather station number)	Years	Latitude	Longitude	Elevation
Greenwood A (8202000)	1957-2024	44°59’00”	64°55’0”	28 m
Halifax Stanfield International A (8202249, 8202251)	1961-2024	44°52’5”	63°30’3”	145 m
Shearwater A and Shearwater RCS (8205090, 8205092)	1956-2024	44°38’0”	63°30’0”	44 m
Sydney A (8205700, 8205701)	1958-2024	46°09’4”	60°02’5”	61 m
Yarmouth A (8206495, 8206496)	1958-2024	43°49’3”	66°05’1”	43 m

These sites are either military or domestic airports. While multiple station numbers were used for four sites, these were in the same location except for the two Shearwater sites where wind data stopped at Shearwater A in 2004, and resumed at Shearwater RCS in 2008. For each month, we extracted the maximum wind gust speed and the number of days per month with gusts ≥ 75 km $h^{-1.}$ These we term ‘storm days’, and this threshold wind velocity corresponds to a strong gale and wind category 9 on the Beaufort scale. This wind velocity is sufficient to break branches on trees. These data were then organized for each site to evaluate annual and monthly changes in: (1) annual maximum wind gust (AM) for the province as a whole, as represented by the five stations with discrete locations, (2) mean annual maximum wind (MAM) from all sites, (3) annual mean of monthly maxima (MMM), (4) number of storm days per month (SD), (5) number of months per year with storms (SM). These metrics account for both stochastic events (i.e., AM) and those associated with seasonal variation and overall climatic trends. Given the limited size of Nova Scotia and the large areas covered by storm paths across the province (e.g., Taylor *et al.* 2020), one would expect these metrics to be highly correlated. After analyzing each metric independently, we then combined them into a single value by standardizing the five metrics, using the Excel function STANDARDIZE, i.e., giving each metric a mean of zero and a standard deviation of 1, and then determining the mean for each year.

To determine if the different sites had similar patterns of changing wind climate, we evaluated the four wind variables (AM, MMM, SD, and SM) together for each site. We first standardized each metric for a given site. Means for each year were determined and a three-year rolling average was calculated in Excel. Three linear regression equations were calculated: (1) over the entire period (1958-2024), (2) from 1958 to the low value in the sequence, and (3) from the low point in the sequence to 2024. If the slopes of these regression equations were significant and in the same direction as the means of the wind metrics, the differences between sites were ignored. This justified the focus on the trends in the wind metrics that incorporated the five sites.

Statistical analyses were carried out using Excel (Microsoft Corporation 2018) for descriptive statistics, with linear regression calculated using GraphPad (2023); and normality tests used an online Shapiro-Wilk test calculator (Statistics Kingdom, 2024). Evaluation of means of monthly wind metrics was done by calculating the average value for the five sites by month and smoothing the values using a three-year rolling average (i.e., 1958-1960, 1959-1961, 1960-1962…). Given that storms are the right-hand tail of wind distribution, much of the data are not normally distributed; significance was based on $P < 0.05$.

RESULTS

Mean annual temperature

There was an overall temperature increase across Nova Scotia of about 1.0°C (Fig 1). Based on the linear regression this change is highly significant (slope = 0.0271°C per year, $R^2 = 0.4150$, $P < 0.0001$). Despite the significance of the overall change, the temperature record resolved into two segments with a step change occurring between 1997 and 1998. This was previously shown by Garbary and Hill (2021, 2025), with each segment showing a different pattern. The early period showed no change (slope = 0.0003°C per year, $R^2 < 0.00001$, $P = 0.9669$), whereas the recent period had a positive trend (slope = 0.0319°C per year, $R^2 = 0.138$, $P = 0.056$). The early and recent periods had annual mean temperatures of 6.3 ± 0.5°C and 7.4 ± 0.7°C,

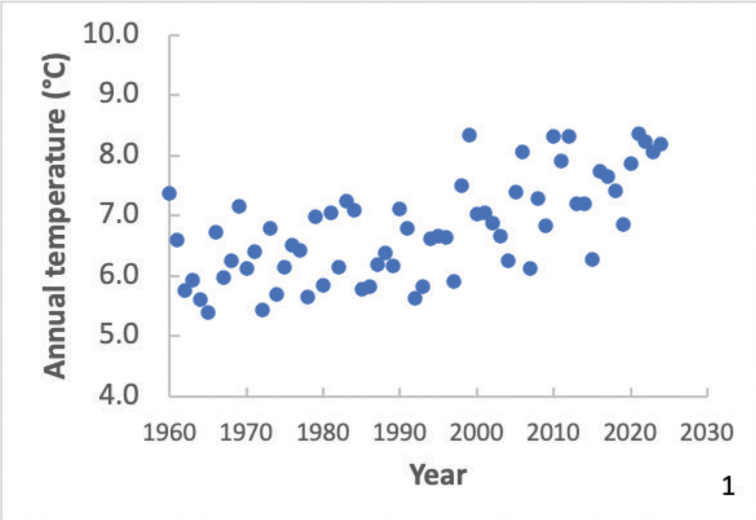


Fig 1 **Changes in mean annual air temperature in Nova Scotia for the five airport sites 1958-2024.**

respectively, and this difference is highly significant (Student's *t*-test, $P < 0.0001$). In only one year (i.e., 2007) was the annual temperature for the recent period below the mean from 1958-1997.

Maximum annual wind gust

Nova Scotia is the windiest province in Canada (ECCC 1990), with the most extreme value in the present study of 188 km h^{-1} occurring in 1976 at Greenwood. Across the province at our five study sites there was an annual maximum (AM) of 121 ± 17 km h^{-1}. While the AM metric would be expected to be the most stochastic of our metrics and show the greatest variation from year to year, a significant overall pattern emerged (Fig 2). The linear regression of the entire period 1958-2024 was negative (slope = -0.3389 km h^{-1} y^{-1}, $R^2 = 0.149$, $P = 0.02$). However, this negative trend masked an early period (1958-2001) that was strongly negative (slope = -0.7971 km h^{-1} y^{-1}, $R^2 = 0.320$, $P < 0.001$), and a later period (2001-2024) that was highly positive (slope = 1.220 km h^{-1} y^{-1}, $R^2 = 0.344$, P = 0.003). The declining period (i.e., wind stilling) showed a change of -1.2 km h^{-1} y^{-1}, whereas the recovery period showed a change of 1.7 km h^{-1} y^{-1}.

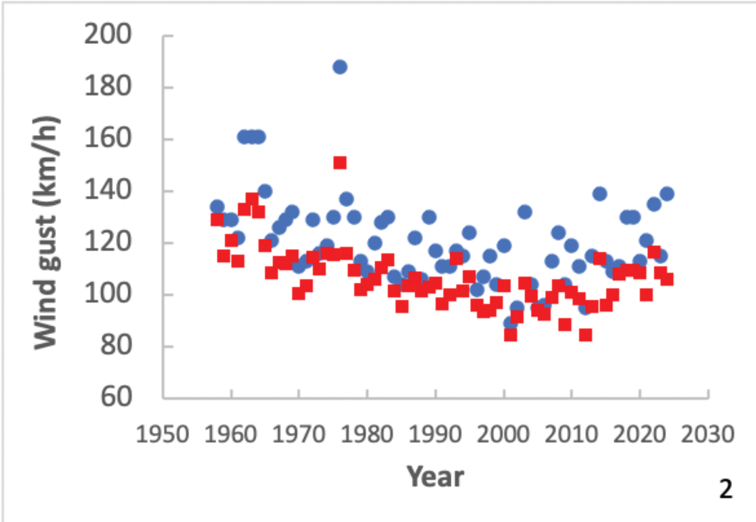


Fig 2 **Changes in annual maximum wind gust speed for Nova Scotia (AM, blue circles) and mean maximum (MAM, red squares) for five airport sites in Nova Scotia) 1958-2024. Note: extreme high values for 1976 are from the Groundhog Day Gale.**

Mean of annual maxima

The mean annual maximum for the five sites (Table 2) ranged from 103 km h^{-1} (at Shearwater) to 110 km h^{-1} (at Greenwood). The trend was higher values in the 1960s (up to 161 km h^{-1}) and a period of lower values between 2001 and 2006 when four of the six years had a maximum wind gust of less than 100 km h^{-1}. Even though values for early and recent periods were significant only for Greenwood and Shearwater ($P < 0.05$), the overall trend was highly significant (Table 2, $P < 0.01$). The linear regression from 1958 to 2022 was negative and significant (as was the early period up to 2000); however, the period from 2001 to 2022 was positive and highly significant (Fig 2). The windiest ten-year period was 1958-1967 (mean annual maximum 135 km h^{-1}), whereas the lowest period was 2001-2010 (mean annual maximum of 107 km h^{-1}). Using a three-year rolling average for maximum annual wind gust up to 2000 resulted in a change of -0.92 km h^{-1} y^{-1} (= -0.26 m sec^{-1} y^{-1}). From 2001 to 2024 the average increase rate was 1.1 km h^{-1} y^{-1} (= 0.30 m sec^{-1} y^{-1}).

Table 2 **Means of annual maximum wind gusts at the five Nova Scotia airport weather stations considered over the entire period (1958-2024), an early period (1958-2000), and a recent period (2001-2024). Values indicate mean ± sd; significance of early versus recent periods based on Student's *t*-tests.**

Site	1958-2024 (km h^{-1})	1958-2000 (km h^{-1})	2001-2024 (km h^{-1})	*P*
Greenwood	110 ± 21	116 ± 21	98 ± 14	< 0.001
Halifax	107 ± 11	108 ± 11	105 ± 13	0.456
Shearwater	103 ± 16	106 ± 15	95 ± 15	0.015
Sydney	109 ± 16	111 ± 16	104 ± 14	0.092
Yarmouth	106 ± 16	108 ±17	101 ± 13	0.074
All sites	107 ± 12	110 ± 12	100 ± 9	0.001

Mean of monthly maximum wind gusts

This metric averages the strongest monthly wind gust for the year from each site. Accordingly, it integrates the monthly storm regime to provide a more generalized description than the metrics in the previous sections. The annual values for means of monthly maxima (MMM) ranged from a high of 93.8 km h^{-1} in 1964 to a low of 64.3 km h^{-1} in 2001 (Fig 3), a decline of 0.57 km h^{-1} y^{-1} (0.16 m sec^{-1} y^{-1}). It subsequently rose to a maximum of 82.3 km h^{-1} y^{-1} in 2022. Linear regressions of the two periods were highly significant ($P < 0.0001$) both in the declining period ($R^2 = 0.662$) and in the recovery period

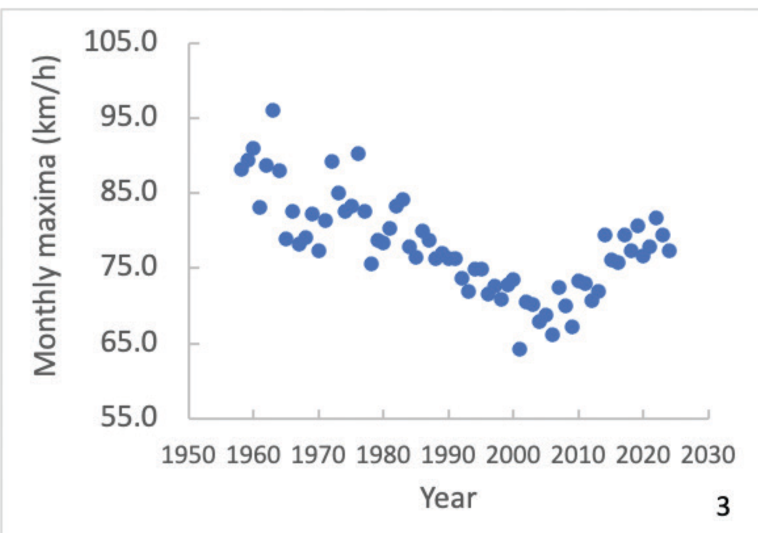


Fig 3 **Changes in annual mean of monthly wind maxima for Nova Scotia 1958-2024.**

($R^2 = 0.7627$). The period 2001-2024 experienced an increase of 0.71 km h^{-1} y^{-1} (0.20 m sec^{-1} y^{-1}), marginally greater than the declining rate.

The difference in wind gusts between the periods of decline and recovery was examined by plotting the monthly maximum wind speeds (MMM) for each month for these distinctive periods (not shown). All months had a similar trend (Table 3). Thus, for every month, the linear regression for the overall period had a negative slope, and except for September this regression was highly significant with $P < 0.0001$. This overall pattern was masked by two opposing trends: a very strong decline in wind strength for all months ending around 2001, and then a strong subsequent recovery. Rates of change during the declining period averaged 0.50 km h^{-1} y^{-1} and ranged from -0.19 km h^{-1} y^{-1} (September) to -0.79 km h^{-1} y^{-1} (October). During the wind recovery period the average yearly increase was 0.63 km h^{-1} y^{-1} and ranged from 0.19 km h^{-1} y^{-1} (August) to 1.27 km h^{-1} y^{-1} (March).

To further demonstrate the magnitude of these changes we considered three ten-year periods: the stormiest, 1960-1969 (84.8 ± 5.9 km h^{-1}), the quietest, 2001-2010 (69.1 ± 2.8 km h^{-1}), and the most recent 2015-2024 (78.2 ± 2.0 km h^{-1}) (Fig 4).

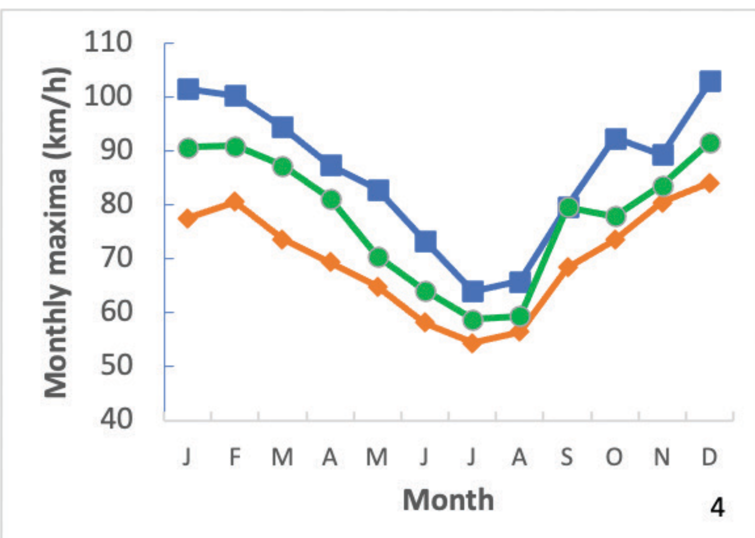


Fig 4 **Monthly means of maximum wind gusts shown for three ten-year periods: (1) period of maximum wind velocity, 1960-1969 (blue squares), (2) period of minimal wind velocity, 2001-2010 (brown diamonds), and (3) most recent ten years, 2015-2024 (green circles).**

Table 3 Results of linear regressions of annual means of monthly wind maxima by month based on rolling three-year averages from the five sites. Each month is considered in three time periods: (1) the entire period, (2) from the maximum at the beginning of the time series in 1960 to the minimum, and (3) from the minimum to 2024. NS – not significant.

Month	Year range	Slope	R^2	Change km h^{-1} y^{-1}	Change m sec^{-1} y^{-1}	*P*
January	1960-2024	-0.3268	0.4663			<0.0001
	1960-2003	-0.4772	0.5260	-0.69	-0.19	<0.0001
	2003-2024	+0.7875	0.7006	0.81	0.23	<0.0001
February	1960-2024	-0.2466	0.2845			<0.0001
	1960-2001	-0.5813	0.5442	-0.63	-0.17	<0.0001
	2001-2024	+0.6700	0.7099	0.68	0.19	< 0.001
March	1960-2024	-0.2583	0.3244			<0.0001
	1960-2006	-0.4549	0.5060	-0.60	-0.17	<0.0001
	2006-2024	+1.1072	0.7196	1.27	0.35	<0.0001
April	1959-2024	-0.2203	0.3390			<0.0001
	1959-2004	-0.4002	0.5351	-0.57	-0.16	<0.0001
	2004-2024	+0.8047	0.7164	0.94	0.26	<0.0001
May	1959-2024	-0.2452	0.4562			<0.0001
	1959-2000	-0.4719	0.6582	-0.33	-0.09	<0.0001
	2000-2024	+0.3518	0.4184	0.32	0.09	<0.0005
June	1959-2024	-0.2411	0.4209			<0.0001
	1959-1999	-0.4232	0.5183	-0.32	-0.09	<0.0001
	1999-2024	+0.4733	0.5613	0.38	0.01	<0.0001
July	1959-2024	-0.1256	0.1541			0.0011
	1959-2005	-0.2549	0.3440	-0.35	-0.10	<0.0001
	2005-2024	+0.5141	0.2138	0.65	0.18	0.0401
August	1959-2024	-0.1261	0.2354			<0.0001
	1959-2002	-0.2155	0.2837	-0.33	-0.0.9	<0.0002
	2002-2024	+0.2268	0.1610	+0.19	+0.20	NS
September	1959-2024	-0.7767	0.0315			NS
	1959-2002	-0.4407	0.5598	-0.61	-0.19	<0.0001
	2002-2024	+1.228	0.6352	2.47	0.69	<0.0001
October	1959-2024	-0.2591	0.3903			<0.0001
	1959-1994	-0.6074	0.4512	-0.79	-0.22	<0.0001
	1994-2024	+0.2264	0.1734	0.36	0.10	0.0198
November	1959-2024	-0.2037	0.3607			<0.0001
	1959-2000	-0.3946	0.5680	-0.50	-0.14	<0.0001
	2000-2024	+0.4024	0.3951	0.48	0.13	0.002
December	1959-2024	-0.2715	0.3431			<0.0001
	1959-2003	-0.5711	0.6168	-0.68	-0.19	<0.0001
	2003-2024	+0.5342	0.2912	0.81	0.23	0.0095

Number of storm days per year

Over the entire period the five sites varied from a minimum of 13.9 ± 14.7 storm days for Greenwood to 21.0 ± 8.3 storm days for Yarmouth, with all sites showing similar trends over time (Fig 5). Thus, from a peak of 45.4 in 1963, mean number of storm days across the province declined to 5.2 storm days in 2001 and increased to 23.8 storm days in 2019 (Fig 5). The mean number of storm days per year mirrors the previously discussed metrics. These changes represent an 88% decline in storm number to the low point in the early 2000s, and then an increase of 500% in the subsequent period to the recent high in 2022. The decreases and increases in the number of storm days represent a reduction of 0.62 storms y^{-1} to the minimum and a subsequent increase of 0.66 storms y^{-1}. The recent higher values are equivalent to the number of storms in Nova Scotia in the 1970s and early 1980s.

Number of months per year with wind ≥ 75 km h^{-1}

The last 65 years have shown dramatic changes in the distribution of storms throughout the year. From a peak of nine to ten months of the year with storms in the 1960s (Fig 6) there was a gradual decline until the early 2000s with fewer than four months with storms. Thus, on average, there was a linear decline of about 50% over the period from maximum to minimum. Once the reversal occurred in the early 2000s this metric increased to almost seven months per year.

Number of storm days per month

The clear difference in number of storm days per year is shown in Fig 6 and this varied both with sites and over the 65 years for which

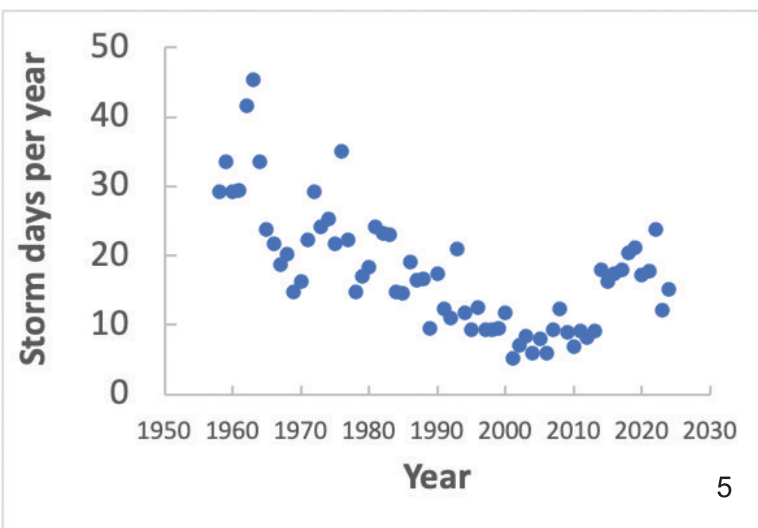


Fig 5 Changes in number of storm days per year for Nova Scotia 1958-2024.

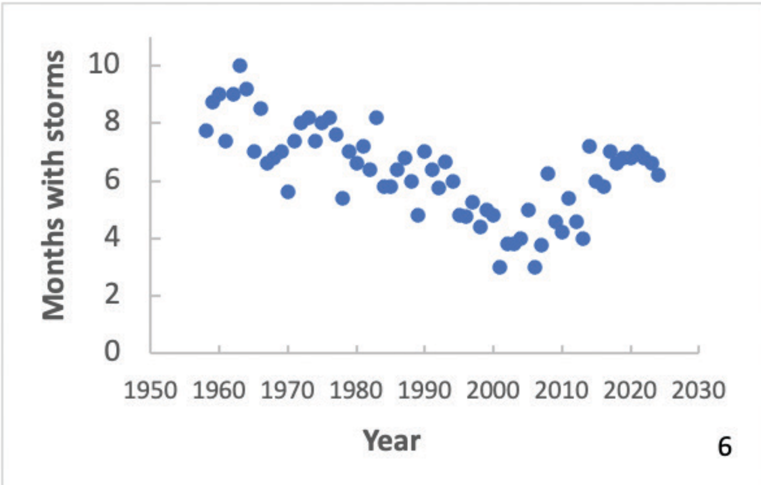


Fig 6 **Annual changes in number of months per year with storms for Nova Scotia 1958-2024.**

we have data that distinguishes a period of stilling and then a period of recovery. These data belie the strong seasonal variation in storm wind for Nova Scotia. Accordingly, storms were more frequent on a monthly basis during stilling than during the more recent wind recovery phase (Fig 7). There was a strong seasonality in the number of storms per month in Nova Scotia; the number was very low from May to September with typically fewer than 0.5 storm days per month. Months from November to March had a storm day frequency almost ten times higher. These differences are accentuated when shown from the perspective of the ten continuous years from the stormiest period in the 1950s and 1960s, the ten least stormy years in the 2000s, and the ten most recent years (Fig 7).

Metrics standardized by site

The combined metrics for each study site (Figs 8-12) were consistent with the combined sites for each storm metric. Of the 15 linear regressions (five sites x 3 time periods), only three had anomalous results, and the remaining 12 had the same slope direction, and high significance of R^2 (i.e., $P < 0.01$; Table 4) as the analyses for each wind metric (Table 5). The largest discrepancy was the 1961-2024 regression for Halifax where the decline during stilling matched the increase in metrics during the recovery period ($P = 0.9306$). The other

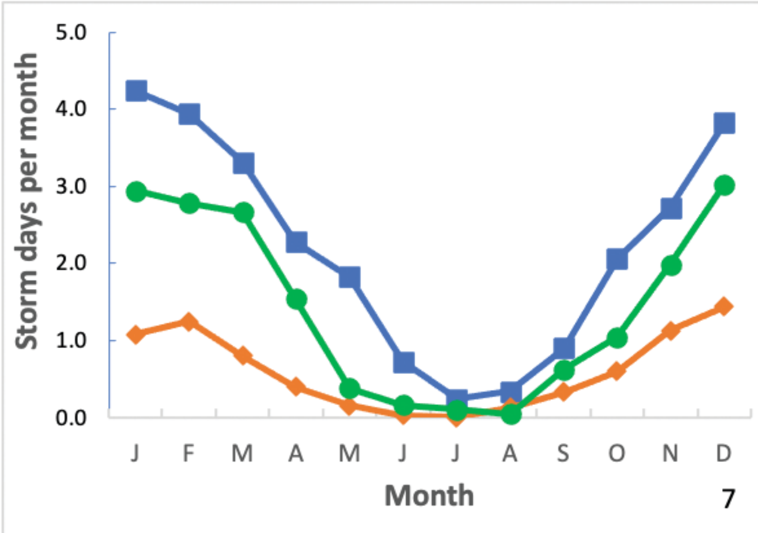


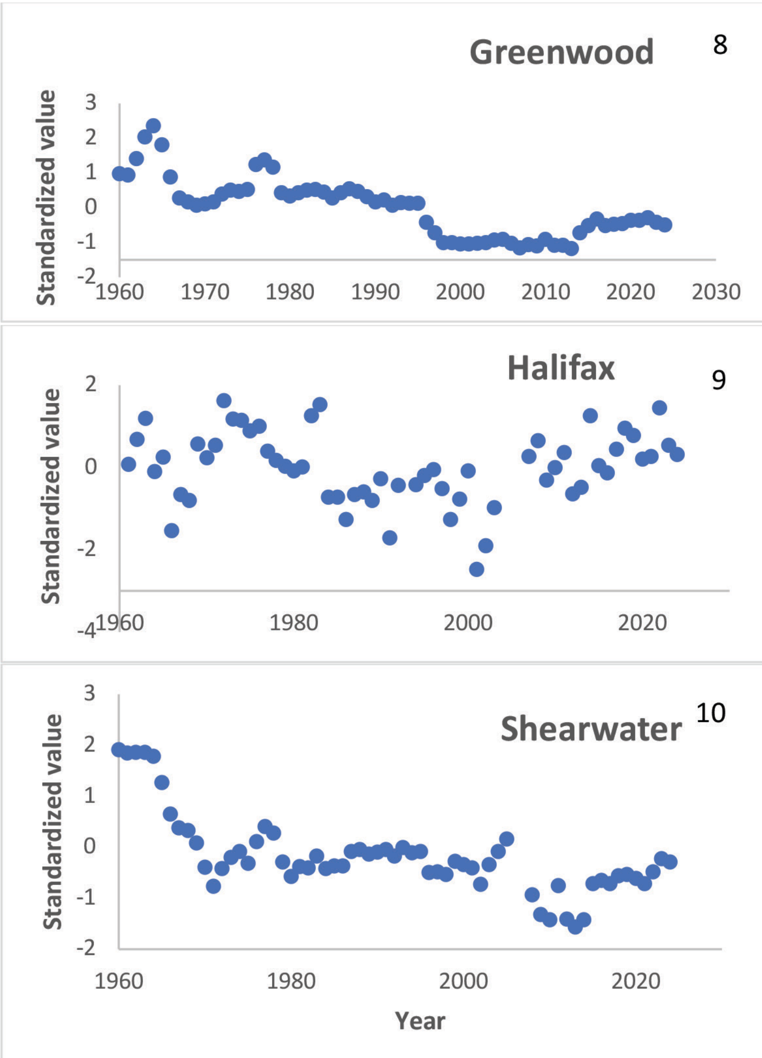
Fig 7 **Monthly means of the number of storm days for three ten-year periods: (1) period of maximum storm days, 1960-1969 (blue squares); (2) period of minimal storm days, 2001-2010 (brown diamonds); and (3) most recent ten years, 2015-2024 (green circles).**

exceptions were the regressions for Yarmouth where $P = 0.0502$ was almost significant and the regression from 2003-2024 for Shearwater where the slope was negative and not significant. The latter trend was possibly compromised by missing data from 2004-2007.

DISCUSSION

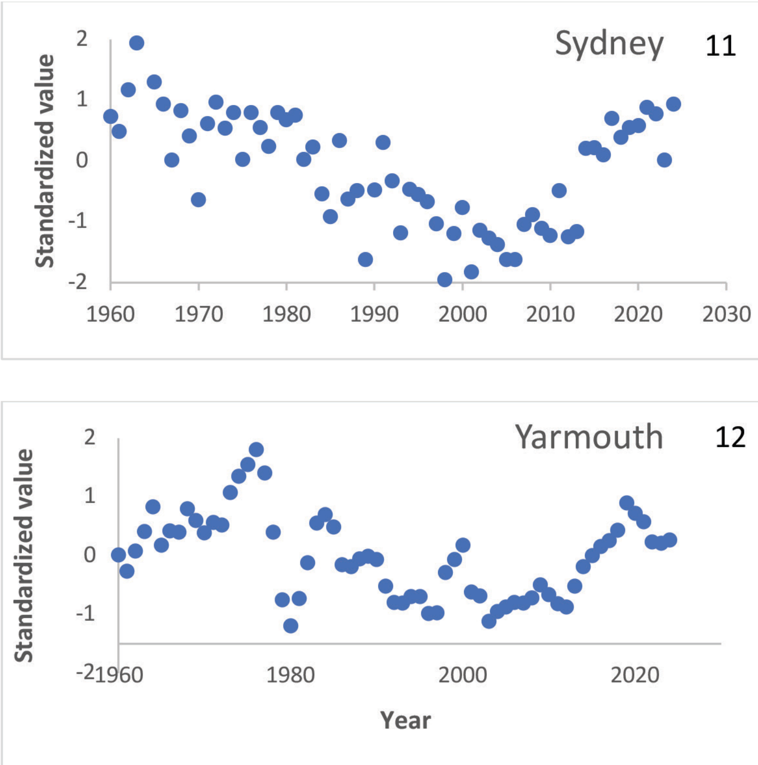
Storm winds of Nova Scotia

Our data for five Nova Scotia sites over the last 65 years describes changing patterns of air temperature, wind, and storm activity. The overall change in wind velocity based on linear regression is negative, whereas the overall change in temperature is positive (Table 5). Correlations of annual temperature with our five separate wind metrics across all years from 1958-2024 are all negative with Pearson r ranging from -0.246 to -0.359 (all significant at $P < 0.05$). Thus, scatterplots for temperature versus mean maximum wind velocity, number of storm days, and months with storms (Fig 13-15) went counter to the assumption of higher winds associated with higher temperatures. This result is despite a highly significant temperature



Figs 8-10 **Means of standardized values for four wind metrics from Greenwood, Halifax, and Shearwater. Note: each point is the rolling mean of values from three years.**

increase of 1°C in the last 27 years when storm metrics were increasing. Thus, average wind strength has not been stronger in this recent period (1998-2025) when average temperatures were 1°C greater than during the preceding 40 years (Garbary and Hill 2021). Regardless of storm wind metric, our wind dataset shows a period of reduced



Figs 11-12 Means of standardized values for four wind metrics from Sydney and Yarmouth. Note: each point is the rolling mean of values from three years.

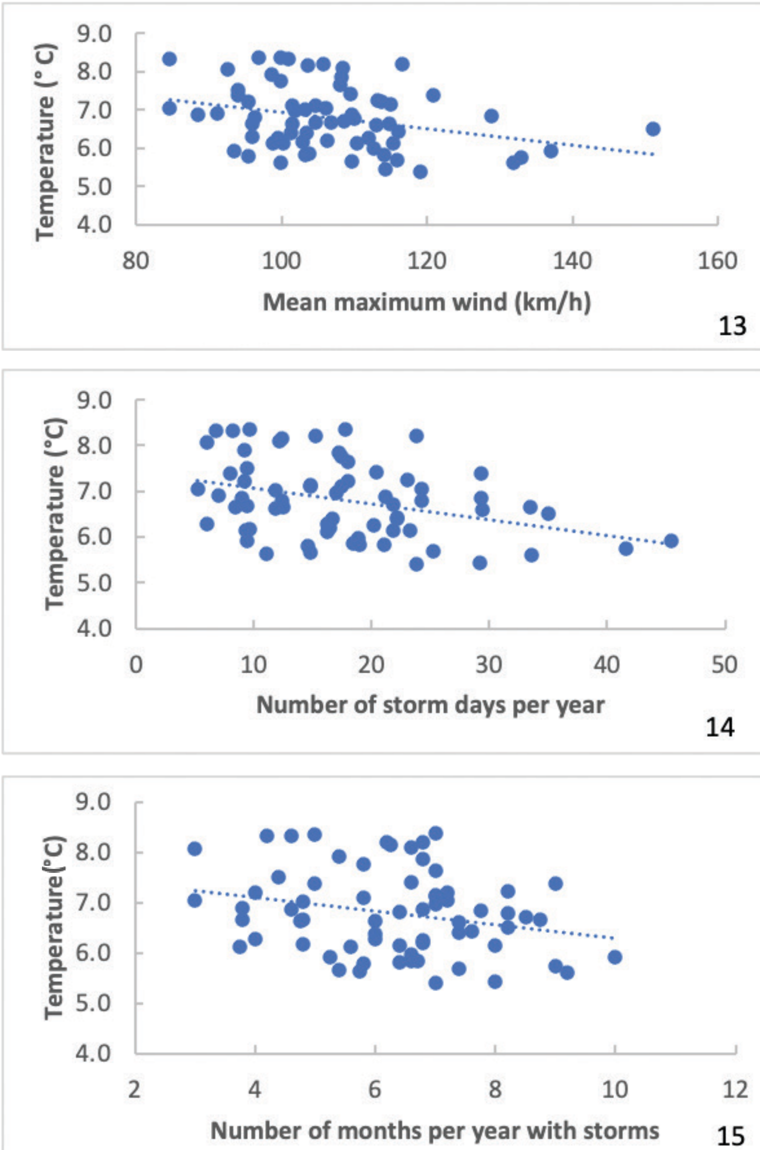
wind activity from the start of our time sequence to the early 2000s. The congruence of the standardized data by site (Table 4) and by wind metric (Table 5) suggests that the resolved trends for Nova Scotia are real, and not an artifact of stochastic processes. These trends are also consistent with a global phenomenon known as wind stilling, and they were consistent for our wind metrics by year and by month. Our results are contrary to those of Hundecha *et al.* (2008) who examined changes in extreme annual wind speed around the Gulf of St. Lawrence and did not resolve significant change over the period 1979-2004. This discrepancy can be attributed to the shorter period examined by Hundecha *et al.* that began only after 20 years of major wind stilling had already occurred. In addition, their account treated a much broader area of eastern Canada, i.e. Quebec, New Brunswick and the island of Newfoundland, with only Sydney overlapping with

Table 4 **Linear regressions of the combined wind metrics for each study site based on the overall period, the wind stilling period, and the wind recovery period.**

Site	Years	Slope	R^2	Significance
Greenwood	1958-2024	-0.0854	0.5246	< 0.0001
	1958-2001	-1.1119	0.4052	< 0.0001
	2001-2024	0.0719	0.3870	0.0012
Halifax	1961-2024	-0.0008	0.0001	0.9306
	1961-2001	-0.0536	0.2357	0.0013
	2001-2024	0.1240	0.4633	0.0007
Shearwater	1958-2024	-0.0567	0.3549	< 0.0001
	1958-2003	-0.0894	-0.3453	< 0.0001
	2003-2024	-0.0139	0.0071	0.7477
Sydney	1958-2024	-0.0256	0.1918	0.0002
	1958-2006	-0.0731	0.7284	< 0.0001
	2006-2024	0.1602	0.7699	< 0.0001
Yarmouth	1958-2024	-0.0139	0.0577	0.0502
	1958-2001	-0.0383	0.1622	0.0067
	2001-2024	0.1054	0.5924	< 0.0001

our study. Using the limited time-period of Hundecha *et al.* in our analysis, two of our metrics (provincial maximum and mean maximum) were consistent with their pattern, i.e., no significant change; however, our remaining three storm metrics were highly significant with $P < 0.0001$. Thus, over the larger region and using only the single metric of annual maximum, the pattern may indeed be consistent with Nova Scotia within the shorter time series.

The absence of a common climate change signal for temperature and wind contradicts patterns showing increasing wind activity in warming tropical oceans (e.g., Young *et al.* 2011) as well as society's expectation that climate change necessarily means more storm activity. We suggest two explanations. First, in eastern Canada the highest wind velocities are typically associated with winter and cold, while the summer wind velocities are typically more moderate. Hence storminess in Nova Scotia is predominantly a winter phenomenon. Thus, on an annual basis, higher temperatures do not positively correlate with the frequency of summer storms (Figs 4, 6). Furthermore, while all months in Nova Scotia have shown significant temperature increases post-1998, these increases are lower in summer and greater in fall and winter (Garbary and Hill 2021, 2025). We have noted that the low point in all storm metrics (between 2001 and 2006), and then their reversal, was preceded by the jump in mean annual temperature beginning in 1998. This change in air temperature was



Figs 13-15 **Scatter plot showing negative relationship between temperature and three wind metrics: mean of annual wind maximum, number of storm days per year and number of months per year with storms.**

Table 5 Results of linear regressions of mean annual air temperature and annual wind metrics in Nova Scotia from 1958 to 2024.

Temperature and Wind metrics	Years	Slope	R^2	Rate of change	*P*
Mean temperature	1958-2024	0.0264	0.394		< 0.0001
	1958-1997	0.0003	< 0.0001		0.9669
	1998-2024	0.0319	0.138		0.0565
Annual wind maximum	1958-2024	-0.339	0.149		0.0012
	1958-2001	-0.7971	0.320	-1.20 km $h^{-1}y^{-1}$	< 0.0001
	2001-20024	1.220	0.344	1.69 km $h^{-1}y^{-1}$	0.0026
Mean wind maximum	1958-2024	-0.332	0.294		< 0.0001
	1958-2001	-0.679	0.474	-0.92 km $h^{-1}y^{-1}$	< 0.0001
	2001-2024	0.776	0.401	1.07 km $h^{-1}y^{-1}$	0.0009
Mean of monthly wind maximum	1958-2024	-0.210	0.399		< 0.0001
	1958-2001	-0.407	0.662	-0.57 km $h^{-1}y^{-1}$	< 0.0001
	2001-2024	0.614	0.763	0.71 km $h^{-1}y^{-1}$	< 0.0001
Number of storm days per year	1958-2024	-0.277	0.393		< 0.0001
	1958-2001	-0.5491	0.624	-0.62 storms y^{-1}	< 0.0001
	2001-2024	0.641	0.654	0.67 storms y^{-1}	< 0.0001
Number of months with storms	1958-2024	-0.046	0.335		< 0.0001
	1958-2001	-0.092	0.632	-0.13 months y^{-1}	< 0.0001
	2001-2024	0.164	0.686	0.19 months y^{-1}	< 0.0001
Means of standardized values (wind metrics)	1958-2024	-0.029	0.356		< 0.0001
	1958-2001	-0.058	0.614		< 0.0001
	2001-2024	0.083	0.678		< 0.0001

coincident with the development of ocean hotspots in the Gulf of Maine and the outer Bay of Fundy (Saba *et al.* 2015, Seidv *et al.* 2021, Herbert *et al.* 2023).

Our data for Nova Scotia also demonstrates a strong recovery in these wind metrics to levels observed in the 1970s and 1980s but still not reaching the maximum of the 1960s (Figs 4, 7). This is consistent with various reports from around the world (e.g., Azorin-Molina *et al.* 2016, Yang *et al.* 2021, Minola *et al.* 2022). Dunn *et al.* (2022) suggested that the reversal of global stilling in Asia and Europe after 2013 may have resulted from overestimation of average wind speeds that arose from an underestimation of the number of calm periods. This is not applicable to our study as we were working with the number and intensity of storms rather than average wind speeds or calm periods.

What is remarkable about the patterns of stilling and recovery for Nova Scotia are the rates of change. McVicar *et al.* (2008) summarized rates of stilling in average wind speed as between -0.004 m sec^{-1} y^{-1} to -0.017 m sec^{-1} y^{-1}. The rate of change in Nova Scotia for mean of annual maximum (MAM) wind gusts was -0.26 m sec^{-1} y^{-1} and 0.30 m sec^{-1} y^{-1} during stilling and recovery, respectively, an order of magnitude higher than the rates described by McVicar *et al.* (2008). Similarly, our metric for mean of monthly maxima (MMM) showed a decline during stilling of 0.16 m sec^{-1} y^{-1} and an increase of 0.20 m sec^{-1} y^{-1} during recovery; again, an order of magnitude greater than the averages reported by McVicar *et al.* (2008). Whereas the difference between declines of average wind speeds and maximum wind speeds might not be expected to be the same, the order of magnitude difference in Nova Scotia suggests localised forcing in addition to continent-wide forcing, e.g., Klink *et al.* (1999). The rate of change in our wind metrics for Nova Scotia was higher in the wind recovery period than in the wind stilling period. This 8%-48% increase in absolute rates in the opposite direction is a sign of a rapidly changing wind climate.

Mechanisms

Explaining the discrepancy between the patterns of change in temperature and wind in Nova Scotia was beyond the scope of this paper; however, we suggest some phenomena that may be involved. Accordingly, the temperature transition in Nova Scotia between the early period, when mean annual temperatures were mostly 6-7°C, and the latter period when mean annual temperatures were mostly 7-8°C coincided with a strong and long-lasting period of La Niña (NOAA 2025, updated monthly), which is driven by air pressure changes in the tropical Pacific Ocean. It may be circumstantial, but the latest multiyear period of > 8°C mean annual temperature for Nova Scotia (Fig 1) also coincides with a long-lasting La Niña. Changes in the Atlantic Multidecadal Oscillation (AMO) which cycles over a 50-80-year period and involves a change of 0.4°C in ocean temperature (Dijkstra *et al.* 2006, Knight *et al.* 2006, Li *et al.* 2009, Wyatt *et al.* 2012, McCarthy *et al.* 2015) may also be a component of the changes observed in Nova Scotia. At the end of the 1950s the AMO entered a negative temperature regime. This was during a period of high storm intensity regionally and associated with generally higher temperatures in Nova Scotia that subsequently declined (Fig 1). Then, at the end of the 1990s AMO reverted to a positive temperature regime that corresponded with the development of ocean hotspots around Nova Scotia and a general increase in air temperature of 1°C. The development of the ocean hotspot in the Gulf of Maine and outer Bay of Fundy correlates with the increase of mean temperature of almost 2°C on Brier Island (Garbary and Hill 2025). This transition was associated with the return of the AMO to a positive temperature phase. Sutton and Dong (2012) concluded that the AMO was a key factor in climate change (for both temperature and precipitation) that began in Europe in the late 1990s. Sutton and Dong also suggested that a reversal of the AMO into its negative phase would bring about a reversal of this trend. Zhang *et al.* (2024) also used the AMO to explain abrupt warming in northeast Asia in the late 1990s. If this hypothesis is correct, the next transition of the AMO into its negative phase may be associated with a return of the ocean hotspots off Nova Scotia to pre-2000 temperature regimes and a regional increase in storminess to levels last seen in Nova Scotia in the 1960s.

Woolway *et al.* (2019) suggested that wind stilling had a dramatic effect on lakes. They concluded that "atmospheric stilling has influenced lake thermal responses to warming." Accordingly, reduced winds increased lake stratification and a delay in turnover. With very large lakes, a lengthening of the period prior to turnover would influence adjoining land masses by slowing the cooling effects of fall and early winter. The congruence in timing of the development of ocean water hot spots off Nova Scotia coastlines along the Atlantic coasts with raised fall and winter air temperatures (Garbary and Hill 2021) is consistent with a similar mechanism. Accordingly, reduced storm activity since the 1970s may be responsible for warmer sea surface temperatures (SSTs). These have resulted in profound changes in the biology of coastal waters (e.g., reduction or loss of kelp populations, Filbee-Dexter *et al.* 2016; declines in the cod fishery in the Gulf of Maine, Pershing *et al.* 2015), and increased fall and winter air temperatures over Nova Scotia post-1998. The same mechanism could explain the pattern of air temperature increases post-1998 in Prince Edward Island (Garbary 2018).

Forests and coastal plant communities

On a transect across southwest Nova Scotia more than two hundred years ago, Titus Smith (1802) noted areas of windfall on 19 days of his 90-day journey. He wrote of "windfalls from the Great Storm" that were growing up in young fir and of an even-aged hardwood forest, the succession from fire that had followed a hurricane 80 years prior. Wind is a major disturbance that helps shape most of the forests of Nova Scotia, from the vulnerable coastal softwoods subjected to a moderate wind disturbance (30% to 60% trees felled) every 60 years to hardwood forests that regenerate through gap replacement dynamics (Taylor *et al.* 2020, McLean *et al.* 2022). On a regional level, our results inform trends in major wind disturbance and provide empirical data to test the expectation that warmer weather brings stronger winds. Despite the paucity of weather stations with wind records, the data (e.g., Fig 6) support the spatial wind disturbance variation for Nova Scotian forests (Taylor *et al.* 2020).

Nova Scotia is a windy province (Environment and Climate Change Canada 1990), with especially strong winds 'Les Suetes', along the west coast of Cape Breton Island (McIldoon and Pilon 2008, The Nature of Things 2021). Wind activity in Nova Scotia is increasing from its 2000s lull. Predicting the impact of increasing wind activity means not simply a return to the past relationship with wind, but rather a contemporary context that differs in several ways from the 1960-1980 period. Increased winds in winter are now occurring in a climate-changed temperature regime where winters have experienced extensive warming, and the duration of soil freezing is greatly reduced (Garbary and Hill 2021). Saad *et al.* (2017) predicted that the decrease in the period of frozen ground in combination with higher winds and wetter soils will lead to an increase in windthrown trees. The increase in windthrow vulnerability increases with greater soil wetness (Xi 2005) and decreased frost penetration (Peltola 1996). Increased wind during warmer wet winters increases the windthrow vulnerability for evergreen conifers (Anyomi *et al.* 2017) and for other shallow-rooted species (Xi and Peet 2011). An increase in wind severity will affect the structure of the forest community and, in turn, can increase the species pool of herbs (Steenberg *et al.* 2011). The spatial patterns of tree uprooting and the differential susceptibility of trees to uprooting were evident after Hurricane Fiona in fall of 2022. We noted (Hill and Garbary, unpublished observations) that while a substantial fraction of other trees (i.e. red maple, white spruce) in a study swamp were uprooted, black ash (*Fraxinus nigra*) alone remained rooted; this tenacity may relate to the greater flood tolerance of black ash than the other sympatric trees which has allowed it to root more deeply and become more deeply anchored in the anaerobic layers of the wetland.

Nova Scotia is part of Braun's hemlock-white pine hardwood region that is "…throughout its extent, a mosaic of hardwood, conifer and mixed forest" (Braun 1950, p 533). A subsequent cluster analysis confirmed Braun's mapping of regional forest types separating this northern forest region into a western (centred around the Great Lakes) and our eastern region which was renamed the northern hardwood-hemlock (Dyer 2006). Gap formation by wind may maintain the species richness of both tree and the understory communities in hardwood forests (Braun 1950, Runkle 1990). A full understanding of how the diversity of herbaceous communities is affected by patch level disturbances in Appalachian hardwood forests, however, remains elusive (Elliott *et al.* 2014). In Nova Scotia, the occurrence of some of the rarest Appalachian deciduous herbs is linked to soil fertility and riparian flood disturbances (Hill and Garbary 2011) but the distribution of the rare upland (S2) *Hepatica americana* is an enigma. Its occurrence, however, in early successional forest communities suggests a dependence on open woodlands that may mimic gap dynamics in pre-contact forests. Analysis of the patch distribution of its congener, *Hepatica nobilis,* in Spain, however, revealed no association between plant size and canopy openness (Pico 2002).

Geographically, the greatest impacts of the most frequent wind type (low severity: annual disturbance rates twice that of each of seven other ecoregions based on analyses of 2800 plots over ten years (2008-2017)) occurred along the Eastern Shore (granite- or quartzite-based spruce forests) and in forests of the Annapolis Valley and the Central zone (Taylor *et al.* 2020). Our weather stations include four of the ecoregions in Taylor *et al.* (2020), yet wind data values are not related to wind disturbance differences (Table 2). The difference between the measurement of wind – our study – and its impact at the tree level has been ascribed to differences in vulnerability to windthrow (Taylor *et al.* 2020). The forests most vulnerable to wind are the coastal softwood and hardwood forests (MacLean 2022) that are exposed to onshore winds and salt spray. These coastlines along the Atlantic coast of Nova Scotia, and those in the Gulf of Maine, have experienced the greatest increases in temperature associated with ocean-warming hotspots (Hobday and Pecl 2014, Pershing *et al.* 2015, Du *et al.* 2022, Lotze *et al.* 2022, Garbary and Hill 2024). Many of the Atlantic coast plant communities are dominated by evergreen, needle-bearing plants, forests by *Picea* spp., and coastal heathland by *Empetrum nigrum* (Porter *et al.* 2020). Evergreen leaves allow needle-bearing plants to photosynthesize in winter though they are vulnerable to freezing embolisms and frost-drought (Niinemets 2016, Maruta *et al.* 2020). Wind exacerbates the loss of water from evergreen leaves in winter when the soil is frozen, and the xylem cannot replace the water stripped from leaves by wind. Winterkill of *E. nigrum* was observed in summer following extreme warming events in the Arctic (Bokhorst *et al.* 2009). We have documented that loss of the crowberry mat is restricted to its open heathland and did not occur in the shelter of the spruce forest (Hill *et al.* 2012). Saville (1972) discussed how arctic environmental factors impact extracellular and intracellular freezing, and snow abrasion and desiccation restrict the mat-forming, evergreen-needled heath, *Cassiope tetragona,* to leeward hollows out of the wind and covered with snow. Although the changes in plant distribution occur in response to multiple factors, changing wind can alter climate change predictions based solely on temperature. An open-top chamber study that increased ambient temperature partly by shielding the chamber from wind, showed positive shoot growth and biomass in *E. nigrum*; however, the authors noted that at continental level, the plant was retreating northward at its southern edge of range (Burt *et al.* 2012). The interaction of increased wind and warmer winter temperatures may generate large changes in these coastal ecosystems by increasing seasonal windfalls. Furthermore, the reduction and fragmentation of forests in Nova Scotia over the last century may result in greater windfalls because of edge effects.

At the shore level, winds of the post-tropical storm Fiona in September 2022 caused massive erosion of beaches and shorelines to both Nova Scotia and Prince Edward Island (e.g., Halam 2022, Parks Canada 2022, Davidson-Arnott *et al.* 2024, Garbary *et al.* 2025). During the stilling reversal period the rates of monthly maximal wind gusts were high from November to April (increases of 0.17 m sec^{-1} y^{-1} to 0.44 m sec^{-1} y^{-1}, Table 3). These wind velocities, though not as high as during storms in the early to mid-period of stilling, are impacting coastal ecosystems facing another temperature-related change: a large reduction in coastal ice in the southern Gulf of St. Lawrence (Greenan *et al.* 2018). If shorelines are not protected by ice, increasing wind velocities will exacerbate shore erosion, already a major problem associated with sea level rise. The combined effects of storms and sea-level rise have already had a major impact on coastal forest margins (Robichaud & Bégin 1997) before the increase in storm intensity and number that we document. These effects will only be exacerbated if current trends continue.

CONCLUSIONS

We can now answer the questions posed in the introduction. First, there has been no overall positive relationship between increasing temperate and increasing storm activity in Nova Scotia over the last 65 years; indeed, the overall relationship is negative for our storm metrics. Secondly, through much of this period, storm number and intensity have declined. Thirdly, reductions in storm activity occurred throughout the year with the least change occurring during summer. Our data are a clear demonstration of wind stilling, a brief period of relative stability followed by a reversal of the stilling process, similar to global patterns. Finally, further moderation of winter temperatures and increasing storm frequency and intensity will likely negatively impact coastal forests and maritime habitats.

Acknowledgements We thank David Richardson and two anonymous referees for constructive comments. This work was supported by grants from the Natural Sciences and Engineering Research Council of Canada to DJG, and the Department of Fisheries and Oceans to DJG and the Gulf Aquarium and Marine Centre Cooperative, Grand Étang.

REFERENCES

Anyomi, A., Mitchell, S.J., Perera, A.H. & Ruel, J.-C. (2017). Windthrow dynamics in boreal Ontario: a simulation of the vulnerability of several stand types across a range of wind speeds. *Forests* 8(7): 233. doi.org/103390/f8070233

Azorin-Molina, C. Giojarro, J.-A, McVicar, T.R., Vincente-Serrano, S.M., Chen, Jerez, S. & Espírito-Danto, F. (2016). Trends in daily peak wind gusts in Spain and Portugal, 1961-2014. *Journal of Geophysical Research: Atmospheres* 121: 1059-1078. doi:10.1002/2015JD024485

Azorin-Molina, C., McVicar, T.R., Guijarro, J.A., Trewin, B., Frost, A.J., Zhang, G., Minola, L., Son, S.-W., Deng, K. & Chen, D. (2021). A decline of observed daily peak wind gusts with distinct seasonality in Australia, 1941-2016. *Journal of Climate* 34: 3103-3127. doi:10.1175/JCLI-D-2-0590.s1

Bichet, A., Wild, M., Folini, D. & Schär, C. (2012). Causes for decadal variations of wind speed over land: sensitivity studies with a global climate model. *Geophysical Research Letters* 39: L11701. doi:10.1029/2012GL051685

Bliss L.C. (1963). Alpine plant communities of the Presidential Range, New Hampshire. *Ecology* 44(4): 678-697.

Bokhorst, S.F., Bjerke, J.W., Tommervik, H., Callaghan, T.V. & Phoenix, G.K. (2009). Winter warming events damage sub-Arctic vegetation: consistent evidence from an experimental manipulation and a natural event. *Journal of Ecology* 97: 1408-1415. doi.org/10.1111/j.1365-2745.2009.01554.x

Braun, E.L. (1950). Deciduous Forests of Eastern North America. Philadelphia: The Blakiston Company, Philadelphia, USA. 596 p.

Burt, B., Weijers, S., van Broken Eidesen,O.M., van Breden, J., de Korte, M., van Rijckevorsel, J. & Rozema, J. (2012). Range shifts and global warming: ecological response of *Empetrum nigrum* L. to experimental warming at its northern (high Arctic) and southern (Atlantic) geographic range margin. *Environmental Research Letters* 7(2): 02551. 9 p. doi:10.1088/1748-9326/7/2/025501

Cain, S.A. (1930). An ecological study of the heath balds of the Great Smoky Mountains. *Butler University Botanical Studies* 1: 177-208.

Davidson-Arnott, R., Ollerhead, J., George, E., Houser, C., Bauer, B., Hesp, P., Walker, I, Delgado-Fernandez, I. & van Proosdij, D. (2024). Assessing the impact of hurricane Fiona on the coast of PEI National Park and implications for the effectiveness of beach-dune management policies. *Journal of Coastal Conservation* 28: 52. 23 p. doi.org/10.1007/s11852-024-01050-5

De Villiers, M. (2006). Windswept. The Story of Wind and Weather. McLelland & Stewart, Toronto, ON. 338 p.

Du, J.B., Zhang, W.F. & Li, Y. (2022). Impact of Gulf Stream warm-core rings on slope water intrusion into the Gulf of Maine. *Journal of Physical Oceanography* 52: 1797-1815. doi:10.1175/JPO-D-21-0288.1

Dunn, R.J.H., Azorin-Molina, C., Menne, M.J., Zeng, Z, Casey, N.W. & Shen, C. (2022). Reduction in reversal of global stilling arising from correction to encoding calm periods. *Environmental Research Communications* 4: 061003. iopscience.iop.org/journal/2515-7620

Dijkstra, H.A., te Raa, L., Schmeits, M. & Gerrits, J. (2006). On the physics of the Atlantic Multidecadal Oscillation. *Ocean Dynamics* 56: 36-50. doi:10.1007/s10236-005-0043-0

Dyer, J.M. (2006) Revisiting the deciduous forests of eastern North America. *BioScience* 56: 341-352. doi:10.1641/0006-3568(2006)56[341:RTDFOE]2.0.CO;2

Elliott, K.J, Vose J.M, and Rankin, D. (2014). Herbaceous species composition and richness of mesophytic cove forests in the southern Appalachians: synthesis and knowledge gaps. *Torrey Botanical Club Bulletin* 141(1): 39-71. doi:10.3159/TORREY-D-13-00054.1

Environment and Climate Change Canada (ECCC). (1990). The climates of Canada. Environment and Climate Change Canada. Canadian Government Publishing Centre, Ottawa, ON.

Filbee-Dexter, K, Feehan, C.J. & Scheibling, R.E. (2016). Large-scale degradation of a kelp ecosystem in an ocean warming hotspot. *Marine Ecology Progress Series* 543: 141-152. doi:10.3354/meps11554

Garbary, D. (2018). Demonstrating climate change in Prince Edward Island – a procedure using climate change normals and weather data suitable for classroom use. *Proceedings of the Nova Scotian Institute of Science* 49: 293-311.

Garbary, D. & Hill, N.M. (2021). Climate change in Nova Scotia: temperature increases from 1961-2020. *Proceedings of the Nova Scotian Institute of Science* 51: 411-442.

Garbary, D. & Hill, N.M. (2024). Climate change on Brier Island: Prospects for long-term survival of *Geum peckii*. In: Wetland restoration for endangered species recovery. A multidisciplinary case study of Big Meadow Bog, Brier Island, Nova Scotia. Edited by N.M. Hill, S. Hines, N.J. O'Driscoll. Springer Nature, Switzerland. p. 99-119.

Garbary, D., **Trevors, A. & Noyes-Hull, G.** (2025). Coastal erosion of sand dunes and barrier beaches on shores of Nova Scotia facing the Gulf of St. Lawrence. Coastal Zone Canada 2025, Charlottetown, PEI. Abstract.

Gardiner, B. (2021). Wind damage to forests and trees: a review with an emphasis on planted and managed forests. *Journal of Forest Research* 26: 248-266. doi:10.1080/13416979.2021.1940665

Goldenberg, S.B., Landsea, C.W., Mestas-Nuñez, A.M. & Gray, W.M. (2001). The recent increase in Atlantic hurricane activity: causes and implications. *Science* 293: 474-479. doi:10:1126/science.1060040

Graphpad. (2023). Linear regression calculator.
www.graphpad.com/quickcalcs/linear1/

Greenan, B.J.W., James, T.S., Loder, J.W., Pepin, P., Azetsu-Scott, K., Ianson, D., Hamme, R.C., Gilbert, D., Tremblay, J-E., Wang, X.L. & Perrie, W. (2018). Changes in oceans surrounding Canada; Chapter 7 in (eds.) Bush and Lemmen, Canada's Changing Climate Report; Government of Canada, Ottawa, ON. p. 343-423.

Halam, H. (2022). PEI dunes may not recover from 'striking' Fiona damage before next storm. Canadian Press.
globalnews.ca/news/9188564/pei-dunes-hurricane-fiona/
Retrieved 15 January 2023

Herbert, D., Layton, C., Brickman, D. & Galbraith P.S. (2023). Physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2022. Canadian Technical Report on Hydrography and Ocean Science 359.

Hill, N.M. & Garbary, D.J. (2011). Habitat may limit herb migration at the northern edge of the Appalachian deciduous forest. *Botany* 89: 635-645. doi:10.1139/b11-055

Hill, N.M., Vander Kloet, S.P. & Garbary, D.J. (2012). The regeneration ecology of *Empetrum nigrum*, the black crowberry, on coastal heathland in Nova Scotia. *Botany* 90: 379-392. doi:10.1139/B2012-022

Hobday, A.J. & Pecl, G.T. (2014). Identification of global marine hotspots: sentinels for change and vanguards for adaptation action. *Reviews in Fish Biology and Fisheries* 24: 415-425. doi:10.1007/s11160-013-9326-6

Hundecha, Y., **St.-Hilaire, A., Ouarda, T.B. & Adlouni, S.E.** (2008). A nonstationary extreme value analysis for the assessment of changes in extreme annual wind speed over the Gulf of St. Lawrence, Canada. *Journal of Applied Meteorology and Climatology* 47: 2745-2759. doi:10.1175/2008JAMC1665.1

IPCC. (2013). Climate change 2013. The physical science basis. Cambridge University Press. doi.org/10.1017/CBO9781107415324

IPCC. (2022). Summary for policymakers. Climate Change 2022: Impacts, Adaptation, and Vulnerability. Cambridge University Press.

Klink, K. (1999). Trends in mean monthly maximum and minimum surface wind speeds in the coterminous United States, 1961 to 1990. *Climate Research* 13: 193-205.

Knight. J.R., Folland, C.K. & Scaife, A.A. (2006). Climate impacts of the Atlantic Multidecadal Oscillation. *Geophysical Research Letters* 33: L17706. doi:10.1029/2006GL026242

Li, S.L., Wang, Y.M. & Gao, Y.Q. (2009). A review of the researches on the Atlantic Multidecadal Oscillation (AMO) and its climate influence. *Transactions of Atmospheric Sciences* 32: 458-465.

Lotze, H.K., Mellon, S., Coyne, J., Betts, M., Burchell, M., Fennel, K., Dusseault, M.A., Fuller, S.D., Galbraith, E. & Suarez, L.Z. (2022). Long-term ocean and resource dynamics in a hotspot of climate change. *Facets* 7: 1142-1184. doi:10.1139/facets-2021-01971142

Lucio-Eceiza, E.E., González-Rouco, J.F., Garciá-Bustamante, E., Navarro, J, Rojas-Labanda, C. & Beltrami, H. (2020). Summertime surface wind variability over northeastern North America at multidecadal to centennial time scales via statistical downscaling. *Journal of Climate* 33: 1969-1990. doi:10.1175/JCLI-D-19-0331.1

Maruta, E., Kubota, M. & Ikeda, T. (2020). Effects of xylem embolism on the winter survival of *Abies veitchii* shoots in an upper subalpine region of central Japan. *Nature Scientific Reports* 10: 6594. doi:10.1038/s41598-020-62651-2

McCarthy, G.D., Haigh, I.D., Hirschi,J.J.-M., Grist, J.P. & Smeed, D.A. (2015). Ocean impact on decadal Atlantic climate variability revealed by sea-level observation. *Nature* 521: 508-510. doi:10.1038/nature14491

McIldoon, T. & Pilon, M. (2008). Examples of mountain induced winds in Atlantic Canada. American Meteorological Society, 13th Conference on Mountain Meteorology (Abstract only).

McVicar, T.R., Roderick, M.L., Donohue, R.J. & Van Niel, T.G. (2012). Less bluster ahead? Ecohydrological implications of terrestrial near-surface wind speeds. *Ecohydrology* 5: 381-388. doi:10.1002/eco.1298

McVicar, T.R., Van Niel, T.G., Li, L.T., Roderick, M.L., Rayner, D.P, Ricciardulli, L. & Donohue, R.J. (2008). Wind speed climatology and trends for Australia, 1975-2006: capturing the stilling phenomenon and comparison with near surface reanalysis output. *Geophysical Research Letters* 35: L20403. doi:10.1029/2008GL035627

Microsoft Corporation. (2018). Microsoft Excel. Retrieved from office.microsoft/excel

Minola, L, Reese, H, Lai, H.W., Azorin-Molina, C, Guijarro, J.A., Son S.-W. & Chen, D. (2022). Wind stilling reversal across Sweden: the impact of land-use and large-scale atmospheric circulation changes. *International Journal of Climatology* 42: 1049-1071. doi:10.1002/joc.7289

Mitchell, S.J. (2012). Wind as a natural disturbance agent in forests: a synthesis. *Forestry* 86: 147-157. doi:10.1093/forestry/cps058

Murthy, K.S.R. & Rahi, O.P. (2017). A comprehensive review of wind resource assessment. *Renewable and Sustainable Energy Reviews* 72: 1320-1342. doi:10.1016/j.rser.2016.10.038

Niinemets, U. (2016). Does the touch of cold make evergreen leaves tougher? *Tree Physiology* 36: 267-272. doi:10.1093/treephys/tpw007

NOAA/National Weather Service. (2023, updated monthly). Cold and warm episodes by season. origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php (Accessed January 2025)

Parks Canada. (2022). Hurricane Fiona recovery. parks.canada.ca/pn-np/pe/pei-ipe/visit/fiona

Peltola, H. (1996). Model computations on the wind flow and turning moment for Scots pine along the margins of clearcut areas. *Forest Ecology and Management* 83: 203-215. ISSN: 0378-1127

Pershing, A.J., Alexander, M.A., Hernandez, C.M., Kerr, L.A., Le Bris, A., Mills, K.E., Nye, J.A., Record, N.R., Scannell, H.A. & Scott, J.D. (2015). Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine fishery. *Science* 350: 809-812. doi:10.1126/science.aac9819

Pico, F.X. (2002). Spatio-temporal variation in population traits of *Hepatica nobilis,* a patchily distributed woodland herb. *Orsis* 17: 77-90.

Porter, C.J.M, Basquill, S.P. & Lundholm, J.T. (2020). Barrens ecosystems in Nova Scotia: classification of heathlands and related plant communities. Nova Scotia Department Lands and Forestry, Biodiversity Reference Guide 2020-001. 72 p.

Richards, W.G. & Abuamer, Y. (2007). Atmospheric hazards: extreme wind gusts climatology in Atlantic Canada 1955-2000. Meteorological Service of Canada. Atlantic Science Report Series 2007-01. publications.gc.ca/site/eng/361234/publication.html

Robichaud, A, & Bégin, Y. (1997). The effects of storms and sea-level rise on a coastal forest margin in New Brunswick, eastern Canada. *Journal of Coastal Research* 13: 428-439.

Roderick, M.L., Rotstayn, L.D., Farquhar, G.D. & Hobbins, M.T. (2007). On the attribution of changing pan evaporation. *Geophysical Research Letters* 34: L17403. doi:10.1029/2007GL031166

Runkle, J.R. (1990). Gap dynamics in an Ohio *Acer-Fagus* forest and speculations on the geography of disturbance. *Canadian Journal of Forest Research* 20: 632-641. doi.org/10.1139/x90-085

Saad, C., Boulanger, Y., Beaudet, M., Gachon, P., Ruel, J.-C. & Gauthier, S. (2017). Potential impacts of climate change on the risk of windthrow in eastern Canada's forests. *Climatic Change* 143: 487-501. doi:10.1007/s/10584-017-1995-z

Saba, V.S, Griffies, S.M., Anderson, W.G., Winton, M., Alexander, M.A., Delworth, T.L. *et al.* (2015). Enhanced warming of the northwest Atlantic Ocean under climate change. *JGR Oceans* 121: 118-132.

Saville, D.B.O. (1972). Arctic adaptations in plants. Canadian Department of Agriculture, Monograph No. 6.

Seidv, D., Mishonov, A. & Parsons, R. (2021). Recent warming and decadal variability of Gulf of Maine and slope water. *Limnology and Oceanography* 66: 3472-3488. doi.org/10.1002/lno.11892

Smits, A., Klein Tank, A.M.G. & Können, G.P. (2005). Trends in storminess over the Netherlands, 1962-2002. *International Journal of Climatology* 25: 1331-1344. doi:10.1002/joc.1195

Smith, T. (1802). A Natural Resources Survey of Nova Scotia 1801-1802. Public Archives of Nova Scotia, Vol. 38. Edited by L.S. Hawboldt, 1955. Nova Scotia Department of Lands and Forests.

Statistics Kingdom. (2023). Shapiro-Wilk test calculator. www.statskingdom.com/shapiro-wilk-test-calculator.html (Accessed 14 January, 2024)

Steenberg, J.W.N., Duinker, P.N. & Bush, P.G. (2011). Exploring adaptation to climate change in the forests of central Nova Scotia, Canada. *Forest Ecology and Management* 262: 2316-2327. doi:10.1016/j.foreco.2011.08.027

Sutton, R.T. & Dong, B. (2012). Atlantic Ocean influence on a shift in European climate in the 1990s. *Nature Geoscience* 5: 788-792. doi.org/10.1038/ngeo1595

Taylor, A.R., MacLean, D.A., Neily, P.D, Stewart, B., Quigley, E., Basquill, S.P., Boone, C.K., Gilby, D. & Pulsifer, M. (2020). A review of natural disturbances to inform implementation of ecological forestry in Nova Scotia, Canada. *Environmental Reviews* 28: 387-414. doi:10.1139/er-2020-0015

The Nature of Things. (2021). Cape Bretoners ride out Canada's strongest winds with epic storm parties. Canadian Broadcasting Corporation. www.cbc.ca/documentaries/the-nature-of-things/cape-bretoners-ride-out-canada-s-strongest-winds-with-epic-storm-parties-1.5880823 (Accessed 10 February 2023)

Utrabo-Carazo, E., Azorin-Molina, C., Serrano, E., Aguilar, E, Brunet, M. & Guijarro, J.A. (2022). Wind stilling ceased in the Iberian Peninsula since the 2000s. *Atmospheric Research* 272: 106153. doi:https://doi.org/10.1016/jatmosres.2022.106153

Vautard, R., Cattiaux, J., You, P., Thépaut, J.-N. & Ciais, P. (2010). Northern Hemisphere atmospheric stilling partly attributed to an increase in surface roughness. *Nature Geoscience* 3: 756-761. doi:10.1038/NGEO979

Walsh, K.J.E., Camargo, S.J., Knutson, T.R., Kossin, J., Lee, T.C., Murakami, H. & Patricola, C. (2019). Tropical cyclones and climate change. *Tropical Cyclone Research and Review* 8: 240-250. doi:10.6057/2019TCRR04.04

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

Wohland, J., Folini, D. & Pickering, B. (2021). Wind speed stilling and its recovery due to internal climate variability. *Earth System Dynamics* 12: 1239-1251. doi:10.5194/esd-12-1239-2021

Woolway, R.I., Merchant, C.J., van den Hoek, J., Azorin-Molina, C., Noges, P., MacKay, E.B. & Jones, I.D. (2019). Northern Hemisphere atmospheric stilling accelerates lake thermal responses to a warming world. *Geophysical Research Letters* 46: 11983-11992. doi:10.1029/2019GL082752

Wyatt, M.G., Kravtsov, S. & Tsonis, A.A. (2012). Atlantic Multidecadal Oscillation and Northern Hemisphere's climate variability. *Climate Dynamics* 38: 929-949. doi:10.1007/s00382-011-1071-8

Xi, W. (2005). Forest response to natural disturbance: Changes in structure and diversity on a North Carolina piedmont forest in response to catastrophic wind events. PhD Dissertation, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA.

Xi, W. & Peet, R. (2011). The complexity of catastrophic wind impacts on temperate forests. In: Recent Hurricane Research – Climate, Dynamics and Societal Impacts. InTech. dx.doi.org/10.5772/16167

Xu M, Chang, C.-P., Fu, C., Qi, Y, Robock,A., Robinson, D. & Zhang, H.-M. (2006). Steady decline of east Asian monsoon winds, 1969-2000: evidence from direct ground measurements of wind speed. *Journal of Geophysical Research* 111: D24111. doi:10.1029/2006JD007337

Yang, Q., Li, M., Zu, Z. & Ma Z. (2021). Has the stilling of the surface wind speed ended in China? *Science China, Earth Series* 64: 1036-1049. doi:10.1007/s11430-020-9438-4

Yang, Y.M., An, S.I., Wang, B. & Park, J.H. (2020). A global-scale multidecadal variability driven by Atlantic multidecadal oscillation. *National Science Review* 7: 1190-1197. doi.org/101093/nsr/nwz216

Young, I.R., Zieger, S. & Babanin, A.V. (2011). Global trends in wind speed and wave height. *Science* 332: 451-455. doi:10.1126/science.1197219

Zeng, Z., Piao, S., Li, L.Z.X., Ciais, P., Li, Y., Cai, X., Yang, L., Liu, M. & Wood, E.F. (2018). Global terrestrial stilling: does Earth's greening play a role? *Environmental Research Letters* 13: 124013. doi:10.1088/1748-9326/aaea84

Zeng, Z, Ziegler, A.D., Searchinger, T., Yang, L., Chen, A., Ju, K., Piao, S., Li, L.Z.X., Ciais, P. & Chen, D. *et al.* (2019). A reversal in global terrestrial stilling and its implications for wind energy production. *Nature Climate Change* 9: 979-985. doi:10.1038/s41558-019-0622-6

Zhang, T., Xu, X., Jiang, H., Qiao, S., Guan, M., Huang, Y. & Gong, R. (2022). Widespread decline in winds promoted the growth of vegetation. *Science of the Total Environment* 825: 153682. doi:10.1016/jscitotenv.2022.153682

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 337-355

BOOK REVIEWS

The Lives of Lichens: A Natural History. Robert Lucking and Toby Spribille. 2024. Princeton University Press, Princeton and Oxford, 288 pp. ISBN 978-0691-24727-4.

With the 2001 publication of Irwin Brodo's monumental *Lichens of North America*, the North American public finally had access to a subject that had long been the domain of only those with scientific training. Chock full of colour photographs, Brodo's popular level text brought the complex world of lichens into public view. Now, some twenty-four years later, *The Lives Of Lichens: a Natural History* expands the scope of our understanding of the symbiotic process that maintains life for these cryptic organisms in a visually pleasing and easy to understand volume. Published in 2024 by Princeton University Press, authors Robert Lucking and Toby Spribille have compiled a work that focuses on explaining, in a way that a thoughtful public can comprehend, the structure and function of the elements involved in lichen symbiosis as revealed by molecular research.

Cleverly and sensibly arranged into broad sections containing short chapters of one to four or five pages, including stunning full-page photos, the tone is informal on an intelligent and knowledgeable level as the section headings demonstrate: The Archetypal Symbiosis, The Players, the Biology of Lichens, Lichen Architecture, etc. In The Players section, chapter headings read: Lichen Fungi and their Relatives; Lichen Algae; Cyanobacteria: Metabolic Powerhouses; More Than One Fungus; etc.

Again, each section includes photos of lichens from all over the globe as visual support to the chapters on lichens' evolution and life processes. At the conclusion of each section, full-colour photos of some individual lichen species appear along with a page of text that continues the conversation on the subject at hand. These lichen "sub-sections" include a worldwide range map for the highlighted species, its common name, growth form, numbers of species in the genus and notable features of the species as well as incidental information of interest, such as why *Cladonia cristatella* is known as British soldiers.

Lucking and Spribille have both been at the forefront of exploration in molecular genetic research in lichens. Lucking, who is Curator of Lichens, Fungi and Bryophytes at the Berlin Botanical Garden and

Botanical Museum, has been a prolific writer of scientific publications. He has described 1,000 or more lichen species in understudied genera, and has contributed much to advancing the field of molecular phylogenetics in lichenology. Toby Spribille, Associate Professor at the University of Alberta in Biological Sciences, within the Faculty of Science, can claim to be one of those who first discovered a third symbiotic partner in many lichens, a basidiomycyte yeast. This upset the traditional view of the lichen symbiosis as consisting of the interactions between a fungus and one or more algal partners. The collaboration of these two authors has created a book that brings the latest research into lichen structure and function, beyond the confines academia, onto the book shelves of the interested public.

Frances Anderson
Nova Scotia Museum, 1747 Summer Street,
Halifax, NS B3H 3A6

_Graphis scripta/_writing lichen. Clare Goulet. 2024. Gaspereau Press, Nova Scotia. 112 pp. ISBN 978-1554-47265-9.

This whole anthology is just a delight – the more I dip into it, the more I want to read. Clare has a completely fresh way of looking at – and thinking about – lichens, and sharing the way that she relates to lichens. There is a genuine fondness and passion, yet curiosity with respect to the strangeness of the lichens, and trying to unravel the way lichens have been recognised and described by mankind over the centuries.

There are some poems that I can comfortably relate to and empathise with, but some others I have struggled with, a bit like looking at lichens. For example, one I like is:

Evernia mesomorpha – boreal oak moss: "The odds are not in favour of existence……..." and the small quote which prefaces the poem "The two prime movers in the Universe are Time and Luck", by Kurt Vonnegut.

I detect that in some of the poems, there is also some slight mockery? Is that the right word or should it be satirical comment, about how perceptions and efforts to understand, categorize and refine, and redefine 'what is a lichen'? How have lichens been altered over time and been perfected? As well, there are further efforts to make the lichen fit to current concepts. I am thinking of her poem:

'Mr. & Mrs. *Japewia tornoensis* – hidden'; the quote that prefaces the poem is from Trevor Goward '*Nameless little things*'. And Goulet's finishing lines of this poem are:

"In the rain on the oak tree on Peel,
That grey-blue sheen, the green: it's all them. Trebouxia.
Trentepholia, Collema. Nostoc, Myrmecia by any
Other
Measure."

I feel that she is saying, don't let's lose sight of 'the lichen', the entity that sits in the rain on the oak tree.

Yet, science, and the urge to explore, to look deeper, and discover will always lead us to continue, just as long as we don't forget to stop and see. And we always seem to need to put 'a name' to an organism. When taking people to show them plants, butterflies or lichens, the first question is always – "what's that called?"

"Lobaria pulmonaria – lungwort" is another good example. Goulet plays with words, senses and perceptions, quite cleverly following the ways and whims this lichen was perceived, from medieval times to fit in with God's purpose, and she includes in her preface the quote from the 1597 Herball Vol., 5: "*it taketh his name Pulmonaria of the likeness of the form which it hath with lungs or lights, called in Latin Pulmones*". So, it falls within the Doctrine of Signatures, and the belief that the universe is created just for us and man has dominion over everything on earth. And then, she takes the story to today, where perhaps 'God' has faded into the background, but 'Man' is still bent on exploring and developing nature to benefit 'Man'. Clare writes:

"Meanwhile Science accelerates, outruns its Generative algorithms……"

I admire Goulet's clever juxtaposition of using the "doctrine of signatures" and comparing it to today's advancements in science and maths. Is AI any stranger than what *God hathe written haere*? And again, she writes "Meanwhile *Lobaria* drapes itself soft over oak", just to remind us.

She clearly loves not just lichens, but the way they are studied, the whole paraphernalia, almost the obsession that can absorb the studying of these organisms. She uses descriptions of laboratories, herbaria, manuscripts and libraries, early literature and lichenologists, but I think overall she has a genuine fondness for the whole gang; it is wonderful stuff, full of fun and humour, and not a little wry comment. The poem entitled "*K – potassium hydroxide*" starts:

"Deep in the forest
Of the laboratory, love
Expresses itself in a line
Of labelled paper packets
Each waiting their turn
Under the microscope's unblinking gaze
To be, for a moment,
The One………"

The poem continues with what happens after the microscope. There is testing with K, then dissection, and finally Pd. She finishes with: "*Now* we think *you're mine*." Almost, almost 'possessing' the lichen. Perhaps a bit harsh – I guess most of us carrying out these procedures are following up a desire to know, a sort of tracking down using clues and tests to arrive at an answer. I do not consciously think that I possess the lichen after 'running it down'. Just a sense of quiet satisfaction, perhaps something to share with other like-minded friends.

I see throughout that Goulet refers to '*The Vanishing Lichens'* by David Richardson. She has obviously got a lot of inspiration from it. I particularly like the way in the poem '*Can you be more specific*' that she has brought together a random selection of facts from the book about lichen locations, niches or ways they are used, jumbled them together in a delightful way, so they read like 'poetry'!

Apart from her own experiences, Goulet has really read around the subject of lichens and her references are quite wide-ranging. She obviously likes Trevor Goward's 'Twelve Readings on the Lichen Thallus'. Then there is the poem "*Lecania hutchinsiae* – bulb, glowdish, eye" prefaced with a quote from a letter from the Irish naturalist, Ellen Hutchins to Dawson Turner (5th January 1810). Ellen Hutchins, (1785-1815) was regarded as Ireland's first female botanist; she is celebrated in Bantry Bay with an annual festival in August, promoting botany and botanical art. Lichenologists are familiar with *Enterographa hutchinsiae*, named in her honour. There is a website dedicated to Hutchins, under the auspices of The Botany of Bantry Bay. ellenhutchins.com/.

Coincidentally, in November 2024, I was asked by *British Wildlife* to write a book review of "*Lichens of Ireland and Great Britain: a visual guide to their identification*" by Paul Whelan, 2024; two volumes, 970 pages, £75. It was quite a daunting task. My review is by-the-by, but included in Whelan's mammoth volumes was one of Clare Goulet's poems , the one about *Lecania hutchinsiae*. It is most appropriate. So, in a roundabout way, coming across that poem while reviewing Whelan's *Lichens of Ireland* book, was my first introduction to Clare Goulet. And for those who want to know more about Clare Goulet, there is a web site: writers.ns.ca/author-spotlights/author-spotlight-clare-goulet/.

Sandy Coppins
Royal Botanical Garden, Edinburgh, UK
coppins.sandy@gmail.com

***Moss and Lichen*. Elizabeth Lawson. 2024. Reaktion Books, London, UK. 256 pp. ISBN 978-1-78914-9939-5.**

Beautifully produced, and amply documented with current and historic references, American naturalist Elizabeth Lawson's *Moss and Lichen* is a must-read for anyone even faintly interested in these extraordinary life forms.

Published in England as one of Reaktion Press's botanical series, the 14x22x2.5 centimetre volume is a visual delight. High quality reproductions of art and photographs of cryptogams and the scientists and naturalists who have studied them appear on nearly every page. Lawson's text manages to weave together complex scientific and historic details in easy to read prose, spanning evolution, discovery, description and molecular investigation of mosses and lichens. Her chapter headings hint at her approach to unveiling the complexities of the organisms and their interactions with each other and their environments: The Cryptogamic Carpet; Moss: Versatile minimalist; Lichen: Complex Individuality; Cosmopolitan Extremophiles, etc. The Addenda include a Timeline, extensive References, scientific and popular Further Reading, Associations and websites, and of course, Acknowledgements and an Index.

Lawson obviously researched an enormous quantity of material on mosses and lichens including scientific literature (Todd N.Rosenstiel et al, *Sex-specific Volatile Compounds Influence Microarthropod-Mediated Fertilization of Moss*. Nature. 2012.) and popular level publications, including websites (*Can You Recognize These Three Common Churchyard Mosses?* www.greenchristian.org.uk. 2023.) She weaves the information together smoothly. The historical perspective she provides on the development of scientific investigation in both fields isn't boring or dry – she is nothing if not a good writer and has taken great care to document extensively. Inevitably, there are small glitches that occur in a work encompassing as detailed and complex as the world of mosses and lichens. Descriptions of the habitat and substrate preferences of Lungwort (*Lobaria pulmonaria*, for example, are not footnoted but describe conditions that are generally true but not totally. While it does like open woodlands, in the Maritimes, Lungwort is also frequent in more closed canopy situations of mixed forested wetlands and can occur on conifer bark in fairly low light, a detail that doesn't negate what she describes, but simply isn't the whole picture. This is nitpicking- the book is comprehensively researched and admirably woven together for a wide audience in addition to being a joy to look through.

Frances Anderson
Nova Scotia Museum, 1747 Summer Street,
Halifax, NS B3H 3A6

***Mushrooms of Ontario and Eastern Canada*. George Barron. 1999. Lone Pine Publishing, Edmonton, Canada. 336 pp. ISBN 1-55105-199-0.**

Naturalists wandering in Nova Scotia woodlands cannot fail to be impressed by the conspicuous and diverse moss and lichen flora, but sooner or later, especially in autumn, will be impressed by the amazing variety and colours of mushrooms in this habitat and want to find out more about them. George Barron, who came from Scotland and was appointed a professor in the botany department at the University of Guelph, wrote a book that provides the answers. It is very sad to report that George died recently, in October 2024, at the age of 96.

George's book is entitled "Mushrooms of Ontario and Eastern Canada" was published in 1999 after he retired from Guelph University and is still in press. To complete the book, he visited Nova Scotia and other parts of Eastern Canada collecting mushrooms, accompanied on several trips by David Richardson, a friend and colleague since 1969, and by Doug Strongman, who obtained his PhD under George's supervision. George was awarded the Lawson Medal by the Canadian Botanical Association and an Honorary Doctorate of Science by Saint Mary's University in Halifax, both in 2004. He gave an outstanding seminar to Saint Mary's University mycology students and took them on a field trip. The specimens and records George collected from Nova Scotia provided valuable data that aided in the completion of his book.

Every year, people come up to me to ask about mushrooms that they have stumbled across on excursions. They say: can I eat them, are they poisonous, and what are they called? My answer is 'Buy George Barrons book'! It describes 600 mushrooms, initially providing a picture key to the nine groups of mushrooms: the Slime Moulds, Sack Fungi, Puffballs, Jelly Fungi, Coral Fungi, Tooth Fungi, Bracket Fungi, Boletes and Gill Fungi. The last group are separated into subgroups based in spore colour and instructions are provided for making spore prints to find out the spore colour that may be pink, blackish, brown, or light coloured. Then the mushrooms in each group or subgroup are dealt with. There is a separately coloured tab at top of the page that distinguishes that group from its preceding or the following group. This is a really an original and helpful approach. Then, in each group, there is an outstanding picture of the mushroom and a description which helps to confirm the suspected identification. There is also a chapter on Mushrooms as food, with advice about eating these fascinating lower plants that play such an important role as symbionts with the roots of trees in the forest and in other plants, and in some cases as parasites on the trees or crops. This outstanding book, beautifully illustrated, should be on every naturalist's bookshelf, a tribute to the knowledge and passing of a great mycologist.

David H.S. Richardson
Environmental Science, Saint Mary's University,
Halifax, NS B3H 3C3

***Wetland Restoration for Endangered Species Recovery. A Multidisciplinary Study of Big Meadow Bog, Brier Island, Nova Scotia*. Hill, Nicholas M., Hines, Sarah & O'Driscoll, Nelson J. (Eds.). 2024. Springer Nature, Cham Switzerland. 353 pp. ISBN 978-3-031-71343-9.**

Whipple Point on Brier Island is the westernmost point of Nova Scotia, forming a boundary between the Bay of Fundy to the north and east and The Gulf of Maine to the west. The island itself is small, only about 1600 hectares, a fractured extension of the North Mountain of the province, which is such a notable feature of Digby, Annapolis and Kings Counties. The bones of the island are two ridges of Jurassic basalt (overlaid by thin post-glacial sediments) between which is a depression that is shown by coring to have been a shallow marine passage that dried and became colonized by land plants, went through a treed phase, and eventually became a freshwater wetland dominated by peat-forming *Sphagnum* mosses. This is the Big Meadow Bog.

Brier Island is best known now for its whale-watching tours, but naturalists have visited it regularly since at least the 1950s (irregularly since the late 19th century) because it is an important landfall for migrating birds, especially in autumn, and because of rare or uncommon plants such as the curly-grass fern *Schizaea pusilla* and dwarf birch *Betula michauxii*, along with stunning displays of orchids in early summer. In 1921 and again in 1922 the Harvard botanist M.L. Fernald (1873-1950) came to Digby Neck for very short visits to look for a botanical rarity, the Golden Crest *Lophiola aurea*, which he located near Little River close to the end of Digby Neck. But he did not venture beyond Freeport on Long Island (the island just northeast of Brier Island) or he would have made a stunning discovery, the presence on Brier Island of Eastern Mountain Avens, *Geum peckii*, described and known previously only from high elevations in the White Mountains of New Hampshire. In 1949, Albert E. Roland and E. Chalmers Smith (authors of *The Flora of Nova Scotia)*, discovered this Avens, mainly around the Big Meadow Bog and nearby smaller *Sphagnum*-dominated bogs on Brier Island. It was this discovery and its implications that led to this book.

After years in a near pristine state, in 1958 to 1960 the Big Meadow Bog was ditched and partially drained, in a short-lived attempt at agriculture. The outcome was catastrophic to this natural ecosystem. Hill and Denton (in the second chapter) describe the outcome:

"…the water flow controlled by the million cubic meters of peat were [sic] lost. This led in the loss of the low shrub margins (the lagg), the blocking of the access to the bog by alder thicket, the fertilization of the whole bog by Herring Gulls, the overgrowth of the bog by tall thorns, and the loss of community traditions: berry picking, duck hunting, and walking to Pond Cove. It also resulted in more intense water flows after heavy rains as the outflow was not regulated by migration through peat but rather flowed through ditches. The addition of gull guano also resulted in poor water quality and high nutrients (the bog is now classed as "hyper-eutrophic")."

I can vouch for this from my memory of walking about 1970 from Westport along one of the drainage ditches southwestward to Pond Cove. It was tough going in brambles and occasional rose thickets, but not impossible. A few years later it had become impossible, at least without heroic measures to cut away the undergrowth, and I never tried again. What had been a raised bog with its marginal fen (the lagg) was becoming a wilderness of adventitious plants responding to drainage and nutrient enrichment. And it had been colonized by Herring Gulls that added enormously to the sparse nutrients present in the drying bog.

By the late 1980s it became clear that the alteration of the bog by ditching was threatening the Avens. This was noted in a 1986 status report to COSEWIC (the Committee on the Status of Endangered Wildlife in Canada) and in a series of reports and proposals that followed in the next two decades. After much deliberation and planning, the brave but risky decision was made to attempt to restore the bog to its pre-ditching state. In this, as the editors state, "the key factor was the will and interest of researchers, government and non-government conservation practitioners, and the local community on Brier Island; this was the overarching catalyst driving conservation focused on the Eastern Mountain Avens."

This monograph is an extensive and intensive account of the environmental setting in which the work took place, an account of attempts to restore the water levels of bog (and critically of the marginal lagg in which the Avens is most favored), and the preliminary results (into 2024) of attempting to restore the water level in the bog and its margins. The main action was to block the drainage ditches, using 123 dams, harvested from the bog's own peat. For the most part water level was restored in the main part of the bog and in the surrounding lagg, but it was difficult to control the nutrient loading of the bog caused by the hundreds of Herring Gulls nesting in part of the area. It became clear too that there was a complex relation between the water level and the success of the Avens – not too wet, as in the bog itself, but not too dry either - restricting its favored area to the marginal lagg. Nutrient levels remained high and the problem remained – not resolved to date – of what to do about the hyper-eutrophication caused by the gull faeces. Another problem is that the climate may be becoming unsuitable for the Avens' growth – Brier Island is the most rapidly warming of any studied location in Nova Scotia, an average of 2°C since 1990. It may be necessary to find another location for the species, using seeds stored in the seed-bank at Acadia University and proven culture and transplantation techniques. A critical and essential part of the restoration, as far as it has gone and for the future, was the buy-in of the Brier Island community, partly through the formation (in 2017) of a thriving Brier Island Trails Committee and its planning and building of a boardwalk (with interpretive signs) well into the restored area. The Big Meadow Bog boardwalk is now a major attraction to local people and to an increasing number of visitors.

It is not easy to review a monograph of this scale. There are 55 authors and 17 chapters (14 of which are scientific papers). However, three chapters (1, 2 and 17) are more general, introducing the bog, placing it in a community context, and comprehensively summarizing the scientific results of a remarkable and adventurous project. There is no index – it would have been a herculean, although very useful, task to prepare one. Typos are common throughout (none crucial, happily); it is clear that a good editorial proofreading didn't happen. A major problem is the very high cost, typical of all Springer publications, of this remarkable book. These quibbles aside, this massive work on the Big Meadow Bog of Brier Island is a tour de force in the literature of environmental remediation. It will be required reading by wetland ecologists and naturalists for a long time.

Eric L. Mills
Dept of Oceanography, Dalhousie University,
Halifax, NS Canada
e.mills@dal.ca

***Sustainable Fishery Systems* (Second Edition). Anthony Charles. 2023. John Wiley & Sons Ltd. 650 pp. ISBN 9781119511793.**

Anthony Charles' "Sustainable Fishery Systems" was first published in 2021 by Wiley and stands as a pivotal resource in any discourse on fisheries sustainability. It is his paradigm on fisheries management and is a synthesis of his work over a long career (as shown by over three pages of references in the book to his academic publications; and those were just the ones where he was first author!). This second edition builds on the foundational work of the first, offering an enriched, interdisciplinary exploration of fisheries management that seamlessly integrates ecology, economics, and social sciences. Charles adeptly bridges scientific rigor with policy relevance, presenting updated research, contemporary case studies, and innovative frameworks that address the complexities of modern fishery systems. The book's holistic approach underscores the interdependence of ecological health and human well-being, making it an indispensable guide for policymakers, practitioners, and scholars seeking action strategies for sustainable resource management.

The book's strength lies in its structured yet flexible examination of fishery systems. Chapters delve into critical themes such as governance models, community-based management, climate resilience, and the socio-economic drivers of overfishing. Charles enhances theoretical concepts with global case studies, from small-scale coastal fisheries to industrial operations, illustrating both successes and ongoing challenges. Practical tools—such as adaptive management frameworks, stakeholder collaboration techniques, and resilience assessments—are thoughtfully presented, empowering readers to navigate trade-offs between conservation and livelihoods. While the text acknowledges the difficulty of balancing diverse interests in fishery management, it consistently emphasizes solutions, offering pathways to align ecological limits with socio-economic needs. Notably, the second edition's expanded focus on climate change and globalization reflects the evolving pressures on fisheries, ensuring relevance in a rapidly changing world.

Written with clarity and precision, "Sustainable Fishery Systems" strikes a balance between academic depth and accessibility. Though some sections demand prior familiarity with sustainability concepts, the logical organization, and illustrative diagrams aid comprehension. Charles' engaging prose and real-world examples make the book suitable for graduate students and seasoned professionals alike.

I was surprised by two significant omissions regarding high profile commercial trap fisheries for lobsters. Firstly, there is a lack of special reference to the ongoing quarter century of conflict over indigenous rights in Canada's largest lobster fishery off southwest Nova Scotia about which he has written elsewhere. Secondly, while Charles outlined the challenges of applying input (effort) controls, he did not extol the virtues of these and other conservation-minded practices. These include return of egg-bearing females, escape vents for undersized lobsters, and bio-degradable panels to minimize ghost fishing by lost traps for managing lobster fisheries. These are among the best examples of sustainable fishery systems in Atlantic Canada (if not the world).

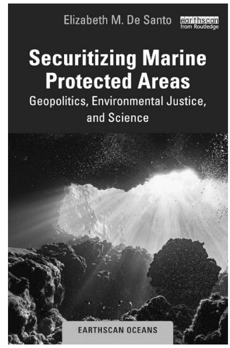
Wiley's polished presentation, including online supplementary materials, enhances the book`s utility as a teaching and reference tool. While the breadth of topics may occasionally overwhelm newcomers (and perhaps a few 'old salts' in the fishery like me), the book's systemic perspective is a vital contribution to the field. For anyone whose life is invested in the future of fisheries—whether fisher researcher, manager, or advocate—this edition is a compelling, comprehensive roadmap toward equitable and enduring sustainability.

Geoffrey V. Hurley
39 Burnaby Lane,
Dartmouth, Nova Scotia B2W 0H4
hurleyenvironment@gmail.com

***Securitizing Marine Protected Areas. Geopolitics, Environmental Justice, and Science*. Elizabeth M. De Santo. 2025. Routledge, New York. 189 p. ISBN 978-1-032-04097-4 (hbk).**

Marine protected areas (MPAs) are widely considered to be the best tool to protect ocean biodiversity. Generally speaking, an MPA is an area of the "ocean set aside for long-term conservation aims" (IUCN, 2017), although many other types of ocean protection fall into this category, including marine reserves, marine sanctuaries, or marine parks, all of which can have different objectives and levels of protection. A significant increase in establishment of MPAs has occurred over the past two and a half decades, due to a combination of climate change, biodiversity loss, and increasingly ambitious global conservation targets to address the two threats. As environmental issues are more and more politicized, this book argues that MPAs are becoming increasingly "securitized," that is, MPAs are deployed as a response to the global security threat of climate change (p.10). Dr. De Santo outlines how MPAs are created for more than biodiversity protection; they can also serve as a tool for political gains, environmental (in)justice, and provide a mechanism with which to examine information pathways at the nexus of science and policy. The book draws on De Santo's numerous years of research and experience in both national and international contexts to examine the implications of securitizing MPAs, which are presented in three sections: 1) geopolitics; 2) environmental justice; and 3) science. These explorations are situated against the new Biodiversity Beyond National Jurisdiction (BBNJ) Treaty, which provides the means to establish MPAs in Areas Beyond National Jurisdiction (ABNJ), and are anchored by case studies related to human rights, misinformation, and military tensions.

Geopolitics



The first section of the book examines rising military tensions and the role of establishing MPAs in overseas territories (OTs) to secure a foothold in advantageous locations. Chapter 2 describes the global arm-wrestling match that is the relationship between China and the US: establishing oil rigs and sending warships into contested waters, fortifying remote islands for military purposes, and strategically befriending each other's enemy's enemies. Chapter 3 examines how the OTs of France and the United Kingdom provide a mechanism to access resources and establish a presence in regions far from their own territories. While dense, these chapters illustrate how, within this increasingly fraught backdrop, MPAs established in these contentious regions are not only prioritized for their conservation value, but also their "geostrategic value" and ability to be "repurposed for action if needed" (p. 37).

Environmental Justice

The second section opens with a sobering examination of the establishment of the Chagos MPA, a process fraught with human rights violations, legal battles, and discriminatory, colonial practices at the hands of the UK and the US. De Santo guides readers through the expulsion of the Chagossian people from their island home in the name of conservation, the subsequent, unsuccessful legal battles to reestablish residency on the island of Diego Garcia, and the eventual passing of the Chagos Archipelago from UK control to Mauritius. She also considers the role of BINGOs (Big International Non-Governmental Organizations) and their potential to oppress local rights in the name of environmental protection. While the Chagos MPA is an extreme example, the underlying issue presented (e.g., expropriation in the name of conservation), is not uncommon. Chapter 5 analyzes ocean management practices and their alignment with the three pillars of environmental justice: 1) access to information; 2) participation in decision-making; and 3) access to justice, leaning on best practices for stakeholder engagement and case studies from Australia, California, and the UK in the establishment of MPA Networks.

Science

The final section focuses on science, namely, managing uncertainty and misinformation, implementing the precautionary approach, and identifying effective pathways between science and policy. Through several Canadian case studies, De Santo demonstrates the importance of consistent messaging, process transparency, and effective pathways for science advice in the MPA establishment process. This section speaks to the inherent complexities that exist in conservation planning, including access and misinformation, and how these complexities will be exacerbated in ABNJ.

This book comes at an interesting moment in marine conservation. In the run up to 2030, MPAs are being established rapidly and under extreme political pressure. Government agencies responsible for MPA establishment will be managing increasingly large areas of the ocean and all functional areas will be impacted: enforcement, operations, monitoring, research. These agencies are also tasked with doing this work quickly, equitably, effectively, and transparently. Given this context, I found some of the recommendations in the book to be somewhat optimistic. For example, advising the conservation community to look beyond the "low-hanging fruit" (p.173), e.g., areas away from heavier marine use. It can be a significant financial and administrative burden to accept liability for areas that are heavily used, not to mention management of the complexity of multiple stakeholders, partners, and users in a process that is under an increasingly tight deadline. I was also surprised that Parks Canada National Marine Conservation Areas (NMCAs) were not mentioned in a more fulsome way. Parks Canada is specifically mandated to create NMCAs in co-management agreements with Indigenous communities, an approach generally accepted to improve ecological and social outcomes of MPAs (Ban *et al.* 2011, Voorberg and Van der Veer 2020). Indeed, Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site is the only co-managed, federal marine conservation area in Canada (Ban and Frid 2018). In terms of access and environmental governance, the unique establishment and management of Gwaii Haanas may have been a worthwhile case study to explore in this book.

I found this book to be a comprehensive and novel examination of MPAs through three lenses that will become increasingly relevant as MPA establishment multiplies over the next five years. Weaving the context of the BBNJ Treaty into the study was an important angle to maintain throughout the book, particularly as the treaty reaches ratification in the next several years. As a policy analyst working on Canadian federal marine conservation initiatives, I found the book approachable, and I gained new insights that will be applicable for my work as an early career professional. Broadly, this book speaks to the dynamic nature of MPAs and the different roles they play in an increasingly politicized sea-scape, as well as lessons learned to ensure equity and success in future conservation initiatives.

REFERENCES

Ban, N.C., Adams, V.M., Almany, G.R., Ban, S., Cinner, J.E., McCook, L.J., Mills, M., Pressey, R.L. & White, A. (2011). Designing, implementing, and managing marine protected areas: Emerging trends and opportunities for coral reef nations, *Journal of Experimental Marine Biology and Ecology* 408(1-2): 21-31. doi.org/10.1016/j.jembe.2011.07.023

Ban, N.C. & Frid, A. (2018). Indigenous peoples' rights and marine protected areas. *Marine Policy* 87: 180-185. dx.doi.org/10.1016/j.marpol.2017.10.020

International Union for the Conservation of Nature (IUCN). (2017). November). Marine protected areas and climate change. Issues Brief. Gland, Switzerland: IUCN. iucn.org/sites/default/files/2022-07/mpas_and_climate_change_issues_brief.pdf

Voorberg, W., & Van der Veer, R. (2020). Co-management as a successful strategy for marine conservation. *Journal of Marine Science and Engineering* 8: 491. doi.org/10.3390/jmse8070491

Hali Moreland
Revelstoke, BC
hali.moreland@dal.ca

***Bones: The Life and Adventures of Doctor Archibald Menzies.* Graeme Menzies 2024. Whittles Publishing, Dunbeath, Scotland. 142 pp. ISBN 978-184995-591-1.**

Quite a few books deal with famous naturalists or scientist but few provide details about what life was like in Nova Scotia in the 1790s. This book is about Archibald Menzies who was born in Scotland, son of a gardener, whose talents were recognised early by the chief of the Menzies Clan who sponsored him to study botany and medicine at Edinburgh University. Archibald became a surgeon in the Royal Navy, surviving battles and missions that included two global voyages over a period of 20 years. The book not only describes his travels and his botanical achievements but also provides a commentary about the conditions and politics that he experienced. Eventually, he returned permanently to London, married and became a highly respected doctor a further 20 years. After this he retired, surviving until the age of 88, a remarkably long life for someone who had travelled twice to Western North America on sailing ships, the first of which was on a commercial mission that traded animal skins for metal tools and objects such as beads; the second was on a circumnavigation, which took almost five years, included a survey of the western coast of North America, with Captain George Vancouver after whom the island was named. Earlier in his naval career, Archibald sailed to Nova Scotia from the Caribbean, arriving in September,1792. Here he spent three years as a naval surgeon in Halifax. He soon went on excursions and in letters home expressed his pleasure at seeing familiar plants as well as those new to him, including a vast number of cryptogamic plants. During his time here, he sent seeds and plant specimens back to his botany professor in Edinburgh and others, including the leading botanist, Joseph Banks. He explored areas around Halifax, western Nova Scotia and PEI, before returning to Britain. Although his visit to Nova Scotia was brief, reading about it in the chapter entitled 'Blood and Botany' is enthralling. Members of the NSIS should purchase this book and follow the rest of his career and fascinating life. The book includes 12 pages of colour plates and is filled with fascinating details of the life and times of Archibald Menzies.

David H.S. Richardson
Environmental Science, Saint Mary's University,
Halifax, NS B3H 3C3

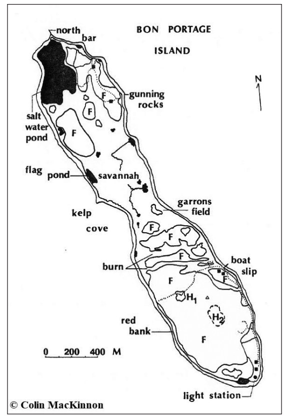
Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 357-361

NSIS FIELD EXCURSION 2025

HANK M.B. BIRD*
15 Amber Drive, Williamswood, NS B3V 1E8

A VISIT TO BON PORTAGE ISLAND, NS

On July12, 2025, seventeen NSIS members and guests participated in an excursion to Bon Portage Island, off the southwest coast of Nova Scotia. Bon Portage (called Outer Island on some maps) is a 240-hectare uninhabited island now owned by Acadia University, which operates it as an ecological research and field education site. It is also protected by a Conservation Easement with the Nova Scotia Nature Trust.



Bon Portage Island

Bon Portage supports a tremendous richness of pristine coastal habitats and species. It is one of Nova Scotia's last remaining large, unspoiled coastal islands, with many botanical species of interest. The island also provides a critical stopover for many migrating songbirds, shorebirds, waterfowl and raptors. It is home to over fifty species of breeding birds, including the largest breeding colony of Leach's storm petrels (*Hydrobates levcorhous*) south of Newfoundland.

The Lighthouse

Historically, it is the location of the famous book "We Keep a Light" by Evelyn Richardson. She and her husband Morrill purchased the island in 1926, moved there in 1929, and lived on it for the

* Author to whom correspondence should be addressed: hbird@eastlink.ca

Our Mode of Transportation

Our First Briefing on the Steps of the Field Station

next 35 years. He was the official lighthouse keeper. Her Governor-General's award-winning book describes their efforts to survive, run the lighthouse, and raise a family under very basic conditions.

We began our excursion on the mainland at the dock at Shag Harbour, south of Shelburne, where we boarded a fishing boat, named the *TGIFF.* The skipper, Mike O'Brien, took us out to the island on a foggy morning and helped us disembark on its only pier. The weather was fine, the winds were calm, and it was a smooth half-hour crossing. A curious harbour seal came close and observed us as we approached the island.

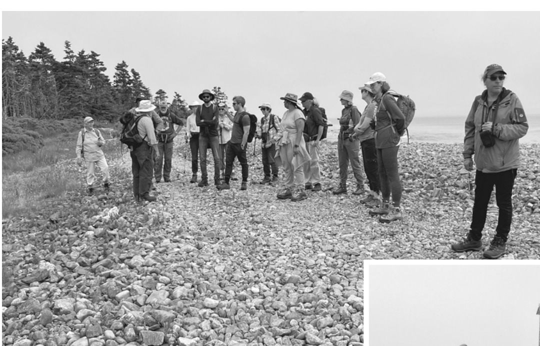
Once there, we made our way to some of the more recent buildings built to accommodate groups of students and researchers who spend several days at a time on Bon Portage. Our scheduled guide, Dr. Sherman Boates from Acadia, was unable to be with us so Mike O'Brien took his place. Mike has many years of experience on the islands and understands a great deal of the work conducted there, as well as the ecological and human history. He started by briefing us on the evolution of the biological field station, its infrastructure, and the focus of the island research. As it happened, no one from Acadia was present working at the station on the day of our visit.

We then headed down to the southern end of the island, the location of the lighthouse. On the way, we observed many costal-plain flora of interest, including Sea Pea (*Lathyrus japonicus* Willd.), nettles

(*Urtica* Spp.), and others (see NS Nature Trust 2005[1]). Mike also pointed out portions of forest flattened by recent hurricanes, and large areas with loss of trees due to the Brown Spruce Longhorn Beetle (*Tetropium fuscum*). Fortunately, these forest areas are recovering with rapid new growth.

The lighthouse no longer requires keepers, having been automated in 1984. The formerly-attached house in no longer there, and we were told that the lighthouse itself had been moved to higher ground, away from advancing seas. There are a few buildings in the vicinity and they are being refurbished for the additional use of students and researchers. The nearby area is quite open, having been used by the Richardsons and their successors for growing vegetables as well as feed for a few domestic animals. There is a marshy area next to this, occupied by many noisy Herring Gulls (*Larus smithsonianus*).

As we headed back to the research station, Mike shared his encyclopedic knowledge about the ecology, the weather systems, the wildlife, and items found along the shore. He commented on the many derelict lobster traps that get torn from their settings during the storms that come through the area and end up along the shoreline, and some even carried inland. He said that work parties collect them and put them to some use, depending on condition. One use is to fill them with rocks and stack them up to help stabilize the shoreline and the wharf.



A Briefing Along the Trail

Arriving at the Lighthouse

[1] Nova Scotia Nature Trust. (2005). "Guide to the Atlantic Coastal Plain Flora of Nova Scotia". Report of the NSNT. 77 p.

Whale Skull
Storm Petrel Nests
Lunch Time

Upon returning to the field station near the pier, we settled down for a nice relaxing picnic lunch and some socializing. After lunch, we headed north, then west on a cross-island path that took us to the opposite side of the island. This path passed through a thick forest with lots of overhead coverage, which turned out to be important habitat. The storm petrels dig deep holes and make their nests in the ground. The woods contained hundreds of holes, and many have been mapped and tagged by researchers. Seagulls and other predators prey on the petrels and their chicks, which are especially vulnerable when in the open. The forest cover provides a lot of protection, making the nests hard to see from above and making it difficult for the larger birds to get down to ground level.

The west side of the island was much the same as the east side, but with even less sign of human presence. The shoreline, as elsewhere on the island, is covered with sizeable rocks, a typical cobble beach; there is very little sand here, making shoreline walking difficult. The weather became a little overcast and slightly misty, so after a short stay, we headed back to the station and the pier.

The tide had gone out and our boat was now moored offshore, so we left the island four at a time using a small outboard motorboat as a ferry. Once all were on board, Mike sailed us most of the way up

Happy Island Explorers

Leaving the Island Behind

the east side of the island and pointed out more items of interest. One was the point of landfall where electricity was finally brought to the island via underwater cable in 1964. After this, we had a smooth, sunny and pleasant crossing back to Shag Harbour.

It was a wonderful day of exploration, touring a little-visited part of our province in ideal weather. Bon Portage is a small island but it has much interesting human and natural history. We learned a lot from Mike about a wide range of topics, and we enjoyed each other's company.

Acknowledgement Many thanks to Mike O'Brien for his valuable time and expertise, and to Acadia University for permission to visit the island.

Photos by H. Bird and P.G. Wells.

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 363-383

NSIS COUNCIL REPORTS

Reports from the Annual General Meeting
May 6, 2025 - 6:30 pm

AGENDA
164th ANNUAL GENERAL MEETING

Meeting held in McNally Auditorium,
Saint Mary's University, Halifax, NS, and via Zoom

1. **Welcome (**Jillian Phillips)
2. **Minutes of Previous AGM: (Jillian Phillips)**
   Minutes of the 163rd AGM on 6 May 2024
   Motion and Vote to accept the Minutes of the 163rd AGM.
3. **NSIS Video:** (Jillian Phillips)
4. **Reports:**
   President (Jillian Phillips)
   Treasurer (Angelica Silva)
   PNSIS Editor (David Richardson for Peter Wells)
   Membership (Jinshan Xu)
   Library (Jillian Phillips for Carol Richardson)
   Publicity (Brent Robicheau)
   Website (Brent Robicheau)
   Lecture Programme for 2025-2026 (Alana Pindar)
   Student Science & Technology Writing Competition for 2024 (Shannon Ezzat)
   Excursions (Hank Bird)
   Motion and Vote to accept the 10 reports.
5. **Awards:**
   Recognition of new Honorary Member (Jillian Phillips)
   Writing Competition Awards (Shannon Ezzat)
   NSIS Awards & Presentations (Judy MacInnis)
6. **By-Laws & Fees:** (Jillian Phillips)
   Increase in Institutional Membership fee.
   Motion and Vote to accept the new Institutional Membership fee.
   Amendment of By-Laws to reassign responsibility for the Membership List.
   Motion and Vote to amend the By-Laws about the Membership List.

7. **Council for 2025-2026:** (Jillian Phillips)
   Nomination of 2025-2026 Council.
   Motion and **Vote** to approve the new Council.
8. **Other Business:** (Jillian Phillips)
   Any Other Business.
9. **Adjournment:** (Jillan Phillips)

NOTE: Following the AGM, at 7:30pm there was a Public Lecture at SMU in-person and via a separate Zoom call. **Dr. Lori Borgal (MSVU)** presented *"Stem Cell Proliferation Gone Wrong: Mechanisms Exploited in Cancer Cell Proliferation"*.

Council Members & Observers Present: Jillian Phillips (President), Angelica Silva (Treasurer), Jinshan Xu (Membership Officer), Alana Pindar (Speaker Series Chair), Hank Bird (Secretary and Excursions), Shannon Ezzat (SSTWC), Bruce Hatcher (Councillor), Judy MacInnis (Councillor), Barbara Zielinski (Councillor), Tim Fedak (Observer, NS Museum), Ailish Sullivan (Observer, Discovery Ctr.), Eli LeDrew (Student Rep., MSVU), Courtney Strugnell (Student Rep., Acadia), David Richardson (Associate Editor).

Members Present: Judy Bird, Christa Brosseau, Michael Casey, Anne Dalziel, Bruce Fraser, Tanner George, Helga Guderly, Francis Jefferieys, John MacNiel, Carol Morrison, Michelle Paon, Crystal Parker, Jona Pedersen, Georgia Pe-Piper, David Piper, Aaliyah Rashid, Patrick Ryall, Jessica Ryuzaki, Connor Smith, Jantina Toxopeus, Sam Veres, John Young,

Regrets & Absent (Council Members & Observers): Stephanie MacQuarrie (Past President), Peter Wells (PNSIS Editor), Brent Robicheau (Publicity Officer & Acting Webmanager), Derick Lee (Councillor), Evan McNamara (Observer, Discovery Ctr.), Audrey Salinger (Student Rep., SMU).

1. **Welcome: (Jillian Phillips)**
   The President welcomed participants and called the 164th Annual General Meeting (AGM) to order at 6:30pm. The President noted that presentations would be kept short and informal and that the reports, excluding the minutes from last year's AGM, would be approved as a unit at the end of the presentations. The minutes will include the contents of the slides and additional material from the written Annual Reports.

2. Approval of the Minutes of the 163rd Annual General Meeting of 5 May 2024: (Jillian Phillips)
A draft of the 2024 AGM minutes was e-mailed on 29 April 2025 for perusal by all NSIS Members.
There were no revisions to those Minutes.

3. Motion to accept the Minutes of the 163rd AGM:
Moved: by J. Phillips to accept the Minutes of the 163rd AGM
Seconded: by A. Dalziel
All in favour: Minutes approved.

Moved: by J. Phillips to adopt the Agenda for the 164th AGM
Seconded: by A. Dalziel
All in favour: Minutes approved.

4. NSIS Video: (Jillian Phillips)
We are preparing a short and longer videos about the NSIS for the website and social media, and for showing to students and other audiences (such as donors). It is almost complete and the short version was shown to the AGM attendees.

5. President's Annual Report: (Jillian Phillips)
The Nova Scotian Institute of Science (NSIS), founded in 1862, is one of Canada's oldest learned societies and continues to thrive with the support of its members and executive council. In the 2024/25 year, NSIS council continued our mission to promote science in Nova Scotia through public engagement, scholarly publishing, student opportunities, and community outreach. Comprised of a dedicated group of volunteers, the Council continues to pursue ambitious goals and actively seeks new members and funding to support our initiatives. The President sincerely thanked everyone serving on this year's council for their dedication. We are a small group that dedicates much of our time, so she is very grateful for the work you have accomplished this year. She invited others with a passion for science to join us, share the responsibilities, and contribute to advancing our mission.

She also recognized our departing Secretary and long-standing NSIS council member and NSIS Life Member, Hank Bird. Hank has been pivotal to NSIS's progress and has served as our voice and main point of communication for the past 5 years as Secretary. While Hank is remaining on the council next season in a different capacity, She thanked him for everything he has contributed to the organization to date and for making her transition to President as smooth as possible with a willingness to support and share his long-term institutional knowledge of the NSIS. With Hank departing from the Secretary role, we have lost a vital role that supports our mission, and she urged current and past members and the council to consider reaching out about the role or sharing with colleagues who may be interested in supporting. With Hank intending to serve as a councillor in 2025-2026, he will serve as an excellent mentor to any incoming secretary.

During the 2024-2025 year, NSIS maintained its commitment to public science communication by hosting monthly hybrid public lectures from October to May. These lectures, held at Saint Mary's University, Cape Breton University, St. Francis Xavier University, and accessible via Zoom, marked a milestone for increasing NSIS reach and speaker diversity, providing the option for speakers across NS (and beyond) to present at their institution of choice, reaching their local audience in person and a wider provincial audience online, something not possible in earlier years with the lecture venue rooted in-person in Halifax. The lectures featured a diverse range of topics, including marine science, climate change, health research, and a fascinating talk from Nobel laureate Art MacDonald. Recordings of these talks are available on the NSIS YouTube channel, extending their reach beyond the events themselves.

The ***Proceedings of the Nova Scotian Institute of Science (PNSIS)***, the institute's peer-reviewed journal, published Volume 53, Part 2 in October 2024, is an excellent read including editorials, commentaries, and scientific articles covering topics such as urban planning, oceanography, and marine biology. The journal is a platform for disseminating regional scientific research and advocacy. A new issue is underway with anticipated publication at the end of September and the editorial board continues to solicit submissions. We encourage this year's Student Science and Technology Writing Competition winners to consider submitting to the PNSIS.

This year, NSIS launched the new **Spring 2025 NSIS Conference Travel Awards** program to support NS-based trainees (postdocs, research assistants, graduate students, and under-graduates) who are members of the NSIS with the presentation of research that took place in NS. In its inaugural year, the initiative drastically increased our student membership, two students received awards of $500 each to help offset travel and presentation expenses, and three additional students received partial, runner-up funding of $100 each. This initiative reflects NSIS's ongoing commitment to fostering early-career scientific development, ensuring students have access to opportunities for professional growth and research dissemination.

The NSIS continued to encourage science communication among students through its **Annual Science and Technology Writing Competition**. This year, we opted to bring back the option for a research paper with the hope of increasing the number of graduate student submissions over the previous year, while also keeping the essay option so the competition remained accessible to undergraduate and college students not completing research, and to high school students. This initiative provides post-secondary and high school students with an opportunity to develop and showcase their ability to communicate complex scientific concepts to a general audience. The competition not only enhances students' writing through meaningful feedback prepared by our panel of judges but also promotes the importance of science literacy to students.

NSIS proudly welcomed two new Honorary Members, Dr. John C.O. Young and Dr. Zoe Lucas, in recognition of their outstanding contributions to science and its communication. I encourage all members and interested parties to read more about Dr. Young's exceptional contributions to chemistry research and education and Dr. Lucas's outstanding contributions to the study and protection of Sable Island ecosystems in their profiles featured on the **Honorary Members Section** of the NSIS Website.

Beyond its formal programs, NSIS created a promotional video to gain awareness and drive new membership, engaged in community outreach activities, including excursions, supported school science fairs financially, and a few council members and observers generously volunteered their time as science fair judges. These initiatives are designed to recognize and engage our members, inspire the next generation of scientists, and promote a broader understanding of science's role in society and how NSIS can support that. Seeing the ingenuity of students at Armbrae Academy's grade 7 science fair and their project topics during science fair judging gives us hope for future generations of Scientists.

While we are supportive and hopeful for future generations of Nova Scotian Scientists, we acknowledge that there is a growing threat to scientific literacy, freedom of speech, and human rights to our fellow scientists and neighbours south of our borders. As an institute dedicated to the free exchange of scientific ideas, NSIS expresses deep concern over the recent restrictions placed on research funding and academic freedom in the United States under the new federal administration. We stand in solidarity with our American colleagues and affirm the importance of protecting scientists' freedom of inquiry, expression, and evidence-based communication. NSIS will continue to advocate for these values, both locally and globally, and calls on our members and affiliates to remain vigilant and vocal in defense of scientific integrity. The President encouraged all general members and council alike to read the timely and thoughtful draft prepared by PNSIS Editor Peter Wells on the matter and to take action. Early copies of the draft, to be revised and later featured in the PNSIS, will be circulated during the AGM.

Looking Ahead

As we move into our 2025/26 year, NSIS remains dedicated to its mission of promoting science in Nova Scotia. With ongoing support for students, continued public engagement, and a commitment to scholarly publishing, NSIS is poised to contribute further to the scientific community and the public understanding of science in the province. We look forward to seeing how the new promo video, and student and member awards, raise awareness of our mission and bring in new members. We are eager to connect with new student representatives to learn how NSIS can best increase our impact and reach among Nova Scotian Students and make new connections with early career scientists. We aim to work with our new and departing Membership Officers and our recently formed financial planning/ fundraising committee to find innovative sponsorship and fundraising opportunities to continue supporting our mission and expand our reach.

For more information on NSIS's activities and how to get involved, visit **nsis1862.ca**.

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

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

$1,000.00 in donations to the NSIS, $154.00 in *ProcNSIS* sales, and a $29.34 refund from PayPal. Last year, as of **March 31st, 2024, the net worth of the NSIS was** $29,348.69, held in our BMO bank account. Of this, $14,348.69 was in cash, and $15,000.00 was in an 18-month GIC which matured in Oct. 2024.

This year, as of **March 31st, 2024, the net worth of the NSIS is** $28,661.52 in our BMO bank account. $13,661.52 is in cash, and $15,000.00 is in a 12-month GIC maturing in Oct. 2026.

Revenue from all sources were $6,634.12. $4,300.00 was individual memberships and $180.00 in Institutional Memberships. We received $970.71 in interest from the GIC that matured in Oct. 2024. There were Expenditures amounted to $7,321.29. This includes $3,592.46 of for layout and printing of the *ProcNSIS.* Other expenditures included $137.03 in postage, $2,000.00 in Prizes for the SSTWC, $600 to support school Regional Science Fairs, $720.00 to support the Sable Island conference, the Fishermen & Scientists Research conference, and student conferences, $100.00 for guides on an excursion, $20.00 in PayPal charges, and $151.80 for a framed certificate for a new Honorary Member.

The Treasurer noted that, as of March 31st, 2025, the NSIS had a total of 151 active members and 9 institutional members. By the date of this AGM, the number of active members has climbed to 189. (See item #7.) Most, but not all of the increase from last year is due to the enrolment of 58 students in the NSIS Travel Awards Competition.

She thanked Carol Richardson (Dalhousie Killam Library) for her continuing contribution with NSIS mail at Dalhousie University, and for library services. Many thanks to all NSIS Council Members for reviewing monthly reports and suggestions as well as to our Membership Officer J. Xu. Many thanks to NSIS Secretary Hank Bird for multiple roles and contributions with mail and banking.

7. Editor's Annual Report (Peter Wells & David Richardson): PNSIS Vol. 53, Part 2, 2024 was published and made available via the website. 50 copies were printed and most were distributed by hand and by post to members who requested them and to several institutions and libraries. The remainder were sold. We should print more (perhaps 100) of the next issue.

Work on **PNSIS Vol. 54, Part 1, 2025**, is well underway. The draft Editorial, on the topic of support for science, especially in the USA, is circulating for comments and will be completed soon. A copy of the draft is provided as an Addendum at the end of these minutes, and printed copies were available at the AGM. Members are encouraged to read it and take action.

Two Commentaries are completed, as is one Research Paper. A third Commentary is under review, one is promised, and two new Research papers are at different stages of preparation and review. Six book reviews are completed and ready for copy editing.

We still need more research papers. Our editorial board is engaged with looking for them, and the Council can help, especially if they know of graduate students finishing their research on scientific topics of Nova Scotia interest and looking for a place to publish.

We are working on a deadline for submissions for Vol. 54-1 of June 30th, 2025, and publication of the Issue by end of September.

We wish to thank the Acting Webmanager, Brent Robicheau, for greatly improving the "Publications" section on the website.

Two questions have been posed; they are: 1) The inclusion of DOIs for each published paper (this is now standard for most scientific publications), and the authors ownership or not of copyright, both of which can addressed and resolved by us with the help of the Killam Library; and 2) The potential influence of AI (artificial intelligence), e.g., Chat GPT, on the content and credibility of submissions to the PNSIS. P. Wells and D. Richardson will address these questions with the Editorial Board, and then with the Council.

8. Membership Annual Report (H. Bird for Jinshan Xu):
To date, there are currently 189 active members of the NSIS, plus 6 institutional members. This is much higher than a year ago.

Type of Membership	**AGM 2023**	**AGM 2024**	**AGM 2025**
Honorary	2	3	5
Life	26	29	35
Regular	76	60	64
Student	6	6	65
Complimentary (Lecturers, SSTCC)	17	22	20
	127	120	**189**
Institutional	10	3	9
	137	123	**198**

There were modest gains in Honorary, Life, and Regular memberships. But most impressive is the surge in student memberships, which jumped from 6 last year to 65 this year. This sharp increase is largely attributed to proactive efforts such as the introduction of travel awards that have made membership more attractive to students.

Several strategic changes have contributed to this revitalization, including the shift of monthly meetings and public lectures from fully in-person formats to online and then hybrid (online and in-person) models, making events more accessible to a wider audience. The adoption of gift memberships and the transition from PayPal to bank direct transfer for membership payments have also played supportive roles in facilitating member engagement and retention.

A key aspect of NSIS's community presence is the regular hosting of free monthly public lectures and a student writing competition, which engage both members and the wider public. Highlights such as Nobel laureate lectures have attracted especially large audiences and enhanced NSIS's reputation. These signature activities enrich scientific dialogue in Nova Scotia and inspire the next generation, supporting the society's ongoing growth and impact.

9. Librarian's Annual Report (Carol Richardson):

- **Proceedings of the Nova Scotian Institute of Science:** During April 2024-March 2025, there were no sales of the Proceedings from the Killam Library's Reference & Research Services office.
- **Access Copyright:** Any payments received from Access Copyright were sent directly to the NSIS Treasurer.
- **Institutional Members and Exchange Partners:** NSIS recently sent invoices to its Institutional Members (a bit later than usual this year). One institutional member has renewed ahead of the mailing. There are currently 6 Institutional members (an increase from 2023/2024) and 81 Exchange partners (no change from 2023/24).
- **NSIS Exchange Journal Collection:** NSIS receives journal issues from exchange partners around the world. As an example, from April 2024 to March 2025, NSIS received 22 journal issues and society publications from the Institute's exchange partners. These items were delivered to the Dalhousie Libraries (Killam Memorial Library location), where they were processed and added to the NSIS collection in the library.
- **NSIS Physical Records:** In July 2024 the remaining hardcopy records of the NSIS were physically transferred from the Killam Library to the Public Archives of Nova Scotia under a Deed of Gift. They included financial ledgers, minutes of meetings, etc., and join records previously transferred to the NS Archives. They will be catalogued, stored, available to the public, and some of them may become digitized.

10. Publicity Annual Report (Brent Robichaud):
Highlights:

- The Publicity Officer generated annual promotional material for the lecture series including monthly printable posters, monthly social media banners, and our annual NSIS brochure (contains full list of seminars for the year and other NSIS information (e.g.: how to become a member).
- He generated monthly Facebook events for each lecture. He also advertised monthly about the lecture series on Facebook, Twitter, and Instagram (about 1–2 weeks before each lecture). Other content was posted to Facebook, Twitter, and Instagram as requested (for e.g., posts about the writing competition).

- He emailed university science administrators about upcoming lectures each month.
- B. Robichaud also worked with Councilor J. MacInnis and Past-President S. MacQuarrie to edit terms of reference for new suite of NSIS Awards. These were voted on and approved by Council.
- The Publicity Officer assisted in judging and chairing the first round of NSIS Travel Awards. We had two main winners and three runner-up awardees.

Facebook (2024-2025): Assessment: In the previous year at the AGM we had 841 followers. In the current year we now have 940, a net gain ar of 99 followers. In comparison in all of the previous year we gained only 58 followers.

Twitter (2024-2025): Assessment: Based on the number of followers, we had 229 followers in May 2024 and in May 2025 we have 215 followers. Hence, a net loss of 14 Twitter followers this past year. We should likely move to BlueSky in the coming year.

Instagram (2024-2025): Assessment: Last May we had 104 followers on Instagram, we now have 113 followers, therefore a net gain of 9 followers. We should aim to put more items on our Instagram page in the next year as we have only been advertising the lecture series once a month.

11. Webmanager's Annual Report (Brent Robicheau):

NSIS Website: As acting Webmanager, B. Robicheau worked to update the NSIS website as requests came in or as circumstances required. This included:

- Made the NSIS website easier to navigate, more organized and with outdated info removed.
- Largely overhauled the following pages:
  - News and Events
  - Publications
- Performed ongoing updates to public lectures page.
- Provided updates for Student writing competition.
- Created the page for 2025 AGM.
- Added profiles of the new Honorary Members.

Wikipedia Entry: (Note added in proof.) This is not a website issue, but one that affects our online presence. We discovered that the Wikipedia entry for the NSIS was 12 or more years old, so we updated it with better and up-to-date information.

12. Lecture Series Annual Report (Alana Pindar):

This was a very successful seminar year. A. Pindar noted that the YouTube channel with our past Lectures has much-increased traffic – between 75 and 426 viewers per lecture. We also saw CBU hosting three seminars outside of HRM, and St.F.X. hosted another. The other three were at SMU. Topics covered climate change, fisheries, brain health and physics.

As we continue into the 2025-2026 year, we encourage all other Institutes to host an NSIS seminar in the future.

This year we hosted our second student career event which saw participants from across Nova Scotia and experts from different career paths. As before, the event focused on careers in science, and what to expect after graduation.

For logistical and other reasons, we were unable to hold a student symposium, where students make brief presentations of their work. In 2026 we will hold the symposium as a featured event as part of the speaker series of lectures, but separately from the normal lecture schedule.

We wish to thank all of the 2024-2025 Seminar Speakers, student career event guests, and of course all of our viewers!

Planning for the student events will begin in **September 2025**, we encourage Councillors to consider joining the student career, and/or the student symposium organizing committees to help organize both events that will be held in 2026.

2025-2026 Confirmed Seminar Series:

- October 2025: Dr. Jennifer Perry (St. F.X) – Hosted by St. F.X
- November 2025: Dr. Matthias Bierenstiel (CBU) – Hosted by CBU
- December 2025: Dr. Svenja Huntemann (MSVU) – Hosted by SMU
- January 2026: Dr. Saurabh Chitnis (Dal) – Virtual Presentation

- February 2026: Dr. Janita Toxopeus (St. F.X) – Hosted by St. F.X.
- March 2026: Dr. Chloe Schmidt (Dal) – Hosted by Dal
- April 2026: Dr. Malama Chisanga (Dal) – Hosted by Dal
- May 2026: Dr. Karyn McLellan (MSVU) – *Hosted by SMU*

The topics include math, chemistry, biology, environmental science, and indigenous medicine.

We request that suggestions for the 2026-2027 Series be sent to her as soon as possible.

13. Student Science & Technology Communication Competition Annual Report (Shannon Ezzat):

This year's competition remained similar in format to previous years with an open call for essays focussed on a science, technology, math, or social science topic.

The overall goals of the competition are as follows:

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

Student Stats:

- 58 students registered for the competition.
    - High-school registrations were from 8 schools: Shelburne, DEVI, Halifax Grammar, C.P. Allen, Halifax West, Maritime Muslim Academy, Citadel, Armbrae.
    - University registrations were from 7 universities: CBU, STFX, Dal, Kings, SMU, MSVU, Acadia.
- 36 papers were submitted at the close of the competition.
    - 27 high-school essays were submitted.
    - 7 Undergraduate and 2 Postgraduate Essays were submitted from the Universities.

Three Winners and four Honorable Mentions (see Item 17. below) were selected based on scoring and judges' feedback. It was suggested that these students be featured on the NSIS website, possibly with a copy (or the abstract) of their papers.

The coordinators would like to thank all the students who participated and all those who made the competition possible. A special thank you goes to our generous donors: Cape Breton University and Saint Mary's University. Many thanks to Jinshan Xu for his support during the early phase of setting up the competition to and Hank Bird, for creating comprehensive score sheets to capture judges' feedback and guide our decision making. Thank you to our 14 judges, who were: Hank Bird, Sheryl Bourgaize, Shannon Ezzat, James Kho, Eli LeDrew, Stephanie MacQuarrie, Jillian Phillips, Alana Pindar, Megan Roberts, Audrey Salinger, Angelica Silva, Ailish Sullivan, Peter Porskamp, and Barbara Zielinski.

14. Excursions Annual Report (Hank Bird):

We did 18 excursions between 2016 and 2025, with a break from 2020-2022 due to Covid-19.

With the able assistance of Bruce Hatcher, we organized an excursion to Scatarie Island in July of 2024. We had a full complement of 20 members and guests. In these times Scatarie is uninhabited and a protected area. It was a perfect day, and the party explored parts of the island on foot and of the coastline by Zodiac. We saw much about the landscape, geology, and botany, and we observed much marine life and birds. There is a description with photos of this excursion in the latest copy of the *Proceedings of the NSIS*.

In 2024 we canvassed the NSIS Membership about 10 possible excursions that we have been considering. Based on the respondents' votes, the top five in terms of interest were:

1. Legacy NS Gold Mines and Remediation
2. Halifax Field Naturalists (joint outing)
3. Bon Portage Island
4. Kejimkujik Peroglyphs and Nature Walk (repeat)
5. Canadian Geological Association (joint outing)

The respondents also contributed 12 other suggestions for outings, so we have 22 possibilities for the next several years.

We are working with Dr. Linda Campbell of SMU to do an outing to a historical gold mine in the Halifax region later in the summer. The objective is to learn about historical gold mining in NS and the resulting remediation efforts required.

We and the Halifax Field Naturalists have begun to exchange and share each other's events and activities on our websites. Later this year we will explore the possibility of a joint excursion.

We are also working with Acadia University on an outing to Bon Portage Island in early July. Acadia owns the island and operates a research station there. The island is off the SE corner of Nova Scotia and has a large number of features of ecological, marine, botanical, zoological, and historical interest.

We welcome additional suggestions.

15. Motion to Accept the Annual Reports:

Moved: by J. Phillips to accept the annual reports.
Seconded: by A. Silva
All in favour: Reports accepted.

16. Awards – Recognition of New Honorary Members: (Jillian Phillips)

Per the by-laws, a Nova Scotian person distinguished in some branch of science or who has rendered conspicuous service to the advancement of science can be elected an Honorary Member.

Dr. John Young of Saint Mary's University is recognized for his outstanding contributions to science in Nova Scotia and beyond for more than 50 years. His academic contributions in mathematics and chemistry extend over 75 years! One of his many notable impacts was pioneering a computer-linked chemistry teaching laboratory at Saint Mary's University and at the National Teacher Training Institute in The Gambia, West Africa in 1997 In addition to many years of successful and well recognized teaching, John has been a prolific researcher and publisher. In recent years his research has focused on improving standard chemical assessments and analytical tests; the results of which have been published in Chemistry Educator and widely read. He published three papers in his 95th year (2023)! During his time at Saint Mary's University John has held a wide spectrum of administrative roles, including acting Academic Vice President and as a member of the Executive and Finance Committees of SMU's Board of Governors. He is a member of the NSIS and was a member of the NSIS Council from 2011 to 2017.

Regarding his education and employment, John taught Mathematics during military service the British Army's Royal

Electrical and Mechanical Engineers in1949-50. He received a BSc in Chemical Engineering (First Class Honours) in 1953 from the Imperial College of Science and Technology, University of London, England; a PhD in 1956, also from Imperial College, and an MBA (with Distinction) in 1965 from New York University's Graduate School of Business Administration.

Dr. Zoe Lucas of the Sable Island Institute is recognized for her lifelong outstanding contributions to the study and protection of Sable Island ecosystems. She has spent over 50 years dedicated to the study and protection of Sable Island, a unique ecosystem in the Northwest Atlantic. Through experiential learning and immersive, hands-on engagement, she transitioned from a background in goldsmithing and art to become a leading natural historian. Her extensive research spans topics such as the island's iconic horses, marine litter, biodiversity, and ecological monitoring, resulting in numerous scientific publications and impactful outreach. Lucas has collaborated with dozens of scientists and students. She founded both the Friends of the Green Horse Society and the Sable Island Institute to support education, research, and conservation. Recognized with honors including an honorary doctorate and the Order of Canada, she is widely regarded as the foremost expert and unofficial steward of Sable Island. In recognition of her outstanding contributions, Dr. Lucas has been elected by Council as an Honorary Member of the Nova Scotian Institute of Science.

17. Awards – 2025 Student Science and Technology Writing Competition Winners: (Shannon Ezzat)

High School Winner ($300):

- **Satya Rimbert**, DEVI International Boarding School, *Microplastics: The effect of microplastics on the human lungs*

High School Honourable Mentions (3 x $150):

- **Francis Jefferies**, Hydrostone Academy, *An Odorous Opponent: Garlic vs. Bacteria and Fungi*
- **Aaliyah Rashid**, Maritime Muslim Academy, *Mouth-Brain Connection: Exploring How Oral Bacteria Affect Brain Health*
- **Annabelle Kamp**, Armbrae Academy, *The Pathways of Plastic: Investigating the contamination and transfer of microplastics into food products*

Undergraduate Winner ($600):

- **Jessica Ryuzaki**, Mount Saint Vincent University, *Revolutionizing Mobility: Brain-Computer Interfaces in Robotic Arms*
- Undergraduate Honourable Mention ($300):
- **Aniqa Jalal**, University of Kings College and Dalhousie University, *Science Through the Sense of Self: Investigating Science Self-Efficacy and Science Anxiety amongst undergraduate psychology and neuroscience students*

Postgraduate Winner ($800):

- **Jona Pedersen**, Saint Francis Xavier University, *Diapause: How overwintering insects adapt to seasonal challenges in a changing climate*

Postgraduate Honourable Mention ($0): None.

18. Awards – New NSIS Awards & Presentations: (Jillian Phillips for Judy MacInnis, Stephanie MacQuarrie, Brent Robicheau)

Last year we established new NSIS awards, and the Council has adopted them. They comprise:

- Service Awards: Dedicated Service (regular + trainee), Exceptional Service
- Travel Award
- Early Career Award
- Editor's Choice Award
- Best Talk Award
- STEAM Award (junior and senior)

This spring we conducted a competition for the 2025 Travel Award:

- Intent - to support presentation of research taking place in NS by NS-based researchers.
- Eligibility - NSIS member trainees (Postdocs, research assistants, graduate and undergraduate students).

Applicants were evaluated on items such as:

- Description of research and strong connection to NS.
- Provision of budget & demonstration of financial need.
- Rationale for conference choice.

The winners were:

- **Ava Sergio** ($500) – Dalhousie U. – MSc – Biology
- **Karen Tang** ($500) – Dalhousie U. – PhD – Psychology & Neuroscience
- **Julie Campbell** ($100) – Dalhousie U Dal – PhD – Health
- **Sam Hawkins** ($100) – Dalhousie U – BScH – Psychology & Neuroscience
- **Alexandros Noussis** ($100) – Dalhousie U – MSc Applied Sci – Engineering

19. Increase in Institutional Membership Fee: (Jillian Phillipa)
A notice of this item was e-mailed on 21 April 2025 for perusal by all NSIS Members.

Last year we increased the dues for Regular Members from $30 to $40 per year, but we did not do the same for Institutional Members. We would like to do it at this time. Any change in membership fees requires approval by the NSIS members at an AGM. Council recommends that you approve this change.

The new rates would be:

Student Member	$10 per year
Regular Member	$40 per year
Institutional Member	$40 per year
Life member	$300 one-time

20. Motion to Approve the New Institutional Membership Fee:
Moved: by J. Phillips to raise the dues for Institutional Members from $30 to $40 per year.
Seconded: by J. Xu
All in favour: New dues schedule approved.

21. Amendment of By-Laws to Reassign Responsibility for the Membership List.
A notice of this item was e-mailed on 21 April 2025 for perusal by all NSIS Members.

Due do the migration of practices from being paper based to being digitally based, and the resulting changes in flow of information, we wish to move the responsibility for creating and maintaining the Membership List from the Treasurer to the Membership Officer. Council concurs, but such a change requires changes in a few of the By-laws – which must be approved by the

NSIS members at an AGM. Specifically, Council recommends the following three changes (red text indicates a deletion, green text represents an addition):

Change Treasurer bylaw 26.e from: "maintain a list of members and their status such that members may be billed each year for the fee owing."

To read: "obtain a list of members and their status from the Membership Officer such that members may be billed each year for the fee owing."

Change Membership Officer bylaw 28.a from: "in conjunction with the Treasurer and the Secretary maintain a list of members and their addresses"

To read: "with information from bank transfers, and input from the Treasurer and the Secretary, maintain a list of members and their email and postal addresses"

Change Secretary bylaw 25.b from: "deal with the correspondence of the Institute, including maintaining a duplicate list of members, as provided by the Treasurer and issuing notices of meetings of members and of Council."

To read: "deal with the correspondence of the Institute, including maintaining a duplicate list of members, as provided by the Membership Officer, and issuing notices of meetings of members and of Council."

22. Motion to Approve the new By-laws:
Moved: by J. Phillips to approve amending the By-laws concerning Membership Lists.
Seconded: by H. Bird
All in favour: By-law amendments approved.

23. Nomination of 2025-2026 Council: (J. Phillips)

The President thanked the outgoing Council. The AGM was asked to elect the following to NSIS Council for 2025-2026:

Officers:	
President	Jillian Phillips
Past President	Stephanie MacQuarrie
Vice-President	Brent Robicheau
Treasurer	Angelica Silva
Editor	Peter Wells
Library Liaison	(open) C. Richardson will support
Membership	Barbara Zielinski
Webmanager	Ailish Sullivan
Publicity Officer	Eli LeDrew
Secretary	(open)
Speaker Series Chair	Alana Pindar
Councillors:	
Councillor (Excursions)	Hank Bird
Councillor (SSTWC)	(open)
Councillor	Shannon Ezzat
Councillor	Helga Guderly
Councillor	Bruce Hatcher
Councillor	Derrick Lee
Councillor	Judy MacInnis
Councillor	Jinshan Xu
Observers:	
Nova Scotia Museum	Tim Fedak
Discovery Centre	(open)
Schools	(open)
CBU	(open)
Associate Editor:	David Richardson

24. Motion to Approve the Nominations:

Moved: by J. Phillips to approve the nominations for the 2025-2026 NSIS Council.

Seconded: by P. Ryall

All in favour: Nominations approved.

25. Any Other Business:

There was no other business to conduct.

26. Adjournment:

Moved by J. Phillips to adjourn the 164th Annual General Meeting of the NSIS at 7:41 pm.

Respectfully submitted,
Hank Bird, Secretary

NSIS 2025-2026 LECTURE SERIES NSIS1862.CA

Oct 6 - St. Francis Xavier University

The Surprising Social Lives of Insects

Dr. Jennifer Perry
St. Francis Xavier University

Many insects live lives of surprising complexity. Dr. Perry will discuss case studies of how insects fine-tune their behaviour in response to the social and environmental context, and how studying insect behaviour can help us understand key evolutionary processes.

Nov 3 – Cape Breton University

Maskwio'mi: The Story and Study of a Mi'kmaq Skin Medicine made from Birch Bark

Dr. Matthias Bierenstiel
Cape Breton University

Are there any natural products in our own backyard? Dr. Matthias Bierenstiel will present the story of maskwio'mi (maskwi = birch bark, o'mi = gathering/oil) and how a chemist ventured into the world of Mi'kmaq myths, topical skincare and a campfire, eptuaptmumk (Two-Eyed Seeing), and the entrepreneurial start of Maskwiomin as ethical commercialization.

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

Dec 1 – Saint Mary's University

Combinatorial games: Would you like some math with your game?

Dr. Svenja Huntemann
Mount Saint Vincent University

You are playing a game of pure strategy, such as chess, checkers, or go, with a friend. Where should you make your next move? Dr. Huntemann will teach you some of the tools mathematicians and computer scientists use to find the optimal move in such games through the example of two games with much simpler rules that are still surprisingly difficult.

Jan 5 – Virtual Presentation

Matter from Air: Replacing Carbon with Nitrogen for Sustainable Materials

Dr. Saurabh Chitnis
Dalhousie University

Society's dependence upon petrochemical plastics is fundamentally at odds with the goal of eliminating fossil fuels in a NetZero future. Dr. Chitnis will describe the vision of using nitrogen as an alternative elemental basis for materials. Such materials would also have the advantage of being "circular" by being turned into fertilizer at the end of their lives. This talk explores carbon-negative and degradable materials instead of fossil-fuel based, carbon-positive, and persistent ones.

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

Feb 2 – St. Francis Xavier University

Ticked off by the cold: How ticks and other critters deal with winter

Dr. Jantina Toxopeus
St. Francis Xavier University

Why are ticks so abundant these days? What does it mean for our risk of getting Lyme disease? Dr. Toxopeus will talk about how ticks and pest insects are affected by warmer fall and winter conditions, and what it may mean for us.

Mar 2 – Dalhousie University

How humans unintentionally affect wildlife evolution

Dr. Chloé Schmidt
Dalhousie University

Humans affect the evolution of other organisms in a variety of ways. For instance, selective breeding can cause trees to produce larger fruit, or insecticide use can put pressure on insects to evolve resistance. But large-scale environmental transformations, such as urbanization, can also have indirect evolutionary consequences. Dr. Schmidt will explore the ways humans can shape the evolutionary futures of other species, and implications for conserving the adaptive potential of wildlife populations.

Apr 6 – Dalhousie University

Nanotechnology-driven Approaches for Rapid Medical Diagnostics and Treatment

Dr. Malama Chisanga
Dalhousie University

Infectious diseases affect all communities, yet we have not figured out how to diagnose and treat them promptly. It takes ca. >48 h to identify a pathogenic disease, leaving physicians unsure what treatment suits patients. Can diseases be detected and treated faster? Dr. Chisanga will answer this question and highlight new analytical tools for the early detection and treatment of microbial infections.

May 4 – Saint Mary's University

Random Fibonacci Sequences and Viswanath's Constant

Dr. Karyn McLellan
Mount Saint Vincent University

You may have heard of the Fibonacci sequence and its growth rate, the golden ratio, but have you heard of a random Fibonacci sequence? In this talk Dr. McLellan will discuss the Fibonacci sequence, what happens when the element of randomness in introduced, and the subsequent search for Viswanath's constant – an elusive number analogous to the golden ratio which tells us how fast a random Fibonacci sequence grows.

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

NOVA SCOTIAN INSTITUTE OF SCIENCE MEMBERSHIP FORM 2025-2026

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

Name: ____

Address: ____

____

____

Phone: H ____________________ W ____________________

Email: ____

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

____

Memberships (please check one):

Regular member $30 _____

Student member $10 _____

Life membership $300 _____

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

Voluntary Donation (Tax receipt will be issued): ___________

Mail to:

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

INSTRUCTIONS TO AUTHORS
[TO BE STRICTLY ADHERED TO]

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

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

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

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

The WORD document for a research paper or review is to be no longer than 40 pages, including the figures and tables.

PAPERS SUBMITTED ARE TO STRICTLY FOLLOW THE INSTRUCTIONS BELOW. OTHERWISE, PAPERS WILL BE SENT BACK TO AUTHOR TO UPDATE.

For the general layout of papers, please refer to recent issues of the Journal. Pages of the submitted WORD document should be numbered. **PROVIDE A SUGGESTED RUNNING HEAD FOR THE PAPER.**

Continued

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

* 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.*

There are **no superscripts on "th" or "st"**. Example: The 1st day of the month / The 5th day of the month.

NO http:// in front of website (this is not needed to open a web page).

Please review your paper very carefully to avoid errors or deletions. Spell check the entire paper before submitting.

TABLES, FIGURES & PHOTOGRAPHS

All **tables, figures, photographs** and **other illustrations** should be numbered and have a self-explanatory caption.

They are to be attached as separate files to the submitted paper as separate high resolution files (Images to be 300 dpi) (Lineart 600).Sized to fit 4" wide. These images are not to be embedded in the working WORD document. Do not send your paper as a pdf. Authors are to indicate where each item might be placed in the manuscript. A second file can be sent of the above with items embedded for reference only.

Authors are encouraged to submit **figures, photographs** and **illustrations** in colour. Colour versions will be placed on the NSIS website and in the PDFs provided to authors. **Black and white versions will be in the print copies, unless color output is otherwise requested.**

REFERENCES

References are to be in alphabetical order – name first, followed by initials, with no space between initials. For cited papers, **give the full title of the JOURNAL (IN ITALICS)**, volume and issue numbers where appropriate. Examples of formatted references, covering monographs, chapters in monographs and papers, and with close attention to spacing. Example:

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

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.

PLEASE NOTE: where a province is listed, add the abbreviated symbol for the Canadian province after the city name with Canada not added. For other countries listed city/state/country with abbreviated state and country (no periods in the abbreviation). Example:

Whitcher, W.F. (1876). Eighth annual report of the Minister of Marine and Fisheries, for the Year 1875. Printed by MacLean, Roger & Co., Wellington Street, Ottawa, ON.

Warner, K. (1965). Fishery management in the fish river drainage. Maine Department of Inland Fisheries and Game. Augusta, Maine, USA. 59 p.
catalog.hathitrust.org/Record/010364514

Continued

Website Citation should follow this pattern: Author (year) title, URL and date accessed. No periods after website. Capital A on "Accessed" with no period at end. **No space after doi or period after.** Examples:

Graymont Western Canada Inc. (2015). Giscome Quarry and Lime Plant Project Application for an Environmental Assessment Certificate. Environmental Assessment Office. projects.eao.gov.bc.ca/p/giscome-quarry-and-lime-plant/docs (Accessed Dec. 18, 2017)

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

PLEASE NOTE:

Authors will receive page proofs from the Production Editor. They are responsible for correcting them as soon as possible after receipt and for resubmitting to that Editor. Particular attention should be made to the correct formatting of references, and to the general formatting of the manuscript. Authors are responsible for correcting and returning page proofs within 1 week.

Authors will be provided with a HIRES PDF of their article, free of charge. NSIS members are able to access the new Issue as soon as published as part of their annual membership. Authors can receive a hard copy upon request. All new Issues of the Proceedings become open access after a six months embargo. All articles are copyrighted with the NSIS, but contributors are free to distribute their articles to interested parties as they wish. Each published article is assigned a DOI (digital object identifier) that identifies its location on the internet.

Each Issue will continue to be printed for members and other associated parties. Copies of any Special Issues of the NSIS proceedings published in hard copy may also be purchased from NSIS at a charge established by the NSIS. See the website www.nsis.chebucto.org/ for details.

No portion of this work may be used for training artificial intelligence (AI) without written permission from the author.

Proceedings of the Nova Scotian Institute of Science (2025)
Volume 54, Part 1, pp. 393

ERRATA

PNSIS 53, Part 2, 2024

Page 290, para. 2 – line 5 – should read: ……there has been some interest in resuming gold mining activities in the province (Drage 2015).