Proceedings of the

# Nova Scotian Institute of Science

Volume 51, Part 2 • 2021

ISSN 0078-2521

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

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This journal is abstracted in:

Biological Abstracts
BIOSIS Previews
GeoRef
Zoological Record
CAB Abstracts

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

**Cover photo credit:** Razorbills (*Alca torda*) and Atlantic Puffins (*Fratercula arctica*) on the rocks of Machias Seal Island, outer Bay of Fundy (Tony Einfeldt).

**Back cover inset photo credits:** Top: Common mushroom (fungi) found in Sir Sanford Fleming Park, Halifax, NS (P.G.Wells); Center Left: Salt marsh ecosystem beside a dyke, along the Cornwallis River as it enters the Minas Basin, Bay of Fundy (P.G.Wells); Center Right: Atlantic Puffin (*Fratercula arctica*) with fish (Arielle Demerchant); Bottom: Early amphibian, *Dendrerpeton acadianum*, from Joggins, NS, Upper Carboniferous, 300 million years ago, on display at the NS Museum, August, 2008. (P.G.Wells).

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# EDITORIAL

## Ocean literacy – communicating science in an ocean province

Nova Scotia, an ocean province, is a regional hotbed for ocean science and technology in Atlantic Canada. Given this fact and the various issues affecting the seas locally and globally, especially climate change, it behoves us to have an ocean-literate population and to promote ocean literacy (herein called OL), in Nova Scotia and throughout the Atlantic Provinces. Indeed, OL is a major focal point of the United Nations Decade of Ocean Science for Sustainable Development 2021-2030 (UNESCO 2021). Therefore, the steps that we take to advance and promote OL in Nova Scotia will be an important contribution to this global initiative.

Within the Nova Scotian Institute of Science (NSIS) and by the interested public, the first question to be asked is: What is OL and why is it so important? What initiatives are occurring in the region and in Canada? Where and how can OL best be promoted, and what could NSIS's role be?

The term OL refers to "the understanding of the ocean's influence on us and our influence on the ocean" (UNESCO 2021), or more simply put, "understanding the ocean and our relationship to it" (CaNOE 2021). OL addresses the need for public understanding of the ocean's role in our lives and collective future. A more ocean-literate population could contribute to understanding and resolving major current issues such as climate change, loss of marine biodiversity, the location of protected areas, the condition of fisheries, the health of both people and ecosystems, and the sustainability of local and global economies. Clearly, ocean literacy and climate literacy are inextricably linked; efforts on both should be mutually supportive.

To achieve this in Nova Scotia, there is a need for more critical understanding of these issues, more public education, and active engagement of people in hands-on ocean projects. To have a continued impact, OL also should be promoted within school systems as an integral part of the curricula from K-12, as well as directly within coastal communities.

Over the past few years, there have been numerous initiatives on OL in Canada, notably under the aegis of such national organisations as CaNOE (Canadian Network for Ocean Education – CaNOE 2021), and the Canadian Ocean Literacy Coalition that recently released its Ocean Literacy Strategy (COLC 2021). There have also been many local initiatives in Nova Scotia, for example CARP (Clean Annapolis River Project Society), the Cliffs of Fundy Geopark in the Minas Basin, and the International Ocean Institute-Canada and the Ocean School, both based at Dalhousie University. Not to be forgotten are the many years of communication regarding Bay of Fundy issues by BoFEP (Bay of Fundy Environmental Partnership – www.bofep.org) that have provided accessible information to researchers and communities on coastal and marine issues and research. It is also noteworthy that the federal Bedford Institute of Oceanography (BIO) states on its website (www.bio.gc.ca) that it is “moving in the direction of enhanced citizen engagement and outreach to the public” on the ocean. Certainly much more focus is needed on many local issues, from fisheries management to marine protected areas.

It would be remiss not to mention that ocean literacy is critical at the policy and decision making levels in government, especially in Canada where much of the population is located inland, far from the sea. So while government departments are engaging the public on OL, that engagement should include all senior officials charged with ocean programs. OL is both a top down and bottom up activity, if integrated coastal and ocean management, and ocean governance are to be effective (see MacDonald *et al.* 2016, Werle *et al.* 2018).

The linkage to, and involvement of, local groups is clearly critical to the success of the overall OL initiative as it enhances the reach of information about our coasts and ocean.

For example, from 2011 to 2016, the International Ocean Institute-Canada, and a number of partner organizations, planned and delivered the Halifax Ocean Film Festival (HOFF) to promote ocean awareness among the general public. Panels discussing OL were also part of the most recent Bay of Fundy Science Workshops on the premise that the subject should be a high priority for the public at large. At the events mentioned above, it became clear that there is a keen interest for the introduction of OL into the Nova Scotia school system in order to produce a more ocean literate public.

Recently, an exciting new OL initiative has emerged with the aim of creating a collaborative Bay of Fundy Coloring and Activity Book (https://drive.google.com/file/d/1C31GcotzORFYeFEuq-YVwiUMjwI-o023/view?usp=sharing). This project was devised by several active fishers and researchers in the Minas Basin, including one of us (S. Eger), and it has been supported by Oceans North, Coastal Routes, and Rural Routes at Memorial University. The project focusses on producing an easily accessible and informative colouring book on the species and ecology of the Bay's marine environment. It is designed for pupils in school and adults. The project is currently solidifying partnerships and enhancing work with various organizations in and around the Bay of Fundy. These include non-governmental organizations, indigenous organizations, university researchers and local community members, all with an interest in public education.

Every group can help make this project a reality through funding support, content contributions and promotion. For instance, the NSIS could help promote this and other such OL projects through its networks, as well as by having more lectures on ocean topics, and even considering a special set of lectures one year on OL.

While contemplating this suggestion, we note that the diversity of marine-related contributions in this issue of PNSIS ranges from the history of the former Marine Ecology Laboratory (BIO), to marine geology, the life history of mysids, and the ecology of coastal seabirds. Amongst the topics published in the Proceedings over many years, marine ones are frequent, reflecting the very active research on ocean science conducted in Nova Scotia and the region. We hope that you enjoy reading this issue of the PNSIS and will think more about our blue planet and its role in our lives. Please consider how members of the NSIS can promote ocean literacy, in our annual program and throughout Atlantic Canada, especially with the involvement of other groups.

*Acknowledgements* This article is dedicated to the memory of Tracy Dean of the Huntsman Marine Science Centre, St. Andrews, NB, in recognition of her life-long career devoted to introducing the ocean to young people in the Maritimes. We thank Dr. David Richardson, Assoc. Editor, PNSIS, for his review.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 257-270

# AN EVER-INQUIRING MIND: A TRIBUTE TO DR. J. SHERMAN BLEAKNEY (1928-2019)

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One of the consequences of the rapid growth and specialization in science in the last half-century or so is the decline in the proportion of scientists who have the training, the time and the inclination to investigate the natural and human worlds from a wide variety of perspectives. A good example of one is Dr. J. Sherman Bleakney of Acadia University. He made significant contributions to our understanding of the natural and anthropogenic history of Nova Scotia and the Bay of Fundy, and left this life on his own terms on October 25th, 2019.

(John) Sherman Bleakney was born in 1928 in Corning, New York, the son of a Baptist minister, and spent his early childhood in Boston. The family's summers, however, were spent at his father's original home in Wolfville, Nova Scotia, and the family moved back to Wolfville permanently when Sherman was a teenager. Here it would appear that he came under the influence of Robie Tufts, at that time the Chief Migratory Birds Officer for the Maritimes. Tufts stimulated several local boys (including Earl Godfrey and Cyril Coldwell) to become passionate ornithologists and conservationists. In Sherman's case, this would only have amplified the influence of his mother, Ruby, who encouraged his interest in the science of the natural world.

Sherman entered Acadia University to study biology in 1945. By that time he was already an accomplished taxidermist and naturalist. He arrived at the university with a large collection of books on nature and a number of specimens, including birds that he had prepared. His friends recall him saying: "If you can't eat it – stuff it". He was apparently an extremely active and popular student, attending all the dances, organized skiing trips and Biology Club meetings, and led his peers on woodland forays on weekends.

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He graduated with a B.Sc. in Biology in 1949. The Yearbook records the following testament from a colleague: " 'Shirmy' [.….] grew up in the wilds of Wolfville. To be like him requires a full knowledge of taxidermy, hunting, skiing, dancing, and half of a large volume on 'How to be a wit' ".

At Acadia, he completed an M.Sc. in Biology in 1951. During and afterwards, he undertook contract work, collecting salamanders and frogs for the National Museum in Ottawa. This led him to the position of Curator for Amphibians, Reptiles and Fish at the National Museum. During the next few years, he also worked on his Ph.D. degree through McGill University in Montreal. His thesis, "*A Zoogeographical Study of the Amphibians and Reptiles of Eastern Canada*", was defended in 1956, and republished as a National Museum of Canada Bulletin (Bleakney 1958b). It became the standard reference on the distribution and post-glacial dispersion of reptiles and amphibians in Canada for many years.

Sherman returned to Acadia as a professor in Biology in 1957, and taught there until his 'retirement' in 1988. His primary courses were Introductory Biology, Histology, Embryology, Comparative Chordate Anatomy, Marine Invertebrate Biology and Animal Ecology, although he later told me that he did not consider himself as an ecologist – "merely a naturalist" (!). He was undoubtedly one of the most popular and effective teachers, receiving the Acadia Alumni Award for Teaching Excellence in 1987. It was not just his legendary (sometimes wicked) sense of humour, but his great breadth of knowledge, his ability to link material across disciplines and to make it relevant to his students, that are among the prevailing memories of many of them. The photograph (Fig 1) shows Sherman holding the forelimb of a leatherback turtle that he had found dead on shore, dissected with the class around him, and then buried in his garden (much to his wife Nancy's chagrin, I believe) in order to recover the skeleton. Given his entertaining lecture style, it is easy to envisage him breaking into an 'air-guitar' riff.

At Acadia, he initially continued his research into the distribution and behaviour of amphibians and reptiles. He recognised that, at that time, knowledge of the natural history of these groups in the Maritimes was very limited, and a number of his contributions are first records of occurrence (e.g. Bleakney 1951, 1955, 1963a, 1965a, Bleakney and Cook 1957a,b, Cook and Bleakney 1960).

**Fig 1 J. Sherman Bleakney (Photo courtesy of the Acadia Archives, Acadia University).**

Others deal with behaviour, taxonomy or morphological variations (e.g. Bleakney 1957, 1958a, 1959, Bleakney and Cook 1957b, Cook and Bleakney 1961). Many of his collected specimens are to be found in the National Museum, the Royal Ontario Museum, and the Nova Scotia Museum. He appears to have been the first person to suggest that the occasional appearance of leatherback turtles (*Dermochelys coriacea*) in Maritime waters represented an annual migration similar to those of shorebirds and many marine fish (Bleakney 1965b). He also established that these huge animals fed almost exclusively on jellyfish; the occasional juvenile fish and crustaceans found in the turtle guts were the prey or the commensals of the cnidarians. The very first leatherback turtle that was satellite tagged in Atlantic waters in 2000 was named ‘Sherman’ in his honour, and a female turtle was later named ‘Ruby’ after his mother.

In the 1960s, Sherman began to focus on other aspects of Nova Scotia’s natural history, exploring the fauna in caves in Hants County (Bleakney 1965c, Calder and Bleakney 1965, 1967). He was also an avid SCUBA diver and conducted what might have been the first underwater exploration of the harbour at Fortress Louisbourg, in preparation for its establishment as a National Historic Site (Hansen and Bleakney 1962).

A feature of his broad talents was his unwillingness to be limited by the absence of established techniques to accomplish his research objectives. This is amply demonstrated by a number of methodology papers over his career (e.g. Bleakney 1967, 1969, 1970a, 1982, Bleakney and DeVenney 1989).

A major shift of focus occurred in the late 1960s and 1970s, when Sherman started to explore the natural history of the Bay of Fundy, particularly the Minas Basin. For that, he had to retrain himself to deal with the invertebrates of mudflats and marshes, and the environmental significance of the large Fundy tides (Bleakney 1972, Bleakney and McAllister 1973). He instantly became fascinated by the rich diversity of molluscs in mudflats, salt marshes and shoreline rocks, particularly the nudibranchs (Nudibranchia), sacoglossans (Sacoglossa), and the 'boring molluscs' (Pholadidae) (Bailey and Bleakney 1966, 1967, Bleakney and Bailey 1967, Frank and Bleakney 1975, 1978, Bleakney and Saunders 1978, Bleakney and Meyer 1979, Bromley and Bleakney 1979, Graves *et al.* 1979, Bleakney *et al.* 1980, Bleakney and Janes 1983, Gibson *et al.* 1986). Shortly before his death, Sherman's foundational work on other, perhaps less known taxa, was recognized by Dale Calder who named a recently discovered species of hydroid, *Eudendrium bleakneyi*, in honour of "Dr. J.S. Bleakney of Acadia University, an esteemed mentor who contributed greatly to the content of this work" (Calder 2017).

In the 1970s, there was once again a renewed interest in Fundy tidal power development, following proposals for construction of large barrages across the Minas Basin, Cumberland Basin, and Shepody Bay. The fact that so little was known about the fauna and flora of the Upper Bay of Fundy – other than the annual migrations of shorebirds from the Arctic and some anadromous fish from the south – meant that a broad and substantial research program had to be carried out in very short order (Daborn and Bleakney 1977). Sherman quickly established a team of students to conduct extensive seasonal collections along transects all around the Minas Basin. These, together with studies in Cumberland Basin and Shepody Bay, constituted the very first systematic surveys of the intertidal and near subtidal environments of the Upper Bay, and produced not only a greater appreciation for the diversity of habitats to be found there, but also a better understanding of why the area attracted so many shorebirds during their southerly migration from the Arctic in summer.

Because the Minas Basin ecosystem had been so poorly studied, Sherman coordinated the preparation of species lists and the first field guide for invertebrates that became essential references for the many scientists that participated in the research (Bromley and Bleakney 1979, 1985).

Invertebrates that particularly engaged his attention were the sea slugs (Mollusca: Opisthobranchia) that he initially encountered in salt marsh pools, but then pursued throughout the Bay of Fundy, the Gulf of Maine, and the Atlantic shore. His fascination with this poorly-known group was immense, and led him to interact with mollusc specialists around the world. His 1996 book, "*Sea Slugs of Atlantic Canada and the Gulf of Maine*", is at once informative, readable (in spite of the terminological challenges) and highly entertaining. There are few guides or textbooks that can match its appeal to the aspiring young naturalist. Sherman was an accomplished photographer and compiled a fine collection of photographs, using a macrophotography tank of his own design (Bleakney 1970a, 1996). I believe that this photograph collection is in the Bleakney fonds in the Acadia Archives, but these are currently unavailable because of the Covid pandemic.

When Sherman retired in 1988, he continued to investigate the marshes and mudflats of the Minas Basin. He had already come to recognise that this dynamic ecosystem exists in a permanent state of disequilibrium: not only do the intertidal mudflats get reworked by ice every winter and recolonised by invertebrates and epipelic algae every spring, but there were longer and more progressive changes associated with sea level rise, increasing tidal amplitudes and human interventions. The discovery of fossil trees and oysters *(Crassostrea virginica)*, dating back some 3,800 years but now exposed at low tide, led him to contemplate how the system had changed since the ice age receded, and the influence this might have had on the biota (Bleakney and Davis 1983, Bleakney and Janes 1983). Inevitably, he became more and more interested in tidal dynamics, particularly the longer variations associated with the Nodal and Seros cycles (Bleakney 1986, 2004). This formed an important part of his understanding of the effects of human activities on the ecosystem, and correspondingly, the effects of the ecosystem on human activities.

Sherman had long been intrigued by the various remnants of Acadian dyke structures that he had encountered over the years. The full history of human impact on the natural system began with the Acadians in 1606, when they adapted some European methods for converting coastal marshes into fertile agricultural land. It has been estimated that over the last 400 years, about 75 to 80% of the Bay of Fundy marshes had been converted, primarily for agriculture. When he retired in 1988, Sherman turned his attention to the archeological history, especially of the Southern Bight of Minas Basin and the area of Grand Pré. He searched all historic records that he could find, interacted with many historians of the Acadian era, and interviewed still-living dykeland owners who could tell him about the traditional techniques of dykeland construction. The result was the book, "*Sods, Soil and Spades: The Acadians at Grand Pré and their Dykeland Legacy*" (Bleakney 2004). This eclectic, informative and insightful work is a celebration of the efforts of dykeland dwellers over some four centuries. Liberally endowed with Sherman's trademark humour and provocative questions for the reader, the work captures a wide variety of documented information about dyking practices, and the complex relationships between the natural history of this changing macrotidal ecosystem and the human history since 1604. It formed an extremely important document in support of the nomination of Grand Pré as a UNESCO World Heritage Site, a designation that was awarded in 2012.

Throughout his life, Sherman looked for scientific, naturalistic explanations for many kinds of human behaviour and ideas, ranging from the common features of human and animal aesthetic awareness (e.g., Bleakney 1970b), to the origins of mythology and religious beliefs. He was particularly intrigued by the extensive development in Inuit communities of shape-shifting stories, since these do not appear to be as prevalent in all indigenous cultures, especially those of lower latitudes. He developed a simple osteological hypothesis: that the dependence of Inuit peoples on several different mammal and bird species for their subsistence led them to recognize the common anatomical basis of vertebrates, especially foetal similarity, and this in turn led to a concept of the potential transmutability of the spirit into different life forms. He developed this idea in an unpublished work, entitled "*Bones and beliefs in hunter-gatherer societies: the Inuit*". The hypothesis led him to consider the potential origins of religious beliefs in general. He discussed this with many of his friends at Acadia University, notably Dr. Bruce Matthews (Professor of Comparative Religion), Chaplain Roger Prentice and myself, and with cinematographer John Houston, and corresponded with other notables such as Jared Diamond and Richard Dawkins.

Unfortunately, he was unable to complete the investigation to his satisfaction. I believe that the Acadia Archives contain much of his correspondence and unpublished writing on this topic that would reward investigation when the present pandemic subsides.

In typical Sherman fashion, his last will and testament specified that after cremation his ashes should be dispersed into the Cornwallis Estuary on the ebb tide so that:

> *"my atoms and molecules will subsequently become incorporated into that unique Minas Basin detritus-driven ecosystem, one which has profoundly influenced my professional life. Given enough time, tides and chance, the probability is high that I shall be recycled through many of my favorite Minas Basin organisms, including* Elysia chlorotica. *A few molecules may even end up in preserve jars in Acadia's Biology Department."*

Each year, when the gaspereau return in the spring and the leatherbacks and shore birds are present in the summer, Sherman Bleakney will be remembered by many with respect, gratitude and affection. Long may he recycle.

*Acknowledgements* I am very grateful for the advice and comments of Dr. Jill Bleakney (Sherman's daughter), Dr. Glenys Gibson, Dr. Bruce Matthews, and an anonymous reviewer. All errors and omissions are part of my contribution.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 271-280

# ELIZABETH RAYMOND KING – A GEOLOGIST INSPIRED BY BAY OF FUNDY MINERALS AND THE NOVA SCOTIAN INSTITUTE OF SCIENCE

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Geologist Elizabeth Raymond King (1923-2010) was born in Halifax, Nova Scotia, and home-schooled by her parents who were both accomplished scientists. According to her father, chemist Harold Skinner King (1892-1967), Elizabeth became interested in geology after several mineral collecting trips along the shores of the Bay of Fundy.

*Our daughter early developed an interest in geology, and we have spent our vacations visiting mines and touring the Province in search of minerals. We have watched coal being mined many miles out under the sea. We have risked our necks collecting zeolites from perpendicular cliffs. We have experienced the tremendous Fundy tides and have walked on the bare sea bottom where, in a few hours, forty feet of red, mud-laden waters obliterated our tracks.* (King 1942: 564).

Harold S. King graduated from Harvard in 1917 and joined the Chemistry Department at Dalhousie University in 1922. Elizabeth's mother, Susan Raymond King (1892-1970), was also an accomplished scientist. Having completed a Bachelors from Smith College, Massachusetts, in 1913, Susan was a Nantucket Associate Fellow in 1915, a Marie Mitchell Memorial Fellow at Harvard Observatory in 1916-1917 (Annual Report 1948), and attended specialist conferences (Fig 1) before completing her dissertation at Smith College (Raymond 1919b). Susan published a summary of her results (Raymond 1919a) that used new photographic methods to study the variability of asteroids, methods that had been established by Harold's father, Edward Skinner King (1861-1931), a prominent Professor of Astronomy at the Harvard Observatory (Campbell 1931). It is likely

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Formal Organization Meeting of the American Association of Variable Star Observers, Cambridge, Massachusetts, November 10, 1917.

**Fig 1** **Susan Raymond shown at the meeting of the American Association of Variable Star Observers, Cambridge, Massachusetts, Nov. 10, 1917. From *Popular Astronomy* No. 251.**

through Susan's work in astronomy that she met Harold (Fig 2), who at the time was associated with the Professor Richards laboratory at Harvard (King 1959b).

Susan and Harold were married on September 12, 1922, in Northampton, Massachusetts, before moving to the Armdale neighbourhood of Halifax when Harold joined the faculty at Dalhousie University. Shortly after arriving in Halifax, Susan and Harold were both elected as members of the Nova Scotian Institute of Science (NSIS) on November 30, 1922 (*PNSIS* 1926). Over the coming years, Harold became an active member of the NSIS, publishing his first paper in the Proceedings in 1923 and contributing an article in nearly every issue until 1935, often describing new insights of an analytical chemistry topic. One of these papers was a summary of his Harvard dissertation research (King 1927), which focused on studies of isotopes. Harold was the editor of the NSIS Proceedings from 1929 to 1938, and the President of the Institute from 1938 to 1940.

This was the academic family environment in which their daughter Elizabeth grew up. Susan focused her attention on raising

Wolcott Gibbs Memorial Laboratory personnel in 1920. From left to right: *Front row*, Dr. Henry Krepelka, Miss Edith H. Lanman, Professor Theodore W. Richards, Miss Rosella J. Borthwick (sec.). *Middle row*, William M. Craig, Oscar C. Bridgeman, John Russel, Harold S. King, Dr. Emmett K. Carver. *Back row*, Charles P. Smyth, A. Sprague Coolidge, William Manning (jan.), Sylvester Boyer.

**Fig 2 Harold Skinner King (second from right, middle row) in 1920 when associated with Professor Richards' laboratory at Harvard University.**

and schooling the two children, Elizabeth, and her younger sister Nancy. Susan even taught the two girls Greek (King 1948) and eventually prepared them for college. This home-school education and the scientific backgrounds of her mother and father resulted in Elizabeth achieving several publications as a teenager. In January of 1935, at the age of twelve, Elizabeth presented a paper as a student member of the NSIS titled "The Goldenville-Halifax Boundary at Fairview, NS" (King 1935a). Elizabeth's first geology paper was inspired by her discovery of two angular limestone pebbles on Dutch Village Road that she interpreted as transported as glacial drift. In her paper, she described occurrences of 'limestone' beds near the boundary of the Goldenville and Halifax Groups (Fig 3), and referenced contemporary sources such as the Physiography of Nova Scotia (Goldthwait 1924) and the Faribault geology map of the area (Sheet 68). Elizabeth offered an interpretation of her geology observations that demonstrated an understanding of complex geological concepts. The limestone units that Elizabeth identified

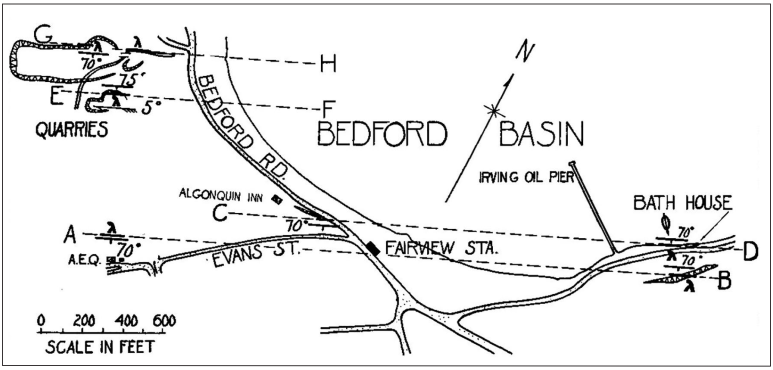

**Fig 3** **Map of Fairview, Halifax, region showing boundary and limestone beds. From King (1935a).**

in the Goldenville are now considered calcite-rich metasandstones (Chris White, pers. comm.) but her original paper continues to be cited in modern work (White 2010).

As a young girl, Elizabeth also contributed several short articles to the *Rocks and Minerals* magazine. In July, 1935, she published a short article summarizing *Pleochroic Haloes*, concentric rings that form inside biotite as it crystallized in magma (King 1935b). This short note was a summary of research that was being carried out by Dr. G. H. Henderson, who had joined the Department of Physics and Atmospheric Sciences at Dalhousie University in 1924. Elizabeth contributed a second article to *Rocks and Minerals* magazine (King 1936), providing a comment about an article from a previous issue and referencing her study of the pebbles that were the focus of her PNSIS paper.

While her family and the NSIS community played an important role in Elizabeth's educational environment, it was also a critical period in the history of the Institute. The Nova Scotian Institute of Science had been established in 1862 and had a long history of association with both Dalhousie University and the Nova Scotia Museum. Harry Piers was the Museum Curator from 1899 until 1940, when he unexpectedly passed away (Mak 1996). In the NSIS Presidential Address in the year Harry Piers died, Harold King included detailed recommendations for a more scientific focus for the Museum when hiring a new curator (King 1941). Harry Piers' curatorial work had been of an exceptionally high standard, organizing and documenting the collection that continued to increase in scope to include cultural artefacts. Piers published a *Catalogue of Economic Minerals* (Piers 1908) and some work on specific mineralogy occurrences (Piers 1912, 1923), among other scientific topics, but much of his museum work had focused on a wider scope of cultural areas. Looking forward, Dr. King suggested that the NSIS desired the Museum to take on more of a scientific focus. Harold's proposal was eventually partially implemented when Donald K. Crowdis became the Director of the Provincial Museum; in 1949, the museum changed its name to the Nova Scotia Museum of Science (Mak 1996). During this reorganization, the Museum also became aligned within the Department of Education and the Museum took on a more active role in public education.

Harold King and his family did not stay much longer in Halifax and so did not see this evolution of the Museum of Science. In an alumni magazine of 1942, Harold King expressed his growing dissatisfaction of living in Halifax during the war years. After sharing stories of his family's initially idyllic life in Halifax, Harold explained:

> *The war has changed all this. I now spend feverish days studying high explosives. Planes roar overhead; troops are training outside my laboratory window. Blackouts are a routine. Convoys pass in and out, and we try to be blind to obvious movements. Halifax is geared to war. The Foreign Exchange Control Board has put restriction on spending money out of Canada, even for educational purposes, and I find that it is becoming impossible to educate my family in the United States if I remain longer in Canada. Throughout the years I have kept up my registration at the American Consulate and am still an American citizen. At present I am looking for an opportunity of utilizing my chemical knowledge and experience in my own country and then, farewell to Canada!* (King 1942: 564)

By 1943, Harold was recalled to the United States, and became a technical advisor for the Chemical Corps. Board of the USA Army, in Edgewood Arsenal, Maryland (King 1948). With Harold in Maryland, Susan King had moved back to Northampton, Massachusetts, and was listed as an Instructor of Astronomy at the Observatory, teaching a course on "Celestial Marine and Air Navigation" at Smith College (Smith College 1943: 74-75). Susan was listed as only having a bachelors (A.B.) degree, so she may not have completed the defense of her dissertation at Smith College before moving to Halifax. During this time, Elizabeth and Nancy were with their mother in Massachusetts.

The Smith College Catalogue of 1944-45 shows Elizabeth King listed as a Freshman of the Class of 1947 (Smith College 1945: 73). However, shortly after entering Smith College, Elizabeth was inflicted with tuberculosis and spent two years recovering in a sanatorium. Elizabeth graduated from Smith College in 1947 and then moved to Baltimore to work developing photographs at a department store. Elizabeth then worked in the pathology department at Johns Hopkins Hospital, where she took photographs of cadavers and autopsied tissues (Schudel 2010). Perhaps her illness inspired some interest in medicine but her mother's expertise in applications of photography in astronomy likely contributed to Elizabeth's knowledge and interest in scientific application of photography.

After this brief period, Elizabeth King then joined the United States Geological Survey (USGS) in 1948, where she would stay to have a sixty-year long career with the USGS as a geophysicist, creating geophysical maps based on magnetic imaging aerial surveys. Elizabeth was often the only woman working in the group conducting these surveys (Fig 4), and she published a regional magnetic map of Florida (Fig 5) in the Association of American Petroleum Geologists Bulletin (King 1959a). In October of 1962, along with Isidore Zeitz and Leroy Alldredge, she presented at a meeting of the Geological Society of Washington on the "Investigation of the Arctic Ocean Basin by Airborne Magnetometer" (GSW 1962).

Elizabeth worked closely with the geophysicist Isidore Zeitz (1919-2013) at the USGS. In a published obituary of Isidore, the authors noted "We suspect that the interpretation for which he will be most remembered is the discovery, with Elizabeth King, of the Alabama-New York lineament" (Taylor *et al.* 2013). Elizabeth was the first author of this important paper (King & Zietz 1978), publishing the results and geomagnetic map of a previously hidden geological feature. This innovative result was published forty years after her first published Fig of the boundary in Fairview, Halifax, as a young researcher with the Nova Scotian Institute of Science.

While conducting the research for this paper, the location of Elizabeth's mineral collection has been located, having been stored in an

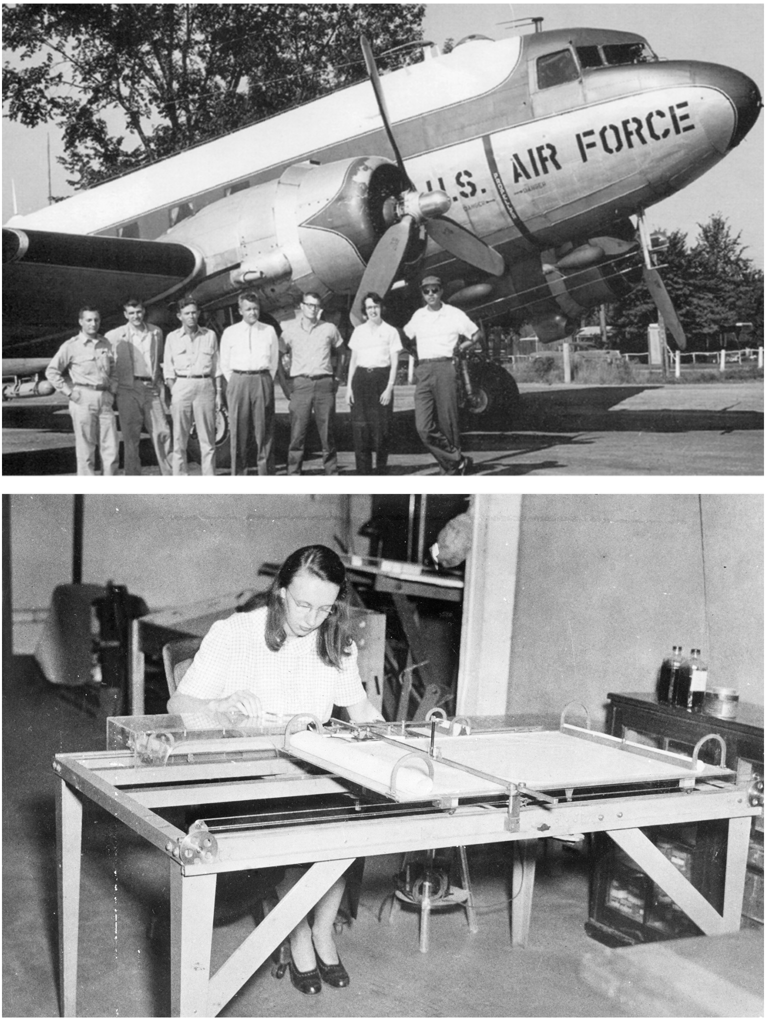

**Fig 4** Elizabeth King working among the crew of the aerial survey group of the United States Geological Survey c.1956 (above), and working a graph rectifier (USGS 1952), a machine to get the continuous magnetic reading into usable form (below).

attic in Maryland along with notes and letters between Elizabeth and her father (Mills 2021). The details and significance of this collection of minerals will be considered in future work. Elizabeth's scrapbook that has been located in the possession of her nephew, Charles Reynes, is also of significance for documenting her interests in geology. Elizabeth's mineral collecting as a young girl, and her

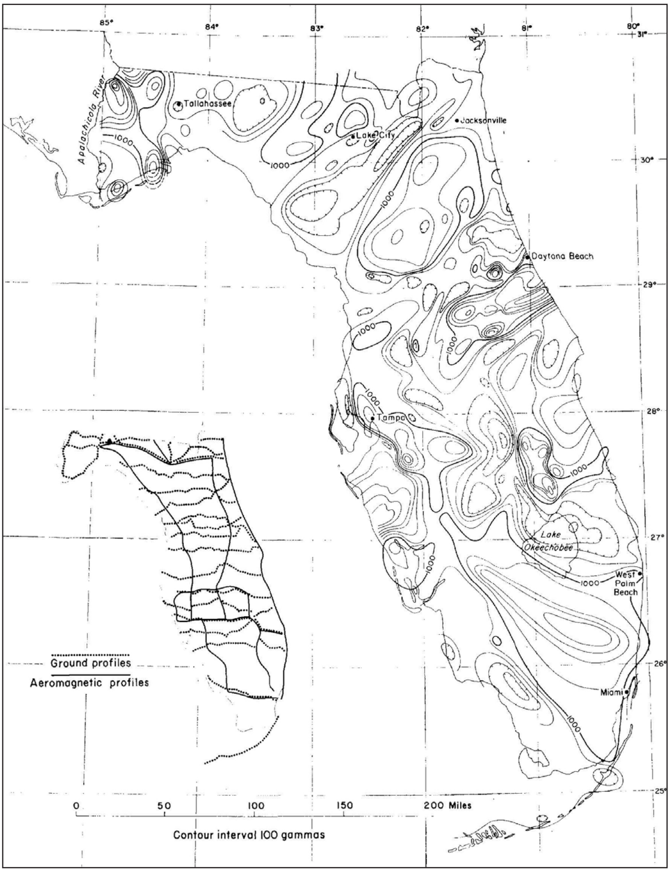

**Fig 5 Regional magnetic map of Florida, published by Elizabeth King in 1959.**

contributions to the PNSIS and special-interest publications such as *Rocks and Minerals* magazine, demonstrate how these publications supported her interest in science as a young girl.

Elizabeth and her family made significant contributions to the Nova Scotian Institute of Science during the time of the second world war. Elizabeth went on to have a long and interesting career as one of the first women to work as a geophysicist with the USGS and made significant contributions to a geoscience field dominated by men. She made these contributions through an application of her knowledge of geology, science, photography and mapping, which she acquired through the support of her academic parents and her early contributions to the Nova Scotian Institute of Science.

The history of Elizabeth King and her family's contribution to NSIS provide insights into the personalities and challenges facing the scientific community of Nova Scotia during the 1940s. Elizabeth King remains a positive role model for young Nova Scotians who may have an interest in minerals and could pursue their interests towards a rewarding career in the geosciences.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 281-297

# REMEMBERING THE MARINE ECOLOGY LABORATORY, BEDFORD INSTITUTE OF OCEANOGRAPHY, 1965-1987: AN HISTORICAL AND PERSONAL PERSPECTIVE

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## ABSTRACT

The Marine Ecology Laboratory (MEL) was one of the principal federal scientific laboratories at the Bedford Institute of Oceanography (BIO) in Dartmouth, NS. Created in 1965 as an independent laboratory under the Fisheries Research Board of Canada, it grew out of the previous Atlantic Oceanographic Group with the broad mandate to study the structure and dynamics of marine ecosystems supporting marine fisheries. With time, it developed a well-rounded program of basic and applied ecological research and earned an international reputation for excellence. In 1987, it fell victim to a major reorganization of the Department of Fisheries and Oceans, driven by Ottawa managers, and was closed despite widespread protest from the scientific community. However, once the dust had settled from this unfortunate incident and, despite declining resources, ecological research at BIO continued to flourish under a new organizational structure.

## INTRODUCTION

This account presents a brief history of the Marine Ecology Laboratory (MEL), one of the principal components of the Bedford Institute of Oceanography from 1965 to 1987. It is condensed from a more detailed history of the laboratory prepared by Gordon (2020) using information from a wide variety of sources including annual reports, published accounts, newspaper articles and personal files. It begins by reviewing the origin of MEL and then describes its evolution over twenty-two years as a federal research laboratory

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under the leadership of three directors who were all prominent scientists and elected to the Royal Society of Canada: Lloyd M. Dickie, Alan R. Longhurst and Kenneth H. Mann. Some of the important scientific accomplishments in the field of marine ecology are briefly summarized. Events leading up to the demise of MEL by the Department of Fisheries and Oceans in 1987 are then briefly reviewed. Fortunately, this highly controversial event did not mark the end of ecological research at BIO and the legacy of MEL is briefly discussed.

## ROOTS

The origins of the Marine Ecology Laboratory (MEL) can be traced back to 1898 when a Board of Management composed of Canadian university and government scientists was established (Mills 2014). This Board was the first research organization in Canada financed by the federal government whose direction was primarily the responsibility of academic scientists. One of its first accomplishments was to construct and operate a moveable floating research station on the Atlantic coast. Building on the success of this venture, in 1908 the Board created two biological stations, one in St. Andrews, NB, and one in Nanaimo, BC, to provide research facilities for academic scientists and their students. In 1912, the Board of Management became the Biological Board of Canada and its membership expanded to include the fishing industry. Then, in 1937, this Board became the Fisheries Research Board of Canada (FRB).

The FRB was organized as an autonomous scientific institution reporting directly to the federal Minister of Fisheries and administered by a Board which included representatives from universities, government and industry. FRB proceeded to develop an expanded network of fishery research stations across the country to conduct investigations of practical and economic problems connected with marine and freshwater fisheries, flora and fauna. With time, FRB earned an international reputation for excellence in aquatic science (Johnstone 1977).

While the focus of FRB was on fisheries, from the very be-ginning it recognized the importance of understanding the physical, chemical, geological and biological properties of the supporting ecosystems. In 1944, FRB established two new organizations to conduct oceanographic research, one on each coast. The Atlantic Oceanographic Group (AOG) was established at the St. Andrews Biological Station in New Brunswick under the direction of Harry Hachey, while the Pacific Oceanographic Group (POG) was situated at the Pacific Biological Station in Nanaimo, BC, and headed by Jack Tully.

In 1960, now headed by Neil Campbell, AOG moved from St. Andrews to Halifax and occupied a group of single story wooden buildings on Terminal Road between Hollis and Water Streets across from the Nova Scotian Hotel. Two years later, along with the Canadian Hydrographic Service, AOG with its staff of about twenty moved into the new Bedford Institute of Oceanography (BIO) in Dartmouth when it opened in 1962 (Gordon *et al.* 2014a). This new facility was built specifically for oceanographic research and equipped with the necessary scientific support facilities, including a fleet of research vessels. By 1965, AOG with its broad oceanographic research program was well established as a major component of BIO under the direction of Ron Trites. However, more major changes were just around the corner.

## EVOLUTION

In 1965, the Atlantic Oceanographic Group (AOG) was elevated to the status of an independent laboratory of the Fisheries Research Board (FRB) and began reporting directly to the Chairman of FRB, F. Ronald Hayes, in Ottawa (Fig 1). Hayes, a native of Parrsboro, NS, had previously served as chairman of the Dalhousie University Department of Biology and as the founding director of Dalhousie's Institute of Oceanography. Soon after, Lloyd M. Dickie was appointed as Director (Fig 2). Hailing from Kingsport, NS, he was the son of a commercial fisherman and had previously worked on scallop biology at the St. Andrew's Biological Station and fish population dynamics at the University of Toronto. The same year also marked the arrival in Halifax of Gordon A. Riley to become the new Director of the Institute of Oceanography (Gordon 2019) and William L. Ford to become the new Director of BIO (Gordon 2016).

Oceanography was a high federal priority at that time and resources for research were plentiful. Under the direction of Lloyd Dickie, the AOG program continued to expand with focus on studying the oceanographic processes underlying marine production with special reference to fisheries. This ecosystem focus was a somewhat different approach from that taken by other FRB labs across the country whose programs were more focused on fisheries and technology. At the time, commercial fisheries stocks were managed primarily on a single species basis, with little consideration of multispecies interactions and ecosystem factors. A formal start to using an ecosystem approach to fisheries management did not begin until the mid-1980s (O'Boyle *et al.* 2014).

Like other FRB laboratories across the country, AOG was responsible for deciding and directing its own research program within its general mandate. Directors of FRB laboratories had full control over all support functions. A-Base funding, an annual allotment provided by Ottawa with few restrictions, was abundant and distributed to projects at the discretion of directors. These funds were quite stable from year to year, which aided the planning of multiyear research programs, and salaries were secure. Hence, there was no need for staff to compete for external funding as university colleagues had to do. Being an integral part of BIO, AOG had full access to the various oceanographic support services available at the institute.

Lloyd Dickie had a free hand in recruiting the new staff. Most recruits were recent graduates who were able to address important questions in their fields of expertise with a minimum of direction. He took great pains to protect them from government administration and his office door was always open for discussion. This approach created a very stimulating and productive research environment that paid handsome dividends. Scientists became leaders in their fields of study and were actively involved in international scientific activities.

In 1966, AOG was renamed the Dartmouth Laboratory of the Fisheries Research Board and by now the staff had increased to 37. Then, in 1968, the lab was renamed the Marine Ecology Laboratory (MEL). The 1960s had been a period of growing public concern about the environment, stimulated by events such as the publication of *Silent Spring* (Carson 1962) and the 1967 *Torrey Canyon* oil spill off Cornwall, UK, and the need for Canadian research programs to investigate the effects of human activities on marine ecosystems was clearly recognized. Accordingly, in 1970, the mandate of MEL was expanded to include the ecosystem effects of pollutants.

The following year, MEL was incorporated into the newly created federal Department of the Environment (DOE).

In 1973, after a 75-year history of excellence in fisheries research, the Fisheries Research Board (FRB) was relieved of direct control over its research programs and facilities and demoted to an advisory body (Anderson 1984). Six years later, the Fisheries Research Board of Canada was formally disbanded marking the end of a highly respected and productive Canadian scientific organization (Johnstone 1977). These changes, while regretted by staff, did not have much of an immediate impact on MEL and by and large its research programs continued as usual.

After nine years at the helm and building MEL into a major marine ecological laboratory with an international reputation for excellence, Lloyd Dickie stepped down as Director in 1974. He moved across the harbour to Dalhousie to replace Gordon Riley as Chair of the Department of Oceanography and to become the Director of the newly created School of Resource and Environmental Studies.

By now, the years of expansion were largely over and MEL had developed a broad ecological program that covered all parts of the marine food web ranging from phytoplankton to marine mammals, including physical oceanographic processes and chemical contaminants. Field programs were being carried out in a variety of environments ranging from coastal waters to the open ocean. The staff, now about 85, worked in close collaboration with other BIO laboratories and university scientists, in particularly Dalhousie where numerous staff served as instructors and research associates. By and large funding was adequate, ship time was easy to get and staff were able to participate actively in numerous international scientific activities. Morale was high. These were indeed exciting and productive times.

The departure of Lloyd Dickie marked the beginning of a four-year period during which MEL had four successive acting directors: Barry S. Muir, Donald C. Gordon, Trevor C. Platt and Richard F. Addison. Fortunately, the general working environment remained relatively stable during this period and most programs continued as usual. In 1977, Alan R. Longhurst arrived as the new director (Fig 3). He came with extensive experience having previously worked at the West African Fisheries Research Institute, the

New Zealand Department of Fisheries, the US Southwest Fisheries Science Center and the UK Institute for Marine Environmental Research in Plymouth. Soon after, in 1979, MEL became part of the newly created Department of Fisheries and Oceans (DFO). That year, Alan Longhurst became the Director General of Ocean Science and Surveys (OSS) Atlantic, and Director of BIO. Hence, another search began for a new director of MEL and Kenneth H. Mann was appointed (Fig 4). Mann had previously joined MEL as a research scientist in 1967, coming from Reading University in the UK where he had worked extensively on the River Thames ecosystem, but in 1972 had moved over to Dalhousie to become the Chairman of the Department of Biology.

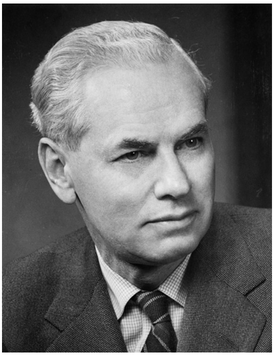

**Fig 1 F. Ronald Hayes (Chairman, Fisheries Research Board, 1964-1969)**

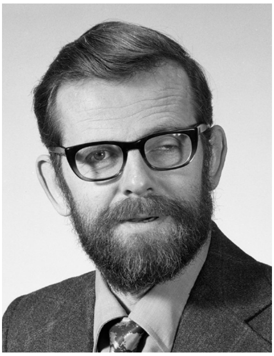

**Fig 2 Lloyd M. Dickie (MEL Director, 1965-1974)**

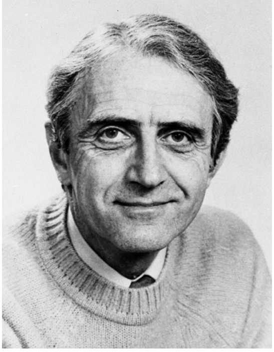

**Fig 3 Alan R. Longhurst (MEL Director, 1977-1979)**

**Fig 4 Kenneth H. Mann (MEL Director, 1980-1987)**

The late 1970s and early 1980s were 'golden years' for all components of BIO. Organizational and policy changes at the Ottawa level up to that time had had limited impact on regional research programs and resources continued to be stable. All components of BIO were thriving and morale was high. By this time, BIO had become one of the major oceanographic institutes around the world, on par with the Woods Hole Oceanographic Institution and Scripps Institute of Oceanography, and functioned very much like a federal university.

## RESEARCH HIGHLIGHTS

Over its history, MEL scientists made many contributions to the field of marine ecology ranging in scale from local coastal areas to the global ocean. Some selected highlights are presented. Pertinent review articles in *Voyage of Discovery*, the book commemorating the 50th anniversary of BIO in 2012, are cited (Nettleship *et al.* 2014).

### New Sampling Tools

Quite often, the tools needed for sampling marine ecosystems in support of MEL projects were not available off the shelf but had to be designed and fabricated in house with the assistance of BIO mechanical and electronic engineers. These included various pumping systems, particle counters, zooplankton samplers, incubation chambers, sediment traps and acoustic fish detection systems (Li 2014). Many of these were copied by other laboratories and some were transferred to industry for manufacturing and sale.

### Physical Oceanography

Physical oceanographic studies were carried out in a large number of key Maritime regions including coastal areas such as Margaree Harbour, Pictou Harbour, St. Margaret's Bay, Halifax Harbour, Bedford Basin and St. George's Bay, as well as the Gulf of St. Lawrence and the Cabot Strait (Smith *et al.* 2014). These provided the necessary foundation for understanding ecosystem properties and processes.

### Non-living Organic Carbon

A wide variety of projects were conducted on the properties and dynamics of the huge reservoir of non-living organic carbon in the sea, including both dissolved and particulate components.

These included determining the concentrations and vertical profiles in the Atlantic, Pacific and Arctic oceans, studying the transformation processes between dissolved and particulate forms, investigating sedimentation rates and pelagic and benthic exchanges, and exploring its role as a food source for marine organisms (Li 2014, Gordon *et al.* 2014b).

### Plankton

MEL was perhaps best known for its many fundamental contributions to understanding marine plankton (Li 2014). These included determining many of the major factors controlling primary production by phytoplankton, examining how its distribution is affected by physical oceanographic properties, discovering the great importance of picoplankton in the transformation of energy in the sea, unravelling many of the details of secondary production by zooplankton, and assessing the ecological geography of the world ocean. Field studies ranged from local waters to the global ocean, including working under ice in the Arctic Ocean.

### Benthos

MEL also made important contributions to benthic ecology (Gordon *et al.* 2014b). These included determining the primary production of seaweeds, benthic algae and saltmarshes in local coastal environments and elucidating the composition of benthic communities, and in some cases their secondary production, in numerous locations ranging from the intertidal zone to the continental shelf.

### Fish

While not directly engaged in providing advice for the management of fisheries, many fundamental studies were conducted that addressed fish metabolism, feeding dynamics, energetics, larval stages, recruitment, population dynamics and predator-prey relationships. In addition, MEL initiated studies of the effects of environmental factors such as freshwater runoff and seawater temperature on fisheries (O’Boyle *et al.* 2014).

### Ecosystems

MEL was one of the first laboratories in the world to conduct studies of whole ecosystems in which emphasis was placed on understanding the interactions between the physical environment and different trophic levels. The first was carried out in

St. Margaret's Bay, followed soon after by similar studies in Halifax Harbour/Bedford Basin and Petpeswick Inlet. These in turn were followed by much more detailed studies in St. Georges's Bay (Lambert *et al.* 2014) and the upper reaches of the Bay of Fundy (Gordon *et al.* 2014c).

Beginning with measurements of the size distribution of particles in surface waters on the Hudson-70 Expedition and later calculations of the biomass of zooplankton, fish and mammals from the scientific literature, MEL scientists observed that, to a first approximation, when plotted on a logarithmic scale there was roughly an equal concentration of pelagic biomass over the whole size range from bacteria to whales. This unexpected observation led to the development of the biomass spectrum theory, another unique MEL contribution to understanding marine ecosystems in the world ocean (Duplisea *et al.* 2014). Given information on the abundance and size distribution of plankton, the theory could predict the equilibrium biomass of fish that a body of water can support. This size-structured view of marine ecosystems provided an effective theoretical and empirical basis for understanding and managing aquatic ecosystems.

Using information from field studies and gleaned from the scientific literature, MEL undertook several projects to develop detailed quantitative numerical models describing the flow of energy through ecosystems of particular interest. These projects included scientists from all oceanographic disciplines and much of the work was done in a workshop environment, often involving international collaborators. One project developed a model of the pelagic ecosystem on the Grand Banks in order to better understand the potential impacts of a major oil spill at the Hibernia development site. Another project developed a model of the Cumberland Basin pelagic and benthic ecosystem in the upper reaches of the Bay of Fundy, which was a site under consideration for tidal power development (Gordon *et al.* 2014c). These models could be used to run simulations to predict the ecosystem impacts of changing important physical and chemical properties.

## Contaminants

MEL made many major contributions to understanding the distribution, pathways and effects of chemical contaminants on marine ecosystems. Considerable emphasis was devoted to chlorinated hydrocarbons, including DDT (and its derivatives) and

PCBs (Addison *et al.* 2014). Transfer pathways and bioaccumulation in marine food webs were measured in different regions including St. Georges Bay, Sable Island and the Arctic Ocean. In addition, major contributions were made to understanding the fate and effect of oil spills, especially in cold-water environments (Gordon *et al.* 2014d). Scientists were also involved in examining the feasibility of disposing of radioactive waste in deep sea sediments. As well as studying the impacts of contaminants, MEL scientists also studied the effects of physical habitat disturbance on marine ecosystems. These included studies of the impacts of causeway construction, as well as the proposed construction of barrages for tidal power development in the Bay of Fundy (Gordon *et al.* 2014c).

### Scientific Advice

As civil servants, MEL provided objective scientific advice on environmental issues as requested. This often included responding to environmental emergencies such as toxic algal blooms, fish kills and oil spills.

## DEMISE

Unfortunately, in the mid-1980s, dark clouds began to appear on the horizon. A-Base funding began to dwindle and MEL had to start looking for other sources of funding to support its research, from both government and industry. For the first time, staff had to invest time in preparing and defending research proposals. These external funding sources came with specific objectives, often quite applied, over which directors had little control. This made it more difficult to pursue research of a more basic nature to address fundamental ecological questions. Then, in 1986, a major national reorganization of DFO driven by Ottawa began which had a huge impact on MEL and ultimately led to its demise. Ken Mann was interviewed by senior officials from Ottawa about the process of scientific research and the role of MEL in the federal service. The concept of the federal government supporting a world-class oceanographic institute such as BIO which focused on long-term research addressing important scientific questions cut little ice. It was clear that the Ottawa mandarins saw that the primary role of MEL should be to provide scientific advice to fisheries and habitat managers and that the government, not scientists, must determine the fields of study that would be of most benefit to Canada. It soon became clear which direction the wind was now blowing.

In early 1986, the DFO Deputy Minister, Peter Meyboom, announced that Ocean Science and Surveys (OSS), which contained all the federal oceanography programs including MEL and the Canadian Hydrographic Service, was being disbanded and merged with the Fisheries Resource Branch. The reason given for this drastic action was that DFO fisheries managers had complained that they were not getting the information from OSS that they needed to manage their fisheries. However, this reason was not actually valid. OSS, including MEL, had always recognized its responsibility to provide oceanographic information for fisheries management and was always open to requests for advice. Over the years, various mechanisms had been set up to facilitate this process and encourage collaboration with the Fisheries Resource Branch. It appeared that the senior managers in Ottawa, mostly with a background in fisheries, were either unaware of these initiatives or deliberately chose to ignore them. Since MEL was the only federal laboratory of its kind in the country, it was seen as an anomaly and scheduled for closure. At the same time, major cuts in funding for all of DFO were announced.

In April 1986, Barry Muir was appointed as acting Regional Director of Science for the Scotia-Fundy Region. This new position reported to the Regional Director-General of the newly established Scotia-Fundy Region in Halifax, J.-E. Haché, not to a senior official in Ottawa. This marked the end of direct reporting by BIO oceanography programs to Ottawa as had long been the practice since it was founded in 1962. As result of this change, there was no longer a strong voice for oceanography around the table in the nation's capital.

Soon after, Peter Meyboom announced the new policy priorities of DFO. These were defined to shape the direction that the department would take in carrying out its mandate to manage fisheries resources, with greater emphasis on conservation and enforcement and on improving the consultative and regulatory process. The new policies also addressed the need to consolidate DFO science activities and ensure that they respond more closely to the needs of clients. Oceanography was no longer recognized as a national priority.

As a result of these actions, several MEL staff began to make sure that word of what was happening got out to university colleagues, other oceanographic institutes and the media. Eric Mills in the Dalhousie Department of Oceanography subsequently played a leading role in spreading the word and raising concerns. He argued that basic oceanographic science was being hit hard and brought firmly under the control of fisheries administrators and that the pending closure of MEL represented a significant step backward for Canadian oceanography (Mills 1986). Letters protesting the federal science resource cuts and the pending dismantling of MEL were written to the Minister of DFO, Tim Siddon, senior DFO managers and key MPs. They were also sent to provincial MLAs. In addition, letters protesting the funding cuts and pending demise of MEL were solicited from scientific colleagues around the world. Also, wilfully breaking departmental communication guidelines, several MEL scientists vented their frustration by conducting interviews that questioned the wisdom behind Ottawa's decision to disband MEL without consulting the scientists involved. These protests were widely reported by the media. As expected, the widespread objections to the planned decisions were not well received by DFO bureaucrats.

All of the protesting actions taken by MEL staff, Dalhousie colleagues and prominent marine scientists from around the world had no impact on the decision-makers and MEL was formally closed on 1 April, 1987. Over 100 staff, including non-MEL scientists, gathered at the main door of BIO wearing black armbands to stage a 'wake for marine science' (Fig 5) (Charbonneau 1987). They wanted to show that MEL's demise was not opposed by just a small band of malcontents, as Minister Siddon had stated several days before in the House of Commons, but also by much of the scientific community in Atlantic Canada and marine scientists around the world. This act of mourning was a symbolic expression of the concern that the need for Canadian oceanographic research was not understood or supported by the senior managers of DFO. It was indeed a dark day for Canadian marine science.

Concerned about the unrest, Peter Meyboom visited BIO a few days later and gave a presentation to all DFO staff explaining the basis for his decisions. As expected, he was coldly received, but at least he had the courage to come down from Ottawa and face an

**Fig 5 Protesting the closure of MEL on 1 April 1978.**

open and somewhat hostile audience. He stated that, because of the pressure to downsize, it was necessary to amalgamate oceanography and fisheries in DFO but that, while some names were disappearing from the organizational structure, functions were not, they were merely being redistributed. He felt that long-term multidisciplinary research of the type carried out by MEL was not threatened. Although this meeting helped to reduce the atmosphere of confrontation, MEL staff were still most concerned about the future.

## LEGACY

Fortunately, the closure of MEL was not the end of marine ecological research at BIO as many had feared. While MEL ceased to exist on paper, after the funding cuts and some transfers of staff to other DFO laboratories, the scientific staff adapted, somewhat reluctantly, to the new working conditions. The Biological Oceanography Division, which was little affected by the organizational changes, was able to carry on much of its program of basic research on marine plankton production processes on regional, national and global scales. The newly created Habitat Ecology Division established a series of more applied projects at local and regional scales to address the expanding needs of habitat managers under the new national DFO fish habitat policy. Most of these projects addressed understanding the impacts of human activities such as aquaculture, oil and gas development, fishing and habitat alteration on marine ecosystems. Recognizing that proper management required more information than just the internal dynamics of individual fish stocks, the Marine Fish Division gave increasing attention to ecological considerations in fisheries management and initiated a number of new ecosystem level research projects. Another factor which led to the development of new ecological programs at BIO was the passing of the Oceans Act (1997) and the Species at Risk Act (2002). As a result of these new legislative mandates, new management projects with an ecological focus were initiated which included preparing reviews, status reports and recovery plans for threatened species, as well as leading the development of integrated ocean management plans for large spatial areas and marine protected areas. With time, the importance of understanding the structure and dynamics of marine ecosystems and how they can be influenced by human activities and climate change became more widely appreciated throughout DFO. By 2012, the 50th anniversary of BIO, all of the three remaining DFO research divisions had either ‘ecosystem’ or ‘ecology’ in their names.

## CONCLUSION

When the Marine Ecology Laboratory was founded, oceanography was a high priority of the Canadian federal government and well supported. MEL scientists were given a wide range of latitude in planning their programs that addressed the structure and dynamics of marine ecosystems, with projects ranging from physical oceanography to marine mammals. Its mandate later expanded to investigate the impacts of contaminants and habitat alteration on marine ecosystems. MEL was most fortunate to have been at the right place at the right time and operated under exceptional circumstances which provided an exciting and creative research environment. As a result, over its twenty-two year history, MEL developed an outstanding international reputation for excellence and made many fundamental contributions to improving the understanding of marine ecosystems and how they can be affected by human activities.

These original scientific contributions have been of great benefit to Canada.

During the lifetime of MEL, there was a pronounced change in Canadian federal government science policy and the organization of its research laboratories (Hayes 1973, Gordon 2020). There was a gradual trend in Ottawa to take authority away from the directors of the research laboratories and focus government science on more practical problems specific to Canada. Senior managers were more interested in operating a business, with specific objectives set by clients, rather than supporting research laboratories devoted to more fundamental studies. The demise of MEL was indeed a passing dark cloud for Canadian marine science. Fortunately, the scientists were able to regroup under the new organization and carry on the tradition of conducting significant ecological research at BIO.

In 2006, thirty-seven ex-MEL staff gathered for a reunion to reflect on the wonderful opportunities and experiences that they had shared together (Fig 6). Despite fewer resources and increasing government bureaucracy in recent years, the MEL legacy of ecological research at BIO has continued.

**Fig 6 MEL reunion in 2006.**

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 299-326

# CONTRIBUTIONS TO THE STUDY OF HIGHER FUNGI ON SABLE ISLAND, NOVA SCOTIA

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## ABSTRACT

This study documents 27 taxa of Higher Fungi found on Sable Island, a remote emergent sand bar 160 km east of the Nova Scotia mainland. Of these, two are new basidiomycete records for the province, *Deconica subcoprophila* and *Volvopluteus* aff. *gloiocephalus*. Thirteen other taxa represent range extensions within Nova Scotia. *Suillus luteus* is suggested as the probable identity of the only ectomycorrhizal fungus described colonizing the roots of the solitary pine tree growing on Sable Island.

Keywords: coprophilous fungi, coastal dunes, *Deconica, Suillus luteus, Volvopluteus*

## INTRODUCTION

Sable Island is located 160 km east of the Nova Scotia mainland. Although the island is part of the province of Nova Scotia, it is distinguished from the rest of the province by its remote location, and by numerous unique features: a landscape dominated by one of the largest coastal dune systems in Atlantic Canada; an extensive freshwater lens; the world's largest grey seal (*Halichoerus grypus*) breeding colony; a population of feral horses (the only terrestrial mammal on the island); and many rare and endemic flora and fauna. The island is a distinct biogeographic region within Nova Scotia and is the smallest ecodistrict in the province (Neily *et al*. 2017).

Sable Island is an emergent sandbar approximately 40 km long, with a maximum width of 1.3 km, and a surface area of 3,400 ha

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(~30 km$^2$) (Colville *et al.* 2016). The island's dimensions vary as its shoreline is subjected to seasonal and long-term changes in patterns of sand erosion and deposition. Severe weather events also have short- and/or long-term impacts on the island's topography. Sable Island's climate is Maritime Temperate (Meteorological Service of Canada 1999), and compared with the rest of Nova Scotia, the island has milder temperatures, less snow, more frequent cloud cover and fog, and stronger winds.

There has been a continuous human presence on Sable Island since 1801. Over two centuries ago, the island was primarily known as a hazard to navigation. In 1801 the Government of Nova Scotia set up the lifesaving service–the Sable Island Humane Establishment–which operated until 1958. The human impact on the island was greatest during this period. Introductions of livestock and cultivation of crops, hunting, construction, and vehicle traffic influenced the island's landforms and the composition of vegetation communities. In 1944, the Meteorological Service of Canada (MSC) established the aerological station on Sable Island, and other organizations such as the Canadian Coast Guard, Fisheries and Oceans Canada, and Dalhousie University have had long-term programs on the island. In 2013 the island became the Sable Island National Park Reserve, and the island and most infrastructure are now owned and managed by Parks Canada. Although MSC's aerological program ended in 2019, the Sable Island Station continues as the operational centre for the island.

Roughly 50% of the island's land surface is vegetated (Colville *et al.* 2016), and about 185 plant species occur in distinctive vegetation communities comprised of herbs and low shrubs. Approximately 20% of plant species are introductions, but many are found mostly in areas where human activities and structures provide suitable habitat.

Given the island's dynamic landscape as well as recent changes in jurisdiction and human activities, there have been changes in many areas where the fungi taxa reported here were recorded. For example, several specimens were collected from a well-vegetated slope at the edge of a freshwater pond south of the Sable Island Station. Since then, the adjacent south beach dune has retreated, and the pond area is now a sandflat frequently subjected to ocean overwash. Other specimens were found in vegetation communities that have since been altered by sand transport, or by nesting and grazing activities. A few fungi specimens were recorded on or near human structures which have since been removed or modified. Since most infrastructure is surrounded by fences to keep the horses away from buildings and equipment, fungi occurring inside these exclosures (e.g., the exclosure at the Sable Island Station) are in habitats generally not affected by horse activities (grazing, trampling, and dung/urine).

Numerous botanical surveys, beginning with Macoun's work on Sable Island in 1899 (Macoun 1902) have contributed to knowledge of the island's vascular plant species and communities. Among the few that have focussed on the less conspicuous flora are Richardson *et al*. 2009 (lichens), and Mills & Lucas 2016 (bryophytes). Prior to this study, the last work on the island's mycoflora was conducted in the 1980s. Redhead & Catling (1983) reported two fungi from Sable Island which were new records for Nova Scotia: *Peziza ammophila* and *Hygrocybe coccineocrenata* (as *H. turunda*). Although David Malloch collected fungi on the island in the 1980s, with results being available in a project report (Malloch 1982) and in a note on a single species, *Protubera sabulonensis* (Malloch 1989), most of the identifications have only recently been published (Malloch 2016). The species reported in Redhead & Catling (1983) and in Malloch (2016) represent a complete list of Sable Island fungi based on collections made in the 1980s, a total of 118 species. Of these, 116 were reported by Malloch (2016), of which 51 were coprophilous fungi that were grown in a moist chamber from horse dung samples collected on the island.

Although Sable Island is considered part of Halifax County for administrative purposes, it is an ecologically unique location (Neily *et al.* 2017) and consequently new reports from the island of species that have been previously recorded on the mainland in Halifax County could be viewed as range extensions within the province. This paper presents two new records for Nova Scotia and extends the range of thirteen taxa within the province.

## MATERIALS AND METHODS

The taxa listed in this publication were collected on Sable Island, Nova Scotia in the summer and fall of 2009, 2011, 2014, and 2015 using an opportunistic sampling approach. Morphological characteristics (e.g., size, shape, colour, odour, etc), dehydrated specimens and spore prints, habitat details, site coordinates, and field number were recorded for each collection. Photographs, mostly *in situ*, were also taken for each specimen. Microscopic characteristics were observed by rehydrating desiccated collections in 3% KOH.

Texts used for identification of taxa were: *Peziza domiciliana,* Beug *et al*. (2014); *Agaricus* aff. *sylvaticus,* Nauta (2001), Kerrigan (2016), and Baroni (2017); *Suillus luteus,* Smith & Thiers (1971) and Grund & Harrison (1976); *Inocephalus murrayi,* Horak (1975); *Gloeophyllum sepiarium,* Gilbertson & Ryvarden (1988); *Neolentinus sepiarium,* Mochizuki (2019); Hygrophoraceae, Bird & Grund (1979), Hesler & Smith (1963), and Stuntz (1975); *Crucibulum leave*, Fay *et al*. (2019); *Mutinus elegans*, Kuo (2006); *Volvopluteus* aff. *gloiocephalus*, Butler (2012) and Justo *et al*. (2011); *Fomes fomentarius,* Gilbertson & Ryvarden (1988); *Panaeolus* spp., Menser (2019), Ola'h (1969) and Stamets (1978); *Psathyrella candolleana*, Smith (1972) and Kits van Waveren (1977); *Schizophyllum commune*, Ginns (2007) and Cooke (1961); *Agrocybe pediades,* Hermansen (1986); *Protostropharia semiglobata*, Kroeger (2009); *Deconica* spp., Guzmán (1983); and *Lepista nuda,* Moser (1983) and Butler (2004).

Index Fungorum (http://www.indexfungorum.org/), the global fungal nomenclatural database, was used to ensure that current taxonomic names were applied to collections. Secondary reports of fungi from the literature, including the electronic databases Mycoportal (http://mycoportal.org) and Canadensys (http://www.canadensys.net/) were used to determine range extensions and new records.

The collections examined in this study, and photographs, are housed at the E.C. Smith Herbarium (ACAD) at Acadia University, Wolfville, Nova Scotia. The ACAD accession number for each collection, followed by the original field number (in parentheses), is provided in the Annotated Species List.

Specimens recorded in 2014 and 2015 (total three) were collected under Parks Canada Agency Research and Collection Permits (permit number SINP-2012-12893). Permits were not required prior to park establishment in 2013.

## RESULTS

Most fungi specimens (88%) reported here were collected in 2009. Of the 43 fruitbody collections studied, 27 taxa belonging to 14 families were identified (Table 1). Of these, six genera and 15 species are new to Sable Island. The six new genera are *Suillus*, *Neolentinus*, *Crucibulum*, *Volvopluteus*, *Fomes*, and *Schizophyllum*. Twelve of the 15 species are also new to Halifax County.

Of the 27 taxa recorded, 19 were found once. Of the remaining eight taxa, four were recorded at two sites, two at three sites, and two at five sites. Most (13 of 15) new records and range extensions are based on a single collection/site. Site and collection details are provided in the Annotated Species List below.

**Table 1 List of fungi taxa collected between 2009 and 2015 on Sable Island, Nova Scotia, with new record status (X) indicated for the province, Halifax County, and Sable Island.**

| Taxa | NS | Hfx | SI[1] | Earlier Record[2] | Month[3] |
|---|---|---|---|---|---|
| **ASCOMYCOTA** | | | | | |
| **Pezizaceae** | | | | | |
| *Peziza domiciliana* | - | X | X | - | July |
| **BASIDIOMYCOTA** | | | | | |
| **Agaricaceae** | | | | | |
| *Agaricus* aff. *sylvaticus* | - | X | X | - | Aug |
| **Boletaceae** | | | | | |
| *Suillus luteus* | - | - | X | - | Oct |
| **Entolomataceae** | | | | | |
| *Inocephalus murrayi* | - | X | X | - | Aug |
| **Gloeophyllaceae** | | | | | |
| *Gloeophyllum sepiarium* | - | - | - | DM | July |
| *Neolentinus lepideus* | - | - | X | - | Aug |
| **Hygrophoraceae** | | | | | |
| *Cuphophyllus pratensis* | - | - | - | DM | Oct |
| *Gliophorus psittacinus* | - | - | - | DM | Nov |
| *Humidicutis marginata* | - | - | - | DM | Aug |
| *Hygrocybe coccineocrenata* | - | - | - | R&C | Oct |
| *Hygrocybe ceracea* | - | X | X | - | Oct |
| *Hygrocybe conica* | - | X | X | - | Oct |
| *Hygrocybe grundii* | - | X | X | - | Oct |
| **Nidulariaceae** | | | | | |
| *Crucibulum laeve* | - | X | X | - | Oct |
| **Phallaceae** | | | | | |
| *Mutinus elegans* | - | - | - | DM | Sep |
| **Plutaceae** | | | | | |
| *Volvopluteus* aff. *gloiocephalus* | X | X | X | - | Jun/Oct |

*Table 1 cont'd*

*Table 1 cont'd*

| Taxa | NS | Hfx | SI[1] | Earlier Record[2] | Month[3] |
|---|---|---|---|---|---|
| **Polyporaceae** | | | | | |
| *Fomes fomentarius* | - | X | X | - | Sep |
| **Psathyrellaceae** | | | | | |
| *Panaeolus papilionaceus* | - | - | - | DM | Jun |
| *Panaeolus semiovatus* | - | - | - | DM | Jun |
| *Panaeolus subbalteatus* | - | - | - | DM | Jun |
| *Psathyrella candolleana* | - | X | X | - | Aug |
| **Schizophyllaceae** | | | | | |
| *Schizophyllum commune* | - | X | X | - | Oct |
| **Strophariaceae** | | | | | |
| *Agrocybe pediades* | - | - | - | DM | Jun |
| *Protostropharia semiglobata* | - | - | - | DM | Jul |
| *Deconica coprophila* | - | - | - | DM | Jul |
| *Deconica subcoprophila* | X | X | X | - | Jul |
| **Tricholomataceae** | | | | | |
| *Lepista nuda* | - | - | X | - | Oct |
| **Total** | **27** | **2** | **12** | **15** | **12** |

[1] Although Sable Island is administratively within Halifax County, a new record from the island for a species previously recorded in Halifax County is viewed as a range extension within Nova Scotia.

[2] Previously reported from Sable Island by Malloch 2016 (DM), or by Redhead & Catling 1983 (R&C).

[3] Month collected during this study.

## ANNOTATED SPECIES LIST

## ASCOMYCOTA

### Pezizaceae

***Peziza domiciliana*** Cooke, *Gard. Chron.*, N.S. 7(no. 182): 793 (1877)

Plant pathologist Ken Harrison first documented *P. domiciliana* in Nova Scotia in 1938, growing in the greenhouses, cellars, and mushroom caves of Kings County (Gourley 1982). This is the first report for *P. domiciliana* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected at an abandoned building near West Light; fruit-bodies (43.93192N, -60.02032W) were growing in a shaded and sheltered area under the outdoor steps, in sand against the concrete wall of the building's basement; Z. Lucas; 19933F (15-04); July 11, 2015.

## BASIDIOMYCOTA

### Agaricaceae

***Agaricus* aff. *sylvaticus* Schaeff.**, *Fung. bavar. palat. nasc.* (Ratisbonae) 4: 62 (1774)

This red-staining *Agaricus* sp. is clearly in the section *Sanguinolenti* and, following Nauta (2001) and Baroni (2017), most closely resembles *A. sylvaticus* Schaeff. The eastern North American members of the section *Sanguinolenti* probably represent a complex of related species requiring more taxonomic work to resolve (Kerrigan 2016). *Agaricus haemorrhoidarius* Schulz., a related species, has been documented growing in Kings County, Nova Scotia, in conifer woods (Gourley 1982). However, due to the heterogeneity of this species complex, it is difficult to know whether the collection listed in Gourley (1982) is the same as our collection from Sable Island without examining the Kings County collection. This is the first report for *Agaricus* aff. *sylvaticus* from Sable Island, and it represents a new record and a range extension for this unresolved species complex within the province.

*Material examined*

1) Collected near the edge of a concrete path inside the station exclosure; the fruitbody (43.93320N, -60.00723W) was growing in soil with 100% vegetation cover; Z. Lucas; 19934F (09-117); August 6, 2009.

### Boletaceae

***Suillus luteus* (L.) Roussel**, *Fl. Calvados*: 34 (1796)

*Suillus luteus*, a widespread and popular edible ectomycorrhizal (ECM) mushroom, was first reported in Halifax, Kings, Pictou, and Lunenburg Counties growing under *Pinus* spp. (Gourley 1982). Although *S. luteus* has been reported from Halifax County, this is the first report of *S. luteus*–and of any known ECM mushroom–from Sable Island. Mycologist David Malloch (2016) provided a brief description of the ECM fungus colonizing a solitary and stunted *Pinus sylvestris* (Scots Pine). This tree, planted in the 1960s, is one of only three trees presently recorded on Sable Island. Two *Alnus incana*, introduced about 30 years ago, survive as thin stems <50 cm high growing in a hollow and sheltered by beach grass, *Ammophila breviligulata.* Malloch (2016) investigated the pine and noted (p. 142) a "well-developed mantle and Hartig net" and that the root tips he collected all seemed to be colonized by one fungal symbiont, but he could not identify the ECM fungus in the absence of fruiting bodies. Our collection, identified as *S. luteus*, was found growing at the base of the same *P. sylvestris*, and is the likely identity of the ECM fungus that eluded Malloch. This is the first report for *S. luteus* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected at the base of an introduced and solitary *P. sylvestris*; the fruitbody (43.93123N, -60.00242W) was growing in a thick layer of decomposing plant material with little sand present in a moist and shaded environment, sheltered by dense vegetation around the tree. Nearby vascular species included *Trifolium* sp., *Achillea millefolium*, *Juncus* sp., and grasses; Z. Lucas; 19935F (09-142); October 9, 2009.

## Entolomataceae

***Inocephalus murrayi*** (Berk. & M.A. Curtis) Rutter & Watling, *Malay. Nat. J.* 50: 231 (1997)

*Inocephalus murrayi*–as *Nolanea murrayi* (Berk. & M.A. Curtis) Dennis–was first collected on wet humus and sphagnum moss in Hants and Colchester Counties, Nova Scotia, in 1931 by Michigan State University mycologists Lewis Wehmeyer and Alexander Smith (Gourley 1982). This is the first report for this species from Sable Island and represents a range extension within the province.

*Material examined*

1) Collected in a shrub-herb community on a low hill just east of a freshwater pond south of the station; the single fruitbody (43.92917N, -60.00962W) was growing in soil with 100% cover including *Thalictrum polygamum*, *Rubus arcuans*, *Symphyotrichum novi-belgii*, and *Anthoxanthum odoratum*; Z. Lucas; 19936F (09-123); August 13, 2009.

## Gloeophyllaceae

***Gloeophyllum sepiarium*** (Wulfen) P. Karst. [as '*Gleophyllum*'], *Bidr. Känn. Finl. Nat. Folk* 37: 79 (1882)

*Gloeophyllum sepiarium* (Fig 1) was first collected in Nova Scotia (no specific location listed) by physician J. Sommers and

**Fig 1** ***Gloeophyllum sepiarium*** **is one of several lignicolous species that occur on woody debris that has washed up on, or been brought to, Sable Island.**

naturalist Alexander MacKay in 1881 (Gourley 1982). This species was previously reported from Sable Island from collections made in the early 1980s (Malloch 2016).

*Material examined*

1) Collected on the inside slope of a low south beach dune; the fruitbody (43.93140N, -59.90980W) was found growing on a piece of driftwood partly buried in the sand; Z. Lucas; 19938F (09-104); July 18, 2009; Fig 1.

2) Collected from a south beach dune 100 m northwest of the Old No.3 house foundation; fruitbodies (43.93167N, -59.88540W) were growing on a large driftwood tree trunk; Z. Lucas; 19939F (09-105); July 18, 2009.

***Neolentinus lepideus*** (Fr.) Redhead & Ginns, *Trans. Mycol. Soc. Japan* 26(3): 357 (1985)

This fungus was first collected in Nova Scotia in 1908 by Alexander MacKay, in Halifax, Kings, and Pictou Counties growing on coniferous and deciduous wood (Gourley 1982). This is the first report for *N. lepideus* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected at the north side of the road to the gas storage building at the Sable Island Station; the fruitbody (43.93332N, -60.00560W) was growing on the base of a wooden post, at the sand surface; Z. Lucas; 19940F (11-014); August 11, 2011.

## Hygrophoraceae

***Cuphophyllus pratensis*** (Pers.) Bon, *Docums Mycol.* 14(no. 56): 10 (1985) [1984]

*Cuphophyllus pratensis,* as *Hygrophorus pratensis* var. *pratensis* (Fr.) Fr., was first documented in Nova Scotia in the 1930's from Colchester, Hants, Kings, and Pictou Counties by Lewis Wehmeyer and Alexander Smith (Gourley 1982). This species was previously reported (as *Hygrocybe pratensis*) on Sable Island from collections made in the early 1980s (Malloch 2016).

*Material examined*

1) Collected inside the station exclosure; fruitbodies (43.93313N, -60.00723W) were growing in sandy soil in an area of vegetated terrain mowed several times a year; Z. Lucas; 19941F (09-157); October 12, 2009.

***Humidicutis marginata*** (Peck) Singer, *Sydowia* 12(1-6): 225 (1959) [1958]

*Humidicutis marginata,* previously known as *Hygrocybe marginata* (Peck) Murrill*,* was first documented in Nova Scotia from Colchester, Kings, and Lunenburg Counties in humus under *Acer* sp. in 1931 by Lewis Wehmeyer and Alexander Smith (Gourley 1982). *H. marginata* was previously reported on Sable Island from collections made in the early 1980s (Malloch 2016).

*Material examined*

1) Collected in a shrub-herb community on a low hill just east of Bartonia Pond (a freshwater pond that has since disappeared); fruitbodies (43.92917N, -60.00962W) were growing on a vegetated slope with 100% cover comprised of *T. polygamum*, *R. arcuans*, *S. novi-belgii*, *A. odoratum*, and mosses; Z. Lucas; 19942F (09-122); August 13, 2009.

***Hygrocybe coccineocrenata*** (P.D. Orton) M.M. Moser, in Gams, *Kl. Krypt.-Fl.*, Edn 3 (Stuttgart) 2b/2: 68 (1967)

*Hygrocybe coccineocrenata* was first reported from Sable Island, and Nova Scotia in general, by Redhead & Catling (1983), as *H. turunda* var. *sphagnophilus* (Peck) Bon. The collections examined in our study most closely resemble Hesler & Smith's (1963) and Stuntz's (1975) description of *H. turunda* var. *sphagnophilus* in that the pileal squamules are not darkly coloured in this species, in contrast to *H. turunda* var. *turunda*. Both *H. turunda* and *H. turunda* var. *sphagnophilus* are now classified as *H. coccineocrenata*. According to Hesler & Smith (1963) and Redhead & Catling (1983), this species is typically associated with moss (often *Sphagnum* moss). Our collection was growing on moist sand, with no moss present.

*Material examined*

1) Collected in a dune slack east of the West Light area; fruitbodies (43.93232N, -60.01643W) were growing in moist sand with *Myrica pensylvanica*, *Vaccinium macrocarpon*, and *Juncus* sp. nearby; Z. Lucas; 19943F (09-134); October 2, 2009.

***Hygrocybe ceracea*** (Sowerby) P. Kumm, *Führ. Pilzk.* (Zerbst): 112 (1871)

*Hygrocybe ceracea*, as *Hygrophorus ceraceus* (Wulfen) Fr., was originally documented in Nova Scotia growing under *Fagus* sp. and *Acer* sp. in Colchester and Kings Counties in 1931 by Lewis Wehmeyer and Alexander Smith (Gourley 1982). Bird & Grund (1979) studied another collection from Kings County made in 1967 and identify the habitat of *H. ceracea* as moist soil or moss in either coniferous or deciduous forests. Hesler & Smith (1963) identify moss and soil as the habitat of this species, with no mention made of forests. This is the first report for *H. ceracea* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected from a gentle northwest-facing slope 10 m south of Pinetree Pond West; fruitbodies (43.93072N, -60.00265W) were growing in sand rich in organic material in an area with 100% vegetation cover, including *M. pensylvanica*, *Fragaria virginiana*, *A. millefolium, Juncus* sp*., A. odoratum,* and *Maianthemum stellatum*; Z. Lucas; 19944F (09-143); October 10, 2009.

***Hygrocybe grundii*** Malloch, *Fleshy fungi (Basidiomycota) of the Atlantic Maritime Ecozone*: 124 (2010)

This species, now known as *H. grundii* (Malloch 2010), was originally described as *Hygrocybe macrosporus* Bird & Grund from one collection made in a hemlock forest in the Kentville ravine, Kings County in 1967 (Bird & Grund 1979). This is the first report for

*H. grundii* (Fig 2) from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected 50 m west of Lily Pond North; fruitbodies (43.93153N, -60.01843W) were growing in soil with 100% vegetation cover including *T. polygamum, Vaccinium angustifolium, R. arcuans, Mitchella repens, Juncus* sp., *A. odoratum*, and *Festuca rubra*; Z. Lucas; 19945F (09-146); October 11, 2009; Fig 2.

***Hygrocybe conica*** (Schaeff.) P. Kumm., *Führ. Pilzk.* (Zerbst): 111 (1871)

*Hygrocybe conica* was first collected on humus in mixed woods, in Nova Scotia, from Kings, Colchester, and Annapolis Counties in 1908 by Lewis Wehmeyer and Alexander MacKay (Gourley 1982). This is the first report for *H. conica* from Sable Island, and it represents a range extension for this species within the province.

**Fig 2** ***Hygrocybe grundii*** **is one of many members of the Hygrophoraceae found on Sable Island. This species is not commonly encountered in Nova Scotia.**

*Material examined*

1) Collected in a sparsely vegetated area ~30 meters inland from the south beach, east of the south beach road; fruitbodies (43.93020N, -60.00139W) were growing in sandy soil on a southwest-facing slope with 20% vegetation cover including *Anaphalis margaritacea*, *Solidago sempervirens,* and *A. breviligulata*; Z. Lucas; 19946F (09-144); October 9, 2009.

2) Collected inside the station exclosure; fruitbodies (43.93313N, -60.00723W) were growing in soil in an area of vegetated terrain that was mowed several times a year; Z. Lucas; 19947F (09-159); October 12, 2009.

***Gliophorus psittacinus*** (Schaeff.) Herink, *Sb. severočesk. Mus.*, Hist. Nat. 1: 82 (1958)

*Gliophorus psittacinus* was first documented growing on humus in mixed woods in Nova Scotia by Lewis Wehmeyer and Alexander Smith in 1931 (Gourley 1982). This species was previously reported, as *Hygrocybe psittacina* (Schaeff.) P. Kumm., from Sable Island from collections made in the early 1980s (Malloch 2016). Interestingly, Malloch (2016) reported that “this species is often bright green when fresh, although the ones on Sable Island were always yellow to orange” (p. 142). Our collection was greenish in colour, conforming to the more standard colour for *G. psittacinus*.

*Material examined*

1) Collected in a shrub-herb community just east of the helipad at the station; fruitbodies (43.93291N, -60.00502W) were growing in sandy soil with a high organic matter content and ~100% vegetation cover, including *T. polygamum*, *M. pensylvanica*, *Empetrum nigrum*, *A. millefolium*, *Sibbaldiopsis tridentata*, *M. stellatum,* and grasses; Z. Lucas; 19948F (14-08); November 14, 2014.

## Nidulariaceae

***Crucibulum laeve*** (Huds.) Kambly, *Gast. Iowa*: 167 (1936)

Seven collections of *C. laeve* have been reported from Nova Scotia from Kings, Cape Breton, and Colchester Counties (Mycoportal 2016). This is the first report for *C. laeve* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected 4 m northwest of the gas storage building at the station; fruitbodies (43.93338N, -60.00542W) were growing on old leaf, stem, and dung litter in sandy soil with 50% cover including *Rosa virginiana*, *A. margaritacea, Juncus* sp. *A. breviligulata*, and *F. rubra*; Z. Lucas; 19949F (09-141); October 7, 2009.

## Phallaceae

***Mutinus elegans*** (Mont.) E. Fisch., *Syll. fung.* (Abellini) 7: 13 (1888)

*Mutinus elegans* was previously reported on Sable Island from collections made in the early 1980s (Malloch 2016), and this was the first record of this species in Nova Scotia.

*Material examined*

1) Collected on Steeple Dune; the fruitbody (43.97490N, -59.76283W) was growing in tall marram grass (*A. breviligulata)* on a sandy substrate in a sheltered, well-shaded area; Z. Lucas; 19950F (11-015); September 6, 2011.

## Plutaceae

***Volvopluteus* aff. *gloiocephalus*** (DC.) Vizzini, Contu & Justo**,** *Fungal Bio.* 115(1):15 (2011)

Our collections represent a new record for *Volvopluteus* aff. *gloiocephalus* (Fig 3)–formerly *Volvariella gloiocephala* (DC.) Boekhout & Enderle–in Nova Scotia. While the cap diameter (>5cm) and the average basidiospore length (>12.5 μ m) conform to the description of *V. gloiocephalus* published by Justo *et al.* (2011), neither pleurocystidia nor cheilocystidia were found in the collections described here which is why our collections are listed as having an affinity with *V. gloiocephalus.*

*Material examined*

1) Collected on a low west-facing slope in a sheltered hollow 2 m from the east side of an abandoned wooden structure (the aframe); fruitbodies (43.93468N, -59.98465W) were growing in sand (possibly on buried beach grass litter) in an area with ~30% vegetation cover (*S. sempervirens* and *A. breviligulata*), and although this is an area of horse rubbing/sheltering activity, there was no fresh dung in the site; J. Barkhouse and Z. Lucas; 19951F (09-091); June 30, 2009.

2) Collected from the inside slope of a south beach dune; fruitbodies (43.93350N, -59.85195W) were growing in sandy soil with

**Fig 3** ***Volvopluteus*** **aff.** ***gloiocephalus*** **reported here is the first for both the Province of Nova Scotia and Sable Island.**

20% vegetation cover including *Lathyrus japonicus* var. *maritimus*, *A. millefolium,* and *A. breviligulata*; Z. Lucas; 19952F (09-162); October 13, 2009; Fig 3.

## Polyporaceae

***Fomes fomentarius*** (L.) Fr., *Summa veg. Scand.*, Sectio Post. (Stockholm): 321 (1849)

Nine collections of *F. fomentarius* have been reported from Nova Scotia, in Kings and Hants Counties on a range of hosts (Mycoportal 2016). The earliest was collected in 1880 by J. Sommers and Lewis Wehmeyer (Gourley 1982). This is the first report for *F. fomentarius* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected on the north beach above the high tide line; fruitbodies (43.93455N, -60.01138W) were growing on the unburied sides of a driftwood birch log, and the condition of the bark suggested that the log may have been on the beach for only a few months or less; Z. Lucas; 19953F (09-121); September 13, 2009.

## Psathyrellaceae

***Panaeolus papilionaceus*** (Bull.) Quél., *Mém. Soc. Émul. Montbéliard*, Sér. 2 5: 152 [122 repr.] (1872)

This species was previously reported on Sable Island from collections made in the early 1980s (Malloch 2016). Alexander MacKay first collected this species in Nova Scotia, as *P. campanulatus* (L.) Quél., in 1908 on cow dung in pastureland from Colchester, Kings, Lunenburg, and Pictou Counties (Gourley 1982). Gerhardt (1996) found that the taxa formerly known as *Panaeolus sphinctrinus* (Fr.) Quél., *P. campanulatus* (L.) Quél., *P. retirugis* (Fr.) Gillet, and *P. papilionaceus* (Bull.) Quél.–a complex of closely related species with overlapping descriptions–were all the same species and grouped them under *P. papilionaceus*. The three collections described below fall into several species of *Panaeolus* that are now classified as *P. papilionaceus*.

*Material examined*

1) Collected on a dune north of the Old Main area; fruitbodies (43.93502N, -60.04983W) were growing on a weathered dung pile among *L. japonicus* var. *maritimus, A. millefolium, A. breviligulata,* and *Poa pratensis*.; J. Barkhouse and Z. Lucas; 19954F (09-054); June 24, 2009.

2) Collected on the West Spit; fruitbodies (43.96320N, -60.13882W) were growing in a fresh dung pile in an area densely vegetated with *Honckenya peploides*, *L. japonicus* var. *maritimus*, and *A. breviligulata*.; J. Barkhouse and Z. Lucas; 19955F (09-064); June 26, 2009.

3) Collected 30 metres south of an abandoned wooden structure (the aframe); fruitbodies (43.93438N, -59.98463W) were growing on dung in a sparsely vegetated area (~20% cover) with *R. virginiana, A. breviligulata,* and *P. pratensis*; J. Barkhouse and Z. Lucas; 19956F (09-093); June 30, 2009.

***Panaeolus semiovatus*** (Sowerby) S. Lundell & Nannf, *Fungi Exsiccati Suecici* 11-12: 14 (no. 537) (1938)

*Panaeolus semiovatus* was first reported in Nova Scotia by J. Sommers in 1881 growing on dung in Halifax County (Gourley 1982). This species was previously reported from Sable Island from collections made in the early 1980s (Malloch 2016).

*Material examined*

1) Collected on the beach at base of the north beach dune; fruitbodies (43.93612N, -59.93128W) were growing on a weathered dung pile; J. Barkhouse and Z. Lucas; 19957F (09-055); June 24, 2009.

2) Collected in a sandy area at the south end of a north-south cut through the north beach dunes; fruitbodies (43.93450N, -59.92273W) were growing on a dung pile on bare sand with sparse *A. breviligulata* nearby; J. Barkhouse and Z. Lucas; 19958F (09-073); June 27, 2009.

3) Collected in the northwest area of Steeple Dune; fruitbodies (43.97455N, -59.76223W) were growing on dung in a field of mostly *A. breviligulata* and *P. pratensis*; J. Barkhouse and Z. Lucas; 19959F (09-077); June 28, 2009.

***Panaeolus subbalteatus*** (Berk. & Broome) Sacc., *Syll. fung.* (Abellini) 5: 1124 (1887)

*Panaeolus subbalteatus* (Fig 4) was previously reported from Sable Island from collections made in the early 1980s (Malloch 2016). Surprisingly, prior to Malloch's (2016) report, this cosmopolitan species had not been previously reported from Nova Scotia. However, one of the authors of this paper (KW) had found, but did

**Fig 4** ***Panaeolus subbalteatus*** **is one of numerous coprophilous mushrooms on Sable Island. The uniform cap colour and apparent absence of horse dung associated with the collections reported here is atypical for this species.**

not formally document, *P. subbalteatus* in the mid-1990's growing on composted horse manure in a residential flower planter box in Shelburne County. Standard published descriptions of *P. subbalteatus* describe the cap colour as dark brown to almost black when moist, fading to cinnamon brown with a darker ring around the cap margin (Stamets 1978). The collections described below match published descriptions of *P. subbalteatus* except that there was no dung evident in the sandy soil beneath the fruitbodies and the cap colour for each collection from Sable Island was dark brown rather than zonate. The colour difference could be due to the fruitbodies being very moist at the time of collection. The apparent lack of horse dung associated with the fruitbodies could be because the horse dung was too well decomposed to discern. Alternatively, the collections described below may represent the natural variation in this species or could be an undescribed species of *Panaeolus*, closely related to *P. subbalteatus*.

*Material examined*

1) Collected in vegetated terrain on the north side of West Spit; fruitbodies (43.95282N, -60.11497W) were growing in sand in a vigorous stand of *A. breviligulata*; J. Barkhouse and Z. Lucas; 19960F (09-050); June 23, 2009.

2) Collected on the northeast side of a small dune hummock inside a north-south cut; fruitbodies (43.93480N, -60.04572W) were growing in a sandy area with *A. breviligulata*; J. Barkhouse and Z. Lucas; 19961F (09-057); June 25, 2009.

3) Collected on top of a small dune hummock in the outer half of the north-south cut (through the north beach dune) just east of the site of the Nova Scotia Field Camp (now demolished and removed); fruitbodies (43.93505N, -60.04573W) were growing in a sandy area with *A. breviligulata*; J. Barkhouse and Z. Lucas; 19962F (09-058); June 25, 2009.

4) Collected on the West Spit; fruitbodies (43.95483N, -60.12215W) were growing in sand with 30% vegetation cover including *H. peploides, L. japonicus* var. *maritimus*, and *A. breviligulata*; J. Barkhouse and Z. Lucas; 19963F (09-060); June 25, 2009; Fig 4.

5) Collected on northwest-facing slope of an inland dune, northeast of No.2 Pond East; fruitbodies (43.93533N, -59.94562W) were growing on an exposed slope with 20% beach grass (*A. breviligulata*) cover; J. Barkhouse and Z. Lucas; 19964F (09-070); June 27, 2009.

***Psathyrella candolleana*** (Fr). Maire, *Mém. Soc. Sci. Nat. Maroc.* 45: 112 (1937)

*Psathyrella candolleana* was first recorded in Nova Scotia (Kings County) in 1931 by Ken Harrison (Gourley 1982). There are four records of *P. candolleana*, all from Kings County (Mycoportal 2016). This is the first report for *P. candolleana* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected from an accumulation of driftline debris in an area of occasional saltwater flooding; fruitbodies (43.92984N, -60.01043W) were growing on a rotting driftwood log near *S. sempervirens* and *Cakile edentula*; Z. Lucas; 19965F (15-028); August 14, 2015.

## Schizophyllaceae

***Schizophyllum commune*** Fr., *Observ. mycol.* (Havniae) 1: 103 (1815)

*Schizophyllum commune* has been reported from Kings County, Nova Scotia, on a range of hosts as early as 1881 by J. Sommers and Alexander MacKay (Gourley 1982). This is the first report for *S. commune* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected 4 m north of the gas storage building at the station; fruitbodies (43.93712N, -59.88960W) were growing on old leaf, stem, and weathered dung litter in a sandy soil with 50% cover including *R. virginiana*, *A. margaritacea*, *Juncus* sp., *A. breviligulata*, and *F. rubra*; Z. Lucas; 19966F (09-102); October 7, 2009.

## Strophariaceae

***Agrocybe pediades*** (Fr.) Fayod, *Annls Sci. Nat.*, Bot., sér. 7 9: 358 (1889)

Over a century ago, in 1880, J. Sommers and Alexander MacKay collected *A. pediades* from open spaces in Halifax and Lunenburg Counties (Gourley 1982). This species was previously reported from Sable Island from collections made in the early 1980s (Malloch 2016).

*Material examined*

1) Collected inland, on a southeast facing slope, 25 m west of Lily Pond-North; fruitbodies (43.93180N, -60.01800W) were scattered

on weathered horse dung in sandy soil with *Juncus* sp. and *A. breviligulata* nearby; J. Barkhouse and Z. Lucas; 19967F (09-034); June 22, 2009.

2) Collected on a dune north of the Old Main area; a group of five fruitbodies (43.93502N, -60.04983W) was growing in a weathered dung pile near *L. japonicus* var. *maritimus, A. millefolium, A. breviligulata*, and *P. pratensis*; J. Barkhouse and Z. Lucas; 19968F (09-053); June 24, 2009.

3) Collected northeast of Gull Pond; clustered fruitbodies (43.93357N, -59.96672W) were growing on dung in an area with 50% vegetation cover including *L. japonicus* var. *maritimus, A. millefolium, A. breviligulata*, and *P. pratensis*; J. Barkhouse and Z. Lucas; 19969F (09-069); June 27, 2009.

4) Collected on the northeast-facing slope of a north side dune; a small group of three fruitbodies (43.93562N, -59.93855W) was growing on a moist dung ball on the sand surface, in a stand of *A. breviligulata*; J. Barkhouse and Z. Lucas; 19970F (09-072); June 27, 2009.

5) Collected in an inland area near the southeast edge of Bald Major; a single fruitbody (43.93197N, -59.87233W) was growing on buried weathered dung in an area of sparse vegetation consisting of *A. margaritacea*, *S. sempervirens, A. breviligulata*, and *F. rubra*; J. Barkhouse and Z. Lucas; 19971F (09-083); June 29, 2009.

***Protostropharia semiglobata*** (Batsch) Redhead, Moncalvo & Vilgalys, in Redhead, *Index Fungorum* 15: 2 (2013)

*Protostropharia semiglobata* was collected, as *Stropharia semiglobata* (Batsch) Quél., on cow dung in Annapolis, Halifax, Colchester, Kings, Pictou, and Lunenburg Counties by Alexander MacKay in 1908 (Gourley 1982). This species was previously reported (as *S. semiglobata*) from Sable Island from collections made in the early 1980s (Malloch 2016).

*Material examined*

1) Collected just inside the station exclosure; fruitbodies (43.93377N, -60.00750W) were growing on horse dung in an area with ~50% plant cover including *R. virginiana, A. millefolium, S. novi-belgii, Juncus* sp.*, A. breviligulata, F. rubra,* and *M. stellatum*; J. Barkhouse and Z. Lucas; 19972F (09-095); June 30, 2009.

***Deconica coprophila*** (Bull.) P. Karst., *Bidr. Känn. Finl. Nat. Folk* 32: 515 (1879)

*Deconica coprophila*, according to Guzmán (1983), is uncommon in temperate regions of the world. Guzmán *et al.* (2008) report *D. coprophila*–as *Psilocybe coprophila* (Bull.) P. Kumm.–from Vancouver, British Columbia. This species was previously reported (as *P. coprophila*) from Sable Island from collections made in the early 1980s (Malloch 2016), fruiting from buried horse dung.

*Material examined*

1) Collected 5 m northwest of a small pond east of the West Light area; fruitbodies (43.93152N, -60.02135W) were growing in a pile of weathered horse dung surrounded by *Juncus* sp. and pond-edge vegetation; J. Barkhouse and Z. Lucas; 19973F (09-098); July 1, 2009.

***Deconica subcoprophila*** (Britzelm.) E. Horak, *Darwiniana* 14: 363 (1967)

*Deconica subcoprophila*–as *Psilocybe subcoprophila* (Britzelm.) Sacc.–was first reported in Canada from collections made in 2008 in British Columbia (Guzmán *et al.* 2008). Prior to this, its documented range included northern and central Europe, Greenland, southern South America and New Zealand (Guzmán 1983; Johnston & Buchanan 1995). This collection represents a new record for *D. subcoprophila* in Nova Scotia.

*Material examined*

1) Collected 30 m southeast of a small pond in the West Light area; fruitbodies (43.93118N, -60.02072W) were growing in a weathered horse dung pile in 100% vegetation cover including *T. polygamum, R. arcuans, Trifolium repens*, *S. novi-belgii, Juncus* sp., *Iris versicolor*, and *Sisyrinchium angustifolium*; J. Barkhouse and Z. Lucas; 19974F (09-099); July 1, 2009.

## Tricolomataceae

***Lepista nuda*** (Bull.) Cooke, *Handb. Brit. Fungi* 1: 192 (1871)

*Lepista nuda*–previously known as *Clitocybe nuda* (Bull.) H.E. Bigelow & A.H. Sm.–was first collected in Nova Scotia by J. Sommers in 1880's from woods and orchards in Halifax and Kings Counties (Gourley 1982). Malloch (2016) identified a related species *Lepista sordida* (Schumach.) Singer from collections he made on Sable Island in the early 1980s. This is the first report for *L. nuda* from Sable Island, and it represents a range extension for this species within the province.

*Material examined*

1) Collected inside the station exclosure; fruitbodies (43.93313N, -60.00723W) were growing in soil in an area of vegetated terrain that was mowed several times a year; Z. Lucas; 19975F (09-156); October 20, 2009.

2) Collected on the West Spit; fruitbodies (43.94703N, -60.10367W) were all attached to stems of *L. japonicus* (some stems decayed, some live) that were buried in sand with other plant litter (but no dung) in an area vegetated with *L. japonicus* var. *maritimus* and *A. breviligulata*; Z. Lucas; 19976F (09-169); October 12, 2009.

## DISCUSSION

This study identifies *Suillus luteus* as the probable mycorrhizal fungal symbiont associated with the solitary pine tree growing on Sable Island. Two new records for Nova Scotia are reported: *Deconica subcoprophila* and *Volvopluteus* aff. *gloiocephalus* (Fig 3). The findings presented here also extend the range, within Nova Scotia, of another thirteen species of Higher Fungi.

David Malloch (2016) draws attention to the almost complete absence of ECM fungi and hosts on Sable Island. Identification of *S. luteus* as the probable fungal symbiont on the one *P. sylvestris* on the island could be determined by morphotyping the ECM on the lone *P. sylvestris* and by DNA sequence comparisons between the mycelium colonizing the root tips and the fruitbody collected at the base of the *P. sylvestris*.

Malloch (2016) noted that despite “the limited number of habitats available on Sable Island, there is a fairly rich coprophilous mycota” (p. 139). Some of the coprophilous, or “dung-loving”, fungi reported here include the Basidiomycota *Panaeolus papilionaceus*, *P. semiovatus*, *P. subbalteatus* (Fig 4), *Agrocybe pediades*, *Protostropharia semiglobata*, *Deconica coprophila*, and *D. subcoprophila*. The degree of habitat specialization varies depending on the species. For example, the generalists *D. coprophila* and *D. subcoprophila* grow on the dung of animals such as horse, cattle, and sheep (Guzmán 1983), whereas *P. subbalteatus*, a specialist, grows almost exclusively on horse dung or horse dung enriched soils (Ola’h 1969).

Other species, such as *A. pediades*, are more cosmopolitan in their preferences, typically favouring fertile soils which often include manure enriched habitats (Malysheva & Kiyashko 2011).

Some species of obligate coprophilous fungi with a restricted substrate, such as *P. semiovatus*, would likely not be present on Sable Island if there were no horses. Without the ready availability of horse manure, other fungi such as *A. pediades*, a non-obligate generalist, would likely be present in significantly reduced numbers, or not at all.

Germination of the dormant, thick-walled spores of many coprophilous fungi–often found on the surface of wild fodder plants–is aided by passage through the animal digestive system, which, with its acidic, moist, and warm environment, is ideal for breaking spore dormancy (Piontelli *et al.* 1981). Piontelli *et al.* (1981) also point towards a potentially rich and unstudied aspect of the ecology of coprophilous fungi–their role in the digestive system and overall health of the animals that consume the spores. Future research could focus on these cross-Kingdom interactions.

It is important to note that while *P. subbalteatus* is included as a coprophilous fungus here, there was no observed horse dung associated with the five collections included in this paper. Also, the cap colour of these collections is somewhat atypical. Normally, *P. subbalteatus* is distinguished by a cinnamon brown to tan coloured cap with a darker-coloured ring or zone around the cap margin (Stamets 1978), whereas the collections discussed here all had uniformly dark brown caps. The zonation seems to occur as fruitbodies dehydrate (Stamets 1978). The uniformly dark cap colour of the Sable Island collections could be indicative of moist caps at the time of collection. Phylogenetic work could help to ascertain the taxonomic position of the Sable Island collections within the genus *Panaeolus*.

Two related species of *Deconica* were identified from Sable Island. One conformed to the published micro- and macro-morphological characteristics of *D. coprophila*. The other collection matched the characteristics described for *D. subcoprophila*. *D. coprophila* has already been reported from Sable Island, growing on buried horse dung (Malloch 2016). Prior to the collection of *D. subcoprophila* on Saturna Island, British Columbia, in 1984 (Guzmán *et al.* 2008), this species was thought to be restricted to northern and central Europe, Greenland, southern South America, and New Zealand (Guzmán

1983, Johnston & Buchanan 1995). The reports of *D. subcoprophila* in British Columbia and now in Nova Scotia suggests that further work is necessary to describe the geographic range of *D. subcoprophila* in Canada.

Justo *et al.* (2011) suggest that "North American collections of *V. gloiocephalus* (Fig 3) should be carefully re-examined as some may represent *V. michiganensis*" (p. 476). The basidiospores for the *Volvopluetus* collections reported here are too long (>12.5 um) to be *V. michiganensis*, and they match published descriptions of *V. gloiocephalus* except that they appear to lack hymenial cystidia (Butler 2012, Justo *et al.* 2011). Justo *et al.* (2011) describe *Volvopluteus earlei* f. *acystidiatus* as lacking cystidia but with a basidiocarp diameter (<5 cm) that is much smaller than the *V.* aff. *gloiocephalus* described here. Further molecular work with this collection and other, related, species of *Volvopluteus* could help to increase our understanding of the phylogenetic relationships within this genus. This report is the first record of *Volvopluetus* aff. *gloiocephalus* for both Nova Scotia and Sable Island.

Several lignicolous species are reported here including *Gloeophyllum sepiarium* (Fig 1), *Fomes fomentarius*, *Neolentinus lepideus*, and *Psathyrella candolleana*. The paucity of endemic woody species on Sable Island suggests that either the spores arrived with the non-native wood or were already present on Sable Island and found a suitable habitat in the driftwood. For example, based on its position and condition, the driftwood trunk on which *F. fomentarius* was collected had been on Sable for only a short time suggesting that the fungal mycelium had started colonizing the woody substrate prior to it entering the water and drifting out to Sable Island. Further studies, examining the population structure and migration patterns of Sable Island's mycota and the fungi on the adjacent mainland could contribute to our understanding of island biogeography, with special reference to Higher Fungi.

Future work will involve pursuing some of the lines of inquiry suggested above as well as developing as comprehensive a mycoflora as possible for Sable Island, with new taxa added to the species list for the island and the publication of additional information on frequency, spatial and seasonal distribution, and habitat for these and previously reported taxa.

*Acknowledgements* Janet Barkhouse provided invaluable assistance with the preliminary collection and identification of specimens reported here. We thank Gerry Forbes and staff of the Meteorological Service of Canada, ExxonMobil Canada, the Friends of the Green Horse Society, and Parks Canada for logistical support and expertise.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 327-345

# THE DISTRIBUTION AND LIFE HISTORY OF *MYSIS GASPENSIS* O.S. TATTERSALL, 1954 (CRUSTACEA, MYSIDA): AN ALMOST ENDEMIC, NEKTONIC COMPONENT OF ATLANTIC CANADA ESTUARINE AND COASTAL ECOSYSTEMS

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## ABSTRACT

Mysids (Mysida) or opossum shrimp are nektonic Crustacea found worldwide in freshwater, hypogean, coastal marine or deep-sea habitats. A poorly known, highly localized species *Mysis gaspensis* O.S. Tattersall, 1954 is found only in Atlantic Canada and Maine, USA. During spring to autumn, localized populations form aggregations at low tide in littoral estuarine environments but individuals also occur at littoral coastal sites. In boreal habitats, this mysid has a univoltine, semelparous life cycle. Beginning in March-April, juveniles are released from the female marsupium at 2.0-2.5 mm total length (TL). Growth in TL is linear ($r^2 = 0.90$), and growth in wet weight is exponential ($b = 2.96$). Females attain 14.1-16.5 mm TL and males 13.9-25.5 mm TL, by November when they begin maturation. During November-January, penultimate and ultimate males and females migrate seaward where copulation is presumed to occur. Males die after copulation. Development of young during winter results in a mixture of embryo development stages in individual female marsupia by spring. Mean brood size is 59 embryos (range 32-83). Females reoccupy estuarine habitats during March-April and release their young. Females survive after release of young and attain a maximum length of ~20.0 mm TL, but most die or are predated upon by late July. Juveniles and adults of some populations form highly visible aggregations during low tide in the shallow water of estuaries occupying sites with low velocity currents (12-41 cm/s) and near the limit of salinity (0.5-19.0). Aggregations range in size up to 38,000 individuals but the population in some estuaries is often scattered at low tide in small groups or individuals on the down-stream side of rocks or underwater structures.

Keywords: aggregations; brood size; growth; maturation; opossum shrimp; reproduction

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## INTRODUCTION

Mysids are a group of small, nektonic, shrimp-like crustaceans with more than 1000 species (Schram 1986, Audzijonyt *et al.* 2005). Approximately 90% of species are found in coastal and deep-sea habitats but others occur in freshwater lakes or hypogean environments (Dadswell 1974, Mauchline 1980, Schram 1986). Their distribution is global, and they are an important component of marine and freshwater food webs, providing nutrition for fishes, seals, and whales (Black 1958, Tyler 1972, Steinansson 1979, Mauchline 1982, Hostens & Mees 1999, Audzijonyt 2006).

Mysids are often referred to as opossum shrimp since females carry developing embryos in a brood pouch or marsupium on the underside of their thorax, which serves to protect her eggs or embryos (Mauchline 1980). Males are sexually dimorphic and when mature have elongated fourth pleopods for transfer of sperm to the female marsupium (Holmquist 1959). After sperm transfer, females release eggs into the marsupium where they are fertilized. Embryos undergo direct development inside the marsupium (Amaratunga & Corey 1979, Mauchline, 1980).

Marine mysids display well developed aggregative behavior and swarms, schools or shoals are often very visible in shallow water (Zelickman 1974, Dadswell 1975, O'Brien 1988). Juveniles and/or adults aggregate together in estuaries and coastal littoral zones around subsurface structures and/or vegetation. Aggregation sites, which are often used daily, appear to be largely in response to environmental conditions such as currents, salinity, or shade (Hulbert 1957, Steven 1961, Dadswell 1975); however, aggregation is also thought to be under intrinsic as well as extrinsic control and is possibly used as a predation defense (O'Brien 1988, Modlin 1990).

Of the three shallow-water *Mysis* species found in the boreal Northwest Atlantic (Brunel 1960, Audzijonyt & Väinölä 2007), *Mysis gaspensis* O.S Tattersall, 1954 is the least studied with few published accounts outside of brief taxonomic, distributional and life history notes (Tattersall 1954, Haefner 1968, Bousfield & Laubitz 1974, Dadswell 1975, Audzijonyt & Väinölä 2007). Known distribution of *M. gaspensis* is in estuaries and coastal habitats from Newfoundland and Quebec to Nova Scotia, New Brunswick, and Maine (Wigley & Burns 1971, Bousfield & Laubitz 1972). The physical similarities between species make mysids difficult to identify but *M. gaspensis* can be distinguished by its unique chromatophore pattern, the most recognizable being four, very large chromatophores on the telson (Tattersall 1954, Brunel 1960, Audzijonyt & Väinölä 2007). A high density of chromatophores also appears on the head, carapace, abdomen, and antennal scales making this species capable of blending into the substrate in shallow water (Fig 1).

Previous observations of *M. gaspensis* suggest it had a one- or two-year life cycle with mating occurring during winter and young released in the spring (Tattersall 1954, Dadswell 1975). The location of overwintering habitat was also in question and some authors proposed it may be at freshwater sites (Bousfield & Laubitz 1972). New observations presented here combined with those published previously should help clarify numerous aspects of the distribution, life history, and aggregation behavior of this almost Canadian endemic.

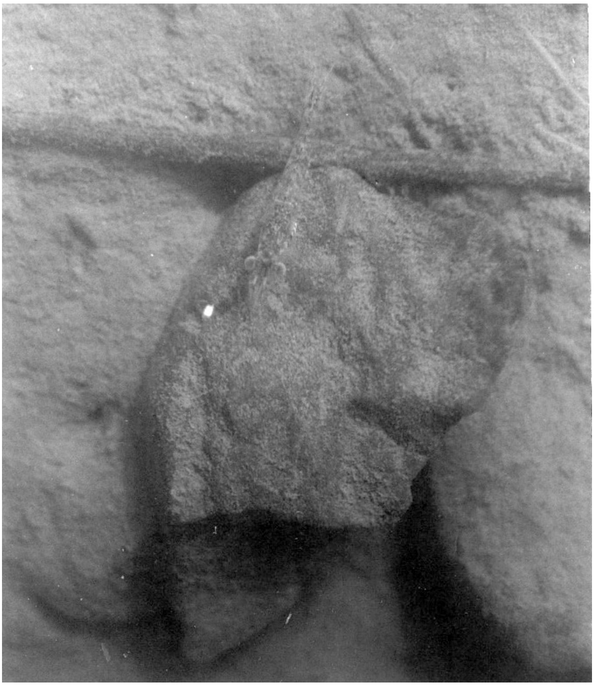

**Fig 1 An individual adult *Mysis gaspensis* in a water depth of 20 cm at the Waweig estuary during low tide. Note the density of chromatophores all over its body which serve to camouflage this mysid species.**

# DISTRIBUTION

Bousfield (1955, 1956, 1962) and Bousfield & Laubitz (1972) carried out extensive faunal surveys for littoral crustaceans that covered the coastlines of Newfoundland, the St. Lawrence estuary, the Gulf of St. Lawrence, Nova Scotia, New Brunswick, and Maine to Massachusetts. A total of 539 sites were sampled between 41° - 50°N and 53° - 71°W at which *Mysis gaspensis* was recorded in 69 locations between 44°40' - 49°35'N and 53°14' - 70°29'W (Fig 2). Haefner (1968) and Larsen & Gilfillan (2004) recorded it from three other locations in Frenchman's and Cobscook Bays, ME, all within the distribution limits previously described by Bousfield & Laubitz (1972). Other studies on mysids along the US Atlantic coast have failed to find *M. gaspensis* south of Maine (Wigley and Burns 1971).

## Further Study Sites and Collections

Specimens of *Mysis gaspensis* were collected at a further four study sites in Atlantic Canada (Fig 2): the estuaries of Deer Brook, NL (49°34'N, 57°50'W), the Kouchibouquac River, NB (46°51'N, 64°57'W), Fullers Brook, NS (45°40'N, 60°12'W), and the Waweig River, NB (45°11'N, 67°7'W). Deer Brook and the Kouchibouquac River estuaries are in the Gulf of Saint Lawrence (GSL) and characterized by warm summers, cold winters with extensive ice formation and a tidal range of 0.5-1.0 m (Bousfield 1956). Summer sea surface temperature (SST) in GSL ranged from 18-22 °C (Bousfield 1955, Dadswell 1975). The Fullers Brook and Waweig River estuaries are in the Atlantic coastal region and are characterized by cool summers, ice-free winters, and tidal ranges from 1.5-7.0 m (Bousfield 1956). Summer SST at Waweig ranged from 12-15 °C (Table 1). All study sites were brackish during May to December (0.5-19.0). The January collection site in the outer Waweig estuary was further seaward than the inner estuary site and had a salinity of 28.9. Collections from Deer Brook were from July 4-31, 1969, Kouchibouquac, June 12, 1978, Fullers Brook, September 9, 2012, and the Waweig River from April 16- December 8, 1982, January 24-June 5, 1984, May 4-October 11, 2009, and April 15-18, 2010. A total of 2485 mysids were collected from Deer Brook, one from Kouchibouquac, 14 from Fullers Brook, and 1042 from the Waweig estuary (Table 1).

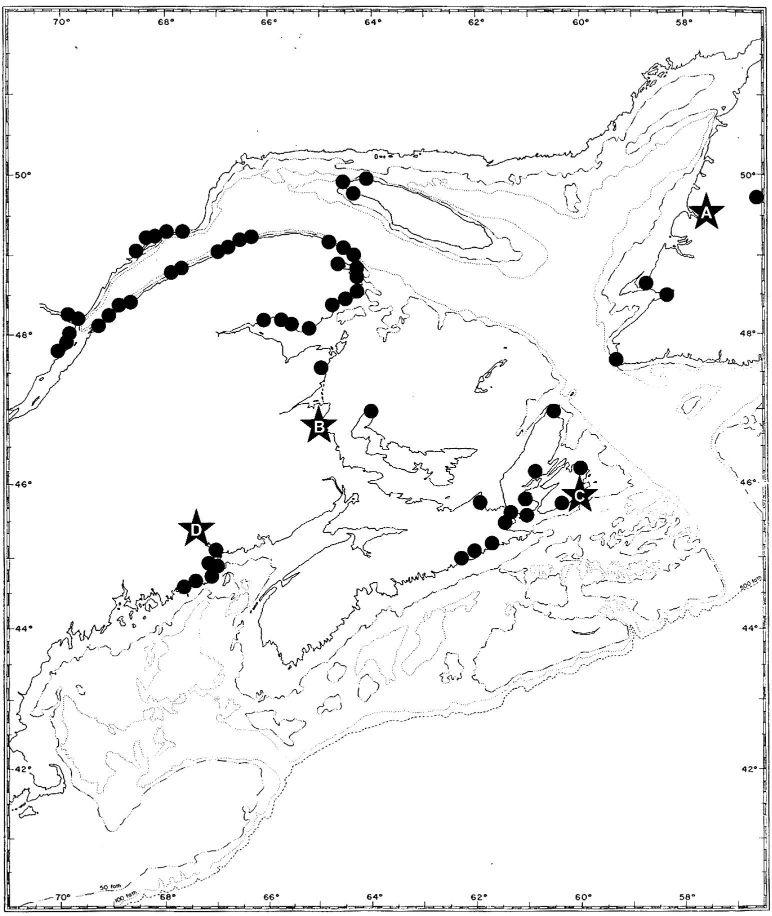

**Fig 2** **Known distribution of *Mysis gaspensis* in Atlantic Canada and the US (black dots, after Haefner 1968; Bousfield & Laubitz 1972 Larsen & Gilfillen 2004). Stars indicate further collection sites from this study at (A), Deer Brook estuary, NL, (B), Kouchibouquac estuary, NB, (C), Fullers Brook estuary, NS, and (D), the Waweig River estuary, NB. Locations in the US are from Cobscook Bay, south to Machiasport, Maine, just over the Canada-US border. Additional records not indicated in Newfoundland are one each centrally on either side of the Burin Peninsula, and three sites along the southern coast of the Avalon Peninsula (Bousfield & Laubitz 1972).**

The gap in the distribution of *Mysis gaspesis* apparent in the inner Bay of Fundy (iBoF) and south-west Nova Scotia (SWNS) appears to be a reality and not an artifact of collecting (Fig 2). Bousfield (1962) occupied 26 stations along the coast of iBoF and 20 sites in coastal

**Table 1** **Collection dates (D/M/Y), sea surface temperature (SST), salinity (S), current speed (CS), sample size (SS), mean carapace length (CL), mean total length (TL), mean weight (W), and female proportion (%) of *Mysis gaspensis* from the Waweig River estuary, New Brunswick. All samples were collected near the upstream limit of salinity at low tide except the collection on January 24, 1984, which was taken at low tide where the Waweig estuary opens into Passamaquoddy Bay.**

| D/M/Y | SST °C | S | CS (cm/sec) | SS # | Mean CL (mm) | Mean TL (mm) | Mean W (g) |
|---|---|---|---|---|---|---|---|
| 5/5/09 | 12.5 | 1.9 | 24.3 | 155 | 2.21 | 6.53 | 0.002 |
| 27/5/09 | 13.0 | 0.7 | 18.5 | 130 | 2.66 | 8.56 | 0.003 |
| 22/6/09 | 14.0 | 4.1 | 19.6 | 135 | 3.15 | 10.30 | 0.004 |
| 18/7/09 | 15.0 | 18.0 | 35.1 | 98 | 3.45 | 10.52 | 0.009 |
| 15/8/09 | 14.5 | 15.5 | 36.2 | 45 | 3.52 | 11.71 | 0.010 |
| 30/8/09 | 15.5 | 19.0 | 25.0 | 76 | 3.53 | 11.56 | 0.013 |
| 7/9/09 | 15.0 | 16.0 | 32.3 | 58 | 4.33 | 11.31 | 0.012 |
| 11/10/09 | 10.5 | 2.8 | 20.7 | 44 | 5.60 | 13.49 | 0.027 |
| 12/11/82 | 5.0 | 1.6 | 22.5 | 94 | 5.69 | 15.24 | 0.030 |
| 8/12/82 | 3.5 | 10.0 | 20.4 | 111 | 5.46 | 15.35 | 0.037 |
| 24/1/84 | 0.5 | 28.9 | 10.1 | 13 | 5.42 | 16.60 | 0.047 |
| 12/4/82 | 8.0 | 10.2 | 24.0 | 35 | 5.40 | 15.27 | 0.040 |
| 15/4/10 | 9.5 | 8.4 | 22.3 | 21 | 5.89 | 18.55 | 0.044 |
| 4/5/09 | 11.5 | 2.5 | 26.8 | 25 | 6.02 | 19.25 | 0.055 |
| 18/5/09 | 12.0 | 1.7 | 18.5 | 27 | 5.88 | 19.14 | 0.049 |

SWNS without encountering *M. gaspensis*. Additionally, 17 sites in iBoF were sampled with small mesh haul seines (5.0 mm; Dadswell *et al.* 1984) and directed efforts to capture *M. gaspensis* in the Martin's and Gold River estuaries and around the shores of Mahone Bay in SWNS were unsuccessful (Dadswell, unpublished data).

## LIFE HISTORY

### Sampling and Analysis of Further Study Sites

Sea surface temperature and salinity were obtained with a YSI temperature-salinity meter accurate to 0.5 °C calibrated each sampling day with a mercury thermometer. Current velocity was estimated by timing the float of a ping-pong ball over a distance of 5 or 10 m depending on the site (mean of three replicates).

Mysids were captured with a scoop net 0.5 m wide with 1.0 mm mesh. Specimens were fixed with 10% formalin in seawater at the collection site and transferred to 70% ethanol in the laboratory within two days. Gravid females were isolated in individual vials when the specimens were transferred to ethanol.

Specimens were measured under a dissecting microscope to the nearest 0.01 mm using an ocular micrometer. Carapace length was measured from the base of the eyestalk to the posterior lateral edge of the carapace, while total length was measured from the base of the eyestalk to the end of the telson. Individual weights were obtained with a Mettler balance accurate to 0.001 g. Individuals were sexed, when possible, males distinguished by an elongated fourth pleopod and females by the presence of a marsupium. All individuals without distinguishable sex characteristics were considered juveniles.

Male maturity stages of mysids are determined by the length of the fourth pleopod (Holmquist 1959). In Stage 1 of maturing males the exopod of the fourth pleopod extends only to the middle of the last abdominal segment and the last exopod segment is uniramous (Tattersall 1954). In Stage 2 or penultimate males the fourth pleopod extends to the end of the abdomen and the last segment of the exopod becomes biramous (Fig 3). In Stage 3 or ultimate males the fourth pleopod extends to the tip of the telson and the biramous last segment of the exopod becomes further elongated and filamentous (Fig 3, Holmquist 1959).

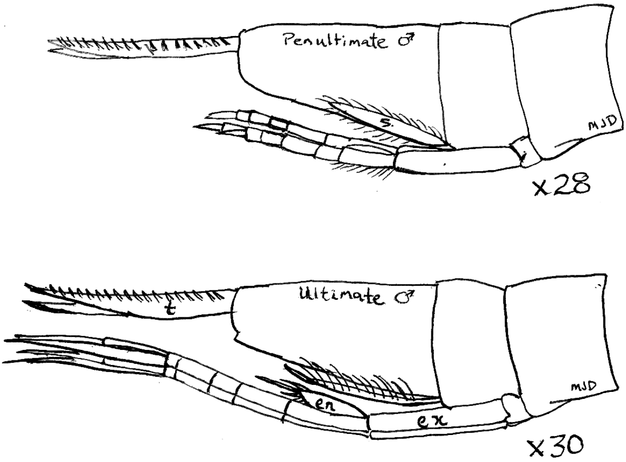

**Fig 3** **The posterior portion of the abdomen in maturing (upper, penultimate), and mature (lower, ultimate), male *Mysis gaspensis*. The uropod's have been removed to display the relationship between the male fourth pleopod (ex) and the telson (t). Other notations are fifth pleopod or swimmeret (s) and endopod of fourth pleopod (en). Specimens were collected from the Waweig estuary.**

Female maturity is determined by the length of the oostegites plates in the marsupium (Holmquist 1959, Amaratunga & Corey 1979). In stage 1 females the oostegites extend only to the base of the fifth swimming legs. In Stage 2 or penultimate females the oostegites extend half the length of the thorax and in Stage 3 or ultimate females the marsupium occupies the entire underside of the thorax.

Eggs and embryos developing inside the female marsupium were staged according to Mauchline (1980), where eggs range between 0.5-0.7 mm in diameter, Stage I embryos are 0.5-1.0 mm TL, Stage II or eyed embryos, 1.5-2.0 mm TL, and Stage III or eyestalk embryos, 2.0-2.5 mm TL. Eggs and embryos were removed from individual female marsupia and counted, measured, and staged at X250 magnification.

## Summary of Life History Characteristics

During April-November *Mysis gaspensis* populations were largely found in shallow water (0.2-2.0 m), low salinity (0.5-19.0), and low current velocity (12-41 cm/s) estuarine sites that were occupied daily by aggregations or individuals at low tide (Table 1, Dadswell 1975). During high tide mysids dispersed throughout their respective estuaries in higher salinities and became difficult to observe or collect. Individuals of *M. gaspensis* have also been routinely captured during all tide stages at higher salinity sites (29.0-32.0) throughout their range in Atlantic Canada and the US (Tattersall 1954, Heafner 1968, Bousfield & Laubitz 1972).

During November-December estuarine populations migrated seaward to outer estuary or coastal littoral sites with salinities in the range of 28.9-30.0 (Table 1, Heafner 1968). At the low salinity site in the inner Waweig estuary Stage 1, immature males represented 33.4% of the population in November but declined to 6.3% penultimate males during December (Table 2). Heafner (1968) collected only males at a coastal beach in Maine on November 10, 1966. These data suggest maturing males migrated seaward first. When efforts to capture ultimate males were extended seaward at the Waweig estuary during January 1984, collections from a site with salinity of 28.9 at low tide contained 38.5% males (Table 1). No males were captured in samples from the inner Waweig estuary during April and May probably because the adult male mysids die soon after copulation (Mauchline, 1960, Amaratunga & Corey 1975, Astthorsson 1990). Females with broods reoccupied the inner

**Table 2** **Collection date (D/M/Y), sample proportion of females and males (%), mean total length (TL), TL range, and mean weight (W) of adult *Mysis gaspensis* collected in the Waweig estuary, New Brunswick. Weight of females with broods was determined after embryos were removed.**

| Date D/M/Y | Gender of Specimens | Sample (%) | Mean TL (mm) | TL Range (mm) | Mean W (g) |
|---|---|---|---|---|---|
| 12/11/82 | Females[a] | 66.6 | 15.22 | 14.1-16.5 | 0.035 |
| | Males[a] | 33.4 | 15.25 | 13.9-17.2 | 0.026 |
| 8/12/82 | Penultimate Females[b] | 93.7 | 15.48 | 14.5-16.7 | 0.039 |
| | Penultimate Males[b] | 6.3 | 15.00 | 13.6-15.4 | 0.029 |
| 24/1/84 | Ultimate Females[c] | 61.5 | 16.19 | 15.1-17.5 | 0.051 |
| | Ultimate Males[c] | 38.5 | 17.01 | 16.3-18.1 | 0.037 |
| 12/4/82 | Females[d] with broods | 100 | 15.27 | 13.9-16.5 | 0.040 |
| 15/4/10 | Spent Females[e] | 100 | 18.55 | 14.3-20.1 | 0.044 |
| 4/5/09 | Spent Females[e] | 100 | 19.25 | 15.5-19.4 | 0.055 |

[a] All females with Stage 1, marsupia oostegites; all males with Stage 1, fourth pleopod.

[b] All females with Stage 2, marsupia oostegites; all males with Stage 2, fourth pleopod.

[c] All females with Stage 3, marsupia oostegites; all males with Stage 3, fourth pleopod, females with eggs

[d] females with broods were 87% of total; with Stage II embryos, 80.6%, Stage III, 29.4%.

[e] females without eggs or embryos in marsupia.

Waweig estuary during late winter and juveniles release occurred either in March or April.

## Growth

Stage III, eye-stalk embryos in female marsupia of *Mysis gaspensis* from the Waweig estuary during early April ranged from 2.0-2.5 mm TL. The first free-swimming juveniles captured on May 5 from the Waweig estuary had a mean length of 6.53 mm TL (Table 1). Overall growth in total length of the Waweig population was linear (Fig 4; $r^2 = 0.90$) but the increase in wet weight was exponential ($b = 2.96$; Table 1). By October mean length and weight of juveniles was 13.49 mm TL and 0.027 g (Table 1). Growth of juvenile TL averaged 0.04 mm/d. In the Deer Brook estuary mean TL of juveniles was 8.6 mm during early July compared to 10.52 mm TL during July in the Waweig estuary. Juvenile growth in TL at the Deer Brook estuary during July was also linear and averaged 0.14 mm/d (Dadswell 1975).

Maturation began during November in the Waweig estuary when the first juveniles with discernible sex characteristics were captured. Mean TL of the population in November was 15.24 mm and mean weight was 0.030 g (Table 1). All males and females

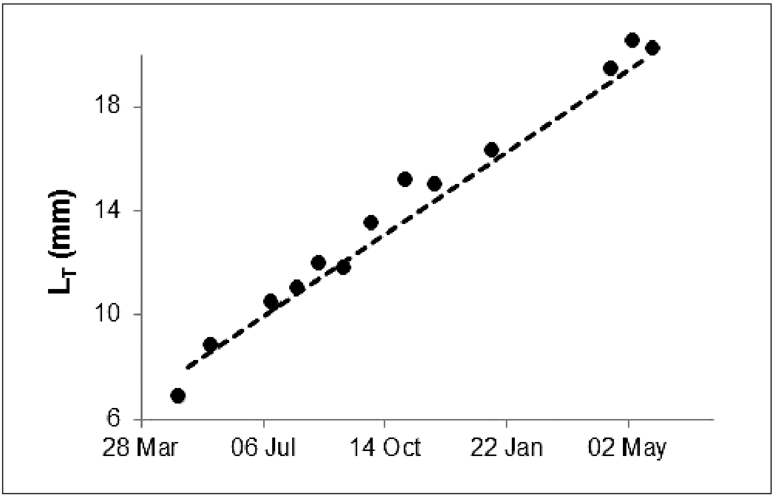

**Fig 4** **Growth in mean total length (mm) over 12 months (April to following May) of the *Mysis gaspensis* population in the Waweig estuary, NB (dotted line, r2 = 0.90).**

during November were in Stage 1 of maturation (Table 2, Tattersall 1954, Holmquist 1959). Males and females molted into penultimate, Stage 2 adults during December (Fig 3). Only ultimate, Stage 3 males and females were captured in late January at the outer Waweig estuary by which time mean TL of sampled individuals was 16.60 mm and mean weight was 0.047 g (Table 1). Penultimate and ultimate females were significantly heavier than males (Table 2; t-test, $p<0.05$). Brooding and spent females captured during April and May at the inner Waweig estuary ranged from 13.9-20.1 mm TL (Table 2). Mean daily growth of maturing adults was 0.03 mm. Mature females were not captured in the Waweig estuary after July. Large females (18.6-20.0 mm TL), that were collected at Deer Brook, NL during late July, were survivors from the previous year's cohort (Dadswell 1975). They had Stage 2 oostegites and may have lived long enough to reproduce. All *M. gaspensis* captured at Kouchibouquac and Fullers Brook were juveniles.

## Reproduction

Brooding females were collected twice in the Waweig estuary, on January 24, 1984, and April 12, 1982 (Table 2). Collections at Waweig on May 4, 2009, and April 15, 2010 consisted of females with empty marsupia. Five of eight females collected on

January 24, 1984, contained only eggs in their marsupia. Mean egg number was 72 (range 33-98). Individual brooding females captured on April 12, 1982, contained a mixture of Stage II (80.6% of females) and Stage III embryos (29.4% of females) in their marsupia. Most females contained either one embryo stage or the other, but some contained both stages. Mean brood size was 59 embryos (range 32-83). Large females (18.5-20.0 mm TL) collected at Deer Brook, NL during July, contained no eggs or embryos.

## Aggregation Behavior

Aggregation behavior was observed at three sites: Deer Brook estuary, Fullers Brook estuary, and the Waweig estuary. Juvenile and adult *Mysis gaspensis* aggregated in either ribbon-like or globular forms.

At Deer Brook, the aggregation that formed at low tide in shallow water (20 cm deep) along the bank of the estuary was approximately 200 m long, 0.1-0.5 m wide, and was estimated to contain 38,000 individuals (Dadswell 1975). At low tide, current velocities in the aggregation site varied from 12-40 cm/s and salinity from 1.4-4.0. The substrate in the aggregation site consisted of sand and small pebbles. Mysids oriented in response to the current with their heads pointing upstream.

At Fullers Brook *M. gaspensis* formed a globular aggregation at low tide just downstream of a bridge abutment surrounded by large boulders. Current velocity was low (10 cm/s) and salinity moderate (18.0). An accurate estimate of mysid abundance was not possible because the water depth was 1-2 m, and the mysids would flee rapidly to deeper water when capture attempts were made. Abundance estimates obtained by counting the mysids while on the bridge above them suggested there were 100-200 individuals in the aggregation. In the slow current at Fullers Brook mysids were less oriented upstream but rather swam back and forth within the aggregation.

At the inner Waweig estuary *M. gaspensis* formed small globular aggregations behind large rocks at the tidal, low-water point, orienting head-first upstream against currents of 19.6-36.2 cm/s and in salinities of 0.7-19.0 (Fig 5, Table 1). Aggregations typically contained 20-40 individuals (visual counts) and were spread out over 200 m of the habitat. Also, at this location single mysids were observed downstream of smaller rocks and were oriented with

**Fig 5** **Low tide collection site at the inner Waweig estuary during the lowest water period when individuals or aggregations of *Mysis gaspensis* stationed themselves downstream of rocks.**

head upstream or resting on bottom with no specific orientation (Fig 1). No estimates of the total population were attempted because the bottom substrate was mud and rock and difficult to negotiate. Once the population migrated seaward in late autumn-early winter they were widely dispersed in the lower estuary and coastal habitat, and difficult to observe or capture.

## COMPARISON OF *MYSIS* LIFE HISTORIES

The life history of *Mysis gaspensis* is remarkably similar to other *Mysis* species found in the arctic, subarctic and boreal North Atlantic and whose life histories have been described (*Mysis mixta* Lilleborg, 1852; *Mysis nordenskioldi* Audzjonyte & Väinölä, 2007 {as *M. litoralis*}; *Mysis oculata* (Fabricius, 1780); *Mysis relicta* Lovén, 1862; *Mysis stenolepis* S. I. Smith, 1873). All species have a life history where females release young in late winter or early spring, juveniles grow to maturity during summer to autumn, the sexes copulate during early winter after which the males die, the embryos develop in female marsupia until release, and females live a few more months until they disappear, probably because of predation

(Grabe & Hatch 1972, Amaratunga & Corey 1975, Ladurantaye & Lacroix 1980, Salemaa *et al.* 1986, Astthorsson 1990, Rudstrom & Hansson 1990). Only at a 240 m deep site off Newfoundland where a population of *M. mixta* lives year around in temperatures of <0 °C does the life history differ by becoming a two-year life cycle, probably because of temperature effect on growth rate (Richoux *et al.* 2004).

The *Mysis* clade in the boreal Northwest Atlantic, which is based on morphological and molecular data (*M. mixta, M. stenolepis,* and *M. gaspensis,* Audzjonyte *et al.* 2005, Audzjonyte & Väinölä 2007, Audzjonyte *et al.* 2012), forms a distributional gradient from high salinity marine environments to low salinity estuarine habitats similar to the *Mysis* species clade occurring in the arctic (*M. oculata, M. nordenskioldi* {formerly as *M. litoralis*}, and *M. relicta,* Holmquist 1959). In offshore and shallow coastal, high salinity habitats *M. mixta* and *M. stenolepis* are the dominant species (Grabe & Hatch 1972, Amaratunga & Corey 1975, Richoux *et al.* 2005). Dormaar & Corey (1973) demonstrated that *M. stenolepis* is almost an osmoconformer, regulating its internal hemolymph between 1.5-2.5 salinity. It did not survive in salinities below 0.5. On the other hand, *M. relicta* which occurs in low salinity environments in the arctic (Holmquist 1959, Salemaa *et al.* 1986) like those frequented by *M. gaspensis* along the northwest Atlantic coast, is a homeoiosmatic hyperosmoregulator at low salinities maintaining their hemolymph at 1.5-2.2 (Belyayev 1949, Dormaar & Corey 1978). To date, no osmoregulation studies have been carried out with *M. gaspensis* but its osmoregulatory abilities are probably similar to *M. relicta* since it frequents and can survive in salinities as low as 0.05 (Dadswell 1975).

Growth characteristics of *Mysis gaspensis* are also similar to other shallow-water *Mysis* species from the North Atlantic although individuals attained a smaller adult size and grew somewhat slower. At the inner Waweig estuary, young *M. gaspensis* were released from marsupia in March or April when they are 2.0-2.5 mm TL and grew at a daily rate of 0.03-0.04 mm TL until they matured the following January at a of size of 15.1-18.1 mm TL. Maximum size collected was 20.1 mm TL. At coastal habitats off Iceland, *M. oculata* were released during April and grew at a rate of 0.05-0.08 mm/d until they matured at 18.7-20.9 mm TL during January

(Astthorsson 1990). In Passamaquoddy Bay, female *M. stenolepis* released young during April-May at 2.0-2.5 mm TL which then grew at a rate of 0.06 mm/d to a maximum size of 6.82-7.39 mm CL (25.3-26.0 mm TL) when they matured in January and February (Wigley & Burns 1971, Amaratunga & Corey 1975, 1979). At the inner Baltic Sea and off eastern Maine, *M. mixta* juveniles were released during April at 2.0-2.5 mm TL and grew at a rate of 0.05 mm/d to a maximum of 22.0-25.0 mm TL by the following January when they matured (Wigley & Burns 1971, Grabe & Hatch 1972, Rudstrom & Hansson 1990). In the Saguenay fjord, Quebec, *M. nordenskioldi* females released young during April-May which grew from 3.8 mm TL to 15.0 mm TL by September, a rate of 0.06 mm/d (Ladurantaye & Lacroix 1980). Mature individuals of *M. nordenskioldi* range from 22-29 mm TL (Audzjonyte & Väinölä 2007). Greater mean daily growth of *M. gaspensis* in the Deer Brook estuary (0.14 mm/d) compared to the Waweig estuary (0.04 mm/d) during July was probably the result of higher temperatures (18 °C vs 15 °C) at the former location (Dadswell *et al.* 1975).

Reproduction in *Mysis gaspensis* conforms to the univoltine, semelparous reproductive cycle common to other North Atlantic *Mysis* species. Juveniles begin maturation in autumn and proceed through penultimate and ultimate molts to sexual maturity during January. Like *M. stenolepis*, *M. gaspensis* adults migrate to more oceanic sites with higher salinity for copulation and males died soon after (Haefner 1968, Amaratunga & Corey 1975, Mauchline 1980). Female *M. gaspensis* brood an average of 59 young which is similar to the brood size of both *M. mixta* (mean 60; Grabe & Hatch 1972) and *M. oculata* (mean 52; Astthorsson 1990) but only about a third the number carried by *M. stenolepis* females (mean 157; Amaratunga & Corey 1975). Broods of *M. gaspensis* developed over a period of approximately 110-120 days from eggs during January to Stage II and Stage III embryos by April with release of free-swimming young during late March to mid-April. The development duration for embryos was similar to that found for both *M. stenolepis* (Amaratunga & Corey 1979) and *M. oculata* (Astthorsson 1990).

Females survive after the release of young but whether any live to reproduce a second time is unknown. Like other females in populations of North Atlantic *Mysis* species, none were encountered after July (Grabe & Hatch 1972, Amaratunga & Corey 1975, Astthorsson

1990). The univoltine, semelparous life cycle appears to be dominant among North Atlantic *Mysis*.

Aggregation during low tide is well developed among *Mysis gaspensis* populations. Studies to date suggest these aggregations are largely in response to environmental stimuli probably including current direction and velocity, and salinity. Formation of aggregations is well-known among other mysids, but researchers disagree about whether these are schools, swarms or shoals, the latter definition implying social interaction (Steven 1961, Zelickman 1974, O'Brien 1988, Modlin 1990). Among species of *Mysis* in the boreal North Atlantic only *M. gaspensis* is known to form aggregations in the environment at consistent locations (Dadswell 1975, this study). Amaratunga & Corey (1975) describe *M. stenolepis* forming small groups around seaweed fronds but there were no consistent groupings or orientation. Prouse (1986) observed that *M. stenolepis* occurred pelagically in Cumberland Basin, iBoF but sampling results appeared to indicate no aggregation behavior. Dadswell (unpublished data) has observed swarms/shoals of many thousands of newly released juveniles of *M. mixta* (4.0 mm TL) around large filamentous macroalgae at a depth of 15 m in Mahone Bay, NS during late March. Astthorsson (1990) makes no mention of *M. oculata* forming aggregations in coastal habitat at Iceland, but Holmquist (1959) reported an aggregation of this species numbering in the thousands, in a depth of 0.5-1.0 m at the harbor of Hunds Ejland, Greenland. Whether these aggregations are true shoals awaits further research.

## COMMENTS ON FURTHER RESEARCH

Further research on the distribution, biology, and physiology of *Mysis gaspensis* is needed. The species range probably extends north of latitude 50N in Quebec, Newfoundland, and Labrador. There are undoubtedly more populations in Atlantic Canada that form aggregations at low tide and their occurrence begs locating. We know nothing about the feeding and diet of *M. gaspensis*. Other *Mysis* species are known to feed on detritus, zooplankton, and each other (Pavlyulin & Kovalchuk 1982, Griffin *et al*. 2020) and *M. stenolepis* can digest cellulose obtained from feeding on macroalgae detritus (Foulds & Mann 1978). At the aggregation sites in estuaries investigated in this study few other organisms accompanied *M. gaspensis.* The amphipods *Gammarus oceanicus* Segerstråle, 1947 and *Gammarus lawrencianus* Bousfield, 1956 were found at Deer Brook, *Gammarus setosus* Dementieva, 1931 in the Waweig estuary, and the mysid, *Neomysis americana* S. I. Smith, 1873 at the Kouchibouquac site. Further studies on the life history are also needed, including the survival duration of males during winter, better information on the timing for release of young, and whether mature females survive long enough to reproduce a second time.

*Acknowledgements* Justine Barry, Tina Moore, Leslie Linkletter, Daphne Themelis, and Gary Melvin assisted with the collection of samples and analysis of biological characteristics of specimens. Aaron Spares prepared figures. The late Edward Bousfield and Charlotte Holmquist stimulated my interest in the taxonomy, distribution, and life history of mysids.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 347-363

# PARASITISM OF BROOK TROUT (*SALVELINUS FONTINALIS*) DURING THE FIRST MONTH POST-EMERGENCE IN STREAMS IN SOUTHWEST NOVA SCOTIA

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## ABSTRACT

Parasite recruitment of recently emerged fry of brook trout (*Salvelinus fontinalis*) in three streams in southwestern Nova Scotia was documented. In early April, fry appeared to leave the protective gravel redds parasite free but began acquiring parasites within the next 2-4 weeks, with prevalence of infections of any given species reaching 21 to 46% by mid-May. The initial infections involved 1) directly transmitted ectoparasites *Gyrodactylus colemanensis* and *Salmincola edwardsii* and 2) food-borne endoparasites (*Echinorhynchus lateralis* and *Crepidostomum* sp.). Colonizing parasites found in the first month post-emergence varied by locality: at Bangor Creek, it involved *G. colemanensis*, *E. lateralis*, and *Crepidostomum* sp., while at Germaine East, it involved only *G. colemanensis* and at Germaine North, only *S. edwardsii.* In each case, the initial colonizers reflected what was abundant locally and within a regional pool of 10 parasite species. Localized skin thickening and sometimes tissue erosion were evident at sites of attachment of *S. edwardsii*. Minor disruption of fin margins was seen with *G. colemanensis*. No pathology was associated with *E. lateralis* nor *Crepidostomum* sp. The predictable timing of emergence and ease of sampling fry of *S. fontinalis* near redds represents a convenient system with which to assess impact of initial parasitism on fish recruitment at the local level.

Keywords: *Echinorhynchus, Gyrodactylus*, initial parasite colonization, regional parasite pool, *Salmincola*

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## INTRODUCTION

Studies on initial parasitism of fishes have included young hosts (larvae, fry, young-of-the-year) in freshwater lakes and streams (Poulin *et al.* 2012, Behrmann-Godel 2013, Markle *et al.* 2014), estuaries (Sirois and Dodson 2000, Bourque *et al.* 2006) and marine seas and reefs (Rybkina *et al.* 2016, Jahnsen-Guzmán *et al.* 2018, Landaeta *et al.* 2020). Metazoan parasites reported in these studies include directly transmitted monogenean and arthropod ectoparasites as well as food-borne digeneans, cestodes and nematodes, some (or closely related species) of which are known to cause mortalities in host fish held in captivity or at fish farms (Schäperclaus 1991, Woo 1995, Hoffman 1999**.** In a review of the impact of parasites on young, small-bodied fish, Muñoz *et al.* (2015) concluded that there are three general, not mutually exclusive, impacts: 1) alteration of nutritional budgets; 2) energetic cost of tissue repair and immunological response to invasion; and 3) mechanical disruption and overall reduction in physiological efficiency on such fundamental issues as swimming performance.

We documented parasites of brook trout (*Salvelinus fontinalis*) fry within a month post-emergence from gravel redds in three streams in southwestern Nova Scotia and added this host to the study of early parasitism in fish. Brook trout spawn in late October to mid-November, with embryos developing over winter in the protective redd and relying solely on yolk as the energy source (Curry *et al.* 1991). In April, developed alevins emerge from the redd and become active daytime feeders, now called fry, 1-2 days post-emergence (2.0-2.7 cm long), preying on drifting invertebrates made up mostly of invertebrates and aquatic insect larvae (Allen 1981, Williams 1981, McLaughlin *et al.* 1994). The period of highest mortality for fry is during the first months post-emergence (Grant 1990, Curry *et al.* 1995**.** It is known that by the end of the first summer of life, the young cohort of brook trout are exposed to most species of parasites present in older fish in the same streams (Muzzall 2008). We do not know exactly, however, when fry first start acquiring these parasites after they leave the protection of the redd and whether impacts identified by Muñoz *et al.* (2015) contribute to the period of high fry mortality.

# METHODS

Trout fry were sampled by electrofishing in early spring of 2012 at spawning beds in three shallow streams within two river drainages in southwest Nova Scotia: 1) Germaine watershed (Germaine North 44°14.356'N, 66°7.611'W; Germaine East 44°14.039'N, 66°7.256'W, and 2) the Meteghan River watershed (Bangor Creek 44°12.899'N, 66°5.565'W) (Fig 1). The streams are alike in drainage area: the Bangor tributary is 1.7 km$^2$, Germaine East Branch 1.6 km$^2$ and Germaine North Branch 1.3 km$^2$. Both watersheds are situated on shallow Goldenville group bedrock formations with low potential to generate acid rock drainage (White *et al.* 2014). This is seen in the Bangor tributary, Germaine East Branch and North Branch having a mean pH of 6.2, 6.3 and 6.8, respectively (R. LeBlanc, unpublished).

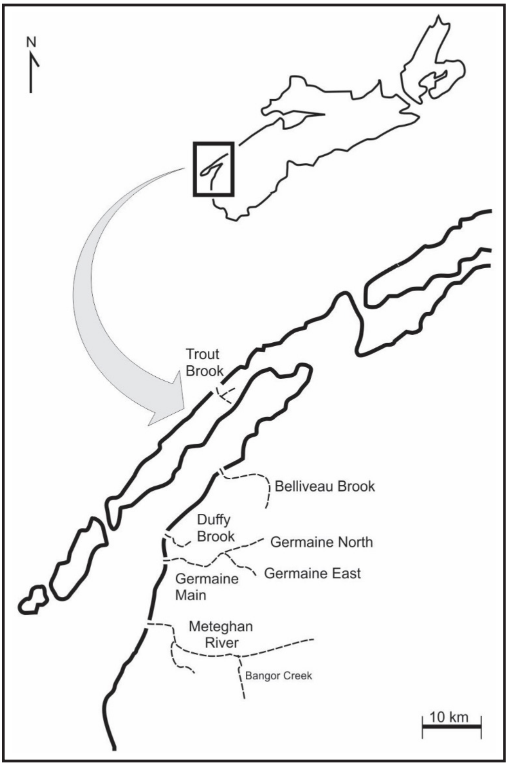

**Fig 1 Map showing localities in southwestern Nova Scotia from which brook trout (*Salvelinus fontinalis*) were sampled.**

The watersheds can be categorized as Class A systems where the mean summer temperature is ≤ 16.5 °C due to ground-water influx (MacMillan *et al.* 2008). Brook trout spawning in such streams (Fig 2) typically occurs in late October to mid-November and emergence in early April (Scott and Crossman 1973).

A total of 106 recently emerged fry were sampled by electrofishing along a 50 m stretch at each study site from April 14 to May 15, 2012. Shocked fish were euthanized in MS222 (about 250 mg/L) and fixed individually with 5% formalin in Falcon tubes. At necropsy, total length (cm) and weight (g) were recorded for each fish. All organs, along with the vial contents, were examined microscopically for parasites. Representative samples of parasites were examined in glycerine wet mounts to confirm identification using relevant taxonomic keys (Beverley-Burton 1984, Kabata 1988, Arai 1989, Gibson 1996). The data set includes prevalence and intensity data on gyrodactylids previously reported by Leblanc *et al.* (2013) in a study estimating standing crop of gyrodactylids on all ages of trout in Bangor Creek. Use of terms prevalence (number of fish infected/number of fish examined expressed as percent) and mean intensity (mean number of parasites/infected fish) follow Bush *et al.* (1997) and considered recommendations of Rózsa *et al.* (2000) on descriptive statistics for parasite populations.

The regional parasite species pool was determined from necropsy of an additional 537 brook trout of all ages (0+ and >1+) sampled

**Fig 2 Bangor Creek in the fall of 2020 showing a young adult brook trout (*Salvelinus fontinalis*) on a spawning bed. The gravel redd is in the upper right corner. The trout was approximately 10 cm long.**

throughout the late spring and summer of 2011-2014 by electrofishing and angling at the sampling sites and three additional watersheds nearby; Duffy Brook (44°14.972'N, 66°7.611'W), Belliveau Brook (44°22.430'N; 66°3.715'W) and Trout Brook (44°32.726'N, 66°1.480'W (Fig 1). Fish were placed immediately in Ziploc bags, iced and frozen later in the day. Thawed fish were processed as described above for recently emerged fry. The regional pool includes the parasites of the 106 recently emerged fry. All samples were obtained under a Department of Fisheries and Oceans Collecting Permit (Fir 7-000140-07) for 2011 with annual renewal.

## RESULTS

The regional pool of brook trout parasites in southwestern Nova Scotia consisted of 10 species, including two monogeneans, two digeneans, one cestode, two nematodes, one acanthocephalan, one copepod, and mixed infections of the ciliates *Apiosoma/Trichodina* (Table 1). One species, *Gyrodactylus colemanensis* (Monogenea), occurred at all five sampling watersheds, with *Echinorhynchus lateralis* (Acanthocephala) occurring at four of five, and *S. edwardsii* (Copepoda) and *Crepidostomum* sp. (Digenea) occurring at three (Table 1).

Necropsy of the 106 trout fry at Bangor Creek, Germaine East, and Germaine North within an estimated first month post-emergence revealed four of the 10 regional species: the directly transmitted ectoparasites *G. colemanensis* and *S. edwardsii* and the food-borne endoparasites *E. lateralis* and *Crepidostomum* sp. (Table 2).

Fry were not encountered at the sites on April 1, 2012. They were first collected on April 14 and 15, having emerged sometime during the previous two weeks. Initially sampled fry rarely had parasites (1 of 32), compared to 24 of 56 sampled on May 7 and 15 (Table 2). Twenty-eight of the 30 infected fish had single species infections; two had mixed infections of *E. lateralis* and *Crepidostomum* sp.

At Bangor Creek on April 15, two weeks or less post-emergence, a single fry had an immature *E. lateralis* (Table 2). On April 30, immature specimens of *Crepidostomum* sp. were found and on May 15, *G. colemanensis* was present (Table 2). At Germaine North on May 7, the initial parasite was *S. edwardsii,* while at Germaine East it was *G. colemanensis* (Table 2).

**Table 1** **Summary statistics of parasite infections in brook trout (*Salvelinus fontinalis*) from the Bangor, Germaine, Duffy, Belliveau, and Trout Brook watersheds in southwestern Nova Scotia collected spring, summer and fall of 2011-2014 to establish makeup of the regional pool of trout parasites. Prevalence, mean intensity, and intensity range in parentheses are presented for 0+ and ≥1 year old cohorts as well as regional totals (SW Nova Scotia).**

| **Parasite** | **Site in Host** | **Bangor** | | **Germaine** | | **Duffy** | **Belliveau** | | **Trout Brook** | | **SW Nova** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Age of fish cohort** | | 0+ | ≥1+ | 0+ | ≥1+ | 0+ | 0+ | ≥1+ | 0+ | ≥1+ | |
| **Sample size (N)** | | 148 | 37 | 77 | 22 | 37 | 58 | 9 | 123 | 132 | 643 |
| **Protozoa** | | | | | | | | | | | |
| *Apiosoma/Trichodina* | gills, skin | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 |
| **Monogenea** | | | | | | | | | | | |
| *Gyrodactylus colemanensis* Mizelle and Kritsky, 1967 | fins | 39.8<br>8.5 (1-44) | 54<br>9.8 (1-35) | 7.8<br>2.0 (1-3) | 4.5<br>4 (4) | 21.6<br>2 (1-7) | 12.0<br>6.4 (1-17) | 55<br>6.4 (3-13) | 5.6<br>1.5 (1-3) | 19.6<br>3.6 (1-4) | 84.7<br>6.5 (1-44) |
| *Gyrodactylus salmonis* Yin and Sproston, 1948 | Body surface | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.7<br>1.2 (1-2) | 0.7<br>1.2 (1-2) |
| **Digenea** | | | | | | | | | | | |
| *Crepidostomum* sp. | intestine | 4.7<br>1.5 (1-3) | 0 | 0 | 0 | 0 | 0 | 11.1<br>1 (1) | 3.2<br>1 (1) | 5.3<br>2 (1-3) | 2.9<br>1.5 (1-3) |
| *Apophallus imperator* Lyster, 1940 | skin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1<br>hundreds | |
| **Cestoda** | | | | | | | | | | | |
| *Eubothrium salvelini* Schrank, 1790 | intestine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.8<br>1 (1) | 0.7<br>1 (1) | 0.3<br>1 (1) |

***Table 1 cont'd***

| Parasite | Site in Host | Bangor | | Germaine | | Duffy | Belliveau | | Trout Brook | | SW Nova |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nematoda** | | | | | | | | | | | |
| *Salmonema ephemeridarum* (von Linstow, 1872) | intestine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24.2<br>5.5 (1-32) | 4.9<br>5.5 (1-32) |
| *Raphidascaris* sp. | mesentery | 1.3<br>2 (1-3) | 2.7<br>1(1) | | | | | | | | 0.4<br>1.7 (1-3) |
| **Acanthocephala** | | | | | | | | | | | |
| *Echinorhynchus lateralis* Leidy, 1851 | intestine | 37.8<br>2.2 (1-17) | 64.8<br>6.2 (1-23) | 0 | 4.5<br>1 (1) | 0 | 3.4<br>1.5 (1-2) | 33.3<br>3 (1-5) | 0.8<br>1 (1-5) | 13.6<br>3.2 (1-18) | 16.3<br>3.3 (1-23) |
| **Copepoda** | | | | | | | | | | | |
| *Salmincola edwards* (Olsson, 1869) | Body, head fins, gills | 0 | 2.7<br>6 (6) | 23.3<br>2 (1-6) | 54.5<br>7.3 (1-54) | 0 | 0 | 0 | 20.3<br>2 (1-6) | 43.9<br>10 (1-77) | 17.7<br>6.4 (1-77) |

**Table 2** Summary statistics of parasite infections in fry of brook trout (*Salvelinus fontinalis*) collected early spring of 2012 at spawning sites in three streams in southwestern Nova Scotia, near the town of Meteghan River, Nova Scotia. Data summarized includes sampling date, surface water temperature (°C), sample size (N), host fork length (cm) and weight (gm) (mean ± SD), prevalence, mean intensity, and range of intensity in parentheses.

| **Spawning site** | **Bangor Creek** | | | **Germaine East** | | **Germaine North** | |
|---|---|---|---|---|---|---|---|
| Sample date<br>Surface water temp (°C) | Apr 15<br>4.9 | Apr 30<br>5.1 | May 15<br>15.6 | Apr 14<br>4.8 | May 7<br>14.9 C | May 7<br>15.1 | May 15<br>14.5 |
| Sample size (N) | 18 | 18 | 14 | 14 | 13 | 16 | 13 |
| Host length (cm) | 2.3 ± 0.15 | 2.6 ± 0.37 | 3.4 ± 0.51 | 2.7 ± 0.05 | 3.8 ± 0.08 | 3.7 ± 0.01 | 4.1 ± 0.02 |
| Host weight (gm) | 0.15 ± 0.04 | 0.2 ± 0.01 | 0.6 ± 0.28 | 0.2 ± 0.5 | 0.7 ± 0.7 | 0.7 ± 0.21 | 0.9 ± 0.37 |
| *Echinorhynchus lateralis* | 5.5<br>1 (1) | 16.6<br>1.3 (1-2) | 21.4<br>1.3 (1-2) | 0 | 0 | 0 | 0 |
| *Crepidostomum* sp. | 0 | 11.1<br>1 (1) | 7.1<br>1 (1) | 0 | 0 | 0 | 0 |
| *Gyrodactylus colemanensis* | 0 | 0 | 14.2<br>1.5 (1-2) | 0 | 38.4<br>2.2 (1-3) | 0 | 0 |
| *Salmincola edwardsii* | 0 | 0 | 0 | 0 | 0 | 43.7<br>1.3 (1-3) | 46.1<br>2 (1-6) |

With *S. edwardsii*, juveniles were firmly embedded in host connective tissue by means of the frontal filament. There was localized epithelial thickening around the site of attachment and, in two fry from Germaine North, the base of a pectoral fin was noticeably eroded but not hemorrhagic. Infection with *G. colemanensis* caused slight disruption to the normally smooth fin margin near the site of attachment and presumed grazing. There was no pathology observed with *E. lateralis* and *Crepidostomum* sp., which were free in the lumen of the intestine. There was no significant difference in length or weight of infected versus non-infected fry tested separately for date and locality (t-test, $p>0.05$).

Diet items included a wide variety of aquatic invertebrates, noticeably copepods, ostracods, and larval insects. One fry (3.4 cm, 0.7 gm) from Germaine East collected on May 7 had the recognizable carapace of the amphipod *Hyalella azteca* in its stomach. Fry typically had a stomach full of invertebrates. However, one fry (5.8 cm long; 3.5 gm) from Bangor Creek on July 19, 2012 had no food items in its stomach and 17 well-developed adult *E. lateralis* (5 females, 12 males; fixed weight 0.07 gm) essentially blocking the intestinal lumen. Also noteworthy, a fry in Belliveau Brook on June 8, 2012, had a well-developed adult *E. lateralis* with the proboscis embedded in the posterior intestinal wall and with its body protruding from the anus (Fig 3), with slight abrasion of the ventral lobe of the caudal fin being evident.

## DISCUSSION

All parasite species found in the present study are common in *S. fontinalis* inhabiting freshwater lakes and streams in northeastern North America (Frimeth 1987, You *et al.* 2011; White *et al.* 2020) and most have been reported from other salmonid hosts in Atlantic Canada (Margolis and Arthur 1979, McDonald and Margolis 1995).

Our goal was to determine when emergent fry start acquiring local parasites and which ones. We did not collect pre-emerged alevins to determine whether fish are parasitized in the redd. However, they appear to begin acquiring infections after emergence since parasites were initially rare with prevalence increasing substantially in subsequent samples. This is expected because, within the redd, young trout are removed from the infective stages of local parasites.

**Fig 3** **Brook trout (*Salvelinus fontinalis*) fry collected from Belliveau Brook on June 8, 2011 with an adult *Echinorhynchus lateralis* attached to the hind gut and protruding from the anus (arrow). Note that the lower lobe of the caudal fin appears shortened, possible because of abrasion on the substrate. Scale bar 4 mm.**

The redd, while allowing protective development and growth, serves to delay initial parasitism within the stream. Similarly, open water dispersal of larvae of reef fishes is believed to reduce exposure of young hosts to parasites cycling on reefs (Cribb *et al.* 2000, Grutter *et al.* 2010, Peyruse *et al.* 2012), while larval migration of certain galaxiid salmonids, observed in coastal New Zealand, postpones early parasitism (Poulin *et al.* 2012). In contrast, hatchlings of the threespine stickleback (*Gasterosteus aculeatus*) pick up directly transmitted parasites, likely because they are associated with the male parents that guard the nest (Rybkina *et al.* 2016). King and Cone (2008) suspected newborn fry of brook stickleback (*Culaea inconstans*) acquired infections of the directly transmitted monogenean *Dactylogyrus eucalius* in the protective nest which males guard.

In southwestern Nova Scotia, emerging brook trout fry (as a cohort) acquired parasites within the first month post-emergence either through: 1) free swimming infective copepodids of *S. edwardsii* (see White *et al.* 2020); 2) adult *G. colemanensis* transferring directly between fish (see Cone and Cusack 1988, 1989); or 3) food-borne infective stages of *E. lateralis* (cystacanths) and *Crepidostomum* sp. (metacercariae) using amphipod/mayfly larva as intermediate hosts (Baggs and Cowan 1989, Caira 1989, Shaw *et al.* 2020). This early acquisition of parasites should be expected given that fry live sympatrically with older cohorts in these streams and are essentially proximal to parasites cycling through older cohorts. This initial colonization of young trout fry by food-borne endoparasites and directly transmitted ectoparasites contrasts a proposed general rule (Dogiel *et al.* 1961) that the initial parasites to infect freshwater fishes are those with simple life cycles, i.e., those without intermediate hosts. The present study shows that at the local level the first colonizing parasites involve the most common local parasites irrespective of the mode of transmission. This was particularly evident in the Germaine watershed, where in Gemaine East *G. colemanensis* was abundant and the first to colonize the new cohort, while in adjacent Germaine North it was *S. edwardsii* that was abundant locally and similarly the initial colonizing parasite species. At Bangor Creek, *G. colemanensis* and *E. lateralis* were colonizers and again abundant locally.

Fry emerge from the redd as active predators feeding on stream invertebrates (Allen 1981, Williams 1981, McLaughlin *et al.* 1994) and therefore are exposed to infective stages of *E. lateralis* and *Crepidostomum* sp. cycling through the local food web. Baggs and Cowan (1989) reported *E. lateralis* from brook trout fry in Newfoundland and suggested that, through coprophagy, young fish acquired infective cystacanths shed by local adult trout and not through an amphipod host, which were thought to be too large for young fry because of gape limitation (Baggs and Cowan 1989). Leblanc (unpublished) offered locally obtained live amphipods (*Hyalella azteca*) to schools of hatchery-reared fry (total length 4.8-5.3 cm; total weight 1-1.8 gm) in a large recirculating tank – fry converged almost immediately on the amphipods, tearing them apart within minutes and consuming the pieces. This presumably could take place in the wild, given that fry tend to aggregate in preferred microhabitats (Grant and Noakes 1987, Grant 1990), with cystacanths of *E. lateralis* and possibly metacercariae of *Crepidostomum* sp. being consumed by fish during the feeding frenzy. In the present study, we found a recognizable carapace of an amphipod in the stomach contents of one brook trout fry, which must have consumed it shortly after emergence, given the fish still had fin folds. This suggests that brook trout fry can acquire infections of *E. lateralis* and *Crepidostomum* sp. directly from amphipod hosts and not necessarily through coprophagy of shed cystacanths.

The colonizing parasites, or close relatives, have documented disease potential in salmonids (Pippy and Sandeman 1967, Cusack and Cone 1986, Bakke *et al.* 2007) with *Gyrodactylus* spp. being considered a major selective force in the wild (Zueva *et al.* 2014). *Salmincola edwardsii* is notorious in this regard with reported epidemics in wild brook trout (Mitro 2016, White *et al.* 2020) and disease outbreaks at fish farms (Dustun and Cusack 2002). Poulin *et al.* (1991) showed experimentally that brook trout infected with *S. edwardsii* were more likely to acquire additional infections than uninfected controls, suggesting that the parasite alters host behaviour or immunity in a way that facilitates subsequent infection. White *et al.* (2020) described pronounced, multiple hyperplastic growths at sites of attachment in wild brook trout from northwestern New Brunswick but did not see wounds that could be attributed to feeding. The tissue damage at points of attachment that we report was minor compared to extensive hyperplasia reported with older brook trout (White *et al.* 2020). Erosion at the base of pectoral fins, however, was significant in two cases and these wounds could have been caused by current-driven abrasion by the parasite's body on the fin base or possibly feeding. Previous studies have reported *S. edwardsii* from age 0+ brook trout fry collected in fall (Mitro 2016, White *et al.* 2020) and expressed concerns over increased gill ventilation rates, stunting, delayed sexual maturation and the overall impact of infections on trout recruitment. The present study indicates this concern should be extended to early spring, given that in a locality like Germaine North, nearly half of the new recruits start acquiring infections within the first month post-emergence, a period of significant fry mortality (Grant 1990, Curry *et al.* 1991). Our survey suggests that at Germaine North, a local epidemic of *S. edwardsii* is taking place and under such conditions young fry are a vulnerable part of the epidemic, essentially from time of emergence.

Infections of *G. colemanensis* were limited to few worms with only minor evidence of grazing and fraying on infected fin margins, which is expected given the nature of attachment and feeding (Cone and Wiles 1989). Leblanc *et al.* (2013) reported that, at the Bangor site, prevalence and intensity of infection of *G. colemanensis* increased during summer and by fall, the majority of the parasite standing crop was on 0+ fish, with no evidence of disease.

The immature *Crepidostomum* sp. and *E. lateralis* were free in the hind gut and not yet attached to the wall. The observation of *E. lateralis* protruding from the anus of one fry later in the summer has been seen occasionally in fry during annual assessments of brook trout in other parts of Nova Scotia (MacMillan, unpubl.). Pippy and Sandeman (1967) described infections of *E. lateralis* in adult brook trout from a lake in Newfoundland (200 adult worms per fish) in which groups of parasites had their posterior end protruded through the body wall and, in some fish, from the anus, as was seen in the present study. Pippy and Sandeman (1967) suspected that a bacterial infection may have contributed to the disease condition of the brook trout, many of which were still alive after capture in gill nets. It appears that *E. lateralis* has disease potential in trout in southwestern Nova Scotia and for fry may be important later in the summer. Thilakaratne *et al.* (2007) showed that in freshwater spottail shiner (*Notropis hudsonius*), infections of the gut dwelling acanthocephalan *Neoechinorhynchus rutili* were negatively correlated with condition factor in 1+ but not 2+ fish and concluded that young fish may be more sensitive to pathological effects than older fish. Similarly, size-selective mortality of rainbow smelt *(Osmerus mordax*) larvae due to infections with the cestode, *Proteocephalus tetrastomus,* resulted from predation on or starvation of smaller infected fish (Bourque *et al.* 2006). Indeed, parasitized larvae had less food in their guts (Sirois and Dodson 2000). Prevalence ranged from 43 to 96% during different years in the St. Lawrence estuary, and this cestode may be important in regulating recruitment to the adult smelt population (Bourque *et al.* 2006). In our samples, the only fry with a completely empty stomach had 17 adult *E. lateralis,* essentially blocking the gut lumen and suggesting a similar impact on feeding.

## CONCLUSIONS

Brook trout fry acquire metazoan parasites within weeks of emerging from the protective gravel redd, directly through free-living infective stages or indirectly through food-borne parasites carried by aquatic invertebrates. Given their relatively small body size, fry may be affected much more than by such infections in larger, older hosts. The predictability of emergence and ease of sampling brook trout fry in gravel redds is a convenient system with which to study impact of the initial infections on survival of young hosts and subsequent recruitment into the local fish population.

*Acknowledgements* This research was supported by an NSERC Discovery Grant awarded to DKC, by the Salmon River Salmon Association, and by the Nova Scotia Department of Fisheries and Aquaculture. The authors thank Philippe Leblanc for assistance in the field.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 365-409

# SEABIRDS IN A CHANGING OCEAN: AN OVERVIEW OF 20 YEARS OF RESEARCH AND MONITORING ON MACHIAS SEAL ISLAND, BAY OF FUNDY, CANADA

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## ABSTRACT

This paper reviews some of the more obvious changes in the populations and diets of seabirds breeding on Machias Seal Island, at the junction of the Bay of Fundy and the Gulf of Maine, from 1995 through 2015. This is the largest seabird colony in this oceanic ecosystem, hosting colonies of cold-water species at the southern edge of their distribution. My lab's research over 20 years has been focused in two directions – exploring how several closely-related species persist in co-existence here, and interpreting changes in the birds' biology in terms of responses to environmental changes. Diet played a major role in ecological isolation, but has changed considerably in response to virtual disappearance of juvenile herring since the late 1990s and the recent appearance of juvenile haddock. Ocean warming since 2000 has accelerated, especially after a sudden decrease in water temperature and salinity around 2005, which had as much deleterious effect as the subsequent warming. A major finding has been that the three most abundant breeders – Atlantic Puffin, Razorbill, and Arctic Tern – exchange individuals with other colonies in the Gulf of Maine and so each constitutes a true meta-population. This study, with similar collaborative work on those colonies, provides a unique spatial perspective on marine seabird population dynamics in a rapidly-changing ecosystem. Two species (Razorbills and Common Murres) show wholly unexpected increases in numbers, despite declines in several demographic measures that bode ill for the long-term sustainability of this colony.

## INTRODUCTION

Recognition of the value of using responses of organisms to environmental change is increasing, as examples of extreme changes in

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wildlife are interpreted in terms of what they tell us about our shared environments (Wagner *et al.* 2021). One of the fastest-changing ecosystems in eastern Canada is the Bay of Fundy, the north-eastern extension of the Gulf of Maine Large Marine Ecosystem where ocean temperature is increasing faster than 99% of the world's oceans (Pershing *et al.* 2015). The small rocky island of Machias Seal (MSI) at the junction between the Bay and the larger Gulf, between Canada and the USA, supports the most diverse seabird colony in the Canadian Maritimes and largest in the broader Gulf of Maine (GOM) ecosystem.

In 1995, my lab at the University of New Brunswick (UNB) set up a long-term research and monitoring program to record and investigate changes in the seabirds breeding on MSI, focusing on how such changes might reflect or reveal changes in the marine ecosystem on which they depend (Diamond and Devlin 2003). The current paper summarises some of the major changes recorded over the next twenty years, focusing on changes in the environment, population size, and diet.

## Theoretical framework

Our research addresses two fundamental ecological concepts. The first is competitive exclusion, an ecological principle reaching back at least to the 1930s (Gause 1934) and arguing that species with identical ecology cannot co-exist because one species will inevitably out-compete the other (see also Hardin 1960). Seabird colonies are classic examples of multiple species feeding on similar prey within reach of the colony to which they must return during the breeding season (Lack 1967). On MSI, two species of tern (Sternidae) and three of auks (Alcidae) live in the same colony and feed principally on small forage fish in the surrounding ocean. The ecological interest, particularly for the two terns and three auks, is in how they keep separate but sympatric breeding populations. Since bird populations are generally limited by food supply (Newton 1998, 2013), studies of diet are particularly germane to this issue.

The second is the concept of seabirds as indicators, principally of marine food supplies (Cairns 1987) but also of environmental change more broadly (Einoder 2009). Seabird breeding colony sizes are commonly considered to be limited by the availability of food within foraging range of the colony, even depleting that supply over the course of a breeding season (Ashmole 1963, Diamond 1978, Furness and Birkhead 1984, Birt *et al.* 1987), so colony size should reflect food abundance. However, the relation between food supply and colony size is an 'ultimate' effect, in the sense that it is the end-point of a chain of more immediate or 'proximate' effects on short-term seabird responses including phenology (date of laying), clutch size (in species laying more than 1 egg per season – on MSI, only the terns), hatch success, chick growth rate and fledging condition, and fledging and breeding success. Fledging refers to maturation of the chick to the point where it leaves the nest, and fledge success is the number of chicks fledged per chick hatched; breeding success (or productivity) is therefore the product of hatch success and fledge success (chicks fledged per egg laid). Food availability likely affects each seabird response (hatch success, fledge success) over different time-scales and to different degrees (Cairns 1987), so each of the demographic parameters reflects both timing and extent of changes in food availability, thus serving as indicators of changes in the food-web supporting the prey species (Scopel *et al.* 2018, 2019). Seabirds can live for many decades, so negative impacts of climate (or any other) change will show up sooner in such measures as low clutch size, poor breeding success etc., than in number of breeders, acting as early warning signs of difficulties long before they become obvious in terms of population size.

Demographic changes and their relation to regional oceanographic and climate changes are described more fully in Scopel *et al.* (2019) and Major *et al.* (in press) for auks, and Scopel (2021) for terns. Here I focus on environmental changes measured on the island: changes in population size (and thus biodiversity); breeding success (reflecting conditions over a whole breeding season); chick growth (indicating conditions when energy demand is greatest); survival, which has most effect on population trajectory; and diet, through which environmental conditions are translated into seabird outcomes.

## STUDY AREA AND METHODS

The island, its habitat types, and our study methods are described in detail in Diamond and Devlin (2003). Briefly, MSI is a small (9.5ha) treeless granite outcrop, equidistant (19 km) from Grand Manan Island and the coast of Maine. It is owned by the Government of Canada, which keeps a manned lighthouse through the Department of Fisheries and Oceans (DFO) and manages the Migratory Bird Sanctuary through the Canadian Wildlife Service (CWS) of Environment and Climate Change Canada. The lighthouse is manned because of a jurisdictional dispute with the USA (Burnett 1990, Gray 1994, Anon 2007), related to its position in the outer Bay of Fundy bordering on the Gulf of Maine (Fig 1).

A rocky foreshore is most exposed on the south and west of the coast, where most Razorbills (*Alca torda* Linnaeus, 1758) and Common Murres (*Uria aalge* Brisson, 1760) (hereafter Murres) nest, and the vegetated interior provides peaty soil in which Atlantic Puffins (*Fratercula arctica* Pennant, 1768) (hereafter Puffins) and Leach's Storm-Petrels (*Oceanodroma leucorrhoa*) dig nesting burrows and on which Arctic and Common Terns (*Sterna paradisaea* Pontoppidan, 1763, and *S. hirundo* Linnaeus, 1758) and Common Eiders (*Somateria mollissima* Linnaeus, 1758) nest.

A research crew of two to four from UNB, usually led by a graduate student, occupies a bungalow loaned by CWS from mid-May through mid-August each summer. CWS hires a caretaker/observer to check tourist numbers for June and July; in recent years, this role has been contracted to UNB and forms part of the research crew.

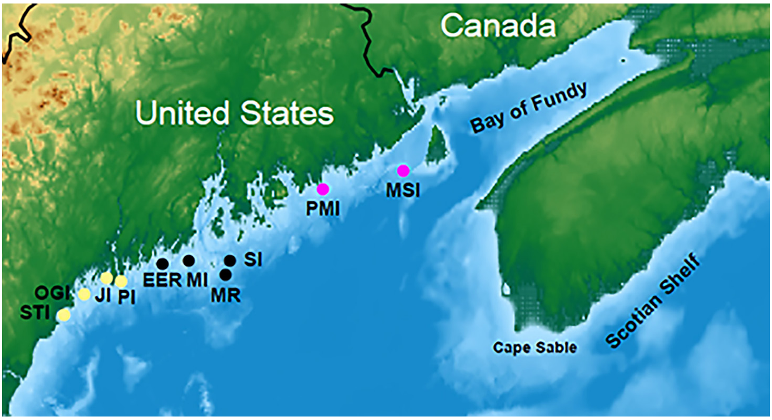


**Fig 1** **Map of seabird colonies in the Outer Bay of Fundy and Gulf of Maine. MSI = Machias Seal Island; PMI = Petit Manan Island; SI = Seal Island National Wildlife Refuge; MR = Matinicus Rock; MI = Metinic Island; EER = Eastern Egg Rock; PI = Pond Island; JI = Jenny Island; OGI = Outer Green Island; STI = Stratton Island. Colours show grouping of colonies (eastern, central, western) based on oceanographic characteristics. Seabird colonies on these islands are connected to various degrees by dispersal.**

Transport is provided by a boat bringing tourists from either Cutler, ME, or Grand Manan, NB. Up to 30 tourists are allowed ashore each day and are guided by boat or lighthouse staff to blinds for close observation of nesting birds. Tourists are not allowed in the northern half of the island and researchers can work there without interference.

Our broad approach was for monitoring (which I prefer to think of as long-term research) to continue side-by-side with more focused graduate-student projects; a typical crew might consist of a mid- or late-thesis graduate student as supervisor, a beginning graduate student, and one or two field technicians hired just for the summer. Graduate students are part of the monitoring crew, and technicians help with graduate research projects as well as monitoring. Crew sizes have ranged from two in some of the early years, to three or four in recent years; numbers are limited by the accommodation and provincial regulations, as well as by funding.

Simple weather measurements (rainfall, wind direction and speed, air temperature, sea surface temperature) are taken daily; details of these and research protocols are in Diamond (2014). Timing and success of breeding of Puffins and Razorbills are measured by visiting around 100 permanently-marked burrows or nest sites of each species on fixed schedules and recording nest contents each time. Tern nests in specific areas are marked when they first appear, and checked daily until eggs hatch and frequently until chicks fledge. Field procedures always represent a balance between precision of data and disturbance to the birds, the latter being minimised wherever possible.

Following training with pictures from previous years and collaborators in the USA, diet is measured by fixed watches of selected areas from blinds, recording prey carried in the bill by adults feeding chicks, and estimating the length of each item by comparison with the length of the bird's bill (see also Scopel *et al.* 2018, 2019). We also collect prey dropped in the colony; by measuring and weighing these, we can convert length to weight (Table S3 in Scopel *et al.* 2018).

Chick growth typically follows a curve, low at first, followed by a rapid linear increase before levelling off to an asymptote before departure from the island (except in Razorbills and Murres where linear growth in wing length continues until departure). For mathematical simplicity, we calculate growth rates by measuring weight and wing-chord two or three times during the linear period of growth, as defined in the literature.

We share research protocols and collaborate closely with colleagues in the USA who manage other seabird colonies in the GOM; the USA Fish and Wildlife Service manage these islands as part of the Maine Coastal Islands National Wildlife Refuge, and contracts much of this work to the Seabird Restoration Project of the National Audubon Society. All seabird researchers and managers, including the UNB team, collaborate in the Gulf of Maine Seabird Working Group. By doing so, we can explore a property of seabirds that is rarely possible to investigate, i.e. the exchange of birds among colonies on different islands. Seabirds have long been considered exclusively philopatric, i.e. breeding only in the colony where they were raised, but this is partly because most long-term studies have been on single islands where it is impossible to measure such movement. We were eager to take the opportunity of multiple colonies within 200 km of each other to assess the possible importance of dispersal among colonies, an important parameter rarely assessed in seabird studies. This collaboration also enables us all to explore the spatial scale of changes in the marine ecosystem, and of seabird responses to those changes. The spatial and temporal extent of this collaboration is unique in seabird studies in the northern hemisphere.

On MSI we focus on three species for intensive study of demography and diet: Puffin, Razorbill, and Arctic Tern. Common Terns were already the focus of a long-term study in Massachusetts (Arnold *et al.* 2004), eiders were the subject of research elsewhere in eastern Canada, and Leach's Storm-Petrels take so long to raise young that we could not measure breeding success before leaving the island in late summer (and are the subject of intensive long-term research on nearby Kent Island). Murres colonised in 2003 and are difficult to incorporate into routine monitoring because they nest under boulders; for the first years after their arrival, we avoided their nesting areas for fear of causing abandonment, but now we band small numbers of chicks and adults, and study their diet the same way as in other species.

Populations are made up of different sexes and age-classes which might respond differently to changes in the environment, so it is important to estimate the proportions of each of these.

This is one of the most challenging tasks in any population study, and requires sustained, systematic recording of individually-marked birds over a period matching the lifespan of the study species – 40 years or more in the case of many seabirds. This we do by banding as many birds as we can without causing undue disturbance, ideally several hundred a year. Standard government bird-bands carry unique nine-digit numbers and are hard to read in the field (i.e., without recapturing the bird), so for Puffins and Arctic terns we order custom-made bands with a four-digit alphanumeric code (e.g., AA 01) from a specialist company in the U.K. These, and the government bands, are made of alloys resistant to the wear which is inevitable in birds which spend the summer on and around granite boulders (Breton *et al*. 2006a).

In the focal species we band more chicks than adults, so that an increasing proportion of the population consists of birds of known age. Banding totals are in Table 1.

Banding a bird is of little value unless that band is then read at another time or place. Thus we spend many more hours looking for banded birds and recording their numbers, than we do banding them in the first place. These band-reading sessions are stints of two to three hours spent with a spotting scope, often in a blind, searching for banded birds and reading their band numbers, from fixed locations around the island (often the same places where we look for birds bringing in prey). Band-numbers read are entered into a database shared with collaborators on other colonies in the GOM. This enables us to measure changes in survival and dispersal to neighbouring colonies in the GOM.

In the focal species the sexes look the same. An important methodological tool that we needed to develop was to allow us to distinguish the sexes in adults, using morphological measurements;

**Table 1 Banding totals of seabirds on Machias Seal Island, 1995-2015**

| Species | Adults | Chicks | Total |
|---|---:|---:|---:|
| Atlantic Puffin | 2,710 | 6,256 | 8,966 |
| Razorbill | 677 | 1,212 | 1,889 |
| Common Murre | 69 | 144 | 213 |
| Arctic Tern | 1,011 | 2,524 | 3,535 |
| Common Tern | 203 | 1,283 | 1,486 |
| Leach’s Storm-petrel | 220 | 268 | 488 |
| Totals | 4,890 | 11,687 | 16,577 |

this was achieved as honours or within master's projects for all three focal species (Arctic Terns – Devlin *et al.* 2004; Puffins – Friars and Diamond 2011; Razorbills – Grecian *et al.* 2003). These allow reliable determination of the sex of 70-80% of adults of these species, using discriminant function analysis (DFA) of two or three standard measurements of head and bill. Individuals falling outside the confidence limits of the DFA were sexed genetically using a few of the feathers we collect routinely.

## RESULTS AND DISCUSSION

### Environmental changes

Rainfall on MSI has increased by 66%, on average, since 2005 (Fig 2). The significance of higher rainfall lies in its effects on downy seabird chicks before they have grown feathers to protect them from both wetting and hypothermia. Down provides insulation but not waterproofing, so wet downy chicks are susceptible to chilling unless they are tightly brooded by a parent. A parent must choose between using its own body heat to keep a chick warm and dry, or leaving the chick exposed while the parent goes to sea to find food to fuel its own metabolism and the chick's. This conflict is particularly evident with terns because they nest on the ground, often near thick vegetation which itself can become wet enough to continue being a threat to a downy chick long after rain has ceased to fall.

Terns also may have more than one chick to protect and feed, making them more susceptible to increased rainfall and decreased food supply. Auks have only one chick and are less susceptible to heavy rain and predation because they nest underground (Puffins) or under cover of rocks (Razorbills, Murres), though they can still be affected (Scopel *et al.* 2019).

The sea surface temperature (SST) around MSI has followed a distinctly cyclic trajectory with an apparent overall upward trend of over half a degree Celsius between 1995 and 2015 (Fig 3). This trend hovers around significance in July ($p = 0.052$) and is significant in August ($p = .034$) but not in May or June ($p > 0.05$ in both cases); inter-annual variation exceeds the temporal trend. Increasing SSTs are potentially most problematic for terns because they feed within the first few centimetres of the surface, while auks dive deep below to cooler water. Seabirds' sensitivity to surface temperature

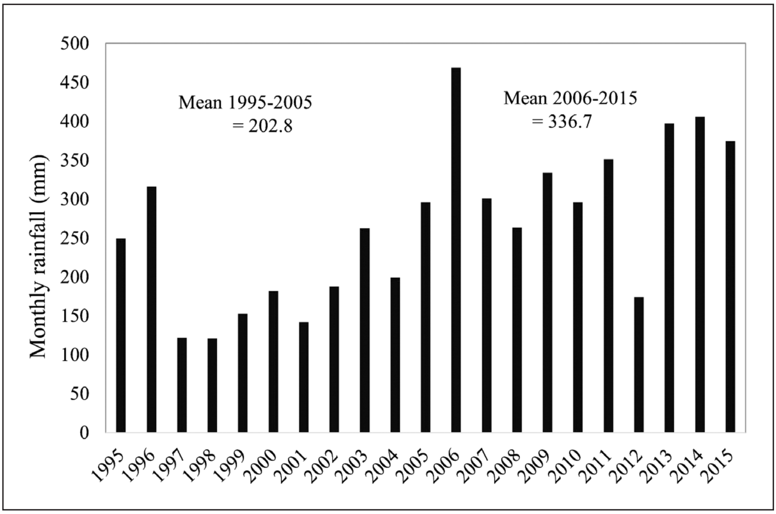


**Fig 2** **Trends in summer rainfall (May-August) at Machias Seal Island. Rainfall varied interannually, but averaged 66% higher after 2005; six of the last ten years had higher rainfall than in any year of the previous decade.**

operates through the temperature sensitivity of prey; most forage fish and macroplankton have preferred water temperatures and if those are exceeded, they can move to cooler water below. Auks can follow them there, but terns cannot. SST increases during the summer, especially in late summer; terns, Razorbills, and Murres have mostly left the island by late July, leaving Puffins and Storm-petrels to endure the increasing heat of late summer.

SST can fall as well as rise, as is evident in 2005 when July temperatures were below those in June. The changes involved in this sudden oceanographic change were more consistent across measures and species than effects of the marine heatwave year of 2012.

## Breeding species and colony size

***Regular breeders.*** In 1995 two species of auk (Alcidae) and two of terns (Sternidae) bred, with smaller numbers of eiders and storm-petrels. There had been regular nest counts of terns every two years, carried out by CWS staff until 2004 when UNB took over that task. The numbers of Puffins had been "estimated" by unspecified methods at irregular intervals between 1883 (60 birds) and 1984 (900-1000 birds) (MacKinnon and Smith 1985). Numbers during this study are compared with the most recent earlier numbers in Table 2.

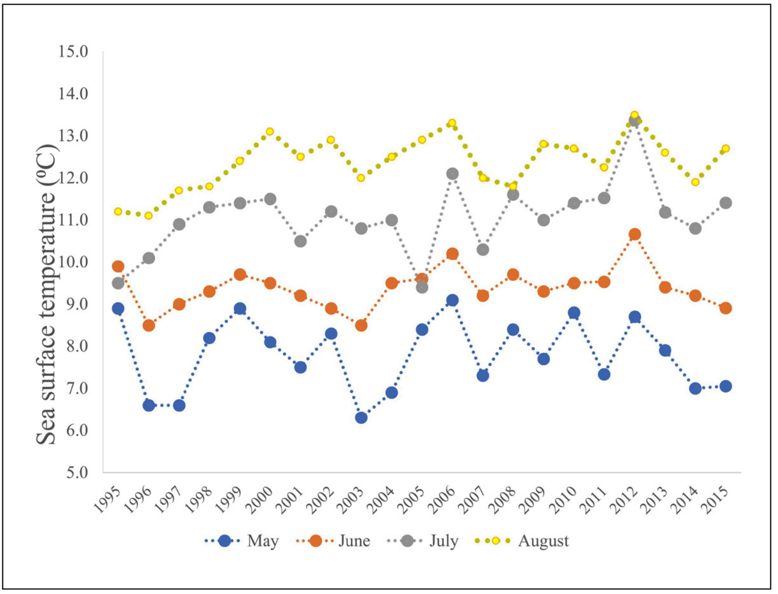


**Fig 3** **Trends in monthly summer Sea Surface Temperature measured at Machias Seal Island. SST has varied considerably between years; July and August show an apparent increasing trend to 2000 and especially high temperatures in 2006 and the "heatwave" year of 2012, but with anomalously cool temperatures in July 2005 and 2007. Note that May and August are represented only by the last and first two weeks, respectively, when crews are on the island. No data are available for August, 2005.**

Puffins breed in burrows dug in the soil, or in cavities among boulders. Counts of nest sites of Puffins were first made in 2000, counting occupied burrows or nest cavities in 4 $m^2$ (2 m x 2 m) quadrats on E-W grid lines every 50 m throughout nesting habitat (identified by presence of burrows). Later censuses have been at irregular time intervals. Since 2000, estimates of numbers of breeding Puffins have ranged between about 6,000 and 8,000 pairs.

Razorbills are larger (mean mass 700 g vs. 430 g in Puffins) and lay mostly in larger cavities in piles of boulders. The first census was a complete count of about 600 pairs (Grecian 2005). Numbers then increased so rapidly that a complete count became impracticable, so in later years they have been sampled in the same way as Puffins, reaching about 2500 pairs in 2015 (Fig 4).

Prior to 2003, considerable numbers of Murres were seen loafing on land and around the island, increasing from 50 in 1999 to over 500 in 2002. A single egg was found in 1994 but there was

**Table 2** **Comparison of number of breeding pairs of seabirds on Machias Seal Island, 1995 and 2015. ~ = approximate number.**

| Species | Number of pairs<br>Nearest previous count or estimate (year) | 1995 (or nearest following year) | 2015 | Comments |
|---|---|---|---|---|
| Atlantic Puffin | ~800 (1982) | ~8,000 (1999-2000) | 6,400 | No census until 1999-2000 |
| Razorbill | 75 (1983) | 600 (2000) | 2,550 | No census until 1999-2000 |
| Common Murre | Not nesting | Not nesting | ~200 | Nesting began 2003 |
| Arctic Tern | 2,419 (1994) | 1,637 (1996) | 141 | Colony collapsed in 2006 |
| Common Tern | 368 (1994) | 608 (1996) | 9 | Colony collapsed in 2006 |
| Leach's Storm-petrel | 82 (1958) | 150 (1999) | 60 (2017) | |
| Common Eider | 31 (1994) | 41 (1996) | 32 | |

no further sign of breeding until 2003, when 47 eggs were counted (Bond and Diamond 2006) but many more could not be counted (AWD, pers. obs.). Breeding has continued ever since; at first, many eggs were laid in the open on the bare rock in the southwest part of the island, seaward of Razorbills and Puffins, but Herring Gulls (*Larus argentatus* Pontopiddan, 1763) and Great Black-backed Gulls (*L. marinus* Linnaeus, 1758) rapidly took those eggs and murres now lay entirely in "caves" roofed by large boulders balanced on other large boulders. We estimate the numbers of eggs and chicks in each "cave" when most chicks are old enough to be banded (about 12 days); this method produces an under-estimate by the amount of egg loss and early chick mortality. Numbers have remained constant at around 200 pairs since 2004 (Fig 4).

Terns nest on the surface throughout the island, and nests are counted by teams of people moving slowly across the island. The colony contained about 2000 pairs of Arctic Terns and 1,000 pairs of Common Terns in 1995, but in 2006 suffered extremely high egg predation by Herring Gulls and it was abandoned. Possible causes of this extreme event included increased egg predation by gulls, bad weather, and poor food supply. Their relative contributions were not sorted out until Lauren Scopel's analysis (Scopel and

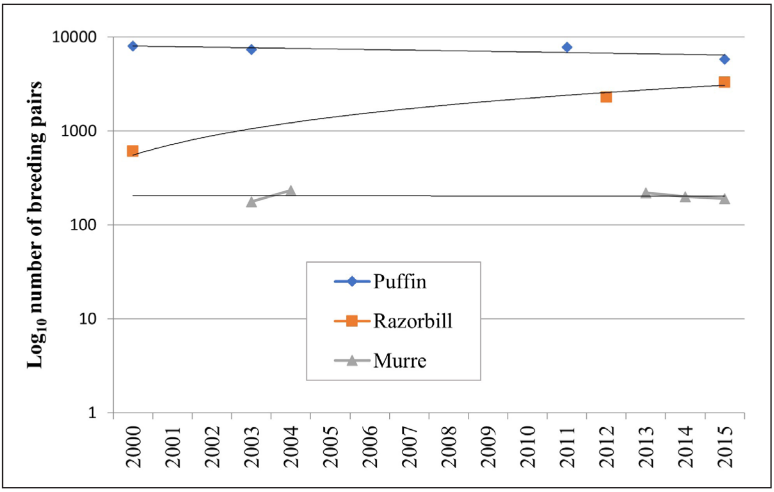


**Fig 4** **Changes in numbers of auks breeding on Machias Seal Island, 2000-2015. Puffin numbers remained fairly stable, with a possible slight recent decrease, while Razorbill numbers increased rapidly after 2000 and Murre numbers increased quickly after colonisation but changed little thereafter.**

Diamond 2018), which attributed the collapse of the colony primarily to high egg predation by gulls, caused by the cessation in 2000 of lethal control of problem gulls (Pyne 2018). From 2006 until 2014, when a very restricted form of lethal control was restored, no Arctic Tern chicks fledged and numbers fluctuated in the low hundreds or fewer, the terns abandoning the colony each year as eggs were depredated in increasing numbers (Fig 5).

The return of limited lethal deterrence of predatory gulls in 2013 was followed by the fledging of tern chicks in 2014 for the first time since 2005, confirming that the colony failure was due to excessive gull predation (Scopel and Diamond 2018). The significance of the loss of the tern colony is that it was the largest Arctic Tern colony in North America and had been in existence since at least the 1880s, during which time it had failed only in two years in the 1940s (MacKinnon and Smith 1985), and that it supplied many recruits to the other colonies in the GOM (see below).

Common Eiders usually nest in clumps of thick vegetation. Counts of nests and eggs are made during censuses of tern nests. Numbers have fluctuated considerably over 20 years with no consistent trend (Fig 6).

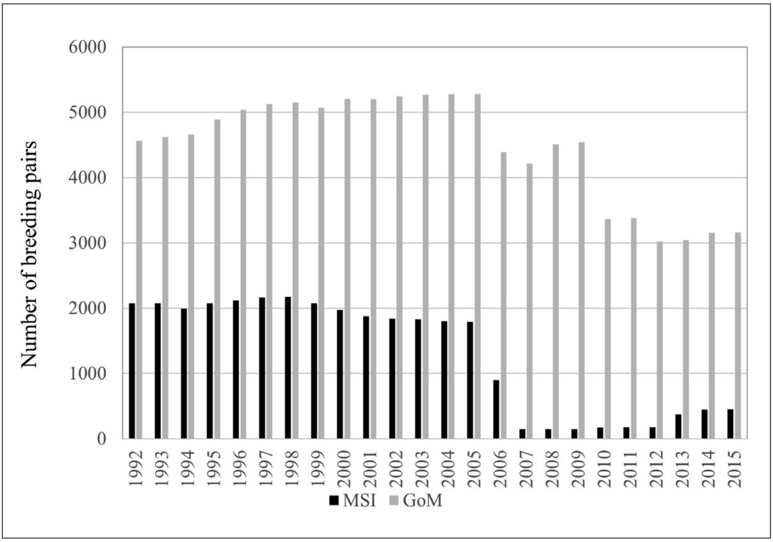


**Fig 5** **Number of pairs of Arctic Terns nesting on Machias Seal Island, and in the entire Gulf of Maine (GoM) metapopulation. The broader metapopulation declined by about the same number of pairs as formerly nested on MSI. Data compiled by Lauren Scopel from island-wide censuses.**

Nesting underground and not visible during daylight – so unremarked by the many tourists who visit the island in summer – is Leach's Storm-Petrel which lays its single egg in narrow burrows in the turf. Burrow entrances are only a few centimetres across and can be extremely hard to find; the lack of grazing animals on MSI means that vegetation can be very tall by the time the petrels lay eggs in mid to late June. Ornithologists visiting MSI in the 1930s and 1950s estimated numbers at about 2000 pairs or burrows; a 1966 estimate was between 200 and 500 pairs; by the 1970s, several estimates by CWS wardens ranged between 50 and 200 pairs; in the early 1980s, 60 and 58 burrows were found by two CWS wardens in successive years. Dorothy (McFarlane) Diamond has made complete counts by intense ground searching coupled with sniffing for the distinctive musky scent of petrels in 1999, 2006, and 2017. Over this period, numbers dropped from about 150 to 77 and then 60 pairs. This clear decline is consistent with population trends at several other eastern Canadian colonies in recent years (Wilhelm *et al.* 2020, d'Entremont *et al.* 2020) and with its Canadian status as Threatened (Species at Risk public registry 2021).

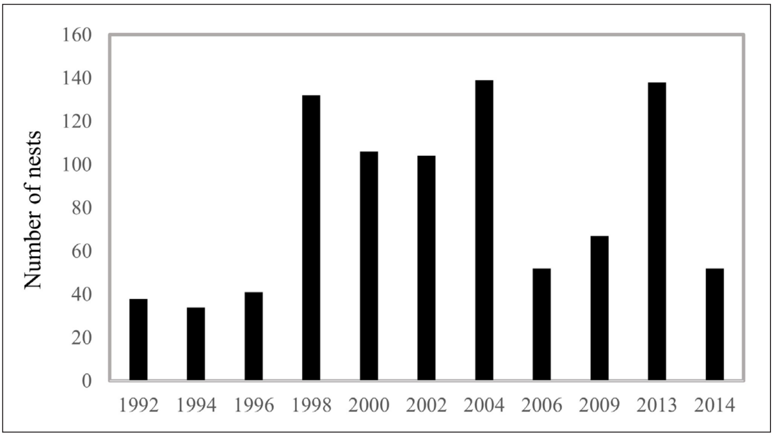


**Fig 6 Counts of Common Eider nests found during tern censuses on Machias Seal Island.**

Herring Gulls and Great Black-backed Gulls nest mostly on Gull Rock, a bare island located a few hundred metres north-east of the northern tip of MSI. Gull nests on MSI itself are destroyed (under permit from CWS) to deter gulls from nesting, as part of the strategy to minimise gull predation on tern eggs (Scopel and Diamond 2017, 2018). Gull nests on Gull Rock are counted and eggs destroyed when opportunity allows, by vigorous shaking followed by pricking the shell; gulls whose eggs are so treated usually do not notice the damage and continue incubation beyond the time when they could re-lay. The numbers of gull nests found and destroyed on MSI and Gull Rock are shown in Fig 7.

***Sporadic breeders.*** Five other seabird species have bred on MSI between 1995 and 2015.

A pair of Roseate Terns (*Sterna dougalli* Montagu, 1813) hatched an egg in 2001, and probably fledged the chick, and a pair laid but failed the next year. Social attraction using sound recordings and decoys, attempted in the following three years, was unsuccessful.

Two pairs of Black Terns (*Chlidonias niger* (Linnaeus, 1758)), typically a freshwater species, laid each year from 2002 through 2005, without success.

A single pair of Laughing Gulls (*Leucophaeus atricilla* (Linnaeus, 1758)) nested in 2001, and two pairs in 2003 and 2005, the former probably fledging chicks but the latter not.

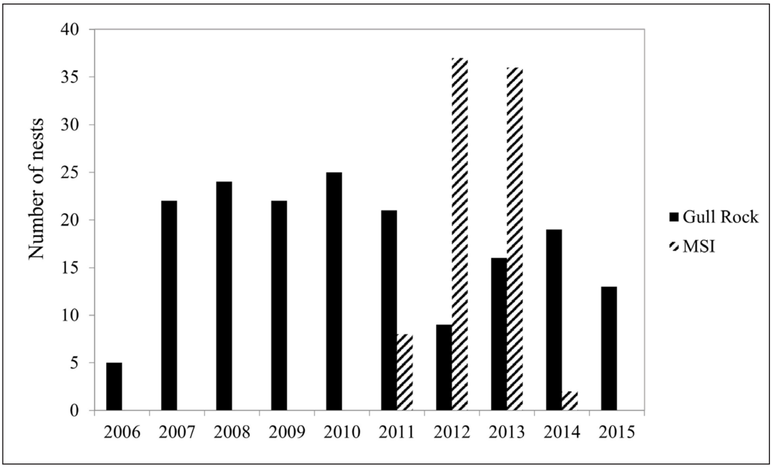


**Fig 7** **Number of nests of gulls (mostly Herring Gulls) on Gull Rock and Machias Seal Island. Nest counts on Gull Rock were started in 2006. High numbers on MSI in 2012 and 2013 were in response to Bald Eagle (*Haliaeetus leucocephalus*) presence on Gull Rock.**

Black Guillemots (*Cepphus grille* (Linnaeus, 1758)) are seen in the bay on the east side of the island in many years, and one pair nested among the boulders there in 2008 and hatched a chick; Northern Gannets (*Morus bassanus* (Linnaeus, 1758)) present in 2010 laid an egg in 2011 which was quickly lost, probably to Great Black-backed Gulls which roosted nearby. This, like the Black Guillemot, Black Terns, and Laughing Gulls, was a first nesting record for the island.

***Diversity.*** In terms of species richness – simply the number of species breeding regularly – diversity has increased since 1995, from six species in 1995 to seven in 2015, the difference being the addition of Murres. Although the tern colony has been greatly reduced, both Arctic and Common Terns still try to breed so are still included as regular breeders.

Of greater interest, though, is a measure of the relative abundance of species within the breeding community, measured as the "evenness" of population size. A community dominated by one abundant species with others being much less abundant, has low evenness, while a community with the same number of species but of more equal abundance has higher evenness and therefore higher diversity. Shannon's Diversity Index (H') incorporates both species number and relative abundances, and ranges between 0 and 1. A community

**Table 3** **Change in Biodiversity of Seabird Community over 20 years on Machias Seal Island. $P$ = proportion of total pairs; Shannon Diversity Index $H' = -\sum_{i=1}^{R} p_i log p_i$ where R is the number of species.**

| | 1995<br>(or nearest following year) | | | 2015<br>(or nearest following year) | | |
|---|---|---|---|---|---|---|
| **Species** | **Number of nesting pairs** | ***P*** | ***H'*** | **Number of nesting pairs** | ***P*** | ***H'*** |
| Atlantic Puffin | 8,000 | 0.7249 | | 6,400 | 0.6814 | |
| Razorbill | 600 | 0.0543 | | 2,550 | 0.2715 | |
| Common Murre | | | | 200 | 0.0213 | |
| Arctic Tern | 1,637 | 0.1483 | | 141 | 0.0150 | |
| Common Tern | 608 | 0.0550 | | 9 | 0.0009 | |
| Leach's Storm-petrel | 150 | 0.0135 | | 60 | 0.0064 | |
| Common Eider | 41 | 0.0037 | | 32 | 0.0034 | |
| | **11,036** | | **0.397** | **9,393** | | **0.356** |

of n species in which one species is much more numerous than the others would have a lower value than one in which all n species had similar numbers. Calculations of H' (Table 3) show that this measure of diversity has decreased slightly from 0.397 in 1995 to 0.356 in 2015, a decline of about 10%. The number of species has increased over this period, but although evenness is raised by the increase in Razorbill numbers, the effect of that increase on H' is balanced by the reduction in numbers of terns, and the added breeding species (Murre) is not sufficiently numerous to raise the overall evenness of the community.

### Metapopulation status

Two of the focal species – Puffin and Arctic Tern – were the subject of capture-mark-recapture (CMR) models by Ph.D. students at UNB, making use of the data provided by resightings and recaptures of birds banded at MSI and the other colonies of these species in the Gulf of Maine (Breton *et al.* 2006b, Devlin *et al.* 2008). In both species, MSI was revealed as the "mothership" of the Gulf of Maine population, supplying recruits (birds fledged on MSI) to the other breeding colonies ("natal dispersal"). Adult Puffins remained faithful once they had decided where to breed (Breton *et al.* 2006b, Whidden 2016), but adult Arctic Terns did sometimes change colonies ("breeding dispersal").

Razorbills were also the subject of a CMR model, by a Ph.D. student from Memorial University of Newfoundland whose own study area was the Gannet Islands in Labrador but who visited MSI and used the data that we had compiled over the previous ten years (Lavers *et al.* 2007, 2008a, 2008b). Lavers (2007) found movement not only among colonies in the Gulf of Maine/Bay of Fundy, but also between those colonies and the Gannet Islands (about 1300 km). One adult on the Gannet Islands had even been banded as a chick in Scotland, suggesting contact throughout the North Atlantic (to which this species, like Puffins, is restricted).

In all three species, our work showed that individual colonies function not as closed populations, but as components of a "metapopulation", exchanging individuals in ways that wildlife management needs to consider. We have clearly demonstrated that conservation of seabird colonies needs to encompass other colonies linked by dispersal, in this case, between the Gulf of Maine and Bay of Fundy.

### Breeding success

Successive parts of a breeding cycle reflect environmental conditions in successive months, allowing each measure to indicate conditions as the season advances (Scopel *et al.* 2019, Scopel 2021): clutch size in terns, and occupancy in auks, depend on food available to the female for building eggs (May-early June); hatch success (the proportion of eggs that hatch) echoes conditions during incubation (mid to late June); fledge success (proportion of chicks that reach independence) and chick growth rate reflect both feeding conditions for the parents, and weather mainly in July (prolonged heavy rain can chill exposed chicks and interfere with the adults' ability to find food) (Scopel *et al.* 2019). These breeding stages can therefore track environmental changes on a fine time scale, and elucidate the separate effects of varying conditions on the components of breeding which finally contribute most to the dynamics of a population, *i.e.*, the number of chicks produced per breeding pair (productivity). This approach was pursued by Scopel *et al.* (2019) for alcids, and Scopel (2021) for terns. In theory, this approach allows for both lagged effects and carry-over effects from one season to another, of which the clearest example yet is the effect of food (percent by mass of herring in chick diet) during the breeding season of Puffins on adult survival over the following winter (Breton and Diamond 2014); in this study, over-winter survival of Puffins was positively correlated with both herring landings and the proportion of herring in chick diet in the preceding nesting season, suggesting a carry-over effect between feeding conditions in summer and survival the following winter (see also Scopel *et al.* 2019).

***Arctic Tern.*** Demographic research on the Arctic Tern colony has been severely compromised by the inadequate measures available to control the effects of predatory gulls on the nesting terns since 1999. Since then, because routine season-long lethal control has not been available whenever necessary, the major factor affecting productivity of the terns has been egg predation by gulls. Scopel & Diamond (2017) showed that throughout the Gulf of Maine seabird colonies, there is a threshold (25%) of egg predation by gulls, above which terns abandon that year's breeding attempts. Accordingly, in the absence of appropriate management of gull predation, tern breeding success cannot be used as an indicator of food supply or other environmental change, and the decline in numbers reflects egg predation by gulls.

Temporal patterns of components of breeding success show that Arctic Tern clutch size was steady at around 1.7-1.8 eggs per nest until 2000, when it dropped to around 1.5 until 2006, the year that the colony collapsed (Fig 8a). From 2007 through 2013, the few pairs that tried to breed laid fewer eggs on average (1.24) than in either previous period, due in part to continuing egg predation by gulls taking place before eggs were counted, and no eggs hatched. The restoration of lethal control of predatory gulls in 2014 was accompanied not only by more birds nesting, and chicks actually hatching (the first since 2005), but by a return to clutch sizes similar to the best values of the late 1990s. Hatch success followed a similar pattern, except that values after restoration returned to those immediately prior to the colony collapse, rather than pre-2000. The number of chicks fledged per nest was extremely variable between 1995 and 2003, and then was extremely low in the two years immediately before the colony collapsed, but increased to equal the highest on record in only the second year after colony restoration.

In Common Terns (Fig 8b) clutch size, by contrast, remained constant until the collapse of the colony, but as in Arctic Terns, hatch success declined as soon as lethal gull control ceased in 2000, and productivity in the three years before the collapse was extremely low. Very few Common Terns have recolonized, so too few data have been collected on this species' behaviour since the collapse.

***Atlantic Puffins.*** This species lays a single egg, so there is no variation in clutch size. There is variation, though, in the proportion of adults that choose to breed in a particular year; we term this "occupancy" and variation in this parameter could be considered as equivalent to variation in clutch size since it is determined at the same (first) stage of the breeding cycle. Occupancy is measured as the proportion of burrows in which an egg is laid, and varies quite widely throughout the time series (Fig 9a) but most values of 0.8 and over were before 2010, and three of the four before 2005. In both hatch success and productivity, the lowest values all occur after 2005, and mean values after this represent declines of 16% in both cases. Occupancy, hatch success, and productivity declined since 2005 by 4.9, 17, and 18.5%, respectively.

***Razorbills.*** Razorbills also lay a single egg. Trends are similar to those in Puffins (Fig 9b), with a break point evident around 2005, but a sharper decline in occupancy; mean values after this year declined by 11.4% in occupancy, 17.9% in hatch success, and 18.3% in productivity.

***Common Murres.*** Murres also lay a single egg, but the nest sites they use on MSI (see above) make it impossible to measure their productivity without causing undue disturbance.

### Chick growth

Measuring the growth rate of chicks gives a fine-grained picture of the impact of short-term changes in the environment as they cascade through the food-web to the tertiary consumers that are seabirds. Chick growth rates reflect food supply over the chick-rearing period (Cairns 1987), in this case between 2-3 weeks (Razorbills), 3-4 weeks (terns, Murres) and 6 weeks (Puffins).

***Arctic and Common Terns*** (Fig 10). Mass and wing growth rates were consistent from year to year though less so in Common Terns, probably because they had more chicks on average and chicks from eggs laid later tend to be smaller and grow more slowly, especially when food is short, increasing variation in the annual mean.

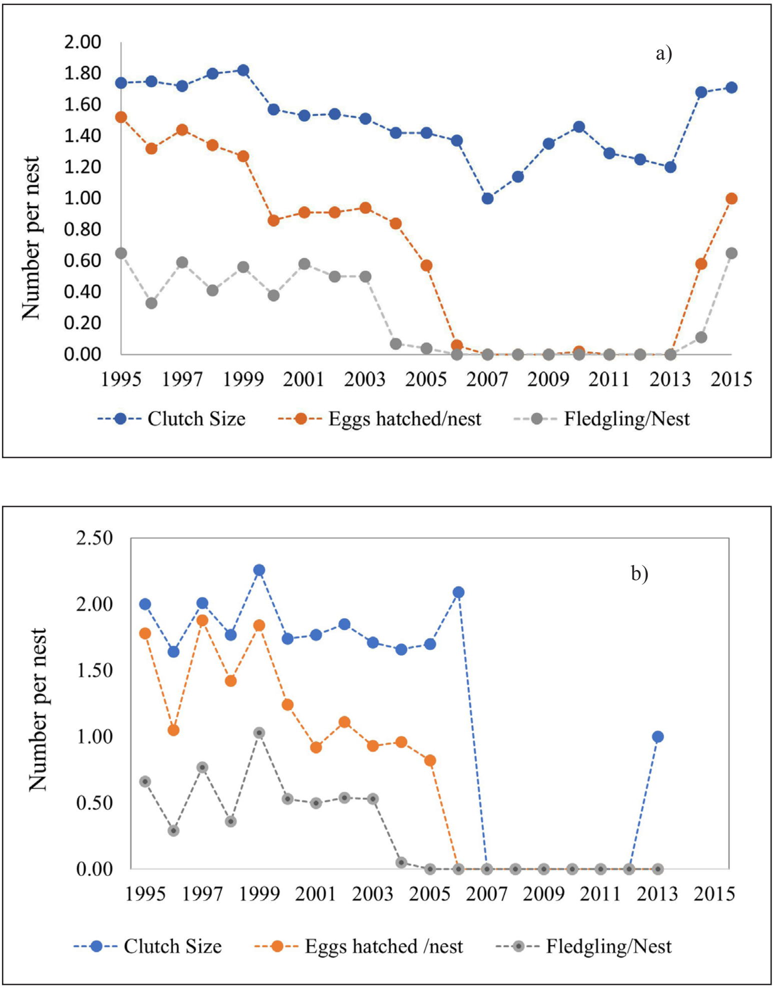
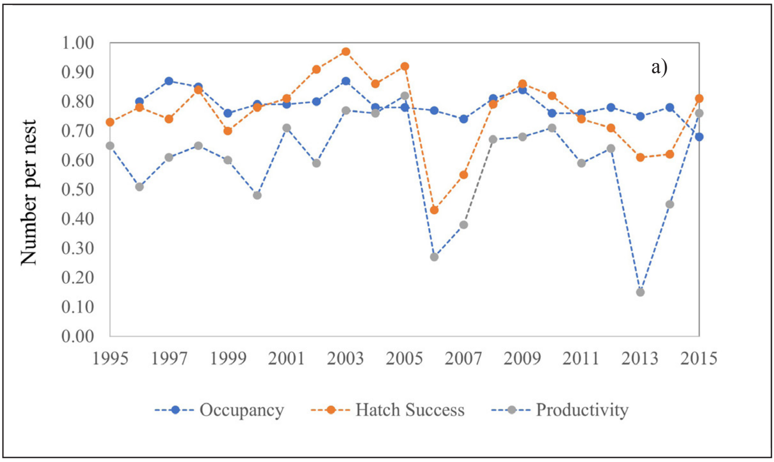


**Fig 8** **Components of nest success of a) Arctic and b) Common Terns. Too few Common Terns nested in 2014 and 2015 to measure productivity. The tern colony failed every year from 2006 through 2012. Clutch size (number of eggs per nest) in Arctic Terns rebounded to pre-2000 levels following restoration of lethal gull control in 2013. Clutch size in Common Terns was constant before 2006, whereas Arctic Tern clutch sizes declined after 1999.**



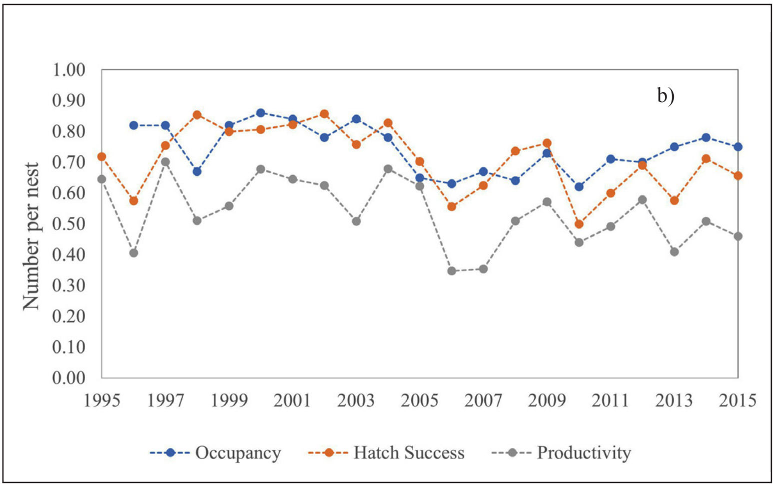


**Fig 9** **Components of productivity (nest success) of a) Puffins and b) Razorbills on Machias Seal Island, 1995-2015. Occupancy declined after 2005, more so in Razorbills than Puffins. In both species, productivity largely tracked hatch success, suggesting that breeding success was determined early in the season. The first unusually warm year in the time series, 2006, is reflected in reduced productivity in both species, which did not recover fully until two years later. The effects of the first "heatwave" year, 2012, were delayed to 2013 and were more evident in hatch success of Puffins than Razorbills, suggesting a greater carry-over effect on body condition of Puffins (Scopel *et al*. 2019, Diamond *et al*. 2020). The record low productivity of Puffins in 2013 suggests that they were not able to recover body condition in time to raise the chick.**

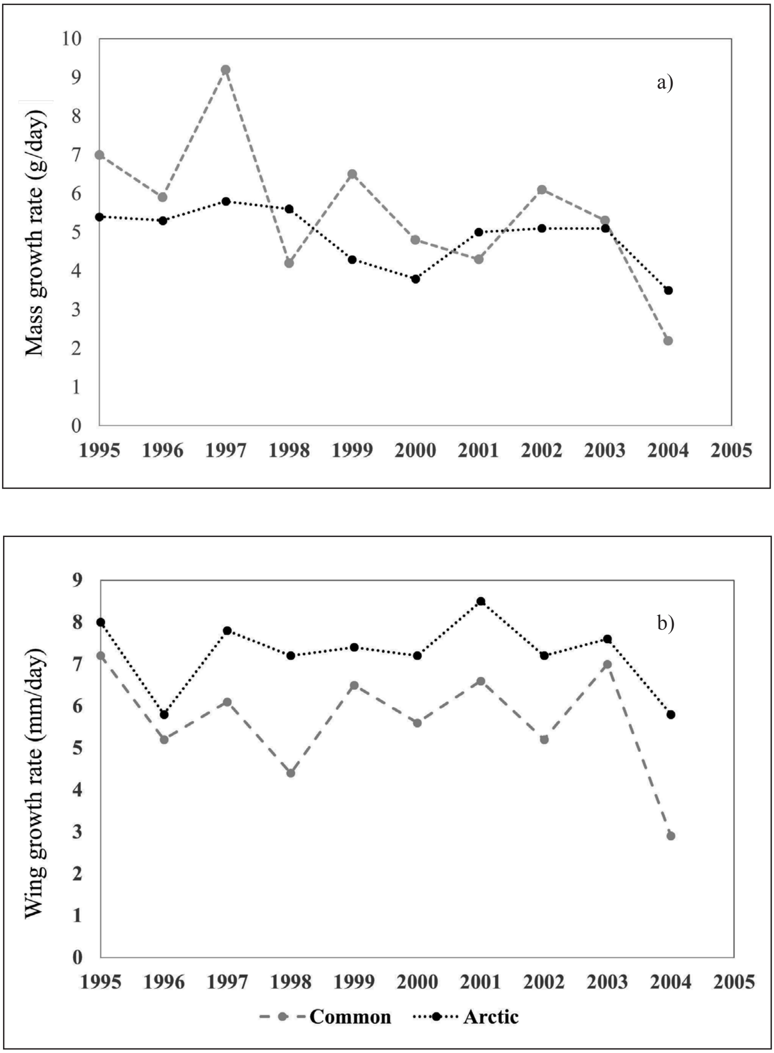


**Fig 10** Growth of tern chicks. a) Mass growth is similar in the two species, varying around 4-6 g/day for nine years before dropping sharply in 2004. b) Wing growth patterns are similar to those of mass, except that Arctic Tern chick wings consistently grew faster than Common Terns.

Steady growth continued at 4-6 g/day until 2004, when it dropped sharply in both species; in that year, chick diet contained few herring and many butterfish, whose deep body makes it too wide for chicks to swallow (Kress *et al.* 2016, Scopel 2021). Too few chicks survived in 2005 to provide comparable data.

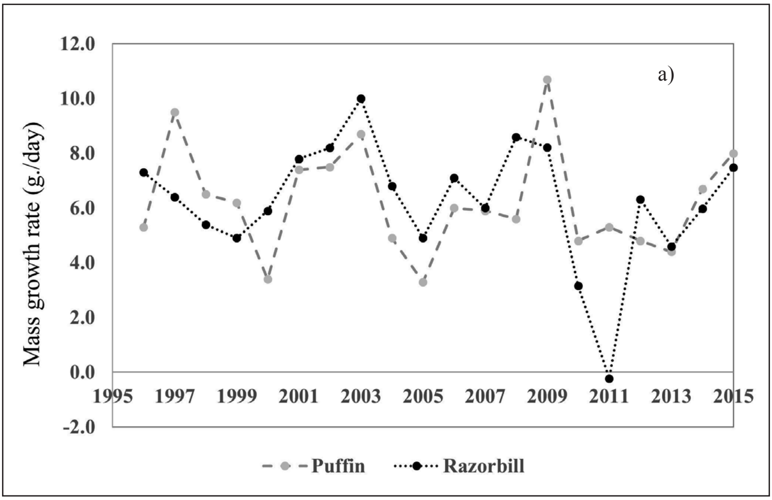
Wing growth shows a similar pattern, but whereas mass values were similar in the two species, Arctic Tern chick wings consistently grew faster than Common Terns, by about 1.5mm/day, despite adult wings of the two species being of very similar length.

***Auks*** (Fig 11). Chick wing growth was similar in Puffins and Razorbills, varying inter-annually between 2 and 3.5 mm/day, and dropping sharply from 2005-2007 to 2.25 - 2.75. Mass growth was much more variable in both species (3-10 g/day), but they varied together more closely than in wing growth, except in 2011 when both mass and wing growth declined sharply in Razorbills but not Puffins. Wing growth also declined sharply in 2013, the season following the "heatwave" summer of 2012, when growth was maintained in wing chord but not in mass.

The sharp decline in growth rates, in both terns and auks, in 2004-2006 coincided with the inflow of cooler, low-salinity, nutrient-poor water entering the GOM from increased melting in the Arctic, by way of the Labrador Current (Townsend *et al.* 2010), and subsequent changes to circulation in the GOM (Greene and Pershing 2007, Smith *et al.* 2012). The beginning of this cooler-water regime appears in the SST records at MSI, where the mean SST in July 2005 was slightly below the June value (Fig 3), a situation which has not recurred. We tend to focus on increasing SST in the GOM since around 2000, and especially since that cooling period, but in the MSI record, that sudden cooling (accompanied by low salinity and nutrient content) was more clearly reflected in the seabird responses (productivity as well as growth) than the heatwave year of 2012.

## Diet

The prey consumed by these seabirds was dominated by juvenile forage fish, some of which are subject to a commercial fishery. Juvenile abundance is commonly not measured by fisheries managers, so our results could contribute to fishery management (Amey 1998, Scopel *et al.* 2018).



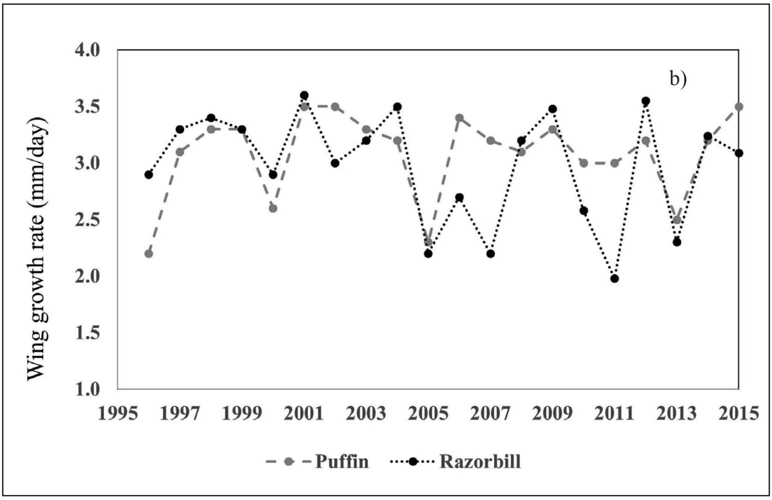


**Fig 11 Growth of auk chicks. a) Mass growth varies in parallel in the two species in most years, except 1997 and especially 2011. b) Wing growth patterns are similar to those of mass, but less variable among years. In 2013, wing growth declined more than mass growth in both species. An unusual increase in herring in 2009 was reflected in mass growth rate of Puffins but not Razorbills. The lowest growth rate in Razorbills (2011) was not paralleled in Puffins.**

Terns and auks carry food for their chicks in the bill. The mass of each item was calculated using its estimated length and published mass:length relationships (Scopel *et al.* 2018) to allow for the great variation in size of the various items, e.g., small euphausiid shrimp, which can be very numerous in some years but still contribute very little to the diet compared with a single large herring. Table 4 shows an example of the difference in proportions by number and by mass. These data have revealed clear differences in diet between species, and changes over time. Changes in diet are the most obvious responses to changes in the marine ecosystem and have revealed several "regime changes" as reflected in the prey field for MSI seabirds (Scopel *et al*. 2018), notably around 2000 and again in 2010 (Kress *et al*. 2016, Johnson *et al*. 2018).

***Arctic Tern.*** Both species of tern catch small prey at or within a few centimetres of the sea surface by shallow plunge-dives from the air. Changes in diet of both Arctic and Common Terns are described in detail by Scopel *et al*. (2018).

In the first few years of the study, diet was dominated by juvenile ("1-group" in fishery terminology) Atlantic herring (*Clupea harengus* Linnaeus, 1758) (Fig 12a), with much smaller proportions of butterfish *Peprilus triacanthus* (Peck, 1804)*,* sandlance *Ammodytes sp*., and white hake *Urophycis tenuis* (Mitchill, 1814), silver hake *Merluccius bilinearis* (Mitchill, 1814) and fourbeard rockling *Enchelyopus cimbrius* (Linnaeus, 1766). These last three species are difficult to distinguish in the field, at least in the size ranges taken by the seabirds, and are recorded in the field as 'hake'. After 2000,

**Table 4 Comparison of differences between % by number and % by mass in krill (euphausiid shrimp) in prey delivered to Arctic Tern chicks on Machias Seal Island.**

| Year | % by number | Number of samples | % by mass |
|---|---|---|---|
| 1995 | 0 | 97 | 0 |
| 1996 | 22.3 | 175 | 2.3 |
| 1997 | 10.0 | 209 | <0.1 |
| 1998 | 4.7 | 169 | 0 |
| 1999 | 0.5 | 208 | <0.1 |
| 2000 | 35.7 | 241 | <0.1 |
| 2001 | 0.5 | 588 | <0.1 |
| 2002 | 90.6 | 891 | 17.6 |
| 2003 | 65.9 | 414 | 1.4 |
| 2004 | 60.4 | 470 | 6.7 |

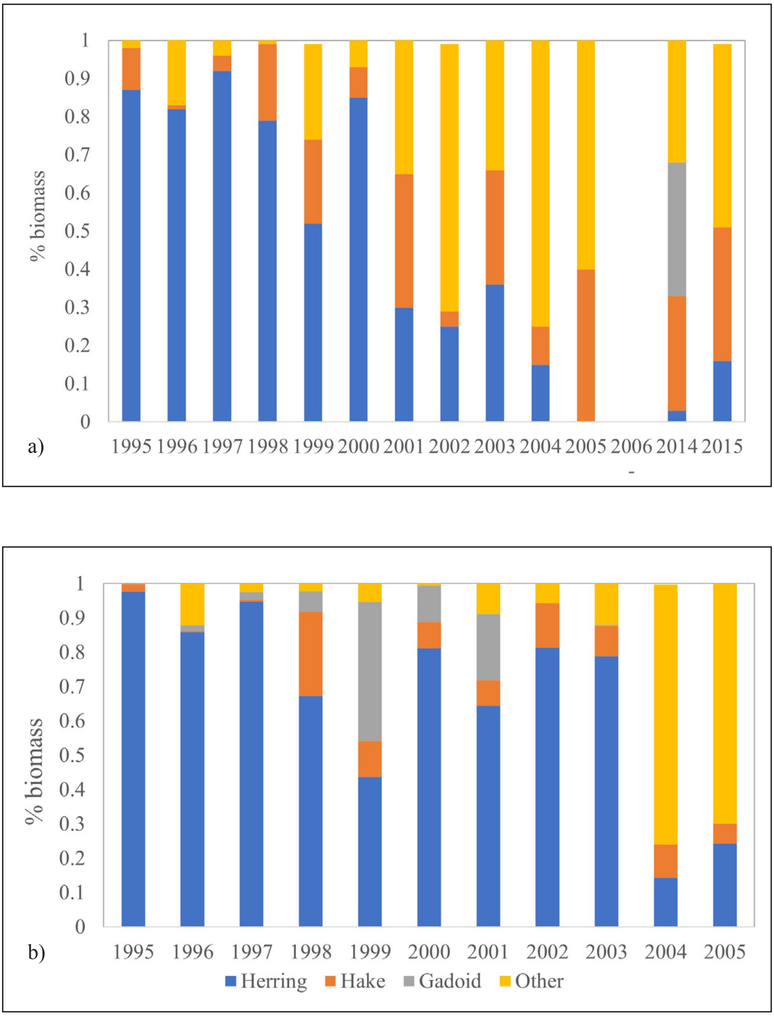


**Fig 12** **Proportion by mass of selected prey types in chick diet of a) Arctic Tern and b) Common Tern on Machias Seal Island, 1995-2015. No chicks hatched 2006-2013, and there were too few Common Tern chicks in 2014-15 to provide data. "Other" includes sandlance (usually larval), larval fish, marine invertebrates or krill (largely *Meganyctiphanes norvegica*), of little nutritive value, and butterfish which has high energy density but is too deep-bodied for chicks to swallow. Both tern species took mostly herring until 2001, when the proportion of herring in Arctic Tern diet declined sharply and remained low while continuing to contribute substantially to Common Terns diet through 2003. From L.C. Scopel (unpub. UNB data).**

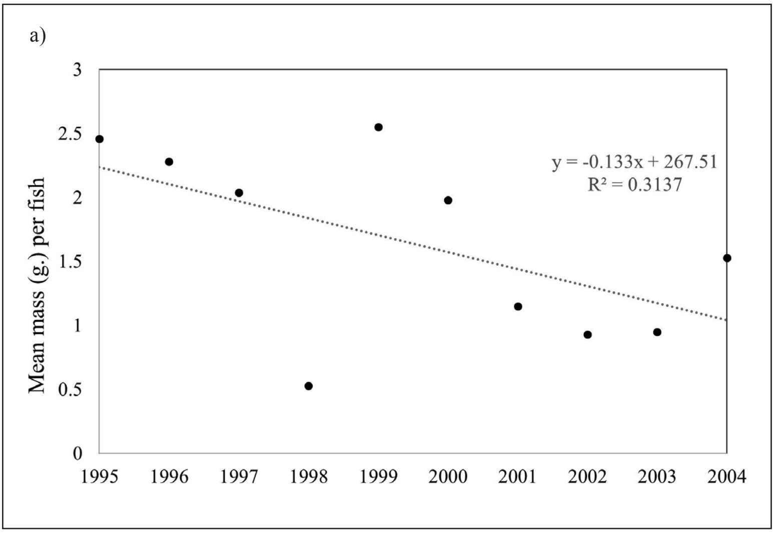
the proportion of herring declined quite sharply as more sandlance and "krill" (euphausiid shrimp, mostly *Meganyctiphanes norvegicus* (M. Sars, 1857)) and hake were taken; in 2005 there were no herring at all in chick diet, though there were few samples that year because many chicks died in prolonged rain. The rate of delivery of herring in the diet (Fig 13a) also declined after 2000, due only partly to a reduction in the size of the fish (Fig 13b); in 1999 and 2000, the rate of delivery declined while the size of herring did not, suggesting that reduced numbers of herring were mainly responsible for the decline in delivery rate, while from 2001 onward, the size and delivery rates were both reduced. There were no diet data after the collapse of the colony in 2006 because very few chicks hatched until 2014, and samples were small in that year and the next.

***Common Tern.*** Common Terns are about 10% heavier than Arctic terns, but otherwise the species are very similar in appearance and nesting and feeding behaviour. The temporal decline of herring in the chick diets of the two species is roughly parallel, though in most years Common Terns had a higher proportion of herring than Arctic Terns, and much less hake; the species replacing herring in Common Tern diet were butterfish and pollock, rather than hake and krill (Fig 12b).

***Atlantic Puffin.*** Changes in diet in Puffins, Razorbills and Murres are described in detail in Scopel *et al.* (2019). Here I compare broad patterns in Puffins and Razorbills (Fig 14).

Puffins are "pursuit-divers", i.e., they dive below the surface and chase down their prey using the wings – they "fly through the water". Adults bring several juvenile forage fish, usually below 16cm long, squid, and invertebrates especially krill, back to the burrow to feed the chick. They are known for carrying multiple prey items at the same time ("multiple-prey loaders"), in contrast with terns that usually bring one item at a time ("single-prey loaders").

The range of prey taken by Puffins (Fig 14a) is similar to that of terns and also showed declines in herring in the early 2000s; 2009 was an exception to this trend but has not been repeated. Hake and sandlance have also been prevalent in the diet since the late 1990s, joined in 2010 by juvenile haddock (*Melanogrammus aeglefinus* (Linnaeus, 1758)) which have been the commonest prey item in several later years.



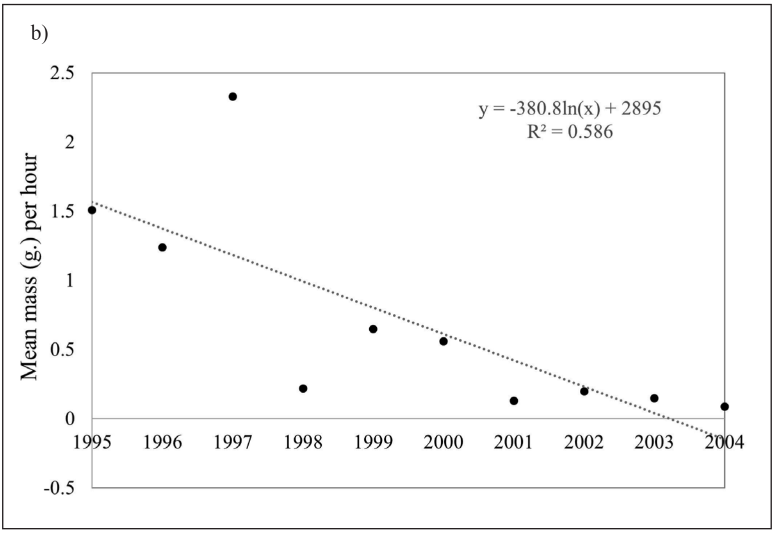


**Fig 13 a) Decline in the size of juvenile herring delivered to Arctic Tern chicks on Machias Seal Island, 1995-2004. b) Decline in the rate of delivery of herring. The highest rate of delivery by far was in 1997 when the prey size was average, suggesting prey was easy to find; and in the year with the largest prey (1999) the rate of delivery was slightly below average, so the herring were presumably less easily caught. The slope in (b) is almost three times steeper than in (a), showing that availability of herring declined more steeply than the size. Data from Lauren Scopel (unpublished UNB data).**

Our diet data come from prey brought to chicks, and there is uncertainty about the extent to which diet of chicks resembles adult diet. Kirsten Bowser explored this topic in Puffins using DNA barcoding of feces of both adults and chicks (Bowser *et al.* 2013), and found no significant difference between adult and chick diets in the year of field-work (2009). However, 2009 happened to be an exceptional year with a higher proportion of herring in chick diet than any year since 1995. There was no significant difference between the proportion of herring measured by the usual observational method, and the frequency of herring DNA detected in chick feces, a reassuring result that needs to be repeated in a year with a more varied diet.

***Razorbill.*** Razorbills are also pursuit-divers, but are over 60% heavier than Puffins. They carry fewer prey items than Puffins, but are still multiple-prey loaders at this colony. They take larger items than Puffins, and more herring (Fig 14b); annual proportions of herring in chick diet are always greater in razorbills than in Puffins. Razorbills take a smaller variety of prey taxa than Puffins, *i.e.*, their diet is more specialised but they sample the same prey field.

***Common Murre.*** Murres are the largest alcids at this colony, weighing 40% more than Razorbills and twice as much as Puffins. They are pursuit-diving single-prey loaders; we have diet data from only three years in this period (2013-15), but these show more herring and gadoids than Razorbills and Puffins (Scopel *et al.* 2019). The most striking dietary difference was in 2015, when Puffins and Razorbills took many sandlance but Murres took mainly herring, gadoids, butterfish and squid, but no sandlance. In all three years, Murres also took rock eel (*Pholis gunnellus*) which rarely shows up in the diet of other seabirds on MSI. The presence of this species in Murre diet reflects benthic feeding, common in murres elsewhere (Ainley *et al.* 2020).

## Ecological segregation

Differences in diet among these three auks, with similar feeding methods, sharing the same colony and surrounding waters, raise several obvious questions in the framework of competitive exclusion theory. Do they in fact hunt in the same oceanographic zones? Or at the same depths? At the same time of day? We have started

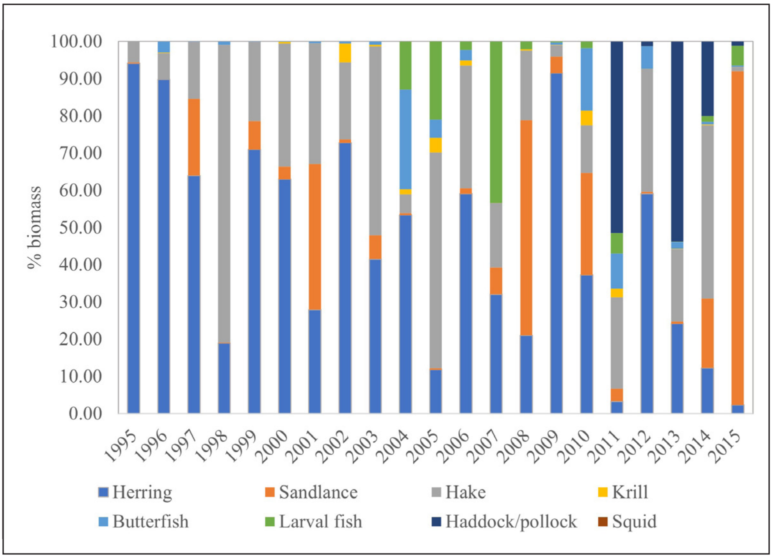


**Fig 14a Percent by mass of prey types delivered to puffin chicks on MSI, 1995-2015. From L.C. Scopel (unpub. UNB data). "Other" includes sandlance (usually larval), larval fish, marine invertebrates or krill (largely *Meganyctiphanes norvegica*), of little nutritive value, and butterfish which has high energy density but is too deep-bodied for small chicks to swallow.**

to address these questions by tracking movements of Puffins and Razorbills when feeding chicks, using GPS transmitters attached to the back of adults using tape and/or zip-ties. This was Stephanie Symons' Master's project, carried out in 2014 and 2015 (Symons 2018, Symons and Diamond 2019). The tags weighed less than 3% of body weight to minimise negative effects on the bird (Kenward 2001; also see Vandenabeele *et al*. 2012).

First, Razorbills and Puffins foraged in mostly different waters, Razorbills in shallow waters (mean depth 30 m) off the coast of Maine to the northwest of MSI, and off the south coast of Grand Manan Island to the east, and Puffins in deeper water (mean 104m) to the south and southeast of MSI, some as far as south of Brier Island, NS. They overlapped, inevitably, mainly in the 10 km or so immediately around the island. Second, the biggest surprise was in the depths to which they dived, Puffins somewhat (but not significantly) deeper (17.1 ± 11.5 m) than Razorbills (11.1 ± 7.1 m), in contravention of a generalisation among seabird biologists that

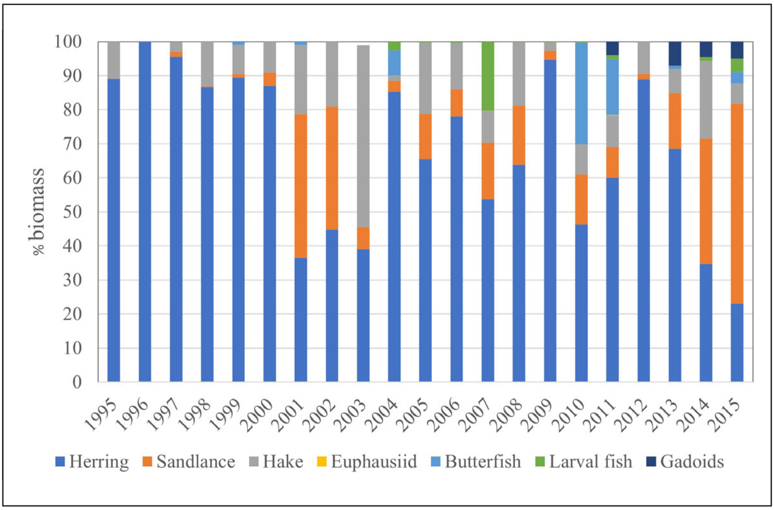


**Figure 14b** **Percent by mass of prey types delivered to Razorbill chicks on MSI, 1995-2015. "Other" includes sandlance (usually larval), larval fish, marine invertebrates or krill (largely *Meganyctiphanes norvegica*), of little nutritive value, and butterfish which has high energy density but is too deep-bodied for small chicks to swallow. Gadoids were mostly haddock *Melanogrammus aeglefinus* after 2010. From L.C. Scopel (unpub. UNB data).**

dive depths increase with body size in auks (Watanuki and Burger 1999). A reversal of expected dive depths has been found in these two species where they coexist elsewhere (Labrador – Pratte *et al.* 2017, and Wales – Shoji *et al.* 2015); in both cases, Puffins fed in deeper water than Razorbills, for whatever reason. Third, the two species both showed peaks of diving activity in the early morning (5-7 am) and late evening (7-9 pm), suggesting no obvious segregation in feeding times and a shared concentration of feeding at times of vertical migration of plankton and planktivores. Razorbills dived more than twice as often in a day as Puffins (661 vs. 290 dives/day), reflecting their larger body size and need for self-feeding. Feeding Puffins ranged on average twice as far from MSI (38 km) as Razorbills (19 km).

An unwelcome but important finding in Stephanie Symon's study was that birds were unlikely to bring prey to their chick while carrying a tag, meaning that the diving locations recorded by the tag were for feeding the adult itself, not the chick (Symons and

Diamond 2019). The technology is moving fast though, and it would now be possible to repeat the study using devices that do not affect the behaviour of the bird (Fayet *et al.* 2021).

## Seabird diet and the herring fishery

Diet is evidently an important contributor to ecological segregation between Puffins and Razorbills. The other reason that we measure it is for possible insight into what it tells us about the availability of juveniles of commercially-exploited fish, especially herring. MSI's first graduate student, Krista Amey, devoted her thesis to exploring possible relationships between the proportion of herring in tern diet, and catches of juvenile herring in the weirs around Grand Manan. Because the terns eat herring too small to be caught in weirs (so-called 1-group herring, i.e., in the first calendar year after spawning), and weirs catch herring aged two years or more, Krista found a significant correlation between the proportion of herring in Arctic Tern diet and total catch of herring in the weirs two years later (Amey 1998). Although suggestive, the link disappeared in later years when the herring content of Arctic Tern diet declined steeply as both size (Fig 11a), and especially availability (Fig 11b), of herring declined; the herring weir fishery declined rapidly over the same period (DFO 2018).

More recent exploration of possible links between seabird diet data and herring fishery data by Lauren Scopel extended to include all of the seabird colonies of the Gulf of Maine as far west as Stratton Island (70.31W – Fig 1), and Arctic and Common Terns, Puffins and Razorbills. Scopel *et al.* (2018b) found several correlations between seabird and fishery data that suggested considerable spatial stratification of herring stocks as reflected in colony location. Perhaps most surprising, seabird diet data suggested that juvenile Bay of Fundy herring migrate with the Maine Coastal Current to the western seabird colonies in the Gulf of Maine, returning to the Bay of Fundy three years later. A similar pattern was proposed by Tupper (1998). Scopel also found stronger correlations of seabird diet data with some fishery measures, such as from acoustic surveys, than with the metrics commonly used in stock assessments, suggesting that the latter might not be the best fit for purpose. Correlations between mobile-gear landings and diets of Common Terns, Puffins, and Razorbills suggest that the seabirds select herring preferentially, as the fishery does, emphasising the need for managing herring fisheries with the needs of these predators in mind (i.e., truly ecological-based fishery management (EBFM)).

Seabirds are commonly overlooked as predators by fishery biologists and managers, probably because they take a much smaller proportion of a fish stock than larger and more abundant predators such as other fish, and often prey on species that are fished lightly or not at all (Cairns *et al.* 1991); seabird consumption is often no threat to the human harvest. However, forage fish such as herring are critical to the reproductive success and survival of seabirds. This is true also at the global scale, where Cury *et al.* (2011) found that seabird reproductive success declined when the stock of forage fish on which they depended declined below one-third of the maximum long-term biomass of the stock. Both the Bay of Fundy and Gulf of Maine herring stocks have been below that threshold for most of our study.

### Winter distribution

One of the most exciting changes in technology over the lifetime of this study has been the appearance of diminutive digital devices for tracking movements of birds (Bridge *et al.* 2011). The GPS devices revealing the movements of Puffins and Razorbills, described above, have revolutionised our understanding of the lives of these birds in summer. But older (radio) technology has its uses too, and we took advantage of that to pursue mounting evidence that MSI Razorbills not only spent much of the winter in the Bay of Fundy, but were joined there by Razorbills from other colonies further north in Canada. This started with old-fashioned visual observations by Brian Dalzell of Grand Manan, and Ph.D. student Falk Huettmann, in the late 1990s. Brian's count of about 25,000 Razorbills off White Head Island, Grand Manan, in February, 1997, prompted Falk to organise regular counts by my lab from land and sea around Grand Manan in winter 1997/98. Together these proved that far more Razorbills used this area in winter than could be accounted for by the few hundred pairs (then) breeding at MSI and the Yellow Murre ledges nearby. We suggested that the Grand Manan area was an important wintering site for all North American Razorbill colonies, especially the Old Proprietor Shoals to the south-east and Long Eddy off the north end (Huettmann *et al.* 2005).

Notwithstanding the strength of these observational findings, scientists seem to find technological results more convincing than mere observation, so M.Sc. student Travis Clarke tried to confirm whether Razorbills from more distant colonies were indeed travelling to the Grand Manan area in winter. The largest colonies of Razorbills in Canada are in the Gulf of St Lawrence and in Labrador, so these were the focus of tracking efforts in summer 2007. Travis attached radio transmitters to plastic bands on Razorbills breeding on the Gannet Islands, Labrador, and colleagues from Quebec did the same on Corossol Island in Quebec, while the MSI crew equipped breeders on MSI. In the following winter, Travis listened for signals from those radios from a light aircraft flying over the seas around Grand Manan, and detected signals from birds from all three origins, confirming that at least some birds from all those colonies spent part of the winter in the Bay of Fundy (Clarke *et al.* 2010). This result is of considerable conservation importance for the species, showing that the outer Bay of Fundy is an important wintering area for the entire continental population, adding another dimension to the importance of a region already recognised for hosting long-distance migrants from as far away as Europe and the South Atlantic during summer (Diamond 2012).

## CONCLUSIONS

### Environmental change

Two years, 2006 and 2012, stand out as warmer than any during the previous decade. 2006 ended a short period of cool, fresh, nutrient-poor water entering the region via the Labrador Current, fed by increased melting of arctic ice (Townsend *et al.* 2010, Smith *et al.* 2012), and included the warmest SST yet measured followed by a sharp decline in the productivity of Puffins and Razorbills. 2012 was the first “marine heatwave” (five days of temperature above the 90th percentile of the day-specific climatology – Hobday *et al.* 2016) recorded in the region, with the annual SST 2 °C above the 1982-2011 average (Mills *et al.* 2013). Among a variety of sudden and unanticipated effects on the marine ecosystem of the Gulf of Maine, including record landings of lobsters and a consequent collapse in prices (Pershing *et al.* 2018), were negative consequences for seabirds, first in winter (Diamond *et al.* 2020) and the following breeding season (especially Puffins - Scopel *et al.* 2019). Productivity of Puffins on MSI was normal in 2012 but declined drastically the following year, probably because the SST anomaly which began in summer 2012 lasted throughout the following winter, implicated in the first known “wreck” of Puffins at Cape Cod, MA, and much larger wrecks of Razorbills (Diamond *et al.* 2020) and demonstrably poor condition of Puffins starting the 2013 breeding season (Scopel *et al.* 2019). In Puffin colonies further south in the Gulf of Maine, breeding success was severely affected in both 2012 and 2013 (Kress *et al.* 2016).

The SST in the Gulf of Maine has been increasing ten times faster since 2004 (0.26 °C/year), than in the previous 30 years (0.026 °C/year) (Mills *et al.* 2013), though this rapid increase is amplified by starting in the unusually cool years of 2004-2006. Model projections over the rest of this century suggest that from 2070 onwards, annual SSTs in every year will be higher than the warmest year in the period 1976-2005 (Alexander *et al.* 2018). The effects of the marine heatwave of 2012 are thus likely to become the norm well before the end of the century.

### Population trends

The rapid increase in Razorbills, and rapid increase following colonisation of Murres, both cold-water species, was unexpected in a fast-warming ocean, particularly in comparison to the stability of Puffin numbers; these three species co-exist widely throughout their North Atlantic ranges and would be expected to show similar population trends. The general hypothesis that cold-water species should respond negatively to a warming ocean – especially at the southern limit of their range, where SSTs are warmer than anywhere else in their range – is supported in short-term demographic responses such as reduced occupancy and productivity, but not in population decline. Increasing populations of Canadian Razorbills and Murres are generally treated as delayed responses to protection from the Migratory Bird Act of 1918 (Gaston *et al.* 2009), but that was over 100 years ago, and a more recent factor seems necessary. One candidate is the closure of the cod fishery in Newfoundland in 1992; this fishery used to kill thousands of auks in gillnets around breeding colonies in Newfoundland, and populations of Razorbills, Puffins and Murres have increased significantly following the closure (Regular *et al.* 2013). Newfoundland and Labrador hold the largest numbers of all three species in Atlantic Canada, so we suggest that increased survival there has supplied recruits to the Bay of Fundy, at least in Razorbills; the nearby colony of Murres on Yellow Ledge, where 424 individuals were counted in 2001 (Ronconi and Wong 2003), are a likely source of the colonisation of MSI by this species. It may not be coincidental that the relative percentage increase in these three species in Newfoundland colonies (Puffin < Murre < Razorbill) is the same as on MSI. The stability of the Puffin population on MSI is possibly due to the population reaching carrying capacity here; Razorbills and Murres may be close to that capacity too, as suggested by a few Razorbills taking over former Puffin burrows in recent years (A.W.D., pers. obs.) and the stable numbers of breeding Murres.

The overall metapopulation of Arctic Terns in the Bay of Fundy/ Gulf of Maine has declined since 2006, by about the same number as used to nest on MSI prior to the collapse of the colony, illustrating the importance of the largest colony to the whole metapopulation. Nest success (productivity) of the terns at MSI has consistently been lower than on other islands in most years (Devlin 2006, Devlin *et al.* 2008) and the colony has acted, in terms of "source-sink dynamics" (Pulliam 1988), as a sink rather than a source despite being the largest colony by far until the mid-2000s (Scopel 2021).

### Ecosystem-indicator implications

Arctic and Common Tern numbers and productivity were poor indicators of bottom-up environmental change because of predation by gulls (Scopel and Diamond 2018, Scopel *et al.* 2018), i.e. top-down pressures. Gull predation is no doubt also subject to bottom-up influences, and the complexities of this relationship are under more detailed investigation by Scopel (2021). However, data on chick diet show considerable promise for assessing recruitment potential in forage-fisheries including herring (Scopel *et al.* 2018) and Acadian redfish (*Sebastes fasciatus*) (Depot *et al.* 2020).

The increase in numbers of two of the auks suggests improving environmental conditions, but as argued above, the population trends are more likely the delayed result of fishery closures far to the north, in Newfoundland. Further, several important environmental changes have been recorded at MSI including in SST and rainfall (Major *et al.* in press), accompanied by declines in several demographic parameters of Razorbills and Puffins

(Scopel *et al.* 2019). These changes, together with the increase in poor-quality prey (Scopel *et al.* 2018, 2019, Depot *et al.* 2020), suggest significant regime shifts in the Bay of Fundy and Gulf of Maine in 2005 and again in 2010, with negative consequences for the auks which are not reflected in recent population trends but are clear in annual monitoring of breeding success (Kress *et al.* 2016, Scopel *et al.* 2018, 2019).

## Conservation implications

As the most diverse seabird colony in the Maritimes, and a federally-designated Migratory Bird Sanctuary and nationally-recognised Important Bird Area (#NB019), there is obvious conservation interest in keeping this colony in a healthy condition. Regular population counts track the size of the colony, but seabirds are long-lived (up to 40 years) and, since each bird needs to produce only one offspring surviving to breeding age over its lifetime to maintain a stable breeding population, many years of failed breeding must occur before any decline is detected in the numbers of adults. Preserving the viability of a seabird community requires advance notice of emerging problems. Negative impacts of climate (or any other) change will show up sooner in such measures as low clutch size, poor breeding success, and reduced chick growth, acting as early warning signs of difficulties long before they become obvious in terms of population size. These signals are now clear in the seabirds of Machias Seal Island, beginning in the early 2000s and especially after the regime shift in 2005.

Overall, I conclude that these early warning signs of impending population decline have been clear in MSI seabirds since about 2005, in contrast to the stable or increasing populations of the three species of auk. The vulnerability of terns to predation by gulls makes their demographics unsuitable as indicators of ecosystem change, but the diets of four species (two auks and two terns) agree in suggesting a decline in availability of juvenile herring since the late 1990s and their replacement by a poorer-quality diet.

## Future prospects

This paper focuses on easily-measured responses of seabirds to changes in weather, oceanographic conditions, and food supply, and confirms that variables such as occupancy, clutch size, breeding success and chick growth do indeed reflect such changes, as proposed long ago by Cairns (1987). By collaborating with researchers elsewhere in the Gulf of Maine region, spatial differences in these responses, and oceanic conditions, are also becoming clearer (Scopel *et al.* 2018, 2019; Depot *et al.* 2020). But as Cairns (1992) also pointed out, population changes of long-lived species such as seabirds respond more to changes in adult survival and recruitment than to these within-season variables. The banding and resighting program on MSI provides such data (Breton *et al.* 2006b, Breton & Diamond 2014, Devlin *et al.* 2008, Lavers *et al.* 2007, 2008a,b), but we have not been reporting on it annually despite annual changes revealing sometimes important fluctuations, such as in Puffins in relation to herring abundance (Breton & Diamond 2014), and reduced survival of juvenile Razorbills from a mass mortality event (Diamond *et al.* 2020). Survival estimates are currently being updated for Arctic Terns by Scopel (in progress) and Puffins and Razorbills by Durham (in progress), but devising a protocol to allow annual reporting of survival and recruitment should become a priority.

Another important feature of seabird biology that is becoming practicable to investigate using miniaturised digital technology is movement, both within the breeding season and outside of it. Symons (2018) has explored the former in Puffins and Razorbills, and Baran (2019) for Puffins and Dodds (in prep.) for Razorbills have documented winter movements. Other seabird tracking studies (Fayet *et al.* 2017, Dias *et al.* 2011) have shown important differences between individuals wintering in different areas, and differences between years, so winter tracking, like survival estimates, should probably be incorporated into regular monitoring, now that research projects have shown their potential value.

Long-term studies of auk biology at colonies elsewhere, notably at the Isle of Man off Scotland (Frederiksen *et al.* 2004), Triangle Island off the British Columbia coast (Hipfner *et al.* 2020), and Hornøya in Norway (Barrett 2015), have recorded changes in breeding success and diet comparable to those that we have seen on MSI. This confirms the value of such work not only to seabird conservation but also towards a more holistic perspective on changes in the ocean ecosystem. It bodes well that annual research and monitoring of seabirds on MSI continues under the supervision of Prof. Heather Major of UNB Saint John.

*Acknowledgements* Funding for this work was provided by NSERC, Environment and Climate Change Canada, Science Horizons Programme, Canadian Wildlife Service (Atlantic Region), Sir James Dunn Wildlife Research Fund, New Brunswick Wildlife Trust Fund, and Connors Bros. Ltd. Research and sanctuary permits, and accommodation, were from Canadian Wildlife Service (Atlantic Region), access permits from Department of Fisheries and Oceans, and Animal Care permits from University of New Brunswick Animal Care Committee. Tour boat captains Andy Patterson (Cutler, ME) and Peter Wilcox (Seal Cove, Grand Manan) supported crews with access and delivery of supplies. The data reported here were collected by many dedicated graduate students and assistants: Krista Amey, Bridget Morrison, Sue Tattersall, Kate Devlin, Laurel Bernard, Chantal Gagnon, Dedreic Grecian, Becky Manley, Amey Black, Sarah Dauncey, Mathieu Charrette, Laura Minich, Katie Pindell, Alex Bond, Sara Fraser, Travis Clarke, Gabrielle Bouchard, Emily Hines, Robin MacNearney, Kirsten Bowser, Manuel Ballasteros, Emily Tompkins, Kevin Kelly, Catherine Jardine, Bryan Martin, Erin Whidden, Rebecca Standen, Alys Granados, Bryan Koval, Lauren Scopel, Sydney Sheedy, Caitlin Smith, Linda Takahashi, Kate Shlepr, Stephanie Symons, Stefanie Collar, Jennifer Symons, Michelle Valliant. Several island caretakers hired by CWS have also contributed significantly to data collection, including Jason Hudson, Peter Bohan, and Colin Buhariwalla, and light-keeper Ralph Eldridge was a frequent contributor to tern census work.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 411-442

# CLIMATE CHANGE IN NOVA SCOTIA: TEMPERATURE INCREASES FROM 1961 TO 2020

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## ABSTRACT

An analysis of temperature in Nova Scotia, using climate normals for 1961-1990 and temperature records from 1961 to 2020, is presented for 16 sites across the province. These records show a slight warming trend in the first 40 years from 6.0 ± 0.5 °C (1961-1990), followed by a more significant increase in average temperature post-1990 of 1.0 °C to 6.7 ± 0.5 °C, and to 7.0 ± 0.5 in the post-1998 period. A jump in average temperature in 1998 is such that in only a few following years did the mean annual temperature fall below the average annual temperature for the previous period. A step change was coincident with La Niña events and increasing Atlantic Ocean temperatures associated with a shift of the Atlantic Multi-decadal Oscillation into a positive phase. The increase in mean monthly temperatures was more apparent in the Autumn when first frosts were later and there were fewer days with frost. This led to a significant increase in continuous frost-free days of 9.2 ± 7.9 days, with increases ranging from 0.4 to 30.6 days. Relative to other sites, Yarmouth had the smallest annual increase in mean temperature, of 0.5 °C, but this was associated with a major increase in continuous frost-free days, of 11.3. Because overall temperature change was based largely on a step change post-1998, rather than a continuous, gradual change (seen only in frost-free days), it is difficult to calculate a rate, or to predict future patterns of temperature increases. We suggest a significant influence of El Niño Southern Oscillation and Atlantic Multi-decadal Oscillation as potential contributors to the temperature increase. Increases in annual temperature and seasonality are discussed in terms of flowering phenology, including flowering in the Spring of 2021 when 31 species were blooming by the end of April.

Keywords: climate change, climate normal, flowering phenology, Nova Scotia, temperature, weather

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## INTRODUCTION

Climate warming is a global phenomenon that, since the industrial revolution, has been driven by human activity, in particular the burning of fossil fuels (e.g., Bush *et al.* 2014, IPCC 2014, 2018, 2019, Walsh *et al.* 2014, Su *et al.* 2017, Cheng *et al.* 2020, Masters 2020, NOAA 2020). The warmest years on human record have been recorded in the last decade, with 2020 tied with 2016 as the warmest (Voosen 2021). In the marine realm, each year has resulted in temperature increases on an annual basis (Cheng *et al.* 2020). These changes have been reflected in increases in temperature in both air and water, with the most dramatic changes occurring in polar regions with loss of sea-ice cover, reduction in permafrost and glacial cover, and rises in sea level (e.g., Chasmer and Hopkinson 2016, Mikkelsen *et al.* 2016, Ding *et al.* 2017, and references therein).

While climate warming associated with increasing temperature is clearly occurring on a global scale, it is important to determine whether the patterns observed on such a scale are actually occurring locally, and the extent to which global changes are being either exacerbated or moderated based on local patterns of geography in both terrestrial and aquatic realms. Vincent *et al.* (2013) examined climate change in Canada from 1950 to 2010 and showed an overall temperature increase of 1.5 °C. Garbary (2018) analyzed climate change in Prince Edward Island (PEI) using historical climate data from the Government of Canada, based on three primary sites with relatively complete datasets and numerous secondary sites with incomplete data series for 1961 until 2016. The principal findings included a temperature rise of about 1 °C with an apparent step change in the late 1990s. In this paper, we focus on Nova Scotia. While some of the results that we report have been described and are publicly available (e.g., climate change.novascotia.ca), in this paper we use the underlying data in the public record (i.e., climate.weather.gc.ca), focus on a 60-year timescale from 1961 to the present, and use a simple method that facilitates replication without access to complex modelling or statistics. In addition, the evaluations of current climate and predictions used by Climate Nova Scotia are based on a model last revised in October 2006 (Lines *et al.* 2006), and it does not include empirical data from the last 14 years. Thus, our analysis provides a more comprehensive perspective on the last 60 years.

Because Nova Scotia (NS) is largely surrounded by the Bay of Fundy/Gulf of Maine and the open Atlantic Ocean, that are warmer in Winter and cooler in Summer than the Gulf of St. Lawrence, differences in temperature change might be expected between NS and PEI. Hence, we ask the following questions with respect to NS:

(1) Has there been significant temperature increase and is it comparable to that in PEI?

(2) If so, are the temperature increases distributed evenly over the entire year, or are particular months or seasons more generally impacted?

(3) Are there regional differences in climate change in NS that can be associated with particular oceanographic phenomena?

(4) To what extent is temperature change in NS consistent with global trends?

(5) Is the scale of any temperature change likely to have important ecological or agronomic consequences (e.g., length of growing season)?

Changes in temperature in Nova Scotia are discussed in the context of the oceanographic features El Niño-Southern Oscillation (ENSO) and Atlantic Multidecadal Oscillation (AMO) that affect global weather patterns on timescales from months to decades (e.g., McPhaden *et al.* 2006). As plant biologists, we use the temperature record to explain the unusual flowering phenology observed in Nova Scotia since the beginning of the century associated with late flowering into December and even January (e.g., Garbary *et al.* 2011).

## MATERIAL AND METHODS

This work follows the analysis by Garbary (2018) on temperature change for Prince Edward Island (PEI) and applied here to Nova Scotia (NS). The previous study used three sites in PEI (Charlottetown, New Glasgow, Alliston) for which relatively complete datasets were available, and a suite of secondary sites for which data were more fragmentary. Our dataset used 16 (or 14, depending on data availability) sites in NS with relatively complete weather data (Table 1). All data were extracted from the official website of Environment Canada (https://climate.weather.gc.ca/index_e.html). Changes in annual mean temperature and monthly mean temperature compared climate normals (i.e., CN – the 30-year averages) for

**Table 1** Locations of sites in Nova Scotia used in analysis of temperature change. Source: climate.weather.gc.ca/index_e.html. See Fig 1 for approximate locations of sites based on abbreviations in column one.

| Site name (Climate ID Station number); abbreviation | Location | Elevation (m) | Comments |
|---|---|---|---|
| Bridgewater (8200600); BR | 44°24'N, 64°33'W | 27.4 m | Missing data: 2007, 2010-2012, 2015-2020 |
| Cheticamp; Cheticamp CS (8200825; 8200827); CH | 46°39'N, 60°57'W; 46°38'42"N, 60°56'50"W | 11.0 m, 43.9 m | Combined data from 2 sites: 1961-1990, 1998-2019 |
| Collegeville; Collegeville Auto (8201000, 8201001); CO | 45°20'N; 62°01'W;<br>45°29'28"N; 62°00'54"W | 76.2 m, 69 m | Changed location of weather station 2016 |
| Deming (8201410) DE | 45°12'59"N; 61°10’40"W | 15.8 m | Data missing 2009-2020 |
| Greenwood A (8202000); GR | 44°59'N; 64°55'W | 28 m | Complete dataset |
| Halifax Stanfield Int’l Airport (8202250, 8202251); HA | 44°52'48"N; 63°30'W; 44°52'52"N; 63°30'31"W | 145.4 m, 145.4 m | Data missing for 2003 |
| Kejimkujik Park; Kejimkujik 1 (8202590, 8202592); KE | 44°26'N; 65°12'W; 44°24'11"N, 65°12'11"W | 126.8 m, 125.0 m | Data missing for 1961-1965; Changed weather station location 1994 |
| Middle Musquodoboit (8203535); MM | 45°04'N, 63°06'W | 47.8 m | Extensive gaps 2006-2019 |
| Nappan CDA; Nappan Auto (8203700, 8203702); NA | 45°46'N, 65°15'W; 45°45'34"N, 64°14'29"W | 19.8 m, 19.8 m | Changed station location 2005 |
| Parrsboro (8204400, 8204402); PA | 45°24'N, 64°20'W; 45°24'48"N, 64°20'46"W | 24.3 m, 30.9 m | Data gap 2002-2004 |
| Shearwater (8205090, 8205092) | 44°38'N, 63°30'W; 44°37'47"N, 63°30'48"W | 44 m, 24 m | Data gap 2006-2008 |

*Table 1 cont'd*

| Site name (Climate ID Station number); abbreviation | Location | Elevation (m) | Comments |
|---|---|---|---|
| St. Margaret's Bay (8204800); ST | 44°42'N, 63°54'W | 17.4 | Large data gaps in 2006, 2007 |
| Sydney Airport (8205700, 8205701); SY | 46°10'N, 60°02'53"W; 46°09'41"N, 60°02'53"W | 61.9 m, 61.9 m | New station begins 2014 |
| Western Head (8206240); WH | 43°59'24"N, 64°39'51"W | 10.1 m | Missing data 1976-1995 |
| Yarmouth Airport (8206495, 8206496, 8206500); YA | 43°49'37"N, 66°05'17"W;<br>43°49'51"N, 66°05'19"W | 42.9 m, 43 m | Dataset complete |

1961-1990, for each location, with subsequent weather data based on monthly means. Further analyses used the weather data from 1961 to 2020 to determine the following: (1) number of frost days (i.e., with minimum daily temperatures below 0.0 °C) between March and June; (2) number of frost days between September and December; (3) number of days until last frost after 01 April; (4) number of days until first frost after 01 September; and (5) number of continuous frost-free days during Summer. These metrics allowed us to evaluate the extent to which temperature has changed in the last 30 years relative to the previous 30 years and to discuss these changes in the context of the wild flora of NS.

None of the datasets for any site were complete. Gaps varied from missing days to missing months, to one or more missing years of data (e.g., Halifax Airport for 2003; see Table 1). In that case, 2003 was omitted from the analysis. When mean monthly temperatures were missing for four or more months, that year was omitted from the calculation of mean annual temperature, although the remaining data might be used for other metrics (i.e., dates of last and first frost). To fill in blanks, several strategies were implemented. For years with up to three missing monthly means, the missing values were estimated as the means of that month for the two previous years. To avoid a potential bias towards our conclusion of climate warming, we treated missing data for the period 1961-1990 (i.e., the climate normal) and our test period (i.e., 1991-2020) differently. Thus, in the period of the climate normal, missing daily data for March-April and November-December were counted as non-frost days. During the 1991-2020 period, missing data in March-April and November-December were counted as frost days. Missing daily data in May-June and September-October were counted as frost or non-frost days based on temperatures for adjacent values in the month.

### Sites

Sites used in the analysis were based on the availability of data rather than on preselected criteria. These sites (Table 1, Fig 1) span almost three degrees of latitude from Cheticamp in the north (46°39'N) to Yarmouth Airport (hereafter Yarmouth) in the south (43°49'N), and six degrees of longitude from Sydney Airport (hereafter Sydney) in the east (60°02'W) to Yarmouth in the west (66°05'W). Elevations ranged from 10.1 m (Western Head) to 145 m

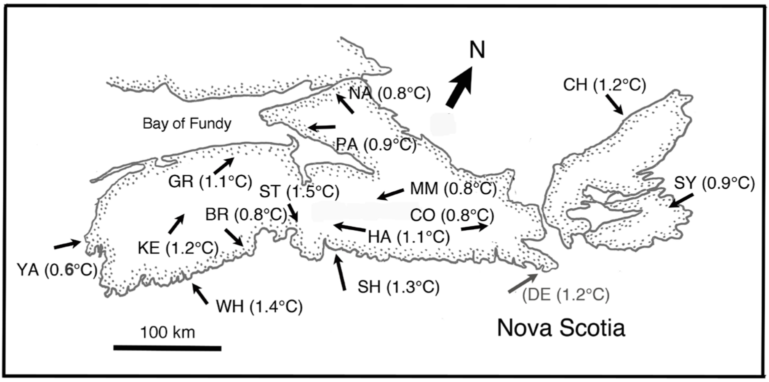

**Fig 1** **Map of Nova Scotia showing sites used for evaluation of climate change. Temperatures in parentheses indicate temperature rise for 1998-2020 relative to climate normal. Sites in southwestern Nova Scotia (YA, GR, KE, WH, BR, ST, and SH, have annual mean temperature > 7.0 °C and HA is at 6.9 °C. See Table 1 for site names and corresponding abbreviations.**

(Halifax Airport; hereafter Halifax), with an overall mean elevation of approximately 40 m. Most sites were less than 10 km from the ocean, and only Kejimkujik National Park (hereafter Kejimkujik), Bridgewater, Collegeville, Middle Musquodoboit, and Halifax were 30 km or more from the ocean. While Greenwood Airport (hereafter Greenwood) is less than 20 km from the Bay of Fundy, its location in the Annapolis Valley represents more inland conditions. Coastal sites were associated with the Bay of Fundy (Nappan, Parrsboro, Yarmouth), or the Atlantic Coast (Western Head, St. Margaret's Bay, Shearwater, Deming, Sydney). Cheticamp was the only site associated with the Gulf of St. Lawrence.

## Statistical Analysis

Values for each metric are presented as means and standard deviations (mean ± *s*). For each location and metric, means for climate normals for 1961-1990 or 1971-2000 were compared with subsequent values (i.e., either 1991-2020 or a subset, the years 1998-2020) using Student's *t*-tests at $P < 0.05$. One-sample Student's *t*-tests were used to compare monthly mean values for the post-climate normal period with the value for the climate normal. Since annual temperature means, pre- and post-1990, were significantly different for all sites except Yarmouth, we used one-tailed tests to compare monthly means. Statistical analyses were carried out using Excel, or online using GraphPad (https://graphpad.com/quickcalcs/contMenu). For the evaluation of monthly means for 1961-1990 and post 1991, paired Student's *t*-tests were used.

## RESULTS

### Change in Annual Mean Temperature

The analysis showed that a significant temperature increase occurred in Nova Scotia from 1960 to 2020. This is based on a comparison of the climate normal (CN) for the period 1961-1990 to the 1991-2020 dataset when the mean temperature went from 6.0 ± 0.5 °C to 6.7 ± 0.5 °C (significant at $P < 0.01$; Table 2). The temperature increase was significant for all sites and ranged

**Table 2 Mean annual temperature for different periods in Nova Scotia. Data for 1961-1990 and 1971-2000 are climate normals. Asterisks (*) indicate significant differences relative to climate normal for 1961-1990.**

| Site | Mean annual temperature 1961-1990 (°C) | Mean annual temperature 1971-2000 (°C) | Mean annual temperature 1991-2020 (°C ± s) | Mean annual temperature 1998-2020 (°C ± s) |
|---|---|---|---|---|
| Bridgewater | 6.7 | 6.9 | 7.2 ± 0.6 | 7.5 ± 0.6* |
| Cheticamp | 6.1 | 6.2 | - | 7.3 ± 0.7* |
| Collegeville | 5.6 | 5.8 | 6.1 ± 0.8* | 6.4 ± 0.8 |
| Deming | 5.6 | 5.8 | 6.3 ± 0.7* | 6.8 ± 0.5* |
| Greenwood | 6.6 | 6.8 | 7.5 ± 0.8* | 7.7 ± 0.6* |
| Halifax | 6.1 | 6.3 | 6.9 ± 0.8* | 7.2 ± 0.6* |
| Kejimkujik | 6.4 | 6.3 | 7.3 ± 0.8* | 7.6 ± 0.6* |
| Middle Musquodoboit | 6.0 | 6.2 | 6.5 ± 0.8* | 6.8 ± 0.5* |
| Nappan | 5.6 | 5.8 | 6.2 ± 0.7* | 6.4 ± 0.6* |
| Parrsboro | 5.4 | 5.9 | 6.2 ± 0.8* | 6.3 ± 0.8* |
| Shearwater | 6.5 | 6.7 | 7.5 ± 0.8* | 7.8 ± 0.7* |
| St. Margaret's Bay | 5.9 | 6.1 | 6.9 ± 0.9* | 7.4 ± 0.7* |
| Sydney | 5.5 | 5.5 | 6.1 ± 0.8* | 6.4 ± 0.7* |
| Western Head | 5.4 | - | 7.0 ± 0.4* | 7.1 ± 0.6* |
| Yarmouth | 6.8 | 7.0 | 7.3 ± 0.8* | 7.5 ± 0.8* |
| **Mean** | **6.0 ± 0.5** | **6.2 ± 0.5** | **6.7 ± 0.5*** | **7.0± 0.5*** |

from a 0.6 °C increase for Yarmouth to 1.6 °C for Western Head, although the latter increase is likely an artifact of extensive missing data. The extent of the temperature increase is more apparent beginning in 1998, with a subsequent mean temperature across the province of 7.0 ± 0.5 °C. The dramatic nature of the difference between the two periods is highlighted by the fact that in the early period, only a single year had a mean temperature above 7.0 °C, i.e., 1983 at 7.1 °C, whereas in the later period, over half of the years do. Annual temperatures below 6 °C occur in over half of the years between 1961 and 1997, but in none of the subsequent years.

Fig 2A shows the change in annual temperature on a year-to-year basis, starting in 1961. Linear regression of mean annual temperatures 1961 to 2020 yields $R^2 = 0.4240$ ($P < 0.0001$), suggesting a strong relationship of time to rising annual temperature over the entire period. However, the relationship between 1961 and 1997 has an $R^2 = 0.088$, with a non-significant regression ($P = 0.074$). Similarly, the period 1998 to 2020 is also non-significant ($R^2 = 0.006$, $P = 0.73$). These linear regressions are consistent with a step change between 1997 and 1998 associated with the 1 °C difference between early and late periods, as discussed in the previous paragraph.

## Changes in Monthly Mean Temperatures

Across NS, monthly mean temperatures post-1991 trended higher in each month, with increases ranging from 0.5 °C for June, to 1.6 °C for December (Fig 2, Table 3). Temperature increases were statistically significant for all months. Monthly temperature increases of 0.7 °C (or above) tended to be highly significant ($P < 0.01$). The most conspicuous seasonal patterns were the lower temperature increases from May to July (mean increase of 0.6 °C), and the highly significant increases in monthly temperature from August to December (mean increase of 1.0 °C; $P < 0.001$).

## Changes in Number of Frost Days in Spring and Autumn

Changes in occurrence of days with frosts in the Spring and Autumn, and the dates of last and first frosts (Table 4), reflect the increases in mean monthly temperatures. Of the 56 comparisons of these metrics across our sites, only five comparisons were not consistent with a warming climate trend: Cheticamp and Yarmouth, number of frost days from March to June; Nappan, number of frost days from September to December; and Nappan and Sydney, days to last frost. Of the remaining 51 comparisons, 17 showed statistically changed values relative to the period of the CNs that is consistent with climate warming. However, the fact that these are population measures rather than sample estimates supports the significance of the changes.

Even though reduction in the number of frost days between March and June was significant only for St. Margaret's Bay (5.0 days), the remaining sites with declines ranged from 1.2 (Parrsboro) to 4.9 (Deming). Including the two sites where slight increases occurred, the average decline over all the sites was 2.5 ± 1.6 (significant at $P < 0.05$). This coincided with a similar decline in the number of frost days after 01 April of 4.2 ± 5.9 (significant at $P < 0.05$).

Days with frost in late Summer and Autumn (September to December) declined 4.0 ± 2.4 days, with declines ranging

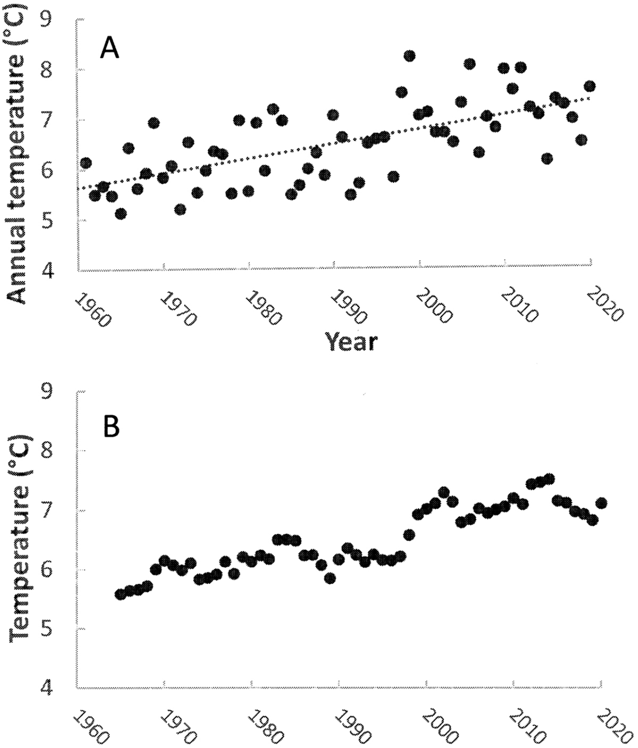

**Fig 2** **Mean annual temperature in Nova Scotia. (A) From 1961 to 2020. (B) Data smoothed to show running 5-year averages; thus, 1965 is the mean of 1961-1965; 1966 is the mean of 1962-1966, etc.**

**Table 3** Mean monthly temperature (°C) in for climate normals (1961-1990) and subsequently (1991-2020). Values derived from 13 sites (see Table 1). Significance based on two-tailed, paired Student's *t*-tests: *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

| Month | Climate normal 1961-1990 (°C) | 1991-2020 (°C) | Temperature increase (°C) | Significance |
|---|---|---|---|---|
| J | -5.5 ± 1.1 | -4.9 ± 1.2 | 0.6 | * |
| F | -5.8 ± 1.1 | -4.6 ± 1.1 | 1.2 | ** |
| M | -1.6 ± 0.8 | -0.9 ± 0.7 | 0.7 | * |
| A | 3.6 ± 0.9 | 4.4 ± 0.6 | 0.8 | *** |
| M | 9.1 ± 1.1 | 9.8 ± 0.8 | 0.7 | *** |
| J | 14.1 ± 1.2 | 14.6 ± 1.0 | 0.5 | * |
| J | 17.6 ± 1.2 | 18.3 ± 1.2 | 0.6 | * |
| A | 17.6 ± 0.6 | 18.3 ± 1.0 | 0.8 | *** |
| S | 13.6 ± 0.5 | 14.8 ± 0.6 | 1.3 | *** |
| O | 8.6 ± 0.5 | 9.2 ± 0.6 | 0.8 | *** |
| N | 3.7 ± 0.7 | 4.3 ± 0.7 | 0.7 | *** |
| D | -2.4 ± 1.1 | -1.0 ± 1.0 | 1.6 | *** |
| **Mean** | **6.0** | **6.8** | **0.85** | *** |

from 2.2 to 7.1 days for Yarmouth and Kejimkujik, respectively. The reduction in Autumn frost days was reflected in a longer period after 01 September until the first frost (Table 4), with values ranging from 3.3 to 13.9 days for Sydney and Kejimkujik, respectively, and an overall frost delay of 6.9 ± 3.2 days. That this metric was significantly longer for seven of the 12 sites shows that changes in the Autumn were more pronounced than in the Spring.

## Change in Continuous Frost-free Period

A conspicuous increase was noted in the number of continuous frost-free days during Summer and Autumn (Table 5, Figs 3A, B). The mean length of the frost-free period from 1991 to 2020 was 149.4 ± 21.6, and this was an increase of 9.2 ± 7.9 days for these sites. While changes for six of the 13 sites were not significant (all with less than an 8-day increase), for six sites they were significantly longer. Linear regression showed $R^2 = 0.309$ ($P = 0.0001$). Comparing only the period 1998 to 2020 to the CN, the frost-free period was extended 14.0 ± 9.0 days. Cheticamp was the frost-free period apparently reduced from 1998 to 2020, and this may reflect

**Table 4** Change in number of days with frost for March-June and September-December, number of days after 01 April until last frost, and number of days until first frost for sites in Nova Scotia. Asterisk (*) indicates significant difference at $P < 0.05$. CN, climate normal.

| Sites | Period | Frost days (Mar-Jun) | Days until last frost after 01 Apr | Frost days (Sep-Dec) | Days until first frost after 01 Sep |
|---|---|---|---|---|---|
| Bridgewater | CN | 50.6 ± 7.3 | 60.0 ± 11.9 | 56.6 ± 8.7 | 23.3 ± 8.1 |
| | 1991-2014 | 47.5 ± 6.8 | 48.4 ± 13.9* | 51.2 ± 7.0* | 33.3 ± 9.3* |
| Cheticamp | CN | 49.8 ± 9.0 | 50.7 ± 11.8 | 39.7 ± 7.2 | 53.9 ± 10.3 |
| | 1991-2020 | 51.0 ± 9.1 | 49.7 ± 9.7 | 35.5 ± 6.1* | 60.3 ± 11.4* |
| Collegeville | CN | 54.8 ± 8.6 | 62.9 ±14.1 | 54.8 ±7.9 | 24.1 ± 9.0 |
| | 1991-2020 | 51.2 ± 16.4 | 62.3 ± 15.7 | 51.0 ± 11.0 | 29.7 ± 11.4* |
| Deming | CN | 45.4 ±10.2 | 35.0 ± 10.4 | 32.1 ± 7.5 | 64.7 ± 12.0 |
| | 1991-2008 | 40.9 ± 8.8 | 34.1 ± 10.3 | 27.4 ± 5.0 | 69.7 ± 10.3 |
| Greenwood | CN | 47.3 ± 6.9 | 45.1 ± 10.4 | 47.3 ± 6.9 | 30.6 ± 12.2 |
| | 1991-2020 | 44.4 ± 6.6 | 41.1 ± 10.2 | 48.0 ± 7.0 | 36.0 ± 11.6 |
| Halifax A | CN | 48.8 ± 8.3 | 37.4 ± 11.9 | 49.3 ± 7.4 | 45.5 ± 10.0 |
| | 1991-2020 | 46.4 ± 7.2 | 34.9 ± 11.8 | 45.3 ± 6.0* | 51.8 ± 10.0* |
| Kejimkujik | CN | 49.5 ± 7.8 | 59.6 ± 12.8 | 57.8 ± 8.3 | 18.4 ± 10.7 |
| | 1991-2019 | 47.9 ± 6.5 | 42.1 ± 12.6* | 50.2 ± 7.6* | 32.3 ± 12.2* |
| Nappan | CN | 50.1 ± 7.4 | 51.2 ± 10.1 | 49.9 ± 8.3 | 26.2 ± 12.9 |
| | 1991-2020 | 48.5 ± 11.1 | 53.4 ± 13.2 | 51.0 ± 7.0 | 32.0 ± 10.9 |
| Parrsboro | CN | 50.9 ± 11.0 | 57.9 ± 11.8 | 54.3 ± 9.0 | 26.0 ± 12.8 |
| | 1991-2020 | 49.7 ± 8.5 | 50.1 ± 11.7 | 50.7 ± 8.1 | 35.0 ± 11.0* |
| Shearwater | CN | 42.9 ± 6.7 | 34.0 ± 9.9 | 42.0 ± 6.1 | 53.6 ± 10.0 |
| | 1991-2020 | 40.0 ± 7.3 | 28.6 ± 8.4 | 36.9 ± 5.7 | 60.9 ± 9.3* |

*Table 4 cont'd*

| **Sites** | **Period** | **Frost days (Mar-Jun)** | **Days until last frost after 01 Apr** | **Frost days (Sep-Dec)** | **Days until first frost after 01 Sep** |
|---|---|---|---|---|---|
| St. Margaret's Bay | CN | 48.3 ± 7.7 | 51.3 ± 10.8 | 54.4 ± 8.5 | 35.2 ± 11.6 |
| | 1991-2020 | 43.3 ± 9.6* | 43.6 ± 12.5* | 45.2 ± 13.0 | 38.2 ± 15.4 |
| Sydney | CN | 59.3 ± 7.3 | 49.9 ± 9.7 | 47.4 ± 8.1 | 47.6 ± 11.1 |
| | 1991-2020 | 56.2 ± 8.3 | 52.4 ± 12.1 | 43.3 ± 6.0 | 50.9 ± 11.5 |
| Western Head | CN | 40.8 ± 5.5 | 31.6 ± 6.9 | 39.3 ± 4.8 | 51.1 ± 9.4 |
| | 1991-2020 | 36.7 ± 7.0 | 31.0 ± 9.1 | 36.7 ± 6.4 | 53.7 ± 11.9 |
| Yarmouth | CN | 34.0 ± 8.0 | 29.4 ± 10.9 | 37.0 ± 9.7 | 50.7 ± 10.3 |
| | 1991-2020 | 36.1 ± 8.4 | 27.7 ± 9.1 | 35.0 ± 6.3 | 57.6 ± 11.4* |
| **Mean difference** | | **-2.5 ± 1.6*** | **-4.2 ± 5.9*** | **-4.0 ± 2.4*** | **6.9 ± 3.2*** |

**Table 5** **Length of continuous frost-free period in days for 1991-2020 and differences 1961-1990 and 1998-2020. Note: *, significant at $P < 0.05$; **, significant at $P < 0.01$; NS, not significant.**

| Site | Frost-free days 1991-2020 | Difference from 1961-1990 | Difference 1998-2020 vs 1961-1990 |
|---|---|---|---|
| Bridgewater[a] | 115.4 ± 15.7 | 3.7 | 23.7** |
| Cheticamp | 162.8 ± 15.1 | 9.0* | 8.6 (NS) |
| Collegeville | 116.7 ± 24.9 | 3.6 (NS) | 5.6 (NS) |
| Deming | 188.2 ± 13.9 | 5.0 (NS) | 7.6 (NS) |
| Greenwood | 149.2 ± 16.7 | 11.2** | 14.5** |
| Halifax A | 168.9 ± 15.9 | 5.5 (NS) | 9.4* |
| Kejimkujik | 142.3 ± 19.8 | 30.6** | 36.9** |
| Nappan | 131.6 ± 19.6 | 3.9 (NS) | 9.0* |
| Parrsboro | 137.0 ± 19.0 | 17.3** | 13.4* |
| Shearwater | 172.8 ± 14.3 | 11.2** | 15.3** |
| St. Margaret's Bay | 140.4 ± 25.3 | 4.8 (NS) | 13.7* |
| Sydney | 149.8 ± 18.5 | 0.4 (NS) | 3.0 (NS) |
| Western Head | 173.8 ± 16.5 | 7.0 (NS) | - |
| Yarmouth | 182.1 ± 15.5 | 11.3** | 15.1** |
| Mean ± s | 149.4 ± 21.6 | 9.2 ± 7.9* | 14.0 ± 9.0* |

[a] values missing for 1961, 2006, 2007, 2012, 2014-2020

the changed position of the new weather station with its slightly higher elevation (see Table 1). The step change post-1998 was also recognized in the linear regressions, in that the values of $R^2$ for the early and late periods were not significant at 0.008 and 0.011, respectively, with $P > 0.5$. Despite the difference in means between early and late periods, the five-year running average showed a steady increase between the late 1990s and 2010, with a seemingly continuous decline in the subsequent 10 years.

## DISCUSSION

Relative to the 30-year period of climate normal (CN) for 1961-1990, we demonstrated for the subsequent 30-year period the following changes in Nova Scotia: (1) an increase in overall mean temperature of 0.7 °C (1.0 °C post-1998) which is reflected in

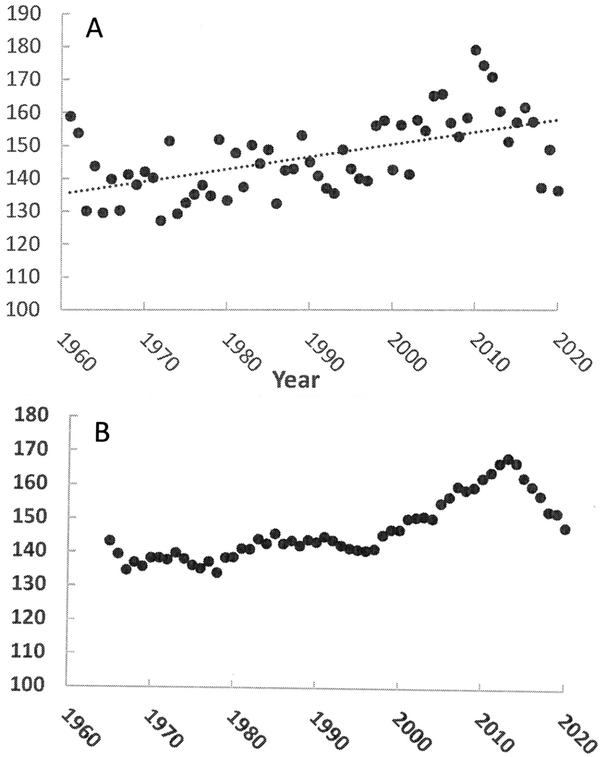

**Fig 3 Continuous frost-free periods in Nova Scotia from 1961 to 2020. (A) Year to year changes. (B) Data smoothed to show changes in running 5-year averages; thus, 1965 is the mean of 1961-1965; 1966 is the mean of 1962-1966, etc.**

statistically significant increases in all months of the year; (2) a decline in number of frost days in both Spring and Autumn; (3) earlier ending and later starting dates of frosts in the Spring and Autumn, respectively; and (4) an increase in the overall average continuous frost-free period of 9 days. While many of these points have been explicitly made by other authors with respect to generalized changes for eastern Canada (e.g., Galbraith and Larouche 2013), here we show considerable variation across the province in the extent of changes that have occurred.

Globally, 2020 was tied with 2016 as the warmest on record (Voosen 2021). Nova Scotia is out of sync with the global average in that for 2020, the mean for NS was only 7.63 °C, well below the warmest years of 1999 and 2006 with means of 8.2 °C and

8.0 °C, respectively. Regardless, temperatures at several sites along the Atlantic Coast of NS have increased more during the last 22 years than the 1.25 °C global increase over preindustrial measures, e.g., St. Margaret's Bay, 1.5 °C. This contrasts with the overall increase for the province of only 1 °C (Fig 2).

There was a slight change in method used here than for the previous analysis of temperature change in PEI (Garbary 2018). In that paper, with only with three primary sites, the monthly means for years after 1991 were normalized by each month-year value. Consequently, monthly changes at the three sites were considered separately (see Table 2 in Garbary 2018). In the current study, because there were either 14 or 16 sites, only mean values of up to 30 years were normalized, i.e., subtracted from the monthly values of the climate normal, averaged, and evaluated using one-tailed Student's *t*-tests. Overall, the patterns of monthly increases relative to CN in terms of the extent of warming, and the individual months that were significantly warmer, were basically the same for both NS and PEI. Thus, the months from August to December were all significantly warmer, consistent with PEI, with monthly increases from 0.7 °C to 1.6 °C.

It is of interest that for the period of the CN, Yarmouth, with a mean annual temperature of 6.8 °C, was the warmest of our sites (Table 2). Currently, the warmest sites based on the post 1998 dataset are two non-coastal sites, Kejimkujik and Greenwood, with means of 7.6 °C and 7.7 °C, respectively, and the coastal site of Shearwater at 7.8 °C. The coolest sites during the CN period were Western Head and Parrsboro, with annual means of 5.4 °C; the coolest sites for the most recent 30-year period are Collegeville and Sydney at 6.1 °C, with the two Bay of Fundy sites (Nappan, Parrsboro) at 6.2 °C. These shifts suggest differential patterns of warming at different sites and would seem to preclude a single regional prediction for NS as a whole.

The pattern of temperature increase in PEI was characterised by a stable annual mean from 1961 to 1997, with a step-like change beginning in 1998 and continuing until 2016. This change is less apparent for NS in that there was an increase of 0.15 °C in the climate normal from 1961-1990 to 1971-2000. However, no year from 1998 to present was below the mean for the period for the preceding 37 years. In addition, only five years (1969, 1979, 1983, 1984, 1990) in that early period were above the mean temperature for the subsequent 22 years (i.e., 6.83 °C). Furthermore, no years between 1961 and 1990 were above the mean for the 1998-2020 period. While these mean values may indicate a step increase in temperatures for NS, there has been a slight decline in annual mean temperature in the last 22 years ($R^2 = -0.044$ for 1998-2020). However, this trend was moderated in 2020 with a mean temperature of 7.6 °C across 12 sites when five sites (Greenwood, Shearwater, St. Margaret's Bay, and Kejimkujik) were over 8 °C. Regardless, the pattern of change since the late 1990s relative to 1961-1997 makes determination of an overall rate difficult. The slight downward trend needs to be put into the context of global temperatures where six of the hottest years since the industrial revolution have been in the past decade.

The extent of climate warming in Nova Scotia is highlighted by the fact that for 1961-1990, only one studied site, Yarmouth, had a mean temperature approaching 7 °C, whereas for 1998-2020 temperatures for only six sites had annual means below 7 °C. The changes in the other temperature metrics described here, i.e., number of frost days in Spring and Autumn, number of days until the last frost in Spring, number of days until the first frost in the Autumn, and the length of the continuous frost-free period, provide a consistent picture of increasing temperature that has accelerated over the last 30 years.

The increased length of the frost-free period may be the most dramatic impact of climate change demonstrated here. The 1998-2020 dataset's average increase of 9.2 days relative to 1961-1990 is similar to the 10-day increase described by Walsh *et al.* (2014) for northeastern USA for the period since 1901-1960. The extreme value of an increase of 37 days for Kejimkujik (1961-1990 vs 1998-2020), associated with a 1.2 °C temperature increase over the same period, is in marked contrast with Yarmouth where a 0.6 °C increase was accompanied by a 15-day increase in the frost-free period. The extreme value of an increase of 37 days for Kejimkujik may be an artifact of 5 years of missing data from the early 1960s. The second largest increase in the length of the frost-free period (i.e., 23.7 days for Bridgewater) may also be an artifact of the extensive missing data. These differences show the subtlety of climate change impacts even over short distances (here approximately 100 km and 85 m elevation change). It is of note that while the website for

Climate Nova Scotia takes note of an earlier Spring in the page 'Terrestrial Ecosystem (Land) Impacts' (https://climatechange.novascotia.ca/adapting-to-climate-change/impacts/terrestrial-ecosystem) there is no mention of the more extensive increases in the frost-free period in the Autumn.

Using modelling Brickman *et al.* (2014) predicted a temperature increase in eastern Canada reaching 2.5 °C in coming decades. They suggested that in coastal regions this increase would be faster in Summer (40-50 yr) and slower in Winter (60-70 yr). This prediction is inconsistent with the empirical results presented here, where the temperature increments for the 3-month periods ending in July, August and September ranked 12, 11, and 8, respectively; and the three months ending in January, February, and March ranked 3, 1, and 6, respectively. Hence, warming to date has been least in Nova Scotia during the warmest season. The most significant warming increases demonstrated here are for the 3-month periods ending in February and December (ranked 1, 2). The 1.25 °C increase in September is consistent with the increase in frost free days after 01 September.

Linear regressions for the paired relationships of three factors, years from 1961 to 2020, mean annual temperature, and number of continuous frost-free days per year, were mostly highly significant (Table 6). Of the 42 regressions, nine were not significant (i.e., $P \geq 0.05$) and all but one of the remaining regressions were significant at $P \leq 0.01$. The overall relationship between year and annual temperature was significant for all sites, consistent with the climate warming described here. Values for $R^2$ ranged from 0.162 for Collegeville to 0.628 for Western Head. The mean of these values, i.e., 0.343, suggests that within this 60-year span, the temperature trend is positive. The relationship between annual temperature and number of frost-free days was typically stronger than was the relationship for year and number of continuous frost-free days (mean $r^2$ of 0.187 and 0.150, respectively). This suggests that the perturbations of yearly annual temperatures and the decline of continuous frost-free days at some sites in recent years resulted in lower $R^2$ values. Thus, mean annual temperature provides a better approximation for continuous frost-free days than does year.

## Oceanographic and Atmospheric Considerations

The overall synchrony in temperature increase in the Maritime provinces of PEI and NS suggests explanations that may be

**Table 6** **Regression coefficients ($R^2$ values) from linear regressions of results from 1961 to 2020 for: (1) year and annual temperature, (2) year and number of continuous frost-free days, and (3) annual temperature and number of continuous frost-free days. Because of missing data, n may be less than 60, and only the smallest value for n is given for each site. Asterisk (*) indicates $P < 0.01$; NS, not significant, i.e., $P > 0.05$.**

| Site (n) | Year and mean annual temperature | Year and number of continuous frost-free days | Mean annual temperature and number of frost-free days |
|---|---|---|---|
| Bridgewater (46) | 0.255* | 0.399* | 0.300* |
| Cheticamp (57) | 0.339* | 0.056 (NS) | 0.133* |
| Collegeville (58) | 0.162* | 0.009 (NS) | 0.027 (NS) |
| Deming (48) | 0.356* | 0.068 (NS) | 0.164* |
| Greenwood (60) | 0.419* | 0.150* | 0.192* |
| Halifax A (58) | 0.395* | 0.042 (NS) | 0.166* |
| Kejimkujik (51) | 0.367* | 0.448 ($P < 0.05$) | 0.323* |
| Nappan (60) | 0.274* | 0.061 (NS) | 0.169* |
| Parrsboro (56) | 0.265* | 0.194* | 0.296* |
| Shearwater (57) | 0.508* | 0.144* | 0.246* |
| St. Margaret’s Bay (52) | 0.528* | 0.154* | 0.185* |
| Sydney (59) | 0.195* | 0.000 (NS) | 0.127* |
| Western Head (39) | 0.628* | 0.034 (NS) | 0.058 (NS) |
| Yarmouth (60) | 0.294* | 0.251* | 0.266* |

associated with ocean temperature changes. While increases in sea surface temperature (SST) globally are caused by increases in global air temperature (e.g., Bernier *et al.* 2018), on a local scale, such as coastal areas of NS, the warmed summer water may provide a buffer in the fall and winter to maintain higher air temperatures along the coast. Accordingly, we examine oceanographic factors that can explain temperature shifts at land-based monitoring stations over the last 60 years. Here, we examine El Niño Southern Oscillation (ENSO) and Atlantic Multi-decadal Oscillation (AMO) in relation to temperature change in NS. Thus, anthropogenic increases in $CO_2$ and $CH_4$ and their consequent greenhouse effect may be the ultimate cause for increasing temperatures in NS; however, ENSO and AMO may provide for more proximal explanations and explain the differing extents of temperature increase within the province.

Galbraith *et al.* (2012) described a high correlation between air and surface seawater temperatures in the Gulf of St. Lawrence both intra-annually and over more than a century. Bernier *et al.* (2018) described the same major increase in ocean temperature in the late 1990s that we found for air temperatures in both NS and PEI. Given the peninsular shape of Nova Scotia, surrounded by three very different oceanic bodies, i.e., Bay of Fundy/Gulf of Maine, Atlantic Ocean, and Gulf of St. Lawrence, there is no question that ocean-land interactions should be a key feature of Nova Scotia's changing climate. The Atlantic coast of Nova Scotia has already been recognized as an ocean warming hotspot (Hobday and Pecl 2014, Filbee-Dexter *et al.* 2016), as is the Bay of Fundy/Gulf of Maine (GOM Symposium papers, Dec. 2019). The last few years have seen successive records in global ocean temperature with the last 5 years being the highest on human record (Cheng *et al.* 2020). These extreme values do not correlate with Nova Scotia in terms of air temperatures, and except for 2020, the last 5-10 years even suggest a temperature reduction from recent maxima.

The limited change in annual mean temperature for Yarmouth may be accounted for by the moderating effect of a tidal-driven 'topographic upwelling' of cold water in southwestern NS (Tee *et al.* 1993). This is relative to a less active, wind-driven upwelling phenomenon along the Atlantic Coast, including Western Head, described by Scrosati and Ellrich (2020). The decrease in winter ice cover in the Gulf of St. Lawrence reflects a further moderating influence for both PEI and the north coast of Nova Scotia (bordering the Gulf of St. Lawrence), as represented here by Cheticamp in northwestern Cape Breton Island. As the longshore current along the Atlantic coast of NS proceeds from Cape North to Cape Sable Island (Bundy *et al.* 2014) along the shallow depths of the land margin (i.e., the Scotian Shelf), it is warmed by increased air temperature during Summer. In turn, this warmer water moderates terrestrial temperatures in Autumn and Winter.

El Niño-Southern Oscillation (ENSO) cycles between El Niño and La Niña phases in the equatorial Pacific Ocean. These alternating phases are responsible for significant changes in sea surface temperatures (SSTs) in the tropical Pacific Ocean that in turn influence global weather patterns, e.g., McPhaden *et al.* (2006). NOAA has documented these alternating SST anomalies starting in 1950 and provides running 3-month averages of the temperature anomalies associated with ENSO (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). These data allow for comparison of coincident changes in air temperatures using Greenwood as our reference. The most conspicuous of these is the La Niña event that began in June-July-August of 1998 and persisted until January-February-March of 2001. This ENSO event is the strongest ENSO of the last century (WMO 2013), and corresponded to the jump in annual air temperature in 1999 in Prince Edward Island (Garbary 2018) and Nova Scotia (this paper) that has largely persisted until the present. Similarly, the extended La Niña period from May-June-July 2010 to February-March-April 2012, and the period beginning July-August-September 2020 and continuing until at least February-March-April 2021, also corresponded to elevated annual air temperatures in NS.

Further evaluation of the ENSO dataset showed that between 1961 and 1997, 57.3% of months had a moderate to very strong El Niño signal, whereas post 1998 the value was 42.8% of months. Table 7 shows the results of our evaluation of ENSO events; we compared annual temperatures for Greenwood when El Niño, La Niña, or neither condition dominated whole or parts of the year (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). Two weak trends were apparent. When El Niño predominated in a given year, there was a tendency for annual air temperatures in Nova Scotia to be lower by 0.33 °C (i.e., 6.8 °C vs 7.1 °C for La Niña, and 7.1 °C when neither predominated); however, with $P = 0.195$ (Student's *t*-test), this is hardly significant. The trend was stronger during La Niña events in the last 4 months of years, where overall temperature increases are higher. Accordingly, there is a weak trend of elevated temperatures in NS associated with La Niña of 0.45 °C ($P = 0.10$). While the statistical significance of these comparisons is weak, it suggests that these global phenomena are relevant to Nova Scotia.

The Atlantic Multi-decadal Oscillation (AMO) refers to changes in SSTs for the Atlantic Ocean. The AMO is similar to ENSO, except that AMO oscillates over much longer time periods (e.g., Chylek *et al.* 2001, 2016; Clement *et al.* 2015; Delworth *et al.* 2017). In addition, AMO may be the cause of longer-term oscillations of ENSO (Levine *et al.* 2017). These longer oscillations (relative to

**Table 7** **Comparison of mean annual temperature for Greenwood from 1951 to 2020 with occurrences of El Niño and La Niña, using the Oceanic Niño Index from NOAA (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). Comparisons between El Niño and La Niña used two-tailed Student's *t*-tests. In comparisons 3 and 4, all four 3-month seasons had to satisfy the criterion.**

| Comparison | El Niño °C (n) | La Niña °C (n) | Neither °C (n) | Comments |
|---|---|---|---|---|
| Predominant ENSO conditions through year | 6.79 ± 0.74 (19) | 7.12 ± 0.85 (23) | 7.07 ± 0.76 (23) | Implies El Niño years cooler ($P = 0.195$) |
| Greenwood temperature 1 year later | 6.99 ± 0.71 (18) | 6.84 ± 0.77 (21) | | No support for offset ($P = 0.530$) |
| Last 4 months (i.e., ASO to NDJ) | 6.86 ± 0.79 (19) | 7.31 ± 0.83 (18) | 6.90 ± 0.82 (22) | Implies La Niña years warmer ($P = 0.100$) |
| First 4 months (i.e., DJF to MAM) | 7.16 ± 0.77 (9) | 7.03 ± 0.94 (11) | 6.97 ± 0.76 (20) | No support for relationship |

ENSO) have not been fully explained, and the links between global SSTs and AMO are still being clarified (e.g., Dong *et al.* 2006, Li *et al.* 2016, Yang *et al.* 2020). While the AMO seems unlikely to explain short-term variation associated with mean annual temperature change in Nova Scotia, the change in the late 1990s of AMO into a positive temperature phase is coincident with the elevation of mean air temperature in Nova Scotia and Prince Edward Island (Garbary 2018). The continued higher annual temperature since the late 1990s, relative to the previous 40 years when AMO was in a negative phase, provides a partial explanation of gross temperature change (i.e., pre- and post-1998) over the last 60 years.

It remains to be demonstrated if warming of the NS climate by global air temperatures will be moderated or reversed when AMO enters a negative AMO phase, and this coincides with a strong El Niño event. For example, 2015 was the coldest year since 1998, and this was associated with an El Niño year. Given the predictions of global temperature increases (IPCC 2018, 2019), such a reversal would seem unlikely, although these phase changes might dampen regional temperature increases in coming decades. The current La Niña phase, beginning in the Autumn of 2020 (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php) may partially explain the elevated monthly mean temperature in NS beginning in November 2020, and presaged the extremely mild Winter and early Spring of 2021 (i.e., November to April). In these 6 months, monthly mean temperatures ranged from 1.1 °C to 3.4 °C higher across the province (Garbary, unpublished data) than averages for the post-1998 period.

## Plant Phenology and Physiology

This paper focuses on the scope and scale of the temperature changes that we have documented over a 60-year period in Nova Scotia. Temperature is one variable, albeit a central one, of the many factors involved in climate change. The suite of changes includes $CO_2$, temperature, soil moisture, precipitation, and wind, all acting to bring about biospheric changes that may be rapid and extreme (Reichenstein *et al.* 2013). The impact of temperature on plants is both fundamental and pervasive. Temperature changes affect a plant's basic processes of respiration (Reich *et al.* 2016, Patterson *et al.* 2018) and photosynthesis (Kirshbaum 2004, Song *et al.* 2014). Potential changes in Acadian forest communities and adaptation to climate change for forestry have been modelled elsewhere (e.g., Bourque *et al.* 2007, Steenberg *et al.* 2011). In this section, we discuss how temperature changes may lead to shifts in diversity patterns. We begin with what naturalists have long noted, that is, the link between warming and flowering.

One of the most commonly described adaptations of the natural world to climate change is the timing of flowering (e.g., Vasseur *et al.* 2001, Menzel *et al.* 2005, Houle 200, Panchen *et al.* 2012). We (along with collaborators) have published several accounts of unusual flowering in Nova Scotia (Taylor and Garbary 2003, Garbary and Taylor 2007, Garbary *et al.* 2007; Hill and Garbary 2013). These late Autumn and Winter, and early Spring flowering events were interpreted as artifacts of unusual weather phenomena, i.e., harbingers of what would occur in nature should significant climate warming occur. In retrospect, the observations can be interpreted as impacts of climate change in action resulting from a warmer temperature regime. For example, the major extension of flowering well into Autumn and Winter is a reflection of the longer frost-free period and the moderation of Autumn and early Winter temperatures. Indeed, flowering of *Viola tricolor* was noted for the first time in early February in Antigonish County by one of us (DG), thus extending the season for wildflowers to all twelve months in northern Nova Scotia, albeit not in the same year or continuous 12 months. In the Annapolis Valley, several species can resume flowering in winter during warm periods; these include *Capsella bursa-pastoris* and *Cardamine pensylvanica*. We predict that winter and early spring flowering will become more prevalent, especially with cold-tolerant members of the mustard and mint families.

The early Spring flowering described by Hill and Garbary (2013) provided a key confirmation for the temperature modelling of Culbertson-Paoli *et al.* (2019) who used the flowering phenology of MacKay (1903, 1906) and a complex mathematical treatment to reflect the changing temperature climate on a time scale of more than a century. The shifts documented above for flowering phenology belie physiological changes which could have implications for plant-pollinator interactions, insect diversity and gene flow in plant populations (Scaven and Rafferty 2013). Flowering for 31 species of herbs and shrubs in March-April 2021 (Appendix 1) resembles that observed by Hill and Garbary (2013). Of the 24 species identified by Hill and Garbary (2013), only *Viola pubescens* was not observed in 2021 and eight additional species were added. We attribute this phenology to the fact that the monthly mean temperatures for February through April 2021 were 1.2 °C warmer than the post-1998 averages for these months.

Our documented temperature increase affected Autumn and Winter disproportionately, as might have been expected from the unusual flowering in both Autumn and early Spring, discussed above. The increased temperature in September and October would be expected to extend the growth period for Summer annuals in Nova Scotia. Annuals are largely absent from the high Arctic; their frequency increases as latitude decreases, although temperatures in excess of 25 °C reduce the photosynthetic performance of annuals (Zubaidi *et al.* 2020, Hatfield and Pruger 2015).

In general, annuals require a disturbed regeneration niche. Most annual plants in Nova Scotia are exotics exploiting anthropogenically disturbed habitats such as fields and roadsides (Hill and Blaney 2010). Native disturbed habitats (e.g., floodplains, coastlines, burns) are less widespread; nonetheless, there have been two new records of Atlantic Coastal Plain Summer annuals on lakeshores (*Cyperus diandrus* in 2000, *Fimbristylis autumnalis* in 2016; Hill and Smith 2017). These occurrences may relate to the substantial increase in temperature in early Autumn (1.3 and 0.8 °C for September and October, respectively) in combination with an increase in the drawdown of lakes relating to Summer droughts. These seasonally open, Atlantic Coastal Plain lakeshores in Nova Scotia are northern, heretofore unrecognized representatives of the North Atlantic Coastal Plain Ponds (NatureServe 2021a, b), where water level fluctuations provide conditions that maintain high diversity, low biomass wetland communities (Schneider 1994, Sorrie 1994).

Given the climate warming that has already occurred, and the expectation of further increases in coming decades, Nova Scotia can expect to see many additional arrivals and the wider distribution of species with southern affinities. At the same time, plants requiring cooler conditions may acquire more restricted distributions in more northern parts of the province or at higher elevations. A more comprehensive evaluation of the impacts of climate change on the terrestrial flora of Nova Scotia is beyond the scope of this paper but is needed.

### Concluding Remarks

We have documented an increase in annual temperature of 1 °C and suggest that its impacts are having greatest effect in Autumn and Winter, which have warmed the most. The warming trend is not uniform across the province and varies from 0.5 °C to 1.5 °C. Lengthening of the growing season and moderation of winter temperatures have already influenced flowering phenology and may provide new opportunities for agriculture and forestry interests. However, environmental changes that are too rapid may threaten the integrity of native ecosystems and the balance in biological communities. The negative impacts of climate change in the marine sphere, i.e., increased number and severity of storms and sea level rise with its associated coastal erosion, provide further challenges in adaptation that must be similarly addressed on both a local and continental scale.

*Acknowledgements* We thank Megan Fass for assistance with preparation of figures and Barry Taylor and anonymous referees for helpful comments on the manuscript. Monica Schuegraf and Ruth Newell provided several records of flowering in 2021. This work was supported by Discovery Grants from the Natural Sciences and Engineering Research Council of Canada to DJG.

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# APPENDIX 1

**Herbaceous and shrubby flowering plants flowering from February to April 2021 in Nova Scotia compared to equivalent records from Hill and Garbary (2012). None of the sites from which the species listed in part (C) are known were examined. Note: amentiferous species of *Salix*, *Betula*, *Alnus* were not included in either study.**

## (A) Species found in both Hill and Garbary (2012) and in 2021

*Amelanchier laevis*, *Caltha palustris*, *Capsella bursa-pastoris*, *Cerastium vulgatum*, *Claytonia caroliniana*, *Corylus cornuta*, *Daphne mezeurium*, *Draba verna*, *Epigaea repens*, *Fragaria virginiana*, *Glechoma hederacea*, *Hedyotis caerulea*, *Lonicera canadensis*, *Myosotis scorpioides*, *Sanguinaria canadensis*, *Senecio canadensis*, *Stellaria media*, *Taraxacum officinale*, *Tussilago farfara*, *Vinca minor*, *Viola cucullata*, *Viola macloskei*, *Viola tricolor*

## (B) Additional species found in 2021 absent from Hill and Garbary (2012)

*Cardamine pratensis*, *Chamaedaphne calyculata*, *Corema conradii*, *Erythronium americanum*, *Lamium amplexicaule, Lamium purpureum*, *Thlaspi arvense, Veronica persica*

## (C) Species from Hill and Garbary (2012) not found in 2021

*Viola pubescens*

Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 443-454

# THE CURRENT ROCKWEED, *ASCOPHYLLUM NODOSUM*, HARVESTING REGIME ON THE SHORES OF NOVA SCOTIA – A REVIEW

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## ABSTRACT

*Ascophyllum nodosum* is an ecologically and economically valuable species of brown seaweed found in Nova Scotia. The large fronds covered in airbladders create distinctive underwater canopy ecosystems in the intertidal zone. *Ascophyllum* is valuable as a soil supplement and fertilizer due to its biochemical composition. Commercial harvest of this wild resource began approximately sixty years ago and has been continuously exploited since. Careful management of *Ascophyllum* stocks is necessary to sustain the industry. In this literature review, the current harvesting regime of this seaweed in Nova Scotia is summarized and assessed in relation to harvesting regimes elsewhere and to the state of the intertidal marine ecosystem.

Keywords: *Ascophyllum nodosum*, ecological impacts, intertidal ecology, resource management, rockweed harvesting, seaweed industry

## INTRODUCTION

*Ascophyllum nodosum* (Linnaeus) Le Jolis, commonly known as Rockweed or Knotted Wrack (and herein, *Ascophyllum*), is a brown fucoid seaweed that covers much of Nova Scotia's rocky shores. It is a common species across North Atlantic coastlines, found from Norway to Portugal along European shores (Sharp 1987) and from the Canadian Artic to the Atlantic Provinces, and extending as far south as New Jersey in the United States (Mathieson and Dawes 2017). Commercial harvest of *Ascophyllum* in Nova Scotia remains industrially significant since its expansion in the 1960s, with industrial harvesters continuing to manage the available *Ascophyllum* resource primarily with the guidance of industrial, not provincial, scientists. In this review, the reasons why *Ascophyllum* is a

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commercially and ecologically important species, and the current status of its commercial exploitation, are discussed.

## Morphology and Ecology

*Ascophyllum* propagules settle in the upper to mid-eulittoral zone of the intertidal on rocky substrate, and the fronds grow to cover wide expanses of the shore in dense beds, often with 100% cover. The species does not tolerate high wave exposure and its distribution is typically limited to sheltered areas such as coves and bays (Lewis 1978). The observed southern limits of this species are at 42N latitude, where ocean warming limits reproduction. The species exhibits clear sensitivity to climate change (Pereira *et al.* 2020). The entire thallus of this perennial seaweed can survive for up to 120 years, while individual fronds can persist for up to 20 years (Åberg 1992).

This seaweed can reach up to 2 meters in length and is primarily composed of dichotomizing branches (Baardseth 1970). Dozens to hundreds of new axes can also form directly from the discoid holdfast. This holdfast anchors the entire seaweed to the substratum, typically rocks or boulders. Characteristic egg-shaped air bladders occur at regular intervals along the length of the fronds' branches and primary axes, giving rise to the common name Knotted Wrack. At low tide the thallus lies prone over the substrata, while at high tide the gas-filled air bladders enable the thallus to float, forming three-dimensional underwater canopies (Kay *et al.* 2016). Thirty-four species of fish, thirteen kinds of birds, and one hundred taxa of invertebrates have been observed utilizing *Ascophyllum* as their habitat, some grazing on *Ascophyllum* and its epiphytes, and others utilizing the canopy for protection from predators (Johnson and Schiebling 1987, Seeley and Schlesinger 2012).

Associated with the vegetative fronds, two additional forms of production occur in *Ascophyllum*. The first is the reproductive bodies, receptacles that form in buds along the frond, appearing first as incipient branches before swelling (Baardseth 1970). Receptacles begin developing early in the summer but do not mature until the following year, within a wide period ranging from late winter to early summer. When mature, the total biomass of reproductive tissues produced and released by an *Ascophyllum* thallus into the ecosystem can reach 150% of the thallus vegetative biomass (Garbary *et al.* 2021b). *Ascophyllum* releases male and female gametes from unisexual sporophytes all at once in the spring, with receptacles rapidly dehiscing (i.e., splitting open) soon after (Josselyn and Mathieson 1978).

There are two sorts of production associated with the vegetative fronds in *Ascophyllum.* The first is the formation of reproductive bodies called receptacles; they form in buds along the frond, appearing first as incipient branches before swelling (Baardseth 1970). Receptacles begin developing early in the summer but do not mature until the following year, within the period that ranges from late winter to early summer. When mature, the total biomass of reproductive tissues produced and released by an *Ascophyllum* thallus into the ecosystem can reach 150% of the thallus vegetative biomass (Garbary *et al.* 2021b). *Ascophyllum* releases male and female gametes from unisexual sporophytes at the same time in the spring, the receptacles rapidly deteriorating and falling off the plant soon after (Josselyn and Mathieson 1978). The second means of production comes from Ascophyllum's epidermal tissue which is shed and prevents any biofouled surfaces from affecting the rest of the thallus (Halat *et al.* 2020). This process of epidermal shedding adds 10% of *Ascophyllum*'s unshed vegetative biomass over again into the ecosystem (Halat *et al.* 2015, Garbary *et al.* 2017).

## Biochemistry

Commercial interests in *Ascophyllum* developed around its traditional use as a soil supplement. *Ascophyllum* has been used as fertilizer in Ireland since the eighteenth century and in Scotland since the Iron Age (Guiry and Morrison 2013, Barbar 2003). *Ascophyllum* is rich in potassium when compared with cow manure. Raw unprocessed *Ascophyllum* fronds make an excellent fertilizer for poor quality soil (Pereira *et al.* 2020). *Ascophyllum* is similarly rich in plant growth regulators, such as cytokinins, gibberellins, and indoles, as well as chelated compounds that make micronutrients in the soil more readily available for plants (Senn 1987). Many commercial extracts from *Ascophyllum* have been developed that improve the growth and quality of specific human food crops (Senn 1987, Pereira *et al.* 2020). *Ascophyllum* thalli are composed of 20% to 29% alginic acid, the precursor for alginates (McHugh 2003). Industrial food manufacturers value sulfated polysaccharides (e.g, alginates, agar, carrageenan) found in

*Ascophyllum* and other seaweeds for their properties as gelling and thickening agents. *Ascophyllum* can also be used as animal feed, either raw or in manufactured meal, as the seaweed also contains vitamins and trace elements that elevate growth and productivity in livestock (Pereira *et al.* 2020).

## COMMERCIAL HARVEST IN NOVA SCOTIA

### History of Harvesting

Fertilizer production from *Ascophyllum* began in eighteenth-century Ireland (Guiry and Morrison 2013). Widespread commercial harvesting of *Ascophyllum* began in Nova Scotia in 1959, primarily in southwestern Nova Scotia and along the Bay of Fundy (Chopin and Ugarte 2006). From 1959 to 1985, annual landings of harvested *Ascophyllum* were under 10,000 wet tons of biomass. This only changed after the introduction of Norwegian mechanical suction cutter technology, enabling annual landings of *Ascophyllum* to increase to up to 30,000 wet tons (Chopin and Ugarte 2006).

This increase in landings drew additional commercial *Ascophyllum* enterprises to Nova Scotia. The resulting intensification of *Ascophyllum* harvesting led to exploitation of widening expanses along the Nova Scotian coastline. During this period, the Nova Scotian government provided little active regulation for this resource, leaving supervision of the *Ascophyllum* stocks in the hands of industry. Overharvesting became a major concern due to the lack of centralized recordkeeping. Observers noted visible degradation of populations especially in so-called “open areas” where anyone could harvest *Ascophyllum*. In 1993, industrial players in Nova Scotia reverted to hand harvesting methods and established a quota system, capping maximum landings from any given *Ascophyllum* bed in Nova Scotia (Chopin and Ugarte 2006). This system persists across Nova Scotia today. Fisheries and Oceans Canada (DFO) evaluated the current stocks and the harvesting system in 2013, and made several recommendations for improving industrial harvest management (Vandermeulen 2013). The extent to which industry, commercial harvesters, and provincial authorities have implemented these recommendations remains unclear.

## Management of the Shore

Fisheries and Oceans Canada outlines the provincial limits on harvesting of *Ascophyllum* under Section 71 of the Fisheries and Coastal Resources Act. Features of the act include limits on the amount of holdfast that may be harvested–15% of the total landing–and the minimum amount of thallus that must be left above the holdfast, approximately 127 mm (Government of Nova Scotia, "Rock Weed Harvesting Regulations – Fisheries and Coastal Resources Act (Nova Scotia)" 2017). As of 2013, no areas within the available plots leased for harvest of *Ascophyllum* have been closed permanently (DFO 2013). *Ascophyllum* harvesting leases span nearly the entire length of Nova Scotia's Atlantic shoreline, but active harvesting primarily occurs from the southern end of the province into St. Mary's Bay and in the Annapolis Basin. Acadian Seaplants Limited (herein called ASL) holds 14 of the 22 rockweed leases currently available in Nova Scotia, totaling 327,728.42 hectares, or approximately two thirds of the leases by area. The remaining leases, totaling 155,748.30 hectares, are held by two additional companies and one private individual (Communications Nova Scotia 2014).

Large scale commercial harvesting also occurs in the United States, with significant activity in Maine since the 1970s (Totten 2019). The Maine Department of Marine Resources sets criteria and limits on *Ascophyllum* harvesting in Maine, including a minimum 16" cutting height, maximum harvest rates, and closed areas (DMR 2014). ASL established operations in Maine in 1999 and capped at harvesting to a maximum of 17% of the standing *Ascophyllum* biomass within their areas of operation in the state (Totten 2019). This is the same harvesting limit as in New Brunswick (Ugarte and Sharp 2001). In contrast, Nova Scotia allows for removal of up to 25% of available biomass (Vandermeulen 2013).

However, a recent court case, *Ross v. Acadian Seaplants, Ltd.,* reduces ASL and other harvesters' ability to collect *Ascophyllum* in the intertidal zone. The Maine court ruled that rockweed and associated harvesting rights are held by the "adjacent upland landowner" (Totten 2019) from the intertidal *Ascophyllum* bed. In Canada, by contrast, private property rights end at the top of the intertidal zone. Analysts suggest that the ruling may lead to withdrawal by ASL from the Maine rockweed harvesting industry (Reiter *et al.* 2020). The loss of accessible harvests in Maine's intertidal zones due to

*Ross v. Acadian Seaplants, Ltd.* may lead to increased exploitation of zones along Nova Scotian shores in the future.

## Rakes and Boats

The manner of *Ascophyllum* harvesting represents a key issue for future conversations about its management. While in other jurisdictions commercial harvesters employ mechanical harvesting boats, in Nova Scotia *Ascophyllum* is only harvested manually with a cutting rake designed specifically for rockweed collection (DMR 2014). This cutting rake is "a 3m pole… equipped with sharp tooth-shaped blades held in a rake head protected by three guides" (Ugarte *et al.* 2006). The design of the rake's guides are meant to prevent *Ascophyllum* from being cut too close to the holdfast, as per Nova Scotian regulations (Government of Nova Scotia, "Rock Weed Harvesting Regulations – Fisheries and Coastal Resources Act (Nova Scotia)" 2017). This design remains in use among harvesters in Nova Scotia as of 2020, though harvesters removed the central guide from most rakes in common use. There appears to be no surviving documentation that details when or why the rake design was changed. However, conversations with harvesters indicated that the middle guide caused greater entanglement of the seaweed frond on the rake, and thus slowed them down during harvesting.

In New Brunswick, ASL manufactures the rakes for harvesters, but there are no regulations in place regarding the rake's design, only that harvesting must be by hand and follow existing restrictions with respect to total biomass removal and cutting height.

Informal interviews held with harvesters in Yarmouth County in August, 2020, provided more data for understanding the shore-level economic impacts of *Ascophyllum* harvesting. Harvesters selling to ASL earned 55 CAD per ton of *Ascophyllum* in 2020. Each harvester deposits their haul into a blue 10-tonne box which is collected by ASL when full. The boats themselves can contain up to 5 tons of rockweed when they return to the docks. Harvesters report that many boats go out more than once in a single tide. At Wedgeport, NS, five of these boats were spotted from the shore on August 21, 2020, at 8:30 am, only three days after this portion of shore was opened for harvesting by ASL. Harvesting leases remain open until they meet the 25% threshold of biomass in that zone, at which point ASL closes the area and opens another.

In theory, this rolling season allows for consistent harvesting over longer periods of the year without over-harvesting any individual bed. Harvesters report that with two workers, two round trips are required to fill a standard box for ASL, taking approximately five hours to complete.

The manual method of *Ascophyllum* harvesting currently employed in Nova Scotia is more laborious and less efficient than mechanical harvesting (DMR 2014). Harvesters therefore focus on denser areas of *Ascophyllum* growth to maximize their catch per unit effort (CPUE), instead of harvesting evenly across available beds (DMR 2014). This results in uneven cutting frequency and density across *Ascophyllum* beds. These inefficiencies, in turn, may currently be leading to inefficient and irregular renewal of *Ascophyllum*.

## Biological and Ecological Changes due to Harvesting

The removal of *Ascophyllum* biomass from the coastal environment impacts the intertidal ecosystem in various ways. Harvesting results in a change in morphology for *Ascophyllum* plants themselves: fronds and branches become shorter and denser, more akin to a bush in structure than an underwater tree (Ugarte *et al.* 2006). Such reactions alter the structural complexity of the *Ascophyllum* beds; while in isolation the effects of these changes might appear negligible, uncut stands of *Ascophyllum* nearby suggest that there is a significant impact as a result of commercial harvesting. Simulated harvesting studies show an unrecoverable decline of species richness, and many species that depend on *Ascophyllum* habitat decline in local abundance after harvesting (Seeley and Schlesinger 2012).

Estimates of biomass removal during harvesting indicate a need for further information and investigation. Industrial sources maintain claims that removal of up to 25% of harvestable *Ascophyllum* biomass from their ecosystem allows for consistent maintenance of available rockweed stocks (Vandermeulen 2013). This number does not account for different subsets of biomass, such as the removal of reproductive tissue or epidermal shedding. Accounting for losses of underdeveloped reproductive tissues removed early in the harvest season, epidermal shedding, and fronds lost to wave action has a significant impact. Studies have estimated that *Ascophyllum* contributes up to 170% of its vegetative weight in shed detrital biomass

(Garbary *et al.* 2021b, in preparation). However, industrial sources contest this claim (Ugarte *et al.* 2017).

## The Responsibilities of Industry and the Provincial Government

There is great benefit for industry to take a proactive approach to management and management science, as there is a financial motivation for maintaining the *Ascophyllum* stocks over the long term, and in avoiding a decline in stock as happened in the Irish Moss (*Chrondrus crispus*) industry (Chopin and Ugarte 2006, Vandermeulen 2013). However, there is some evidence that the aims of industry, the province, and coastal ecologists may not be as aligned. In a rebuttal to a new estimate of detrital biomass loss to harvesting, industry ecologists allude to fear that the present harvesting regulations are "to the detriment of the *Ascophyllum* harvesting industry on both sides of the Atlantic, which currently provides considerable employment in areas where jobs are in short supply" (Halat *et al.* 2015, Ugarte *et al.* 2017).

The value of the industry overall is difficult to determine. One can estimate total pay to harvesters based on overall landings and the prices reported by harvesters, but this does not account for rockweed as a value-added product. In Maine, the *Ascophyllum* industry has been reportedly valued at $20 million USD, but no such assessment exists for the Nova Scotian industry, which harvested four times the biomass collected in Maine prior to the *Ross v. Acadian Seaplants, Limited* law case (Willick 2017). Given that the global seaweed industry is expected to be worth $30.2 billion USD by 2025 (Anon. 2020, "Seaweed Cultivation Market by Type, Method of Harvesting, Form, Application And Region – Global Forecast to 2025,"), the sustainability of a largely self-managed industry with limited provincial oversight and cooperation should be of concern.

In addition, one wonders about the state of communication between the scientists tasked with monitoring the rockweed stocks and the harvesters actually doing the collections. The large body of literature on *Ascophyllum* commonly agrees that the seaweed grows no more than 15 centimetres per year (Hill and White 2008). However, conversations with harvesters indicated a general impression of much faster growth, with some decreeing that rockweed could recover a meter of length in a year (personal communications, 2020). With this impression amongst the harvesters, will appropriate care be taken with respect to conservation by those operating the harvesting boats? Unlike the situation in commercial wild-catch fin-fisheries, there are no government observers stationed on the small rockweed harvesting boats or at the docks when they return, to confirm these findings.

### The Composition of the Fucoid Zone

Another threat arises in the *Ascophyllum* zone, irrespective of the harvesting. *Fucus serratus* is an invasive species of brown alga from the same family as *Ascophyllum*. It has been expanding its foothold in the province since the 19th century (Brawley *et al*. 2009). Recent work indicates that *Fucus serratus* is newly present on Nova Scotia's South Shore, both in the traditional subtidal and intertidal zone, moving into *Ascophyllum* harvest beds (Garbary *et al*. 2021, in press). The spread of this species is likely enhanced by warming surface ocean temperatures so that it now occupies a new portion of the shore (Filbee-Dexter *et al*. 2016). The growing prevalence of the species is of immediate concern to industry, as it looks likely to crowd out and replace *Ascophyllum* at the bottom of the shore (Garbary *et al*. 2021b, in press).

## CONCLUSIONS

*Ascophyllum nodosum* is an ecologically and commercially important seaweed in Nova Scotia. The exploitation of this resource creates economic opportunities and brings industry to the province. However, the sustainability of the harvesting industry as it currently stands is in question. There are pressing questions about the impact of harvesting on *Ascophyllum* and its intertidal community that require clarification. To keep the *Ascophyllum* harvest sustainable, adjustments may have to be made by industry in the near future.

*Acknowledgements* Part of the observational work outlined here was conducted under the supervision of Dr. David Garbary as part of ongoing thesis work at Saint Francis Xavier University. He has agreed to the inclusion of these observations in the paper, and I am grateful for his review of it. I also thank Dr. Herb Vandermeulen for his invaluable review of the paper. Sections of it may be used in the final thesis presented upon my graduation.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 455-457

# BOOK REVIEW

***The Science of Citizen Science*. K. Vohland, A. Land-Zandstra, L. Ceccaroni, R. Lemmens, J. Perelló, M. Ponti, R. Samson, & K. Wagenknecht. (eds.). 2021. Springer International Publishing, Cham, Switzerland: vii, 529 pp. ISBN 978-3-030-58277-7; 978-3-030-58278-4. Open Access: https://doi.org/10.1007/978-3-030-58278-4**

Citizen science is not a new concept. It has been practiced for centuries, although the term itself was first coined in the mid-1990s. Initially, citizen scientists were mostly regarded as bird watchers or amateur astronomers, but citizen science as a field of research has been growing in popularity in many scientific areas in recent decades. In the current landscape, where data are valuable assets, citizen scientists are filling gaps in the global collection of data. Their contributions are recognized as revolutionary in innovation and policy impact. *The Science of Citizen Science* endeavors to provide an overview of the diverse aspects of citizen science while reflecting on current developments, the contributions of citizen science, and the different concepts, practices, challenges, and outcomes of this research field. The editors claim that this volume "aims to contribute to the good practice of citizen science to develop citizen science as an acknowledged and broadly practiced approach in universities, other research institutes, and civil society organizations" (p. 9). The book combines the work of the research network, Cooperation in Science and Technology (COST), which is part of the EU-funded European Cooperation in Science and Technology, the intergovernmental framework to "promote creativity, scientific literacy, and innovation throughout Europe" (p. 10).

The book's 26 chapters are divided into four parts. The first three chapters lay the foundational concepts of citizen science, its definition, challenges, and exploration of citizen science across Europe. Part one of the volume (Chapters 4-12) explores the impacts of citizen science on various disciplines such as natural sciences, humanities, health, environmental justice, and social science. The chapters also critically reflect on the debatable aspects of citizen science, such as data quality, managing science as a commons, co-creation of knowledge, and participation methods in research design commonly adopted in citizen science projects. Part two (Chapters 13-20) takes a deeper dive into the societal impact of citizen science with a focus on policy, innovation, learning, and other aspects like diversity, inclusion, consent, and other ethical considerations. Part three (Chapters 21-25) elaborates on the various instruments and practical tools that aid in supporting citizen science. In part four (Chapter 26), the authors expand on the COST action, providing more context to the past and the anticipated future work in citizen science.

This book is a good comprehensive introduction for beginners who want to learn more about the various processes and aspects of citizen science. The volume's approach to situate citizen science in multiple disciplines and its impacts on the outcomes from these research fields provides a window into the potential of citizen science as its own field. This multidisciplinary perspective would be useful for scientists, policymakers, and academic programs to integrate and expand the use of citizen science in their respective areas. The layout of this book is another notable strength, i.e., organizing the chapters into a theme family enables the reader to develop a cohesive understanding of the broader scope of citizen science before moving into the more specific topics.

*The Science of Citizen Science* is different from the other books published on this subject, such as *Field Guide to Citizen Science: How You Can Contribute to Scientific Research and Make a Difference* (2020), *Citizen Science: How Anyone Can Contribute to Scientific Discovery* (2019), and *Citizen Science: How Ordinary People are Changing the Face of Discovery* (2016), in terms of its comprehensiveness in addressing a spectrum of topics within the realm of citizen science. This volume provides a survey of topics that are not often addressed, including data quality, ethical considerations, socio-economic-political issues, team building strategies, best practices, and project participants' behavioral aspects. Another aspect that sets this book apart is that each chapter was written by subject experts. The editors acknowledge the limitations and barriers to citizen science. Recommendations are provided for almost all of the subjects addressed in the book; however, often the recommendations are quite broad and there is room for further exploration.

The audience for this book goes beyond academic communities, which the Open Access format supports. As a newcomer to citizen science, I found the book to be heavy reading. To policymakers, project leaders, citizen science practitioners, and the general public, its verbose content could be a limiting factor to the uptake of practical applications covered in the book. However, *The Science of Citizen Science* contributes to a deeper understanding of various aspects of citizen science from interdisciplinary and multidisciplinary points of view, and the dedicated reader will learn much from it.

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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 459-491

# NSIS COUNCIL REPORTS

## Reports from the Annual General Meeting
## May 3, 2021 - 6 pm

## AGENDA

## 160TH ANNUAL GENERAL MEETING
## (This meeting will be virtual, via Zoom)

1. Minutes of the 159th AGM, 14 September 2020
2. Vote to accept Minutes of the 159th AGM
3. President's Annual Report (Tamara Franz-Odendaal)
4. Treasurer's Annual Report (Angelica Silva)
5. Editor's Annual Report (Peter Wells)
6. Librarian's Annual Report (Michelle Paon)
7. Membership Annual Report (Shea McInnis)
8. Webmaster's Annual Report (Patrick Upson)
9. Publicity Annual Report (Nicole LeBlanc)
10. Student Science Writing Competition Annual Report (Evans Monyoncho)
11. Excursions Annual Report (Hank Bird)
12. Lecture Programme for 2021-2022 Report (Anne Dalziel)
13. Vote to accept the 10 Reports
14. Nomination of 2021-2022 Council (Tana Worcester)
15. Vote to approve the new Council
16. Any Other Business
17. Adjournment

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

Dr. Sarah Wells, Associate Professor, School of Biomedical Engineering, Dalhousie University will present "What We Can Learn From the Strength of a Mother's Heart".

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

# MINUTES OF THE 159TH NSIS ANNUAL GENERAL MEETING

**September 14, 2020**

*Meeting held virtually, via Zoom.com*

**Council Members present:** Tana Worcester (President), Tamara Franz-Odendaal (Vice-President), Sherry Niven (Past President), Angelica Silva (Treasurer), Michelle Paon (Librarian), Peter Wells (Editor), Dylan Miller (Membership Officer), Hank Bird (Excursions and Student Science Writing Competition Coordinator), Shea McInnis (Student Representative), Jillian Phillips (Observer, Discovery Centre), Sally Marchand (Observer, Schools)

**Members present:** Patrick Ryall, Yashar Monfared, Evans Monyoncho

**Regrets (Council Members):** Lorraine Hamilton (Secretary), Nicole LeBlanc (Publicity Officer), Patrick Upson (Webmaster), Alan Ruffman (Councillor), Richard Singer (Councillor), Darlene Smith (Councillor), Tim Fedak (Observer, Nova Scotia Museum), Sarah Kuehm (Schools), David Richardson (Associate Editor)

The President welcomed members and called the 159th Annual General Meeting (AGM) to order. The President noted that presentations would be kept short and informal and that the reports, excluding the minutes from last year's AGM, would be passed as a unit at the end of the presentations.

1. **Approval of the Minutes of the 158th Annual General Meeting of 6 May, 2019:**
   There were a few minor revisions to these Minutes.

2. **Motion to accept the revised minutes of the 158th AGM:**
   **Moved:** Tana Worcester
   **Seconded:** Tamara Franz-Odendaal
   **All in favour:** Carried

3. **President's Annual Report (Tana Worcester):**
   The president thanked the 2019-2020 Council for its work and accomplishments during the past year, and the Nova Scotia Museum for hosting the NSIS lectures. And she gave special thanks to those Councilors who are leaving at the end of the term:

Lorraine Hamilton (secretary), Dylan Miller (membership officer), Darlene Smith (councilor), Alan Ruffman (councilor), Richard Singer (councilor), Alexa Kirste (student rep), Sarah Kuehm (observer).

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

It was a successful year, even though Covid-19 compelled us to cancel the April public lecture. And although the Council had to work virtually from April onwards, it was able to get some productive work done. We have many achievements to celebrate this year, including the addition of a PayPal option to the NSIS website; the development of a beautiful publicity pop-up banner; several great excursions, including a behind-the-scenes tour of the Discovery Centre; and the production of the *Proceedings of the NSIS* Volume 50, Part 2.

The President thanked Darlene Smith and Nicole LeBlanc for organizing the very successful Public Lecture Series this year. She also thanked all the lecturers for sharing their knowledge, experience, and time on such diverse and wide-ranging topics. This year Nicole LeBlanc made some of these available to a virtual audience through live streaming.

In August 2020, Council had a strategic planning session which was quite productive. A number of measures have been started, and efforts are underway to update the strategic planning document that was presented at the AGM last year, with updated priorities for action. All Members are welcome to provide input and help set the direction of the NSIS for the years to come!

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

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

As of 31 March 2020, the net worth of the NSIS was $37,826.29 with $16,973.08 at BMO account plus current Investments of $20,853.21. There was a revenue from all sources of $2,282.08 (mostly memberships) and expenditures of $7,052.12 (mostly for *Proc. NSIS*, Science Fairs and the Writing Competition).

The Treasurer noted that her reporting period was 1 April 2019-31 March 2020 and reported that the NSIS has 76 members:

2 honourary, 16 life, 40 regular, 4 student and 14 institutional members

Angelica thanked Patrick Upson for setting up the PayPal link on the website, which allows members to more easily pay their dues.

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

The Editor reported that Vol. 50 No. 2 of the *Proceedings* has been published in hard copy in February and will be digitally available (6 months following publication). Volume 51, No. 1 of the *Proceedings* is in progress.

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

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

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

The Librarian reported that in 2019-2020, sales of the *Proceedings,* from the Reference and Research Services office of the Killam Library, yielded $30.00.

Other results of note during the year:

- 210 complimentary copies of the Proceedings (from the overstock inventory) were distributed. In the past 2 years or so, a total of 1280 copies have been thus distributed.
- the required forms to Access Copyright for the repertoire payment to publishers were submitted and NSIS received a payment of $473.59.
- 11 institutional partners renewed their subscriptions, currently there are 15 institutional members and 84 NSIS exchange partners.
- 76 journal issues and society publications were delivered to Dalhousie's Killam Library (before the Covid-19 shutdown) from the Institute's exchange partners.

- At the next opportunity to access the Killam Library, the latest copies of *Proc.NSIS* will be sent out.

7. **Lecture Program for 2020-2021 – Report of the organizing committee (Tamara Franz-Odendaal):**

**Sept. 14, 2020** (AGM) – Anne Dalziel (Dalhousie, Dept. of Biology), Diversity in a Minnow Trap

**Oct. 5, 2020** – Erin Bertrand (Dalhousie, Dept. of Biology), Operating Phytoplankton Need Their Vitamins Too: How the foundation of ocean food webs depends on micronutrients

**Nov. 2, 2020** – Glenys Gibson (Acadia, Dept. of Biology), Life & Times of Minas Basin Marine Invertebrates: A tale of polychaetes, plasticity, and microplastics

**Dec. 7, 2020** – Amy Tizzard (NS Geological Survey, Energy Dept.), Evolution of the Oxford Sinkhole

**Jan. 4, 2021** – Michael Parsons (Geological Survey of Canada), Metal Mining in Nova Scotia: Learning From the Past to Improve Future Environmental Performance

**Feb. 1, 2021** – Derek Fisher (MSVU, Dept. of Psychology), Seeing Through the Smoke: Cannabis and the Brain

**Mar. 1, 2021** – Gordon McOuat (U. King's/Dalhousie, History of Science & Technology), Brewing Civilization: The Science and Culture of Beer

**Apr. 12, 2021** – Russell Wyeth (St.F.X., Dept. of Biology), Wayfinding Under the Waves

**May 3, 2021** (AGM) – Sarah Wells (Dalhousie, School of Biomedical Engineering), The Strength of a Mother's Heart: What we can learn

8. **Excursions in 2019-2021 (Hank Bird):**
Hank Bird reported that successful excursions took place in 2019:

- 2 crows Brewing Company April 2019 (Halifax)
- Geological Museum + Ottawa House + Tidal Power Exhibit in July 2019 (Parrsboro)

- Discovery Centre (incl. behind the scenes) in December 2019 (Halifax)

The following excursions were being planned for 2020-2021 but were postponed due to Covid-19:

- Petroglyphs and Guided Nature Hike (Kejimkujik N.P.)
- Waterfalls of Nova Scotia (various sites)

The likelihood is that they will not take place until 2021.

The following excursions are also being considered for 2021:

- Cape Split Nature Hike (Scots Bay)
- NS Museum of Industry (New Glasgow)

Hank mentioned that suggestions for other excursions would be most welcome.

**9. Student Science Writing Competition Annual Report (Hank Bird):**

Hank Bird reported that there was improved participation this year with 23 students (13 undergrad and 10 postgrad) registered for the competition, and 11 students (7 undergrad and 4 postgrad) actually sending in manuscripts. He thanked his fellow judges (Tim Fedak, Sally Marchand, Pat Ryall, Antony Simpson) for their diligence, insights, and assessments.

The overall quality of the papers was quite high. The winner in the undergraduate category was Danielle Knott (Dalhousie). It was not possible to draw a clear distinction between the two best papers in the post-graduate category, so for the first time we had two winners – Michael Smith and Jennifer Kolwich (both SMU). There were no honourable mentions this year. As the NSIS Public Lecture on April 1st was cancelled due to Covid-19, the awards were mailed to the winners.

Hank Bird is retiring from the position of Coordinator for this competition. Two post-doctorate fellows from Dalhousie – Yashar Monfared and Evans Monyoncho – have volunteered to be co-cordinators. The hand-over is in progress.

**10. Publicity Report (Nicole LeBlanc):**

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

11. **Webmaster's Report (Patrick Upson):**
Mr. Upson was unable to attend, but a summary of his submitted report is as follows.

In addition to routine maintenance, numerous updates were made to the content on the website. One of the Webmaster's big achievements was to sign up for and activate an NSIS account on the PayPal electronic payment system, which now allows members to pay their dues online. In addition, he bought and set up the domain name nsis1862.ca which links directly to our homepage. The Executive Page was updated, and all 2019-2020 Lectures were added to the website.

In progress: the NS Hall of Fame index is being re-organized to use person's last name then first name.

12. **Membership Report (Dylan Miller):**
By the end of the 2019-2020 year, we had 101 total members (up 11 from last year), which includes:

- 2 Honorary members (no change from last year)
- 13 lifetime members (up 2 from last year)
- 72 other paid members including regular and students (up 9 from last year)
- 14 free members from presenters of Lectures and students from the writing competition (up 1 from last year)

In addition, there are 14 institutional members.

We continued our policy of offering free 1-term memberships to both speakers and the students who submit for the writing competition.

Dylan also thanked Patrick Upson for setting up the PayPal link on the website.

13. **Motion to accept the Annual Reports:**
**Moved:** Tana Worcester
**Seconded:** Michelle Paon
**All in favour:** Carried

### 14. Report of the Nominating Committee for the 2020-2021 Council (Sherry Niven):

Sherry Niven thanked the outgoing Council, and remarked that the Nominating Committee made efforts to increase the Council's diversity for institutions represented, disciplines, age, gender, and geographic location.

The President asked the AGM to elect the following to NSIS Council for 1920-21:

| | |
|---|---|
| President | Tamara Franz-Odendaal |
| Vice-President | (Vacant) |
| Past-President | Tana Worcester |
| Secretary | Hank Bird |
| Treasurer | Angelica Silva |
| Publicity Officer | Nicole LeBlanc |
| Membership Officer | Shea McInnis |
| Librarian | Michelle Paon |
| Editor | Peter Wells |
| Webmaster | Patrick Upson |
| Councillor | Sherry Niven |
| Councillor | Tamara Franklin |
| Councillor | Stephanie McQuarrie |
| Councillor | Anne Dalziel |
| Student Representative | Romman Muntzar |
| Observer (Discov. Ctr.) | Jillian Phillips |
| Observer (NS Museum) | Tim Fedak |
| Observer (Schools) | Sally Marchand |
| Observer (SSWC) | Yashar Monfared |
| Observer (SSWC) | Evans Monyoncho |
| Assoc. Editor | David Richardson |

There was a call for additional nominations from the floor, including the vacant position for Vice President. None were forthcoming.

### 15. Motion to approve the Nominations:

**Moved:** Sherry Niven
**Seconded:** Peter Wells
**All in favour:** Carried

**16. Any Other Business:**

Tamara Franz-Odendaal thanked Tana Worcester for her service as President, and said she is looking forward to the coming 2020-2021 year.

**17. Adjournment:**

Motion by Tana Worcester to adjourn the 159th Annual General Meeting of the NSIS.

*Respectfully submitted*
*Hank Bird*
*Secretary*

# PRESIDENT'S REPORT
## 2020-2021

What a year we have had? With the global pandemic reaching Canada in mid-March of 2020, we had to make some major shifts in how we do things in the NSIS. For the 2020-2021 year, we pivoted all our council meetings and all our public lectures to an online format. While some were skeptical about this move, we had no choice. Now nine months later, we have decided to continue with council meetings virtually in the future, so as to be more inclusive to our members who want to serve on council who are outside of HRM. Virtual council meetings also avoids a lot of unnecessary travel in rush hour traffic. For the upcoming year, we have also decided to hold our lecture series virtually. We are discussing a hybrid format (half virtual and half in-person) for two years' time, when hopefully the pandemic is well and truly behind us.

I have to give a special thanks to the Student Writing Competition leads, Evans Monyoncho and Yashar Monfared, who did a tremendous job in advertising the competition, rallying up judges and communicating with our student writers. Both Evans and Yashar are leaving Council this year and we wish them well on their continued studies. I would like to extend a huge thank you to our Proceedings Editor, Peter Wells and Associate Editor David Richardson and the entire PNSIS editorial board including Gail Leblanc for their behind the scenes work on reviewing manuscripts and publishing the scientific journal of the society. A special thanks to Patrick Upson who has made many tweaks to our website throughout the year. The website is our public face and it is our goal to revamp it even further. However to do this, we need to raise more funds and increase our membership. While we have made some very good strides in increasing our membership this year, we need to continue our membership drive. Thank you to Shea McInnis for keeping track of our membership database. To our publicity officer Nicole Le Blanc who has unfortunately not been able to attend many council meetings due to her "real job" commitments, we all thank you for the tremendous work you have done over the last few years launching many new initiatives for the NSIS. Anne Dalziel, Stephanie McQuarrie and Tamara Franklin who joined council for the first time, thank you for your participation. Our regular council members, Angelica Silva, who keeps track of our finances, and Michelle Paon, our librarian thank you for all your many years of service. To Sherry Niven and Tana Worcester, Past Presidents of the NSIS, thank you to you for your continued support. To our observers who keep us connected to on-the-ground science activities in the province – Tim Fedak (NS Museum), Jillian Phillips (Discovery Centre), Sally Marchand (Schools) – thank you – it is so important for us to have these community linkages. To our student councilor Romman Muntzar, we have valued your input on our discussions. Finally, I would like to especially thank Hank Bird, who stepped into the NSIS secretary role this year and who has been a steady hand ensuring we are documenting our progress.

### Public Lectures

While we pivoted our public lectures to on line this year for the very first time, these lectures have been very well attended, often with audience members from across the province and in one case, internationally. We thank all our speakers of the series this year.

**Sept, 14, 2020:** Dr Anne Dalziel (Saint Mary's University)
– Diversity of the Minnow Trap

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

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

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

**Jan 4, 2021:** Dr Michael Parsons (Geological Survey of Canada)
– Metal Mining in Nova Scotia: Learning From the Past to Improve Future Environmental Performance

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

**March 1, 2021:** Dr Gordon McQuat (King's College,
Dalhousie University)
– Brewing Civilization: The Science and Culture of Beer

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

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

New this year, we video recorded all the lecture series talks and posted them on our new You Tube Channel. Another thank you to Nicole Le Blanc and Sally Marchand for recording and posting these videos. Finally, I would like to thank WISEatlantic for sponsoring several of our Public Lectures this year.

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

## TREASURER'S REPORT 2020-2021

### April 1, 2020 - March 31, 2021

| | |
|---|---|
| **ASSETS 2020-2021 as of March 31, 2021** | |
| Bank Account BMO (as of March 31, 2021) | 14,780.30 |
| Investments (as of March 9, 2021, to BMO) | 21,259.35 |
| **Total Assets at BMO March 31, 2020** | **$36,039.65** |

| | |
|---|---|
| **INVESTMENTS as of March 9, 2020 after transference to BMO** | |
| Renaissance High Interest Savings Account @ 1.0% | 4,240.72 |
| Equitable Bank GTD Investment Cert A (due March 9, 2021 @ 1.91%) | 5,095.50 |
| Equitable Bank GTD Investment Cert A (due March 8, 2021 @ 2.72%) | 11,923.13 |
| **Total Investments as of March 31, 2020** | **$21,259.35** |

## REVENUES AND EXPENDITURES 2020-2021

### REVENUE 2020-2021 as of March 31, 2021

| | |
|---|---|
| NSIS Membership<br>(via paypal – Regular, LIFE, and Students) | $2,854.63 |
| NSIS Membership regular | 420.00 |
| NSIS Membership Life | 600.00 |
| NSIS Students | 40.00 |
| NSIS Membership Institutions | 360.00 |
| Income/ACCESS Copyright Royalties | 422.09 |
| WISE Atlantic contribution to NSIS lectures | 1,500.00 |
| **TOTAL REVENUE** | **$6,246.72** |

### EXPENSES 2020-2021 as of March 31, 2021

| | |
|---|---|
| NSIS Proceedings PNSIS /Printing | $4,284.06 |
| NSIS Proceedings PNSIS/Layout | 2,537.82 |
| NSIS Brochures | 47.62 |
| NSIS 2019 Writing Science Competition | 1,500.00 |
| NSIS website Chebucto Community Net | 70.00 |
| **TOTAL EXPENSES** | **$8,439.50** |

## Finances

The net worth of Nova Scotian Institute of Science as of March 31, 2020 is **$36,039.65** that includes $14,520.30 at BMO account plus transference of $21,259.35 from CIBC Wood Gundy investments.

During 2020-2021 period, NSIS had a total income of $4,274.63 that resulted from all paid NSIS Memberships via paypal and via cheques deposited to BMO account. NSIS Memberships dues did include Regular, Life Memberships and Institutions. Other income was received from Access Copyright Royalties of $422.09.

Total Expenditures of $8,439.50 resulted from costs associated to Printing of Proceedings of Nova Scotia Institute of Science (PNSIS) for $ 4,284.06, PNSIS layout costs of $2,537.82, plus expenses related to lectures advertising of $47.62, maintaining a NSIS website with Chebucto Community Net for $70, Contribution to NSIS Student writing Competition of $1,500.

As mature investments with CIBC Wood Gundy were transferred to NSIS BMO account, NSIS no longer has any investments. CIBC Wood Gundy did originally charged $250 to NSIS account as management fee and they appear to have refunded the total amount which will be confirmed once all documents are received.

## Membership

**2020- 2021:** NSIS had a total of 129 active members, 111 of these are paid members that include 75 regular memberships, 15 student memberships, 21 Life Memberships and 13 paid Institutional memberships during the year. Additional NSIS memberships were awarded to NSIS lecturers (9) and University student writers (7) plus 2 Honorary Memberships.

New this year is that with Patrick Upson's assistance NSIS CURRENT and NEW NSIS Members were able to renew their memberships or became new NSIS members using paypal directly from the website nsis.chebucto.org. Some renewals and new memberships continue to be received via regular mail and we thank Carol Richardson from Dalhousie University for her great help with NSIS mail collection and distribution. Also, many thanks to Shea McInnis for his contribution as a Membership officer.

The Nova Scotian Institute of Science continues to dedicate all its resources towards communication and support of scientific issues relevant to all Nova Scotians. NSIS continues to support science lectures, conferences, student science writing competitions, printing and producing the Proceedings of the Nova Scotian Institute of Science (PNSIS) that are distributed to all members. Another important NSIS contribution has been the funding support to all ten Regional Science Fairs in the Province of Nova Scotia, however due to COVID-19 these have not taken place.

Thank you to all that kindly donated memberships for students.

I recommend that we ask Dr. Robert Cook for his availability to conduct an audit of the 2019-2020 and 2020-2012 Financial Report since last year was not audited due to COVID 19.

*Respectfully submitted*
*Angelica Silva*
*NSIS Treasurer*
*May 3, 2021*

# EDITOR'S REPORT
# 2020-2021

Production of the Proceedings (PNSIS) continues to run well, thanks to having an excellent Editorial team and the continued interest of the scientific community from across the Province. The *PNSIS* 51, Part One (2021), was completed in February 2021. The printed copies were then kindly distributed by mail to NSIS members by Carol Richardson of the Killam Library. The Issue was made available immediately as free access on the NSIS website to members. It will be completely free access in August this year.

Many thanks are due to Gail LeBlanc, who once again did a superb job on the layout of PNSIS 51(1) and on working with me to copy edit and complete the Issue, and to get it to the Printers in February. This process took several weeks, due in part to the size of the Issue – 252 p. We double-checked two galley printings before approving it for final production.

Many thanks are once again due to Dr. David Richardson, Assoc. Editor, the Editorial Board and the external reviewers for their work handling the reviews and moving papers along for this issue. Dr. Richardson has worked especially hard on smoothly managing the review process, a critical feature of running a quality journal.

Work has been underway since January on the next Issue – *PNSIS* 51, Part 2, 2021-22. To date, we have a line-up of five Commentaries (2 submitted, 4 promised or underway); four Research Articles (2 submitted, 3 underway); and one student paper (submitted, under review). As well, there will be an Editorial (topic yet to be decided) and a complete set of the May 2021 AGM Council Reports. There may be some short book reviews too, on recently published scientific books of interest to the region. We are continuing to seek contributions for this issue and have contacted all the student winners in the writing competition for their submissions; to date, one nibbled the bait!

As in previous years, all members of Council are encouraged to either write articles, especially Commentaries, or to help seek articles from colleagues for the *PNSIS*. This includes obtaining articles from past and present speakers and from current members – this seems to be an annual plea! As stated in last Septembers AGM report –

"in this prolonged period of pandemic shutdown and uncertainty, we all have lots of time to think and write or to encourage people whom you know could contribute an article".

The Editor's report is respectfully submitted to the 2021 AGM, April 29th, 2021.

*Peter G Wells*
*Editor, PNSIS*

# LIBRARIAN’S REPORT
## 2020-2021

*(submitted for the May 2021 AGM)*

The NSIS Librarian serves as a liaison between the Dalhousie University Libraries and the Nova Scotian Institute of Science. The Librarian communicates with NSIS journal exchange partners from around the world and oversees the receipt of partner journals. She also works with Dalhousie Libraries’ staff members in the Killam Memorial Library who prepare these journals for the shelves and facilitate access to the online *Proceedings of the Nova Scotian Institute of Science*.

Due to the COVID-19 pandemic, Dalhousie University, including all Dal Libraries locations, closed on March 18, 2020, and staff transitioned to work from home. The Killam Library’s Reference & Research Services Office usually serves as the mail delivery location for NSIS mail. As a result of the campus closures as well as limited postal delivery, for a lengthy period of time it was not possible to access NSIS incoming mail.

### Proceedings of the Nova Scotian Institute of Science

During 2020/2021, there were no sales of the *Proceedings* from the Killam Library’s Reference & Research Services Office. During the summer of 2020, the Dal Libraries gradually began to open a limited number of bookable study spaces to Dalhousie students, faculty and staff. In this new phase, the Killam Library’s Administrative Assistant Carol Richardson arranged to enter the building to pick up the NSIS mail. She also packaged and mailed to members the issue of the *Proceedings* published in the spring (vol. 50.2). Subsequently in March 2021, Carol packaged and mailed copies of the new issue (vol. 51.1) to NSIS members.

The most recent issue of the Proceedings is available online to NSIS members only for a period of six months from its date of publication, at which point, the online issue becomes freely available to anyone. The most recent online issues of the Proceedings (2002-2021) can be found at: https://ojs.library.dal.ca/nsis/issue/archive and older digitized issues (1863-2013) are located at: https://dalspace.library.dal.ca/handle/10222/11192.

### Indexing and Abstracting Services

NSIS sent complimentary copies of the most recent issue of the *Proceedings* to Library & Archives Canada, the Library of Congress, and several indexing services.

### Citations to PNSIS articles

Indexing sources such as Biological Abstracts, the Scopus database, and the Google Scholar search engine provide citation indexing of PNSIS articles. A recent search of these sources reveals that since their publication dates, a number of PNSIS articles have been relatively highly cited (see Appendix A). For example, "A Forest classification for the Maritime Provinces" by Loucks, has been cited at least 167 times. Some articles that were published decades ago have been cited as recently as 2020, which shows that they continue to have research impact. For example, Hicklin & Smith's 1979 PNSIS article on the diets of migrant shore birds was cited in a June 2020 issue of *Avian Conservation & Ecology*.

### Access Copyright

During the summer of 2020, the NSIS Librarian submitted the required forms to Access Copyright for the repertoire payment to publishers. NSIS subsequently received a payment of $422.09.

### Institutional Members and Exchange Partners

NSIS sent renewal invoices to its institutional partners, 11 of which have renewed their subscriptions. There are currently 14 institutional members and 84 NSIS exchange partners.

### NSIS Exchange Journal Collection

On behalf of NSIS, I would like to thank Carol Richardson and the Dalhousie Libraries' Resources staff, who while working under considerable constraints over the past year, continued to process the exchange journals and make them shelf-ready. NSIS receives journal issues from exchange partners around the world. As an example, from mid-March 2020 to mid-March 2021, NSIS received 36 journal issues and society publications from the Institute's exchange partners. This is a significant reduction compared to previous years. For example, from April 2019 to mid-March 2020, NSIS received 76 journal issues and society publications from the Institute's exchange partners. It's possible that COVID-related restrictions resulted in delayed production schedules and postal delays for the small societies that share their print journals with NSIS.

In October 2020, NSIS received a letter from the Muséum National d'Histoire Naturelle in Paris, which publishes the journal *Adansonia*. They indicated that "due to administrative reasons", they would terminate their exchange program in November 2020. Instead of providing an exchange, they will subscribe to the NSIS Proceedings, which is fortunate for NSIS.

*Report respectfully submitted by*
*Michelle Paon, NSIS Librarian*
*April 29, 2021*

# APPENDIX A

*Proceedings of the Nova Scotian Institute of Science* – Highly cited articles (Table indicates the number of times articles have been cited as of Nov. 28, 2020 - as reported in citation indexing sources.)

| Article Title | Biological Abstracts | Scopus | Google Scholar | Most recent citation |
|---|---|---|---|---|
| Loucks, O.L. (1962). A forest classification for the Maritime Provinces. *Proceedings of the Nova Scotian Institute of Science*. 25(2): 85-167. | n/a | n/a | 167 | 2020 |
| Hicklin, P.W. & Smith, P.C. (1979). The diets of five species of migrant shorebirds in the Bay of Fundy. *Proceedings of the Nova Scotian Institute of Science*. 29(4): 483-488. | 58 | n/a | 84 | 2020 |
| Ackman, R.G., & McLachlan, J. (1978). Fatty acids in some Nova Scotian marine seaweeds: A survey for octadecapentanoic and other biochemically novel fatty acids. *Proceedings of the Nova Scotian Institute of Science*. 28(1/2): 47-64. | n/a | n/a | 77 | 2015 |
| Boates, J.S., & Smith, P.C. (1979). Length-weight relationships, energy content and the efforts of predation on Corophium volutator (Pallas) (Crustacea: amphipoda). *Proceedings of the Nova Scotian Institute of Science*. 29(4): 489-500. | 45 | n/a | 64 | 2019 |
| Bird, C.J. (1993). First record of the potential nuisance alga Codium fragile ssp. tomentosoides (Chlorophyta, Caulerpales) in Atlantic Canada. *Proceedings of the Nova Scotian Institute of Science*. 40(1): 11-17. | 37 | n/a | 66 | 2020 |

## *Appendix A cont'd*

| Article Title | Biological Abstracts | Scopus | Google Scholar | Most recent citation |
|---|---|---|---|---|
| Taylor, A. (1986). Some aspects of the chemistry and biology of the genus Hypocrea and its anamorphs, Trichoderma and Gliocladium. *Proceedings of the Nova Scotian Institute of Science*. 36(1): 27-58. | 33 | n/a | 51 | 2020 |
| 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. | 17 | n/a | 38 | 2020 |
| Roland, A.E. (1946). The flora of Nova Scotia. *Proceedings of the Nova Scotian Institute of Science*. 21(3): 94-642. | 1 | n/a | 38 | 2015 |
| Ferguson, D.C. (1954). The Lepidoptera of Nova Scotia. *Proceedings of the Nova Scotian Institute of Science*. 23(3): 161-375. | n/a | n/a | 38 + 45 (citations to 1954 & 1955) | 2017 |
| Livingstone, D.A. (1953). The fresh water fishes of Nova Scotia. *Proceedings of the Nova Scotian Institute of Science*. 23(1): 1-90. | n/a | n/a | 36 | 2018 |
| Beazley, K.F., Snaith, T.V., MacKinnon, F., & David, C. (2004). Road density and the potential impact on wildlife species such as American Moose in mainland Nova Scotia. *Proceedings of the Nova Scotian Institute of Science*. 42(2): 339-357. | 9 | n/a | 31 | 2020 |
| Dale, J., Freedman, B., & Kerekes, J. (1985). Experimental studies of the effects of acidity and associated water chemistry on amphibians. *Proceedings of the Nova Scotian Institute of Science*. 35(2): 35-54. | 18 | n/a | 26 | 2017 |

## *Appendix A cont'd*

| **Article Title** | **Biological Abstracts** | **Scopus** | **Google Scholar** | **Most recent citation** |
|---|---|---|---|---|
| Imrie, D.M.G., & Daborn, G.R. (1981). Food of some immature fish of Minas Basin, Bay of Fundy. *Proceedings of the Nova Scotian Institute of Science*. 31(2): 149-154. | 16 | 10 | 22 | 2016 |
| Bleakney, J.S., & Meyer, K.B. (1979). Observations on saltmarsh pools, Minas Basin, Nova Scotia 1965-1977. *Proceedings of the Nova Scotian Institute of Science*. 29(4): 353-372. | 14 | n/a | 25 | 2020 |

*Report respectfully submitted by*
*Michelle Paon, NSIS Librarian*
*June 13, 2020*

# WEBMASTER'S REPORT
## 2020-2021

This year we mainly focused on reordering the Hall of Fame portion of the website to order Hall of Fame members alphabetically by last name. We also added a section for Honorary Members (Dr. Arthur B. McDonald and Dr. Mary Anne White). Finally, we have added forwarding features to the NSInstituteOfScience@gmail.com account to automatically forward e-mails to the President, Membership and the Secretary when the subject line of the e-mail contains the phrasing Attention President, Attention Membership and Attention Secretary, respectively.

Otherwise the webmaster efforts were spent updating and adding the monthly talks to the site.

Traffic for the website has remained consistent with analytics for previous years showing spikes in traffic in the months between September and April.

We're still dealing with the 503 Server error that occurs when too many links on the website have been clicked with short periods between clicks. I admit this is my fault for not following up with Chebucto (our web service provider). I will continue to work on the issue.

*Submitted by*
*Patrick Upson*
*Webmaster*

# STUDENT SCIENCE WRITING COMPETITION 2021

This year we had a successful writing competition. After closing the submissions, we sent the final papers to the reviewers (# of reviewers = 7) and received the feedbacks and scoresheets from all the judges. On April 7, we hosted a virtual Teams meeting with the judges to select the winners in undergraduate and postgraduate categories. After a long discussion, we selected a winner and an honorable mention for undergraduate papers:

> **Winner: Olivia Melville** (title = Identifying the critical nitrogen to phosphorous ratio in food-grade wastewater for the growth of the diatom Thalassiosira pseudonana)
>
> Honorable mention: Kat Kabanova.
>
> In the postgraduate competition, we selected a winner and two honorable mentions:
>
> **Winner: Morgan Mitchell** (title =Long term surface ozone trends and transport in Nova Scotia)
>
> Honorable mentions: Thomas Robert Davies and Megan Fass.

The results were communicated to the winners, NSIS treasurer, and the proceedings editor for those students who might want their papers to be published in our journal.

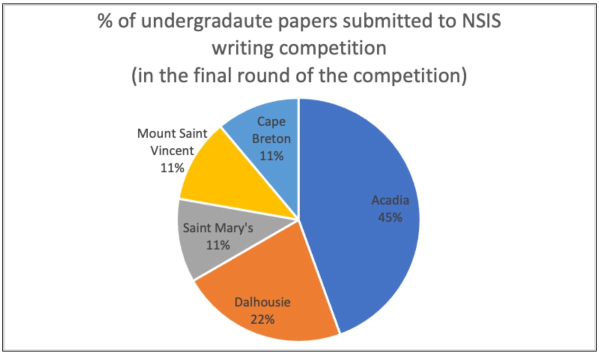
Below you can find a detailed overview of the NSIS writing competition 2021:

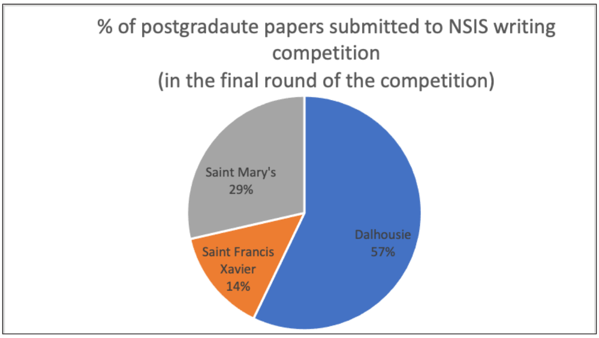
> Total number of students who showed an interest in submitting their papers = 47
>
> Total number of papers submitted = 32
> (Acadia University initial submissions = 19, others = 13)
>
> # of Papers in the final round of the competition = 16
> (undergrad papers = 9, postgrad papers = 7)
>
> We had submissions from 6 different universities in Nova Scotia including Dalhousie University, Saint Mary's University, Mount Saint Vincent University, Cape Breton University, Acadia University and Saint Francis Xavier University.

A few suggestions that came up during the meeting with the judges for the next year writing competition:

- Possibility of splitting the judges between undergraduate and postgraduate competitions to reduce the number of papers for each of the judges.
- Providing a list of the tips for effective writing (either in the video format, workshop, or just in writing) to the students.
- Possibility of increasing the number of awards while keeping the budget constant.
- Providing a page count or word count to limit the length of the papers.

*Yashar Monfared and Evans Monyoncho*
*Co-coordinators of writing competition*





## NSIS EXCURSIONS 2021

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

Early in 2020 we were considering the following excursions but cannot proceed until the coronavirus restrictions are sufficiently relaxed:

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

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

We welcome additional suggestions and possibilities.

—

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

- Natural History of McNab’s Island
- Annapolis Royal Historic Gardens
- The Science and Art of Making Beer
- Burke-Gaffney Observatory
- Joggins Fossil Cliffs
- Shubenacadie Canal
- Bedford Institute of Oceanography
- Dalhousie Planetarium
- Habits and Habitats of NS Birds (in association with the NS Birding Society)
- Otter Ponds Demonstration Forest
- The Science and Art of Making Beer, at the 2 Crows Brewing Company

- Fundy Geological Museum, Ottawa House, and the Tidal Power Exhibit
- Discovery Centre (including “behind the scenes”)

*Hank Bird*
*Excursions Coordinator*

# PUBLIC ONLINE LECTURES 2021-2022

**October 4, 2021**
NS forestry – Otter Ponds demonstration forest and recent updates to the biodiversity act

**November 1, 2021**
TBA – Energy sustainability in NS

**December 6, 2021**
Student showcase – COVID-19 student research in Nova Scotia

**January 3, 2022**
TBA – COVID-19 impacts in NS or Mi'kmaq Calendar of the Seasons

**February 7, 2022**
Tidal wetland restoration and ecosystem services in the Bay of Fundy Dykelands

**March 7, 2022**
Tiny Materials for Big Challenges:
Designing Next Generation Nanomaterials

**April 4, 2022**
TBA – Sustainable agriculture

**May 2, 2022 | Agm 2022**
TBA (COVID-19 impacts in NS or Mi'kmaq Calendar of the Seasons)

# ANNUAL MEMBERSHIP OFFICER REPORT 2021

## Summary

At the 2020 AGM, it was reported that there were 101 total members of the NSIS. At this AGM, there are currently 130 active members of the NSIS. Since the month following the previous AGM (October 2020), our membership increased from 77 total active members to 130 active members, a 1.7x increase. Over half of these members (73 total) paid via PayPal, showing that this feature was well worth the effort needed to get it working.

We encouraged members to buy gift memberships for others and this resulted in nine new members, eight of which were students. This is great, as discussions were held about how to increase student engagement with NSIS.

## Membership Overview

To date, there are currently 130 active members of the NSIS. This is up 29 members from the last AGM.

- 76 Regular (up from 38 in October): 58% of membership
- 21 Life (up from 19 in October): 16% of membership
- 16 Student (up from 3 in October): 12% of membership
- 8 Lecturers: 6% of membership
- 7 Student writers: 5% of membership
- 2 Honourary: 2% of membership

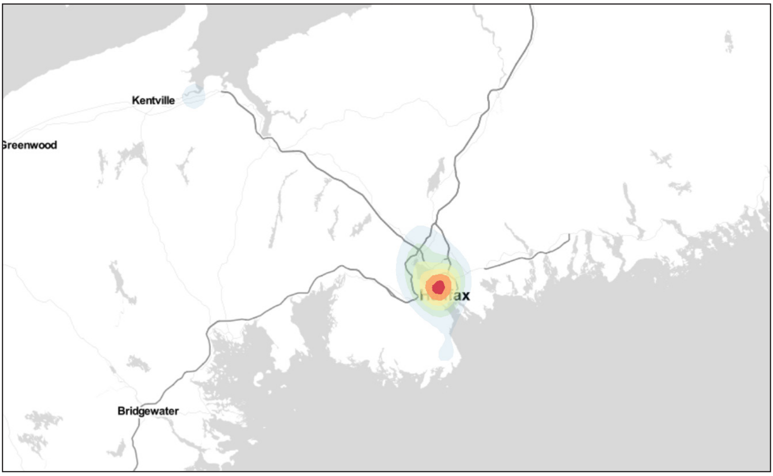
## Membership Distribution

Since moving to an online format, we became curious about the geographical distribution of our membership. We created a heat-map (pictured below) of active members and found that the majority of members lived within HRM. Surprisingly, it was found that some NSIS members live as far away as British Columbia!

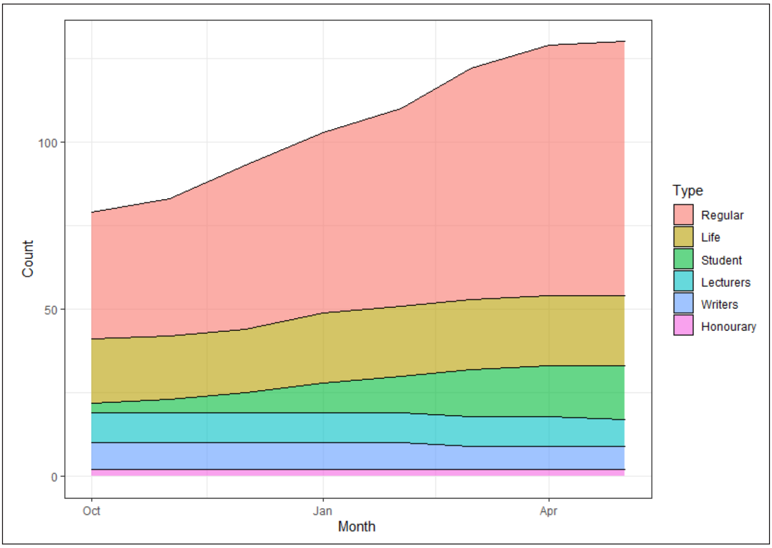
## Membership Growth

Regular membership (2x growth) and Student membership (5,33x growth) showed the most growth this year. However, all membership categories grew over time (1.6x growth; illustrated next page)

*Shea McInnis*



**Membership Distribution**



**Membership Growth**

# NOMINATIONS FOR NSIS COUNCIL
# 2021-2022 SLATE

| | |
|---|---|
| President | Tamara Franz-Odendaal |
| Vice-President | Stephanie McQuarrie |
| Past-President | Tana Worcester |
| Secretary | Hank Bird |
| Treasurer | Angelica Silva |
| Editor | Peter Wells |
| Librarian | Michelle Paon |
| Publicity Officer | Molly Murray (and Nicole LeBlanc) |
| Webmaster | Patrick Upson |
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Proceedings of the Nova Scotian Institute of Science (2021)
Volume 51, Part 2, pp. 493-494

# ERRATA

We, the Editors, and of course, the writers, try for perfection, but inevitably, a few errors creep through in the final copies. Hence, this page! Serious errors are fixed on the NSIS website versions. We have to live with minor formatting, grammatical or spelling errors, the latter in this age of Spell-Check being rare. Many thanks are owed to the sharp-eyed readers!

—

**Vol. 50-1 (2019)** – Table of Contents – one author – should be Culbertson-Paoli, M., not Culbertson.

**Vol. 50-1 (2019)** – R.H. Field's article – quite a few pesky typos, especially on p. 117.

**Vol. 50-1 (2019)** – first Book Review - it should be Elisabeth Mann-Borgese, not Elizabeth. It is misspelled in several places.

**Vol. 50-1 (2019)** – second Book Review – the book is The Rise and Fall of the Dinosaurs (3rd para., p. 185), and the magazine is Scientific American, not America (p. 186).

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**Vol. 50-2 (2020)** – Table of Contents – the word 'Editorial' is missing in front of the article by Wells.

**Vol. 50-2 (2020)** – Table of Contents – in M. Dadswell's article, one author should be "E. Porter", not "Potter". Same error occurred in the article itself – p. 283.

**Vol. 50-2 (2020)** – Book review by Don Gordon – the author's name, John F. Marra, and the publication date, 2019, are missing from the title of the review.

**Vol. 50-2 (2020)** – Book review by Tim Fedak – pagination is 397-403, not 404.

**Vol. 50-2 (2020)** – NSIS Council Reports – are in Volume 50, Part 2, 405-439.

**Vol. 50-2 (2020)** – inside back cover – Editorial Board – R. Austin and D.W. Piper are no longer members; Ian Spooner from Acadia University is a new member.

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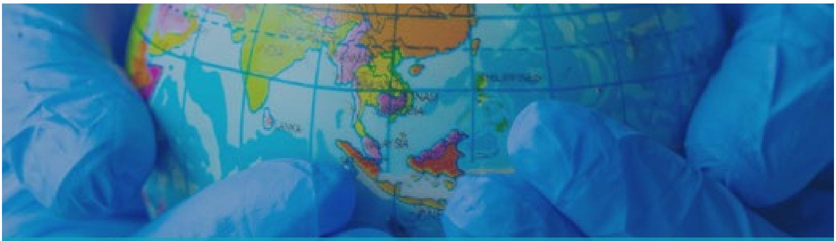
**Vol. 51-1 (2021)** – p. 2 – it should be David Attenborough, not Richard A.

**Vol. 51-1 (2021)** – inside back cover – Editorial Board – Andrew Hamilton-Wright is now at the University of Guelph.



# NSIS 2021-2022 VIRTUAL LECTURE SERIES

## OCTOBER 4

**Money Often Costs too Much**

*Reconsidering forest practices in Nova Scotia*

**Andy Kekacs**
Executive Director,
Nova Scotia Woodlot
Owners &
Operators Association
(NSWOOA)

For 50 years, Nova Scotia embraced an industrial model of forest management, which emphasized the growth and harvesting of small-diameter softwood trees for commodity products such as wood pulp and small dimensional lumber.

Andy Kekacs discusses the impacts of that strategy on Nova Scotia's forest; the growing discontent among woodland owners; foundations of our current interest in ecological forestry; and following the path toward holistic forest management.

## NOVEMBER 1

**Making the Transition to Low-Carbon Energy in Atlantic Canada: How Will We Get There?**

**Dr. Wayne Groszko**
Professor,
Nova Scotia
Community College
(NSCC)

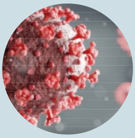
The transition to clean, renewable energy to reduce carbon dioxide emissions and address climate change is now proceeding rapidly around the globe.

What might that transition look like in Atlantic Canada? In this talk Dr. Wayne Groszko will explore pathways to a low carbon global society and the options and progress ahead for our region, with examples from the applied energy research being conducted at the Nova Scotia Community College.

*Access the Zoom link on the NSIS Public Lectures page one hour before lecture start.*

## DECEMBER 6

**COVID-19 Student Research in Nova Scotia**



**Kaleigh McLeod**
Saint Mary's University

**Sumaiya Amin**
St. Francis Xavier
University

**Hillary Fry**
Mount Saint Vincent
University

**Mark Maclean**
Dalhousie University

### Student Showcase Topics

- An exploration of NS Thermomechanical Wood Pulp for Mask Production
- A genetic programming approach to find an effective vaccination strategy
- Infant Feeding during COVID-19 in Nova Scotia
- COVID-19 and the Nervous System: The role of inflammation and the blood-brain barrier

## JANUARY 3

**Traditional Ecological Knowledge and Molecular Biology Side by Side**

*Engaging students, communities, and industry*

**Rod Beresford**
Cape Breton University

**Lindsay Marshall**
Potlotek First Nation
Cape Breton University

**Anita Basque**
Potlotek First
Nation

Mi'kmaw Knowledge Holders, Basque and Marshall, and CBU's Beresford, have worked together on the restoration of the Bras d'Or Lake oyster industry for the past 15 years and will share the stories of their shared journey

Last year, Basque, Beresford, and Marshall presented "The Mi'kmaq Calendar of the Seasons" at Cape Breton University, where Mi'kmaq Knowledge Holders and Biology Faculty explored topics of the Mi'kmaq Calendar.

**MONDAYS 7:30 PM**

**nsis1862.ca**

# NSIS 2021-2022 VIRTUAL LECTURE SERIES

## FEBRUARY 7

**Tidal Wetland Restoration & Ecosystem Services in the Bay of Fundy Dykelands**

**Dr. Jeremy Lundholm**
Saint Mary's University

**Dr. Alana Pindar**
Cape Breton University

**Dr. Danika Van Proosdij**
Saint Mary's University

**Dr. Kate Sherren**
Dalhousie University

The Fundy Dykelands are a dynamic, working landscape threatened by sea level rise.

Communities are faced with deciding whether to shore up dykes to protect agricultural land, or move dykes back, allowing for tidal wetland restoration. Understanding these issues requires input from the physical, biological and social sciences.

This interdisciplinary panel will discuss how scientists are working with local communities to help restore resilience to our coastlines.

## MARCH 7

**Tiny Materials for Big Challenges**
*Designing Next Generation Nanomaterials*

**Dr. Mita Dasog**
Department of Chemistry, Dalhousie University

Nanomaterials can be up to 10,000 times smaller than the width of a human hair and yet they possess great potential to address some of the big challenges humanity faces today.

They have already been applied in food, cosmetics, electronic devices, medical diagnosis and treatment, and environmental remediation, just to name a few. Dr. Dasog discusses nanomaterials that can harvest sunlight and use it to generate chemical fuels, electricity, and potable water.

## APRIL 4

**Tick Talk:**
*Small Pest, Big Problem*

**Dr. Nicoletta Faraone**
Department of Chemistry, Acadia University

Ticks vector the widest array of disease-causing organisms of all blood-feeding arthropods and are second only to mosquitoes in their capacity to transmit disease agents of importance to human and veterinary health.

Being almost totally blind, ticks rely on chemosensation to identify and locate hosts for a successful blood meal.

Understanding the mechanism behind attraction and repellency induced by certain chemicals in ticks is pivotal to develop effective tick repellent products and avoid the transmission of pathogens that vector diseases, like Lyme disease.

## MAY 2 | AGM 2022

**Public Health Systems in Canada**
*Pandemics, Plagues, and the Power of Prevention*

**Dr. Gaynor Watson-Creed**
Assistant Dean of Serving and Engaging Society,
Faculty of Medicine,
Dalhousie University

Dr. Watson-Creed will review and comment on how public health in Canada really works, from an insider's point of view, including during pandemics like the COVID pandemic of the past two years.

*Access the Zoom link on the NSIS Public Lectures page one hour before lecture start.*

**MONDAYS 7:30 PM**

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

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

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**Lee, G.F.** (1975). Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel, P.A. (ed.). Heavy Metals in the Aquatic Environment. Pergamon Press, Oxford, UK. pp. 137-147.

**Nielsen, K.J. & France, D.F.** (1995). The influence of adult conspecifics and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). *Journal of Experimental Marine Biology and Ecology* 188(1): 89-98.

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https://projects.eao.gov.bc.ca/p/giscome-quarry-and-lime-plant/docs (Accessed Dec. 18, 2017)

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Date of Publication: October 2021
Halifax, Nova Scotia
ISSN Print: 0078-2521
ISSN Online: 2292-7743