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Cover photo credit: Peter Wells, winter scene, Frog Pond, Sir Sandford Fleming Park, Halifax.

Back cover inset photo credit: Peter Wells, ocean plastics display, on the Cornwall coast, UK 2018; dinosaur fossil – head skeleton of *Tyrannosaurus rex,* Royal Tyrell Museum, Drumheller; ducks, Frog Pond; shoreline of Kejimkujik Lake, Kejimkujik National Park, NS.

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EDITORIAL

Nova Scotia's many environmental issues – facilitating scientific understanding and action on multiple fronts

Since 1862, the Nova Scotian Institute of Science (NSIS) has been promoting science and the value to the province and all of Maritime Canada of scientific research and evidence-based information. Activities of NSIS have been to inform, discuss and sometimes to advise but not to advocate a particular position on a topic requiring scientific understanding. However, a question arises in these challenging times – should NSIS let its voice be heard more vigorously on some issues that are key to the province's future, especially those related to protecting and conserving its natural environment? For a learned scientific body and its members to remain silent in this era of rapid technological and environmental change is not really an option. Encouraging discussion and debate on important science-based topics has always been part of the Institute's mandate.

Currently, the Nova Scotia provincial government seems to be overwhelmed by a broad spectrum of environmental challenges. Many important issues demand attention, thoughtful discussion, and timely decisions and action. Amongst the most prominent ones are: the various effects of climate change, certainly a predominant issue (IPCC 2018, Wells and Richardson 2018); the potential impacts of treated pulp mill effluent to be discharged directly into the Northumberland Strait; the effects of brine discharges into the Shubenacadie River and its estuary; the impacts to wildlife and the forests from clear cutting huge swaths of our woodlands; the potential health effects of continued glyphosate spraying on forests and burning tires in cement plants; the health and ecological impacts of raw sewage still discharged from homes into the LeHave River, near Bridgewater; the potential damage to the salt marsh, albeit man-made, from twinning the highway at the Windsor causeway; and the continued pollution of lakes and rivers in south-western Nova Scotia from mink farms. The reader can likely identify others.

The current provincial government and the responsible departments have been quite slow to address these issues in a meaningful and comprehensive way. In some cases, e.g., the Northern Pulp mill at Pictou, the government is in a conflict of interest. Overall, the situation points to significant barriers operating at the interface of relevant information, political will, and decision-making in the responsible provincial ministries. Clearly, there needs to be timely decision- making and action on these issues, based on the scientific and other evidence at hand. In the case of the new report on forestry (Lahey 2018), there should be a timely response to its extensive recommendations (Armstrong 2018, Guderley 2018, Pross 2018). Happily, as of late 2018, this has started. But unfortunately, too often the responsible departments and ministers are very slow at finding or suggesting workable solutions. Clear cutting continues unabated. Delay rather than resolution seems to be the mantra on such problems demanding action.

Given this situation, NSIS along with other organizations should consider being more engaged in helping to find resolutions to these issues. Actions could include fostering the exchange of reliable, i.e., scientifically credible, information; encouraging debate on the more contentious issues (most of them are!); and asking the government and the public to further engage with one another and to do so frequently and in a timely fashion.

For example, on the questions of how to protect, manage and our provincial forests on both private and crown lands, and whether or not to use forest debris and wood chips for generating electricity, we should encourage further discussion and support for ecological forestry, as put forth in Lahey's report (Lahey 2018). That would entail the broad public being well briefed on the contents and recommendations of the report, as well as informed about the concept of ecological forestry (what is it, can be done in a practical way, and why is it so important that it be attempted)? In this particular case, NSIS could facilitate this understanding and foster the linkage between the science and the required policy and decision making. NSIS could help the province move in the right direction on such contentious issues.

Further, there are connections between some, if not all, of these environmental issues as they impact the quality of the province's lands, forests and waterways - how we as a society manage the forests influences stream and river water quality; where we discharge industrial effluents may impact our fisheries and in some cases, migratory wildlife species; and how well our sewage is treated determines whether our health and aquatic ecosystems are protected. If terrestrial and aquatic environments are not protected comprehensively and so continue to decline in quality, their capacity to support us and other species will be imperilled. On this point, it is extremely sobering to know that over 1000 species are listed as being at some level of risk in the Public Registry associated with the Canadian Species at Risk Act (D.H. Richardson, pers.comm.).

It is especially worth reading the recent IPCC report (IPCC 2018) and WWF report – the Living Planet 2018 (WWF 2018). These reports and their observations about what is happening to the planet do not stand alone; both reports point to the many changes and stresses faced on land and sea. Important to note is that there is a commonality in the breadth of the problems. As well, there is great scientific concern about cumulative change/impacts from multiple stressors acting together in time and space (Breitburg *et al.* 1998, among others). The quality of our land and our waters often declines slowly, piece by piece, one stress building upon another, and all unnoticed until the change is massive, reflecting a new state of the environment that is far from the natural state, a so-called "new normal" (MacKinnon 2013) or shifting baseline (Pauly 1995, Papworth *et al.* 2009). Indeed, this is exactly what has occurred with the loss over several centuries of our Acadian forest in Nova Scotia; our landscape is now largely covered by the impoverished "sticks" of a few species of trees rather than healthy, old growth, highly diverse forests. We take this new highly disturbed landscape as being natural and normal.

Despite this, optimism and commitment must fuel our way forwards as we collectively tackle these environmental issues, engage the public and support the government to foster better policies and effective solutions. NSIS can be engaged through its annual programs. The Institute also should be supportive of the considerable citizen science practised across the province on many of these issues (see previous editorial, Wells and Richardson 2015). Our lectures and other activities should recognize this immense effort and the value of natural history studies (Anderson 2017). Citizen science is carried out by volunteers devoted to the environment and the public good. Work done to conserve and protect species and habitats abound across the province. This work provides information directly relevant to the various current wildlife issues faced by the province. For example, amazing field work is conducted on turtles, snakes, fish, loons, terns and water quality conducted by the Friends of Keji Cooperating Association and the Mersey Tobeatic Research Institute (www.merseytobeatic.ca).

NSIS and its members across the province could work with one or more of the citizen science groups – volunteers are always needed and the new information is of interest to the wider public and invaluable to the responsible provincial and federal agencies.

Nova Scotia is part of a region with a plentiful and diverse natural environment but one continuing to suffer a range of threats and challenges. Tackling them demands timely decision making and effective policies informed by science. Hence, a greater engagement of NSIS can only be a positive contribution to understanding the issues and using our science-based information to aid their resolution. Protecting our natural world deserves nothing less than a full joint effort.

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GORDON ARTHUR RILEY: THE COMPLETE OCEANOGRAPHER 1911-1985

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ABSTRACT

Gordon Riley was an outstanding scientist who played a leading international role in the development of oceanography as a field of scientific study in the mid-twentieth century. His multidisciplinary approach, quantitative skills, imagination and intuition advanced our knowledge and understanding of the ocean enormously. Of his many significant scientific contributions to oceanography, he is best known for his pioneering work in developing simple numerical models for improving the understanding of the dynamics of marine ecosystems with a focus on plankton. He helped transform oceanography from a descriptive to a quantitative science. His early career was spent in the United States at the Bingham Oceanographic Laboratory of Yale University and the Woods Hole Oceanographic Institution. In 1965, at the peak of his career, he immigrated to Canada to become the director of the Institute of Oceanography at Dalhousie University. Under his leadership, the Institute evolved into the Department of Oceanography, which became an internationally recognized centre for marine research and teaching. During this period, he also played a prominent role in the development of the broader Canadian oceanographic community. He served as a wonderful example of how scientific research, teaching and a life should be carried out.

INTRODUCTION

This article presents an overview of the life and career of Gordon Riley, a remarkable individual who spent most of his oceanographic career in the United States before immigrating to Canada in 1965 to lead the creation of the Department of Oceanography at Dalhousie University. Recent publications have reviewed his many diverse scientific accomplishments (e.g. Wroblewski 1982, Mills 2012, Anderson and Gentleman 2012, Egerton 2017). This article concentrates on the

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progression of his career as a scientist, teacher and administrator, including some personal information. He had a huge and lasting impact on Dalhousie University and the Canadian oceanographic community.

EDUCATION

Gordon Riley was born in Webb City, Missouri, a small town located in the Ozarks far from the ocean in almost the geographic centre of the United States. When he was seven, his family moved to nearby Springfield. As a child, Gordon developed a keen interest in the out-of-doors and natural history. He found school boring but became a voracious reader of literature and science. For a while, he considered a possible writing career but later decided to pursue a path in science. After high school, he attended Drury College, a small liberal arts college in Springfield. This was during the Great Depression when money was tight so he lived at home. He took all the science courses available in biology, chemistry, geology, physics and math. During his undergraduate years, he developed an interest in embryology and decided to pursue graduate studies in this field. He applied to several graduate schools and was accepted by Washington University in St. Louis which provided him with a scholarship. Hence, after graduating from Drury College, he moved on to earn a Masters degree in the descriptive embryology of tunicates. His thesis advisor at Washington University encouraged him to continue graduate studies in the new field of experimental embryology and recommended the Department of Zoology at Yale University in New Haven, Connecticut. He applied, was accepted and awarded a teaching assistantship that covered all expenses.

In 1934, Gordon left Missouri for the first time and moved to New Haven, a move that had a huge impact on his subsequent life and career. He thoroughly enjoyed the new experience and saw the ocean for the first time. He started a doctoral program in experimental embryology under the supervision of Ross Harrison but he floundered and found it difficult to find a suitable thesis topic. By chance, during his second semester he took a course in limnology that was taught by Evelyn Hutchinson, a young and dynamic instructor recently arrived at Yale from the UK by way of South Africa. Riley was immediately enthralled with both Hutchinson and the topic and within the first week decided that limnology was the field where he wanted to be.

There were many challenging questions waiting to be solved and, being a naturally outdoors person, he welcomed the opportunity to conduct field research. Therefore, he changed supervisors and became Hutchinson's first graduate student.

With time, Hutchinson became a world-renowned ecologist who was later honoured with a Celebratory Issue of the journal Limnology and Oceanography (Edmondson 1971). His full life story and extensive accomplishments have been thoroughly documented by Slack (2010). Over his lengthy career at Yale, he supervised a large number of graduate students in a program of studies often referred to as the 'Hutchinson School', many of whom became leading ecologists around North America. In addition to Riley, other Hutchinson students who later migrated to Dalhousie University included Peter Wangersky, Ian McLaren, Eric Mills, Roger Doyle and Edward Deevey. In 1971, the highest concentration of Hutchinson students (and their students) was found in the Halifax and Dartmouth area (Kohn 1971).

Hutchinson suggested that Riley investigate the copper cycle in some Connecticut lakes. While he would have preferred a biological problem, the novelty of investigating something that no one had tried before appealed to him. He carried out fieldwork in three small natural lakes (Linsley, Quonnapaug and Quassapaaug) just outside New Haven in collaboration with Hutchinson who was studying the various forms of phosphorus and nitrogen nutrients. They made observations together all seasons of the year including through the ice in winter. As well as measuring various forms of inorganic and organic copper, Riley also measured temperature, colour, transparency, alkalinity, pH, oxygen and organic seston, and developed an improved colorimetric method for determining chlorophyll in lake water as a measure of phytoplankton biomass. In conducting his thesis research, Riley readily embraced Hutchinson's approach to science of testing hypotheses and studying variables in terms of dynamic processes such as rates of production and consumption, a quantitative synthetic approach he followed for his entire career.

While completing his doctoral thesis in early 1937, Riley received an invitation from Albert Parr, an ichthyologist and physical oceanographer who was the director of Yale's Bingham Oceanographic Laboratory, to join him on an oceanographic cruise to the mouth of the Mississippi River in the Gulf of Mexico. This two-week cruise was on *Atlantis*, the 142-foot ketch that was the principle research vessel of the Woods Hole Oceanographic Institution (WHOI) in

Woods Hole, Massachusetts. Riley measured nutrients and chlorophyll and discovered that the Mississippi River carried large quantities of nutrients which produced a zone of high phytoplankton biomass near its mouth, demonstrating for the first time the important biological effect of river outflow on Gulf waters. This cruise was his first time at sea. He loved the experience and was pleased to discover that he was immune to seasickness, a trait maintained throughout his lengthy sea-going career to the envy of many colleagues. This was to be the first of many cruises on *Atlantis* and other oceanographic research vessels.

After this short interlude, he returned to Yale to complete and defend his thesis on the copper cycle in Connecticut lakes and its biological significance. Using multiple regression techniques, he demonstrated that precipitation, sedimentation, regeneration from sediments and release from decomposing vegetation were important factors affecting the copper content of lake water but concluded that copper had no biological significance in the lakes studied. Although conducted in a small freshwater ecosystem, this unique thesis presented a new comprehensive approach to studying aquatic ecosystems that Riley later successfully applied to studying the dynamics of biological production in the ocean.

BINGHAM OCEANOGRAPHIC LABORATORY

Upon completing his doctorate in 1937, Riley accepted a postdoctoral fellowship at Yale to undertake a seasonal plankton study in Linsley Pond, again working in collaboration with his 'guiding spirit' Evelyn Hutchinson. Over a ten-month period, he measured phytoplankton, zooplankton, chlorophyll, organic seston and phytoplankton photosynthesis and respiration. He was able to demonstrate that the use of regression equations in analyzing ecological data provided a valuable quantitative measure for evaluating complex interrelationships. He found that light and temperature were the most important factors controlling productivity in Linsley Pond.

This project came to a premature end when cottagers poisoned the pond with copper sulphate to rid it of nuisance algae. As there were no other attractive opportunities in limnology, he accepted an offer from Albert Parr of a full-time position in the Bingham Oceanographic Laboratory. Little did he know that he was initiating a stellar long-term career in oceanography. This was not such a major leap because he could use the same ecological principles in the ocean that he had done in Linsley Pond, although the spatial scales were vastly different.

He began this assignment by initiating some plankton studies in Long Island Sound, working out of the US Bureau of Fisheries laboratory in nearby Milford, Connecticut. This was the beginning of a long-term study of phytoplankton abundance, production and the controlling physical and chemical processes that was the prime interest of his research for many years. However, soon after starting these studies, another opportunity came along in the summer of 1938 that he decided to pursue. The Carnegie Institution of Washington had established a small marine station in the Dry Tortugas, Florida, a cluster of islands west of Key West, and was looking for some new scientific projects. Riley developed a novel proposal for a study of phytoplankton production that was accepted. The station was very isolated with no women staff but Riley welcomed the opportunity to observe the beauty of coral reefs and work on subtropical plankton. He discovered that the quantity of plankton was very low and established that nitrate was the most important limiting factor for photosynthesis.

At the end of the summer, Riley returned to New Haven and resumed his Long Island Sound studies, again working out of the Milford laboratory. His major goal was to get an understanding of the seasonal cycle of phytoplankton production in the Sound. The notorious 1938 hurricane that inflicted unprecedented damage on Long Island and New England occurred soon after his return.

His Long Island Sound studies were interrupted again in the spring of 1939 when he had the opportunity for another cruise on *Atlantis* of the Woods Hole Oceanographic Institution (WHOI). He joined *Atlantis* in Cuba and carried out plankton studies at a series of oceanographic stations on the return trip to Woods Hole with stops at Miami and Bermuda. Variables measured in the euphotic zone included temperature, oxygen, phosphate, nitrate, chlorophyll and phytoplankton production and respiration. He observed that phytoplankton production in southern waters was about half that in northern waters but due to greater transparency the maximum depth of photosynthesis was three times greater in southern waters so that production per unit area was similar. He enjoyed the cruise immensely and met several Woods Hole scientists for the first time, some who later became close colleagues, including Dean Bumpus.

The port call in Bermuda was the first of many visits to come and, most appropriately, his first view of Woods Hole was arriving by water. He then returned to New Haven to write up his cruise results and resume his Long Island Sound studies.

This same year, WHOI began a major study of the productivity of Georges Bank under the direction of George Clarke of Harvard University. Riley was invited to study phytoplankton, plant pigments, nutrients, oxygen and phytoplankton production while George Clarke and Dean Bumpus carried out studies of zooplankton. While still living in New Haven, he took part in a series of cruises on *Atlantis* all seasons of the year during the period of 1939 to 1941. In his initial analysis of this extensive data set, he again used regression equations to examine the interrelationships among the variables controlling productivity. Influenced by previous work by British and Norwegian marine scientists, his approach tied together for the first time the essential variables controlling the abundance of phytoplankton over a seasonal cycle. He discovered that no single variable controlled abundance but different factors came into play at different times of the year. Solar radiation and turbulence were important during late fall, winter and early spring while nutrients, grazing and temperature were the limiting factors during the rest of the year. He also examined the theoretical relationship between vertical turbulence and the

Fig 1 Photo taken by Riley in 1939 of *Atlantis* going to windward on Georges Bank.

Fig 2 Riley collecting water samples for oxygen analysis from Nansen bottles on *Atlantis* about 1940.

spring phytoplankton bloom, as well as the physiological aspects of the spring phytoplankton bloom.

In 1939, he met a recent graduate from Yale School of Nursing named Lucy Fuller and they enjoyed numerous dates together. They were married in September of 1940.

WOODS HOLE OCEANOGRAPHIC INSTITUTION

In 1942, just after the USA entered World War II, Riley put biological oceanography aside for a few years. He turned down an offer to replace Albert Parr as director of the Bingham Oceanographic Laboratory. Instead, he accepted an offer from WHOI to work on Navy wartime contracts and moved to Woods Hole. During this period, Lucy worked in Boston and they commuted back and forth on weekends. He felt somewhat guilty not enlisting for the military but realized that he was doing important work for the Navy in support of the war effort. He was first assigned to a contract testing anti-fouling paints for amphibious aircraft. He later worked closely with a team headed by Maurice Ewing, a young geophysicist, exploring the use of the bathythermograph (BT) for predicting sound transmission in seawater. They adapted the BT for use on submarines to assist with ballasting and using acoustics to verify wreck sites along the US east coast. In time, this work took him to Miami and Key West where he gave lectures to Navy personnel on sound transmission in seawater and demonstrated the use of BTs. He was also responsible for preparing monthly charts of sound transmission conditions in the Florida Straits which involved frequent short cruises to collect

BT data. During this period, Riley demonstrated his ability to think globally by using his earlier work on marine productivity to estimate the photosynthetic efficiency of the whole Earth which he found to be very low. In 1944, Lucy gave birth to their first daughter in Key West during a hurricane.

His first assignment upon return to WHOI was writing a small text on physical oceanography in non-technical language in collaboration with Fritz Fuglister. He was diverted in early 1945 to assist a project studying sound transmission in seawater off the mouth of the Mississippi River. This project was headed by Henry Stommel, a new WHOI employee, whom Riley met for the first time. They hit it off immediately and their lively discussions led to later collaborations in Georges Bank and North Atlantic studies. Upon return to Woods Hole, he worked on other sound transmission projects and completed the physical oceanography text. However, at this stage of his career he was eager to get back into biological oceanography and in his spare time started to work further on his earlier Georges Bank plankton data. For recreation, he purchased a Cape Cod knockabout which he enjoyed sailing in local waters.

In early 1946, soon after the conclusion of World War II, Riley was directed against his will to participate with some other WHOI scientists in Operation Crossroads, a program of two nuclear weapon tests conducted by the US military at Bikini Atoll in the Marshall Islands in the western Pacific Ocean. These were the first peacetime detonations of nuclear devices after the atomic bombing of Hiroshima and Nagasaki in August 1945. The purpose of the tests was to investigate the effect of nuclear weapons on ships. They were the first of many nuclear tests held in the Marshall Islands and the first to be publicly announced beforehand and observed by an invited audience, including a large press corps.

After steaming across the Pacific on the *Bowditch*, the WHOI scientific team conducted numerous baseline studies in physical, chemical and biological oceanography and fisheries around Bikini Atoll prior to the tests. This enabled the effects to be properly assessed in post-blast surveys and the flushing rate of radioactive products subsequently estimated. Riley was responsible for heading up the physical oceanographic team and work included designing and carrying out field surveys in both the lagoon and surrounding waters that required extensive seagoing operations. Riley did not enjoy this project for it took him away from his young family and he was

Fig 3 Scientific staff involved with Operation Crossroads on the USS *Bowditch* of the US Navy Hydrographic Office enroute to Bikini Atoll in 1946. Staff squatting in the first row include William Ford (second from right), Gordon Riley (fourth from right), William von Arx (fifth from right) and Walter Munk (sixth from right).

morally opposed to the development of nuclear weapons. When some of the study results were published, he refused to be an author for he did not want the world at large to know that he had been involved. Also participating in Operations Crossroads was William Ford (1913-1992) who later became the Director of the Bedford Institute of Oceanography in 1965 (Gordon 2016). Other participants who also went on to distinguished careers in oceanography included Walter Munk and William von Arx.

When Riley returned to Woods Hole, he re-joined Fritz Fuglister's physical oceanographic group assisting with the analysis of BT data collected by the Navy during the war and conducting coastal surveys, including Long Island Sound. Collaborating with Alfred Woodcock, he participated in an *Atlantis* cruise to study the acoustic properties of seawater east of Bermuda that included intensive BT observations to investigate physical processes in the surface layer. He later joined a project headed by Charles Fish analyzing data to explore the interrelationships between physical oceanographic properties and plankton distribution. Fish, a plankton expert, had previously worked for the International Passamaquoddy Power Commission in the early 1930s investigating the effects of the proposed tidal power project.

As time allowed, Riley continued to work on the Georges Bank plankton data collected before the war. In collaboration with Dean Bumpus, he examined the quantitative relationships between phytoplankton and zooplankton and concluded that the significant inverse relationship observed was due to grazing. With the availability of the zooplankton data, it was now possible to develop a relatively complete statistical treatment of the ecological relationships of the Georges Bank plankton. Accordingly, he developed equations to calculate phytoplankton abundance on the basis of controlling factors such as temperature, depth of water, nutrients and zooplankton and obtained good agreement with observed values. He also evaluated the seasonal cycle of phytoplankton from a more theoretical framework using differential equations. He postulated that the rate of change of phytoplankton abundance was equal to the difference between the photosynthesis rate and that of respiration and zooplankton grazing. The resultant curve over the seasonal cycle showed good agreement with observed values. Using similar methods, he also constructed a theoretical seasonal curve of zooplankton abundance that was also in general agreement with observations.

In 1947, Riley participated in an *Atlantis* cruise to Sargasso Sea and conducted quantitative studies of summer plankton. He observed that phytoplankton biomass and production rates were much lower than observed in New England coastal waters and offshore banks.

Working in collaboration with Dean Bumpus and Henry Stommel, Riley carried out further studies of the quantitative ecology of plankton in the western North Atlantic based on the available data from the region. Theoretical equations were developed to explain the distribution of variables on the assumptions that any marine population is quantitatively controlled by the processes that increase or decrease the organic content of the population and that the rates of the processes are determined by a complex of environmental factors that acts by affecting the physiology of the organisms and their physical dispersal. The most important environmental factors were found to be radiation, transparency, temperature, vertical eddy diffusivity and phosphate. He also developed a theoretical food chain.

BINGHAM OCEANOGRAPHIC LABORATORY

In 1947, Lucy gave birth to their second daughter. While Riley and his young family were very content in Woods Hole, with the end of wartime contracts there was considerable uncertainty about the future nature of oceanographic research at WHOI. As a result, Riley started looking for other opportunities. He was offered a job by Johns Hopkins University to develop a new oceanographic laboratory on Chesapeake Bay but declined. However, in 1948, he accepted an offer to return to the Bingham Oceanographic Laboratory at Yale and, somewhat reluctantly, the family moved back to New Haven. Not much had changed at the Bingham laboratory during his six-year absence. It remained a small lab of marine biologists, not a true oceanographic laboratory with seagoing programs.

Once settled in back at Yale, Riley initially turned his attention to Block Island Sound off Rhode Island and carried out studies of its hydrography and phytoplankton. He conducted an analysis of the physical oceanographic processes that produced the observed distribution of temperature and salinity and documented the seasonal cycle of phytoplankton abundance. Under his coordination, colleagues at Yale and the University of Rhode Island carried out associated studies of zooplankton, fish eggs and larvae and herring.

Riley then began investigating biological processes in the deep-sea. Vertical profiles of oxygen, phosphate and nitrate provided convincing evidence that oxygen was consumed and nutrients regenerated in deep water below the euphotic zone. He used existing data to examine the deep circulation of the Atlantic Ocean and developed estimates of food requirements and metabolic rates of deep-sea organisms. He calculated from oxygen consumption and phosphate regeneration that approximately one-tenth of the surface production by phytoplankton was utilized in the entire water column. These studies were highly original and the results have largely stood the test-of-time, including the findings of the Geochemical Oceans Sections Program (GEOSECS) carried out over twenty years later.

At this time, Riley also worked with phytoplankton samples and BT data that were collected in the Sargasso Sea on a regular basis as part of the US Weather Ship program. This data set allowed him to investigate phytoplankton variability over time at one location in subtropical offshore surface waters. He observed a spring bloom similar to that observed in temperate coastal but that phytoplankton production was about one third lower.

In 1950, Riley and family spent several months at the Scripps Institution of Oceanography in La Jolla, California, where he served as a visiting professor and gave a series of lectures on plankton. He also examined data collected during a large-scale oceanographic program off the California coast and offered recommendations for improving its design. Riley enjoyed the visit and interaction with Scripps' scientists, especially Walter Munk. They collaborated in a unique theoretical modelling study of the absorption of nutrients by aquatic plants that considered various factors including size, specific gravity, nutrient concentrations and physical properties.

Riley did not have a formal academic appointment at the Bingham Oceanographic Laboratory but did start to take on graduate students through the Department of Zoology. Building upon his earlier work in Long Island and Block Island Sounds, in 1952 he established a major field program with his graduate students to carry out a long-term study of the major components of the productive Long Island Sound coastal ecosystem. Frequent cruises were carried out during all seasons over four years. Riley covered the physical and chemical oceanography of the Sound while Shirley Conover investigated the phytoplankton, Georgiana Deevey and Robert Conover studied the zooplankton and Howard Sanders examined the benthos. Riley was able to calculate the transport of water into and out of the Sound at different times of the year. Further information was collected on the seasonal cycle of phytoplankton and Riley calculated that production of Long Island Sound was twice that observed in the English Channel. This ambitious undertaking was one of the first comprehensive studies of a large coastal ecosystem conducted anywhere. With the exception of Howard Sanders, under the influence of Riley these graduate students later moved to Nova Scotia and became prominent in the local marine science community.

Another graduate student participating in the Long Island Sound program was Eugene Harris who arrived from Dalhousie University after completing a master's degree under Ronald Hayes. He initiated a study of the nitrogen cycle in the Sound but unfortunately came down with cancer and passed away before completing his degree. Following his death, Riley wrote up his research results and published them under Harris's name with a footnote explaining that he had compiled the paper posthumously as a memorial. During this period, Riley also served on the supervisory committees of several of Hutchinson's graduate students, including Peter Wangersky, Eric Mills and Ian McLaren, all of whom later joined the faculty of Dalhousie University.

Throughout the late 1950s and early 1960s, Riley and colleagues carried out further oceanographic studies in Long Island Sound that considered water transparency, surface currents using drift bottles, nutrients, particulate matter, microbiology and benthic fauna. With almost thirty years of sustained study under his leadership, Long Island Sound had become one of the best understood coastal ecosystems in North America.

In early 1952, Riley traveled to Ottawa to give an invited paper on the application of theoretical population principles to ecology at a meeting of the Canadian Fisheries Society. This was his first trip to Canada and provided him with the opportunity to meet leading Canadian aquatic scientists for the first time, including Ronald Hayes from Dalhousie University that would loom important later in his career. Soon after he returned to New Haven, Lucy gave birth to their third daughter.

As expected for a scientist with a growing reputation, during the 1950s Riley became involved in numerous external scientific activities. For example, he was elected to the Board of Trustees of the Bermuda Biological Station and later served as president. He was a member of an advisory committee for the Narragansett Marine Laboratory at the University of Rhode Island (which later evolved into the Graduate School of Oceanography) as well as advisory panels to review grant applications for the Office of Naval Research and National Science Foundation. He participated in a series of three annual conferences at Princeton University where free and informal discussion among a group of scientists was tested as a more effective way of disseminating knowledge than sessions of formal papers. These conferences enabled him to interact with other leading North American, British and European marine scientists including Einer Steeman-Nielsen, Ramon Margalef, Trygve Braarud and John Strickland. He was also a member of the US National Academy of Sciences Committee on Oceanography (NASCO) that was charged with reviewing the state of oceanography in the US, a field of science that had been growing rapidly after the war, and with making recommendations for further development. This involvement over five years, with other leading

US oceanographers, resulted in an influential book that laid out a framework for orderly growth in US oceanography.

For many years, Riley sought a formal academic appointment at Yale in the Zoology Department in recognition of his service to the university and to make it easier for supervising his graduate students. He was most pleased when he was finally appointed as Professor of Oceanography in 1959. However, his long-term goal was to create a separate department of oceanography at Yale. His previous experience with the NASCO review had helped crystalize his thinking of how a university oceanography department should be organized and operated and there was an increasing demand for well-trained oceanographers. Riley started to work in this direction by bringing new scientists from other marine disciplines into the Bingham laboratory. One of these was Peter Wangersky, a chemical oceanographer who had also been one of Hutchinson's graduate students.

Riley's research interests underwent another major shift in the late 1950s. He became interested in dynamics of particulate organic matter in seawater. He observed in Long Island Sound that organic detritus was more abundant than phytoplankton in surface water and showed little correspondence to the seasonal production cycle of phytoplankton. He suspected that the traditional viewpoint that particulate organic matter degraded into smaller particles and ultimately dissolved with little ecological role may not be completely correct and that there may be ecologically significant processes operating in the opposite direction. In collaboration with Satoshi Nishizawa, a post-doctoral fellow from Japan, Riley expanded his research program in Long Island Sound to study organic aggregates. These are amorphous particles containing both organic and inorganic materials with inclusions of bacteria and phytoplankton. He found that organic aggregates appeared to be formed mainly by adsorption of dissolved organic matter on bubbles, a process readily duplicated under laboratory conditions, and speculated that they could be an important alternative food source for zooplankton. This program expanded to include observations of organic aggregates in the tropical and subtropical North Atlantic in collaboration with Peter Wangersky, using *Trident*, the research vessel of the Graduate School of Oceanography in Rhode Island. He demonstrated that organic aggregates are of ecological significance in both oceanic and coastal environments.

During this period, Riley renewed his ties with the Bermuda Biological Station and for two summers helped teach a graduate course

Fig 4 **Riley drawing water samples on the *Panulirus* of the Bermuda Biological Station in 1964.**

on animal-sediment interrelationships. In 1961-1962, he served as president of the American Society of Limnology and Oceanography

Meanwhile, his attempts to develop a department of oceanography at Yale were unsuccessful. Riley was getting frustrated and restless. He saw no future for the Bingham Oceanographic Laboratory so, in 1964 at the age of 54, he decided the time had come to look elsewhere. He was at the peak of his career and, as word got around that he was looking for a new appointment, he started to receive numerous offers. These included the nearby Graduate School of Oceanography at the University of Rhode Island and the University of Alaska.

DALHOUSIE UNIVERSITY

In the late summer of 1964, Peter Wangersky visited Dalhousie University to be interviewed for a job with the Institute of Oceanography. This institute had been created in 1959 as part of the growing Canadian oceanographic community, ten years after the creation of the Institute of Oceanography at the University of British Columbia (Mills 1994). He was quite impressed with the potential of the young institute and learned that it was seeking a new director to take over from Ronald Hayes who had recently moved to Ottawa to become the Chairman of the Fisheries Research Board of Canada. Upon return to Bingham, he recommended to Riley that he apply.

Riley wisely heeded this advice and within a few weeks came to Dalhousie for an interview. Riley and President Henry Hicks hit it off immediately and he too was impressed with what he saw. Although the Institute was small, there were many positive features and great potential for growth. Institute staff had sole responsibility for the admission of graduate students, the formulation of curriculum and recommendations for degrees. Ship time on federal research vessels operated by the Bedford Institute of Oceanography (BIO) across the harbour was available without charge and there was a substantial block grant from the National Research Council for general operating expenses. The only negative aspect of concern to Riley was that professional appointments of Institute staff were in the associated basic science departments, which therefore controlled appointments, promotions and tenure. Soon after Riley returned home, he was offered the position and immediately accepted. Leaving the United States was a difficult decision to make but he felt the Dalhousie position offered great potential to develop the department of oceanography he had envisioned. And, most fortunately, Lucy and the family were agreeable to the move. His career was now about to take another major change in direction.

The Riley family arrived in Halifax in July 1965 and moved into a house on Vernon Street, just a short walk from his new office in the basement in the Forrest Building on the Carleton Campus. A few months earlier, William Ford, his good friend from WHOI days, also arrived in Halifax to become the new director of BIO (Gordon 2016). Hence, a friendly and collaborative relationship across the harbour was assured.

The principal mandate of the Institute was to produce oceanographers for the federal research laboratories that were rapidly expanding across the country at the time. When he arrived, Institute full-time associates were Michael Keen (geophysics), Daniel Stanley (sedimentary geology), Donald Swift (sedimentary geology), Carl Boyd (zooplankton ecology) and E.H. Anthony (microbiology). In addition, Peter Wangersky (chemical oceanography) arrived with Riley from Yale to join the Institute. There were no physical oceanographers on staff at the time but these courses were taught by Earlston Doe and Ronald Trites, honorary lecturers from BIO. A. Levin (engineering physics), Bosko Loncarevic (geophysics) and Cedric Mann (physical oceanography) were part-time associates. There were 21 graduate students, mostly in biology and geology. Staff and students were physically housed in their home departments spread across the campus. The Institute supported field stations at Baddeck on the Bras d'Or Lakes and Purcell's Cove at the mouth of the Northwest Arm.

As director of the Institute of Oceanography, Riley's duties were primarily administrative. He soon began to recruit new faculty members to expand and broaden the expertise of the Institute to cover all the major oceanographic disciplines. He sought out highly qualified young faculty members and promoted an open and free attitude to research. These early additions included Walton Watt (phytoplankton ecology), Eric Mills (benthic ecology), Roy Hyndman (geophysics), Roy Overstreet (physical oceanography), Christopher Garrett (physical oceanography), Robert Cook (chemical oceanography) and Robert Fournier (biological oceanography). Riley also played a roll in recruiting Robert Conover and William Sutcliffe for the Marine Ecology Laboratory at BIO.

Soon after he arrived, with the full backing of President Henry Hicks, Riley started to work on plans to convert the Institute into a Department of Oceanography, a process that took several years to bring to fruition. In so doing, he met with some opposition from other science department heads (Waite 1998) but with time this was overcome. He was also appointed to chair the building committee charged with planning the new Life Sciences Centre for the Oceanography, Biology and Psychology departments. This task, which included planning the Aquatron running seawater facility, was a major time commitment. In addition, he was involved in numerous external activities including various National Research Council grant committees and the Canadian Committee on Oceanography, as well as numerous US scientific committees.

Despite this heavy administrative load, Riley continued to participate as much as possible in scientific activities. He taught a course in biological oceanography and supervised graduate students. With the assistance of associates, he continued his research on non-living organic matter in seawater, including laboratory experiments examining the role of bacteria in the dynamics of organic aggregates. He also brought his work in Long Island Sound to completion, developed additional plankton models and wrote several major review articles. Whenever he could, he enjoyed going to sea with graduate students on BIO research vessels.

Riley and family settled well into life in Halifax. Lucy resumed her nursing career and later became actively involved in the

Unitarian Church, the New Democratic Party and senior's issues. They both were particularly impressed with the amount of relatively wild country so close to the city and, in 1966, bought a large acreage of woodland with a cottage on Cox Lake in Yankeetown, just outside Halifax. This was Riley's first introduction to boreal forests and he immediately loved them. Weekends in the country became very important to them both. He enjoyed exploring his property and adjacent crown lands and building a network of trails while Lucy enjoyed looking after her garden. He became very proficient in using a chain saw and enjoyed thinning trees, cutting firewood and crafting rustic furniture. They welcomed visits from oceanography graduate students who came out for picnics, paddling, hiking and cross-country skiing. Whether paddling a canoe, tramping in the woods or working with wood, Riley found a sense of peace that he had not experienced for a long time. The woods and waters became his 'church' where he completely relaxed. He was beginning to put down roots for the first time since leaving his boyhood home in the Ozarks.

In 1970, he was offered the Captain Cook Chair of Oceanography at the University of Hawaii but by this time he had no interest in leaving his new home in Nova Scotia and trading its variable weather for constant summer.

Riley's administrative skills bore fruit with two major events at Dalhousie University in 1971. The first was completing the conversion of the Institute of Oceanography into the Department of Oceanography. Creating a department of oceanography, including all major disciplines, had been his goal for many years. He had attempted to do this at Yale but did not get the support of the university administration. He took great pride in accomplishing this feat at Dalhousie. The second event was the completion of the Life Sciences Centre which brought the new Department of Oceanography together, under the same roof for the first time, along with the Departments of Biology and Psychology. Riley was pleased that all faculty and graduate students would now have offices and laboratories larger than what he had had in the basement of the Forrest Building.

Riley's last oceanographic cruise was in March 1972, thirty-five years after his first on *Atlantis*. He joined a team of BIO and Dalhousie colleagues in Bermuda for a return trip on *Dawson* to BIO. Soon after departing St. Georges, the ship encountered a severe storm and had to heave to in heavy seas for several days. All scientific operations were suspended. Riley was one of the few members of the scientific

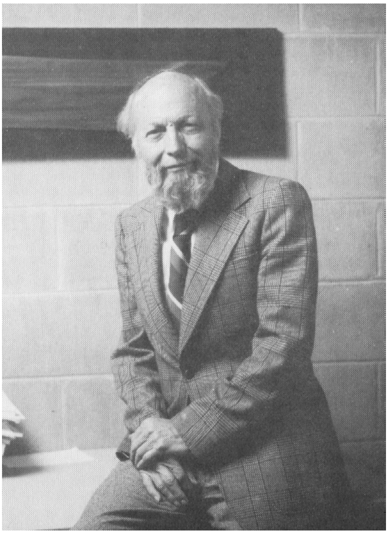

Fig 5 Riley in his new office in the Department of Oceanography in 1971. In the background is a half model of *Atlantis*.

party to show up for meals on a regular basis. Unfortunately, the violent motion of the ship inflicted some injuries and Riley realized that he no longer had the endurance to work at sea.

Most fittingly, in 1973 Riley was elected as a Fellow of the Royal Society of Canada. He took particular delight in this accolade to "a boy from the Ozarks".

By 1974, Riley felt burned-out as an administrator and resigned as department chairman. However, he still taught his biological oceanography course and supervised graduate students. He enjoyed having more time to read and catch up on the scientific literature. The same year, he and Lucy built a new road and larger cottage on their land on Cox Lake and sold the original cottage to Ken Mann, Chairman of the Dalhousie Biology Department.

In 1976, Riley was, most appropriately, awarded the prestigious Rosenstiel Award in Ocean Sciences by the University of Miami in recognition of his outstanding lifetime achievements in oceanography. The same year he decided that the time had come to retire and was appointed Professor Emeritus.

In 1982, his Dalhousie colleagues produced a volume of his most influential scientific publications which were reprinted in their entirety (Wroblewski 1982). Many of these papers were classics and are as relevant today as when they were first published. This wonderful tribute included a foreword by Henry Hicks and essays by Evelyn

Hutchinson, Eric Mills, Robert Fournier, Peter Wangersky and Edward Deevey. His other scientific publications are also listed in this commemorative volume.

Riley enjoyed nine years of retirement. He and Lucy sold their house and moved into a nearby condominium on Coburg Road. He put considerable effort into writing his personal memoirs which he privately shared with family and close associates. They spent as much time as possible at Cox Lake where Riley continued to enjoy his favourite activities, both in the woods and on the water.

Fig 6 Gordon and Lucy Riley at their camp on Cox Lake in 1980.

He developed an interest in wood carving and created numerous carvings of local wildlife. He also began to write poetry and one of his many reflective poems is presented below.

After a long battle with cancer, Riley died in 1985. His ashes were spread in his beloved woods at Cox Lake. Fitting tributes were written by Evelyn Hutchinson (Hutchinson 1986) and Lloyd Dickie (Dickie 1987). In his memory, the Department of Oceanography created the Riley Lecture, given annually by a prominent oceanographer selected by its graduate students. The private road leading to the Cox Lake cottage was later named Riley Road by the County of Halifax. Lucy continued to enjoy using the cottage for another twenty years and when she passed away her ashes too were spread in the woods with Gordon's.

SYNOPSIS

Gordon Riley was a pioneer in oceanography. His multidisciplinary approach, quantitative skills, imagination and intuition advanced our knowledge and understanding of the ocean enormously. He believed that science is fundamentally an artistic endeavour and enjoyed the aesthetic pleasure of trying to fit the fragmentary facts into a logical picture. In the early stages of his career, oceanography was a relatively small field of study and Riley personally knew and interacted with many of the major players. These included Maurice Ewing, Henry Stommel, Dean Bumpus, Alfred Woodcock, Columbus Iselin, William von Arx, Fritz Fuglister, Alfred Redfield, Bostwick Ketchem, George Clarke, Raymond Mongomery, Roger Revelle, Harald Sverdrup and Walter Munk. His personality led to unusually effective collaborations with other notable scientists in the various oceanographic disciplines.

Riley was always a lover of the natural world. His career was firmly rooted in observation. He worked before the advent of electronic sensors, satellites and computers in the age when field and laboratory work was done mostly by hand. Temperature was measured at discrete depths using reversing thermometers, water was collected using sampling bottles strung on hydrographic wire and zooplankton were collected by nets. Analyses of oxygen, chlorophyll and nutrients in seawater were carried out using laborious wet chemical techniques on shipboard or later in a laboratory ashore. There were no computers so data processing was limited to pencil and paper, slide rule and mechanical calculators. With these limitations in data collection and processing, Riley was forced to think carefully about the basic questions he was asking and make sure he was gathering the most essential data to answer them. He was a genius in using a limited amount of carefully collected information to provide profound insight into important oceanographic processes. A hallmark of his work was demonstrating the complexity of these processes with an apparent simplicity and clarity that provided direction for the development of biological oceanography for over thirty years (Mills 2012).

Riley was particularly well known for his work on developing mathematical models of phytoplankton dynamics. His great achievement lay not so much in the simulation of plankton dynamics per se but rather in promoting the concept of using modelling as a tool for understanding the dynamics of marine ecosystems. He demonstrated that simple models with formulations chosen carefully on the basis of observation and experiment could be used to provide valuable insight into ecosystem dynamics. His models of planktonic dynamics on Georges Bank are considered milestones in the history of marine ecosystem modelling (Anderson and Gentleman 2012). In a recent review of the history of ecological sciences between 1920 and 1970, Riley's contributions were put in the same category as those of Rachel Carson, Jacques Cousteau and Eugenie Clark (Egerton 2017).

Riley was a very modest and quiet person who withdrew in a crowd and never sought the spotlight he deserved. He was an unsung hero who possessed a remarkable independence of mind as well as a dry wit and talent for pungent statement. He maintained the highest of professional standards but could be a bit irreverent in his contempt of colleagues who did not. He had a strong dislike of academic formality and never hid behind a screen of rank and authority. He treated his students and technical assistants as equals, considered them as 'family' and insisted they call him by his first name. He was always approachable, took a personal interest in their lives and enjoyed social interactions outside of the laboratory. Graduate students were amazed how he and Lucy enjoyed coming to their parties. Riley refused to put his name on the research papers written by his students because he wanted them to stand scientifically on their own. He never discouraged them from thinking differently and often said it would not be any fun if all his students agreed with him. Throughout his career, Riley encouraged the participation of women in science and one third of his co-authors were women. He commanded the highest respect from all that knew him.

Dalhousie University was extremely fortunate to have landed Gordon Riley. Had the Yale University administration supported his desire to create an oceanography department, he probably would never have left for Canada. He was looking for a change in his career and the Institute of Oceanography was looking for a new director. It was a perfect fit, with perfect timing. He and Lucy quickly adjusted to their new lives in Halifax, became an integral part of the local community and never looked back.

Riley's most outstanding administrative success was the creation of the Department of Oceanography at Dalhousie University. The previous Institute of Oceanography had been a loosely associated group of scientists primarily pursuing their own particular disciplinary interests in the ocean. From his extensive previous experience in the US oceanography community, he knew exactly how the new department should be organized and administered. Under his guidance and tutelage, staff and students alike began to realize that oceanography was more than the sum of its parts and that addressing the interaction of physical, chemical, biological and geological processes was critical to understanding oceanographic processes. Working from the foundation he built, the department soon developed into a major international centre for oceanographic research and education, a feather in the hat for Dalhousie University.

The essence of Gordon Riley and his work is well captured in the following quotes:

> *"The meek may ultimately inherit the Earth; Gordon has shown that the modest may inherit the Sea."* G. Evelyn Hutchinson

> *"Riley's first paper on Long Island Sound is one of the most significant in all plankton ecology because it illuminates knowledge that had accumulated for forty years in the powerful light of statistical analysis and experiment. His results have a paradigmatic quality that is virtually absent in even the most important of earlier works. He applied quantitative techniques with considerable success to the study of plankton dynamics, and equally important, the logical grounds for evaluating causative factors in plankton dynamics were persuasively presented."* Eric L. Mills

> *"Reading Gordon's papers, I am always reassured that one good man with good ideas capable of using his native inborn insight, intuition and awareness can make important, lasting and elegant contributions."* Robert O. Fournier

> *"Riley was remarkably self-critical in his outlook and writing, displaying a discerning and shrewd rationality of thought in his approach to science"*. Thomas R. Anderson and Wendy C. Gentleman

Acknowledgements First and foremost I thank Gordon for bringing me with him to Halifax in 1965 as a graduate student, a move that had a profound impact on my life and scientific career. He was a wonderful mentor, colleague and close friend who set a wonderful example to follow. I am indebted to him for giving me a copy of his personal memoirs that were the source of much of the information in this article. I thank his daughters Louise Gemeinhardt, Grace Riley and Milly Riley for ensuring the accuracy of the more personal aspects of Gordon's life. Eric Mills, Robert Fournier, Gareth Harding and Jonathan Sharp checked the accuracy of the scientific content and, along with Joleen Gordon and three anonymous reviewers, kindly offered numerous suggestions for improvements. And finally, I thank Lucy Riley and her daughters for selling the Cox Lake property to my family so that we could continue to maintain the Riley legacy with fond memories for many more years.

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DOCTORAL GRADUATE STUDENTS
(and subsequent professional affiliations)

Yale University

Howard Sanders (Woods Hole Oceanographic Institution)
Robert Conover (Woods Hole Oceanographic Institution, Bedford Institute of Oceanography)
Rudy Haffner (Wesleyan University)
Eugene Harris (Died while a student)
Gerald Posner (Unknown)
David McGill (Woods Hole Oceanographic Institution)
Elizabeth Wood (Unknown)
Andrew Carey (Oregon State University)
William Pearcy (Oregon State University)
Theodore Napora (University of Rhode Island)

Dalhousie University
Donald Gordon (University of Hawaii, Bedford Institute of Oceanography)
Janet Eaton (Mount Saint Vincent University)
Jonathan Sharp (University of Delaware)
Gareth Harding (Bedford Institute of Oceanography)
Colin Duerden (Environment Canada)
Shirley Conover (Environmental consulting industry)
Patricia Johansen (Died soon after completing her degree)
John Marra (Lamont-Doherty Earth Observatory, Brooklyn College)

A REPRESENTATIVE POEM

Musings of an Old Oceanographer

Tropical night, a lazy swell
And a palely luminescent wake,
Or sailing before a spanking breeze
With only a softly whispering sound
Of water swishing past the hull,
Or then again the wild shriek
Of a gale in shrouds and sheets
And the creaking of the tortured hull
And flying spume and crashing waves
With every laboured pitch.

These are memories of the sea
And thoughts and feelings about it,
Varied as the moods of the sea
And ordered by its restless change.
There are secrets to be sought
By wearisome work; we're often cold
And wet, and that's fair weather work,
'Til a roaring storm gives us time
For a little uneasy rest.

This is our life aboard the ships;
Why do we do it? I suppose
They'd say it's the lure of the sea,
And there's always beauty and lure,
But I wonder if those who love the sea
Really know the sea; it dwarfs
That kind of human emotion.

I think for us there's a different need,
Not a drive to cross its vast expanse
Nor a challenge to brave its restless might.
Well, perhaps a little of those,
But there's always a greater passion.
Returning to the life ashore
And driven by curiosity
To puzzle over the things we've found –
And call it science or call it art –
Trying to weave all the scattered facts
Into a logical tapestry
That helps us better understand
The mystery of the sea.

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SHOULD CANADA'S FOREIGN AID POLICY HELP ADDRESS THE ENVIRONMENTAL IMPACT OF SINGLE-USE PLASTICS?

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The international community, including those from governments to environmental non-governmental organizations and from individuals to corporations, have been inundated recently with talk about the environmental impacts of single-use plastics (SUPs) - especially plastic shopping bags and straws (Schnurr and Walker 2018). In Nova Scotia, marine debris collected as part of the Great Canadian Shoreline Cleanup included SUP items such as cigarette butts, food wrappers, plastic bottle caps, straws/stirrers, and plastic beverage bottles, which broadly mirror those across the rest of Canada. In addition, there were plastic fishing ropes and strapping bands (Pettipas *et al*. 2016). Microplastic fibers have also been found in intertidal sediments and blue mussels in Halifax Harbour (Mathalon and Hill 2014), and in most seawater grab samples collected in an ongoing study near Lunenburg (CBC News 2018).

Canada's Presidency at the 2018 G7 in Charlevoix had reducing marine plastic pollution, as one (of five) themes in *"Working together on climate change, oceans and clean energy"* (Government of Canada 2018; Ocean Plastics Charter 2018). After the June G7 meeting, all but two G7 leaders (including the European Union as one whole) committed to, among other announcements, an Ocean Plastics Charter (Japan and the US did not sign on, albeit for vastly different reasons) (Ocean Plastics Charter 2018). In democratic and bureaucratic fashion, the Plastics Charter contains five working areas, each with between two and six commitment actions. All are geared towards *"[taking] action toward a resource-efficient lifecycle management approach to plastics in the economy"* (Ocean Plastics Charter 2018). The plan is to move towards zero plastic waste, by reducing and recycling SUPs (Walker and Xanthos 2018). This is an admirable endeavour – getting some of the largest economies in the

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world, committing to invest in research and development, to engage with industries or other stakeholders, and to encourage interventions that change linear plastics consumption habits. Developing strategies to be less wasteful is no small task.

Developing economies contribute much more to the global plastics problem than G7 countries and so there seems to be a dissonance that goes unacknowledged. A study by Jambeck *et al*. (2015) highlighted the fact that developing economies, especially those in Asia and Southeast Asia, are the top plastic ocean polluters. China, Indonesia, Philippines, Thailand and Vietnam are the top producers of plastic waste (Jambeck *et al*. 2015). This is caused in part by a booming middle-class consumer population and increasing standards of living, yet waste management infrastructure (or environmental regulation, policy, or societal behaviour) has not kept pace. Furthermore, China was the largest global importer of plastic waste, mostly from developed countries (Liu *et al*. 2018; Walker 2018a). Finally, these countries also have long coastlines, allowing plastic pollution to leak into the oceans or to become stranded along the coast.

The value of SUP interventions in economies that, on a global scale contribute very little marine plastic pollution to the oceans have been hotly debated (Xanthos and Walker 2017; Knoblauch *et al*. 2018; Schnurr *et al*. 2018). This does not mean that a Canadian plastic straw ban or an Australian plastic bag ban are ineffective, but it does highlight that interventions differ between jurisdictions (Schnurr *et al*. 2018). Like others, we believe that this is crisis worthy of global intervention (e.g., Borrelle *et al*. 2017; Dauvergne 2018; Walker 2018b). Some international development, foreign aid, and NGOs have historically and traditionally been fraught with imperial and self-serving attitudes resulting in ineffective, interventions by rich economies onto poor economies under the guise of '*assistance*'. Contemporary iterations have focused on the environment even though it is increasingly recognized that the impact of climate change is felt by different people from those that are significantly more '*responsible*' for contributing to the problem.

Developed nations like Canada, invest heavily in climate change mitigation (such as international carbon market trading) via our foreign aid. Should we also be investing in mitigating plastic polluters in other countries if we are not the ones throwing our plastic wrappers into the oceans (European Commission 2018)? Does our answer to this question change when we know that developed economies send their plastics waste to developing economies (Brooks *et al*. 2018; Liu *et al*. 2018)? The answers depend on your ethical, social, and moral stance. In theory, one could argue there is enough reason to avoid feeling guilty for marine plastic pollution given Canada's small contributions. Environment and Climate Change Canada estimates that Canada '*leaked*' only about 8,000 metric tonnes of plastic into our freshwater and marine waterways in 2010. Canada is in the low-range category of mismanaged waste '*able*' to enter the oceans, at around 0.01 0.25 million metric tonnes (Jambeck *et al*. 2015). However, wiping one's hands clean and walking away because "*I'm not at fault*" is a case of the tragedy of the commons in effect on our oceans – it becomes selective environmental activism that makes for a poor ally for the earth. Indeed, of the eight billion tons of plastic produced in the last fifty years, only 9% has been recycled and 12% incinerated, leaving the remainder in landfills or finding its way into lakes, rivers or the Ocean (Geyer *et al*. 2017).

What should this mean for Canada, that has just held the G7 Presidency, and for our future international obligations? Canada should show strong environmental leadership on the international stage when reconsidering international development priorities, programming, or strategic engagements. Global Affairs Canada can and should consider assisting funding waste management infrastructure in places where the gap between social development and said infrastructure is highest (Liu *et al*. 2018; Oceans North 2018). In the same way that Canadian foreign aid helps build wells and schools in developing countries, we must contribute to the development of a global circular economy with respect to plastics (Walker and Xanthos 2018). Currently, many of the innovations and technologies that could promote the transition to a circular plastics economy stem from non-developed nations (Liu *et al*. 2018). Opportunities for mutual learning and knowledge transfer are calling to us.

Canada's international engagements, including the G7, but at other bilateral or multilateral fora as well, could provide great avenues to advance an anti-SUP agenda (like the Ocean Plastics Charter). The aim should neither ignore the more glaring sources of marine pollution nor makes Canada an environmental hypocrite and in fact, the Charter already makes mention of this (Ocean Plastics Charter 2018). Two key points in the Charter commit developed economies to target the most significant contributors to the marine plastic pollution problem, and to assist populations that are the most vulnerable (these two groups are often not the same). Environment Minister Catherine McKenna was optimistic the Ocean Plastics Charter could be a '*Paris Agreement for plastics*'. The Canadian leadership has spoken and has latched onto plastics as the eco-campaign of 2018. Now Canada needs to walk the talk.

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DEREK DAVIS – NOVA SCOTIA NATURALIST EXTRAORDINAIRE

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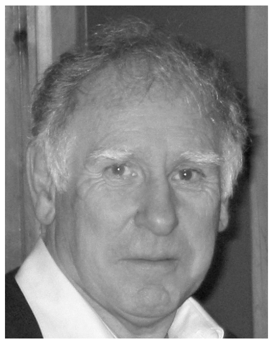

Derek Sidney Davis

Dr. Derek Sidney Davis passed away on August 7th, 2017. Derek was a distinguished Nova Scotia naturalist and was the Chief Curator of Science at the Nova Scotia Museum of Natural History for 25 years. He was a long-time NSIS member, on the Council from 1972-1982 and the NSIS President (1981-1982). This short article celebrates his life and his substantial contributions to our understanding of the natural history of Nova Scotia.

Derek was born in 1938 in East Ham, London, England. As a child he was evacuated with his family from the bricks and pavement of the war-time city to a village near the River Thames. Exploring the county-side, looking in ponds and ditches he became interested in the wild life he saw: birds, insects, small mammals and especially snails. After the war, Derek discovered the British Museum of Natural History which had no entrance fee. He began to go there every week, fascinated by the specimens in its vast collections and learning about the biology of the animals they represented. He joined the museum's Junior Naturalists Club and later the Field Observers Club. He was supported and greatly influenced by the museum educator Jaqueline Palmer. She encouraged Derek to begin his first field observations by

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tracking the movement of the snails in his family garden. The Field Observers Club held summer camps on Alderney in the Channel Islands with the support of Miss Palmer and here Derek learned to run transects, observe and sketch specimens and keep card catalogues. Jaqueline Palmer's mentorship played a key role in developing Derek's interest in natural history and shaping his passion for the environment and environmental education.

He studied Biology and Geology at Chelsea College, University of London. In 1965 he immigrated to Canada and began a PhD program at Dalhousie. Within a week of arriving in Canada, he went to the old NS Museum on Spring Garden Road and three years later he became the first Chief Curator of Science at the new museum on Summer Street.

Derek believed strongly in the vital role museums play in educating and encouraging people to experience, learn about, and value their local environments. To assist with environmental education within schools he designed and wrote the Field Studies Series for Grade 10 Biology which created field guides so high school teachers could provide hands-on experiences for their students in their local communities on the Atlantic, Northumberland Strait, Fundy and Northeastern Cape Breton Shores.

Derek participated as a scientific advisor to the N.S. Government's Committee on Land-use Policy and as a member of the Special Places, Parks, Off-shore and Significant Wild Habitats Issue Groups, Wildlife Habitats Advisory Issue Group and the Coastal Zone Mapping Sub-Committee.

In the late 1970s, following the lead of Parks Canada, those concerned with parks planning in the Province decided to include environmental protection as well as outdoor recreation needs in the selection of new parks and in planning for activities within all parks. Needing an environmental rationale to support logical decision making, Parks Canada adopted a landscape classification system based on geological, climatic and botanical factors. The Federal government had already created a national classification to be used for selection of new national parks. The Nova Scotia Parks Department (part of the then Department of Lands and Forests) desired to create such a bio-geographic land classification system for the Province. The expertise and data for this inter-disciplinary effort was dispersed among several government agencies. The Nova Scotia Museum was asked to lead the inter-departmental group created to lead the initiative, and Derek was assigned to this role by the Museum.

This effort was financed by the Province through a budget administered by the then Maritime Resource Management Service (MRMS) and allocated by the Nova Scotia Deputy Ministers' Committee on Use Policy Committee for this purpose. A group of technical experts, chaired by Derek from the Museum, and including Lands and Forests, and MRMS, hired Griffiths-Muecke Consultants to assemble and integrate the necessary data sets. Data, and assistance in interpreting it, was obtained from personnel from many other government agencies responsible for geological, soils, meteorological, hydrological, vegetation, wildlife, and entomological data.

Rather than terming it a bio-geographical analysis as such work has been termed elsewhere in Canada the expression "theme regions" was preferred. "Theme regions" recognises the origins of the work as a rationale for parks planning in which inter-dependent environmental themes are identified. Derek also particularly liked this descriptive term and its appeal to environmental education.

The effort took several years during which Derek's enthusiasm for the work of integrating these many data sets continued to grow. Like many complex projects the need for money also continued to grow and Derek was always there to make whatever contributions he could, and especially to assemble money from other agencies. When the work was eventually completed it was published by the Museum and has formed the basis for environmental decision making in Nova Scotia ever since.

Derek conducted biological research on the distribution and ecology of benthos and land and freshwater molluscs. He also lectured in Ecology in the Department of Environmental Planning at the N.S. College of Art and Design, and was a frequent lecturer and field trip leader for local universities, teacher in-services and the general public. It was here that he conveyed the importance of a holistic view of the landscape. Derek wrote over 60 publications.

Derek's enthusiasm, great knowledge and commitment to Nova Scotia and Canada's natural history were noted by all who met him. He will be greatly missed by all who knew or worked with him, and long remembered as a mentor, and for his many significant contributions to our understanding and appreciation of the natural history of our Province.

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REMEMBERING DR. JAMES "JIM" EDWARD STEWART OF THE NSIS

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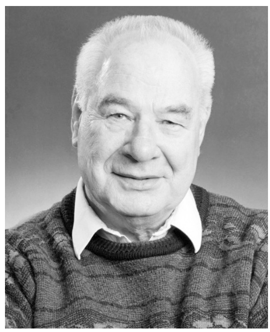

James "Jim" Edward Stewart

The NSIS lost a long-time supporter, and dedicated marine scientist with the passing on March 1st, 2018, at age 89, of Dr. James "Jim" Edward Stewart. He was a member of NSIS for many years, President of NSIS from 1992 to 1994, and Editor of the PNSIS from 2000 to 2008. Jim was a prominent marine scientist who had a long career in Halifax and Dartmouth, NS. This short piece commemorates and records Jim's many contributions to marine science. It includes a bibliography of his work, compiled by the author.

Born in Anyox, British Columbia (BC), Jim "paid his way through university by working as a logger in the coastal forests of British Columbia. He studied microbiology and biochemistry at the University of British Columbia and later at the University of Iowa." (Halifax Today 2018). He began his career as a federal scientist with the Fisheries Research Board of Canada in 1958, based in Halifax, NS, and completed it as an Emeritus Scientist with the Department of Fisheries and Oceans (DFO) at the Bedford Institute of Oceanography (BIO), Dartmouth, NS. Jim spent many productive years in active research at the former Halifax Fisheries Research Laboratory, on Lower Water

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Street. He then moved to BIO in 1986 as Director of the Biological Sciences Branch, responsible for freshwater and marine programs. He eventually returned to research and after formal retirement in 1996, continued to work at BIO.

I first met Jim in the mid-1970s to discuss a shared interest in lobster biology and the general responses of marine organisms to oil pollution. It was a few years after the *Arrow* bunker C spill in Chedabucto Bay, NS, where both of us had been briefly involved in assessing the impacts of that spill on local fisheries. I recall his great warmth and interest in what I was doing, being a young biologist at the time. Jim went on to assess the microbial degradation of that spill and the effects of oil spill dispersants on biodegradation (see the papers by Mulkins-Phillips and Stewart). Based on that work, he served on the US National Academy of Sciences 1973 oil pollution review group, contributing to the first extensive review of oil in the sea (NAS 1975).

Throughout his career, however, Jim's primary interest was on topics relevant to fisheries species and their management. His initial passion was research on the diseases and disease defense mechanisms of lobsters, as shown by his extensive publication record on this topic. He was an international expert on the bacterial pathogen, *Gaffkya homari,* and its pathogenicity to lobsters and other decapod crustaceans. His research greatly "contributed to the economic viability of the lobster fishery, through the replacement of wooden plugs with rubber bands, now used by fishermen to prevent movement of the claws of the captured animals; this change significantly reduced gaffkemia transfer and incidence" (M. Sinclair, pers.comm.). As Head of the Disease and Nutrition Section, Jim also investigated various aspects of lobster, molluscan and fish aquaculture, including the need to consider aquaculture within the broader framework of integrated coastal management (Stewart 2001). After moving to BIO and back into research, he returned to another interest, toxigenic marine algae, making major contributions very late in life (Stewart 2014).

Several colleagues have recollections of Jim. John Castell, a former DFO scientist now living in NB, recalls that "I was always impressed with Jim's interest and knowledge in a wide diversity of research programs. He was an inspiration to all of his research team" (pers. comm.). Bob Cook, former Director of the Biological Station at St. Andrews, NB, remembers that "Jim had established an incredible team of scientists and professionals in the fisheries disease and nutrition field at the Halifax Laboratory" (pers.comm.). Mike Sinclair and Rene Lavoie, both of whom knew and worked with Jim at BIO, remember that "an additional feature of his management style was his focus on excellence and his encouragement of young scientists to publish their research findings; he was a demanding research manager but one who led by example" (pers. comm.).

As Editor of the PNSIS, Jim and a colleague (Stewart and Safer 2005) wrote a seminal article on the history of the Halifax Fisheries Research Laboratory, and edited a series of marine science essays recognizing the upcoming 50th anniversary of BIO (Stewart 2006). His broad interests and technical skills were quite extraordinary, exemplifying his capacity to address some key problems in marine and fisheries science as a whole.

In his personal life, Jim was devoted to his family and greatly enjoyed working outdoors. Living in Allen Heights at the Head of St. Margarets Bay, NS, he took "great pride and pleasure in landscaping and in harvesting and splitting his own firewood" (Halifax Today 2018).

In retirement, Jim routinely attended NSIS lectures; his presence there will be greatly missed. Above all, he will be remembered as a hard-working, dedicated and highly productive scientist, a wonderful model to all others in the marine sciences following in his footsteps.

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CELEBRATING THE CAREER OF DR. JOSEPH J. KEREKES – INTERNATIONALLY RENOWNED, NOVA SCOTIA LIMNOLOGIST

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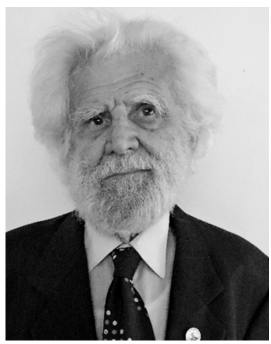

Fig 1 Dr. Joseph ("Joe") J. Kerekes, the "last limnologist", at age 85.

Over ten years ago, Dr. Joseph ("Joe") Kerekes, Emeritus Research Scientist of Environment Canada's Canadian Wildlife Service, was congratulated on his 75th birthday (Faragó 2008). Recently, we had the honour to celebrate his 85th birthday (Figure 1). He remains a member of the editorial board for *Hungarian Waterfowl Publications*. This Hungarian born scientist has lived in Canada since 1956, receiving his graduate degrees in Canada and spending a career as a federal government limnologist. All the while, he maintained relationships with colleagues all over the world, especially with Hungarian limnologists and waterfowl ornithologists. Burnett (1999) wrote a chapter on Joseph Kerekes with the title, "*The Last Limnologist*". His outstanding career in Canada, as well as his publications

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[1] This article was edited and adapted for the PNSIS by both Editors, PGW and DHR. Wells had the privilege of knowing "Joe" Kerekes while working with the Canadian Wildlife Service, Conservation and Protection, Environment Canada, Dartmouth, NS. They currently work together on Bay of Fundy issues and share a deep interest in the waters and wildlife of "Keji" (Kejimkujik National Park).

(see below and Farago 2008), show what an inspiration he should be to the younger generation of limnologists and ornithologists.

In Atlantic Canada, the shift towards pure limnology was actively encouraged by Jean-Paul Cuerrier who recruited Joseph Kerekes, then a graduate student at the University of Alberta in 1965. Kerekes had become "indoctrinated" (his word) at the University of Alberta in the virtues of the Wildlife Service by Bill Fuller, who was teaching a graduate seminar in wildlife management. In December, 1965, while attending a conference in Montreal, Kerekes was approached by John Tener said "*if I wanted a job I should call Jean-Paul Cuerrier in Ottawa. So I did, and the first question Cuerrier asked me was whether I had any furniture that had to be moved. Well, a poor student just graduated sure didn't have furniture to worry about. That was in the good old days when there was expansion and people could make real decisions, just like that! The Park Service expected I would be another trout biologist, but the job title was limnologist, so I took it literally and practised limnology*" (Kerekes 1997).

Terra Nova National Park, in eastern Newfoundland, had been established in 1957, only eight years prior to Joseph Kerekes's appointment. He responded enthusiastically to the suggestion that he concentrate his efforts there. Starting in 1967, he began an inventory of all the water bodies in Terra Nova. Of those, he selected four for closer investigation of their productive capacity. This entailed monitoring the growth rates and feeding habits of Brook Trout (*Salvelinus fontinalis* Mitchill) and attempting, from this information, to estimate the total biomass and sustainable yield of these populations. As part of his analysis of the Terra Nova lakes, Kerekes had routinely measured total phosphorus and chlorophyll in water samples. He was struck by the correlation between the two and became one of the very first limnologists anywhere to appreciate the importance of phosphorus in the productivity of inland waters (i.e., lakes and rivers). This marked a departure from conventional park fisheries management. It led to research in a new area, resulting eventually in his Ph.D. (Dalhousie University) and a new and highly original dimension of limnological studies and environmental monitoring.

Kerekes'work attracted international attention. He was invited to participate in an OECD (Organisation for Economic Co-operation and Development) program on eutrophication. This involved studies of 128 lakes in 18 countries. In the late 1970s, he was seconded to the OECD for two years to work as coauthor of a report on these studies.

This would eventually play a key role in accomplishing the widespread banning of phosphate detergents (Vollenweider and Kerekes 1980).

Around this time, the Canadian Wildlife Service (CWS) of Environment Canada undertook the task of assessing the wildlife resources in Canada's national parks. Kerekes was assigned to coordinate the work on aquatic resources. Kejimkujik National Park, in southwest Nova Scotia, was one of the first parks to be surveyed (Kerekes 1992). It was a fortunate choice. Most of the lakes in the park are naturally acidic. Kerekes was intrigued by the question of how acidic deposition ("acid rain") would influence them. In 1977, he put forward a proposal to investigate the long-range transport of air pollutants and their deposition in the Kejimkujik lakes (Kerekes 1977). His international reputation from his OECD experience probably aided the proposal's ultimate approval, in spite of the fact that the initial reaction at CWS headquarters was less than enthusiastic.

At first, people dismissed my proposal. I was told that I shouldn't study acid rain there because the amount was immeasurably small. Others said, "The acid is from organic sources, don't bother about it." I was even told that you couldn't study birds in Kejimkujik because the population density was too low. But I have to admit that I went and started working in a small way anyway. Eventually, in 1980, the proposal came to the attention of the national acid rain coordinating people and they liked it, so I was asked to do it officially. I worked on it then until 1983, when the Inland Waters Directorate came in with their own people to work on water quality (Kerekes 1997).

The study showed that highly sensitive, naturally acidic lakes such as the ones in Kejimkujik were affected even by minimal inputs of acid precipitation from distant sources. It was that sensitivity that won international recognition for the park as a very special site for the monitoring of environmental quality (Vollenweider and Kerekes 1980). Thanks in large part to the acid rain study, the park eventually became the prototype site for Canada's national Environmental Monitoring and Assessment Network (EMAN).

When the Inland Waters Directorate, Environment Canada, assumed an active role at the park, Kerekes turned to other tasks. He took part in the CWS Latin American Program, first in Brazil and later in Mexico, where he evaluated the productivity of lagoons and lakes in the states of Oaxaca and Chiapas. Only in 1988 did he return to the study of aquatic invertebrates, fish, and fish-eating birds in Kejimkujik National Park. This brought him in a full circle, back to the early work in Terra Nova. Once again, he found himself looking at phosphorus as the determining factor to the abundance of plankton, fish and, by extension, fish-eating birds (Fig 2). The Kejimkujik findings were among topics highlighted in an international symposium on aquatic birds and limnology that was organized in Sackville, New Brunswick, in 1991 (Kerekes 1994). The interest expressed at that event moved him to establish an international working group on aquatic birds, which has subsequently held workshops in Hungary, Canada, Spain, Sweden and the Yucatan, Mexico.

Fig 2 Joe Kerekes investigating aquatic vegetation in Kejimkujik National Park, NS, 30-35 years ago. (picture by Eric Mullen, Parks Canada).

Kerekes retired in 1996, with an inescapable feeling that limnology in Environment Canada (CWS) had retired with him. In an interview in 1997, he reminisced:

Back in the 1970s, Canada was on the cutting edge of limnology on a world-wide scale. If you came from Canada, people paid attention. Nowadays, it's neither here nor there. Today, it might be impossible to start the Keji (Kejimkujik) study. Of course, there's still water quality work going on, but that's not limnology. The fishery is one part of the lake. The water quality is another. It takes the holistic view of the limnologist to integrate them. But nowadays, everyone is backing away from that generalized work. The federal departments say it's not in their mandate. The provinces say they have no money. And so a lot of good research, in areas that are not clearly defined by legislation and regulation, is just being abandoned.

I was really lucky to be working when I did. I used to say, back then "The good old days are happening right now." And I was right.

At the time of his retirement, Kerekes received a Scientific Emeritus appointment with CWS that he kept until 2014. He continues to work, being directly involved with the annual loon (*Gavia immer*) survey in Kejimkujik National Park and serving on the steering committee of the Bay of Fundy Ecosystem Partnership (Wells, pers.comm.). On the occasion of his 85^{th} birthday, everyone wished him many more birthdays and celebrated his career as one of Canada's outstanding aquatic scientists. One fervently hopes that he will not be one of "the last limnologists" in Nova Scotia and the Maritime Region, so filled with streams, rivers, ponds and lakes requiring continued research, monitoring and management.

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THE MARINE MACROALGAE OF BRIER ISLAND, NOVA SCOTIA, CANADA*

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ABSTRACT

From May to October 2017 seaweeds were identified in the field and laboratory from 20 sites around Brier Island, Nova Scotia. While most sites were intertidal rocky shores, there were one small salt marsh and one eelgrass bed included in the study, and some subtidal sampling was conducted utilizing SCUBA and snorkeling. The Brier Island seaweeds comprised 152 species and varieties of which 62 were Rhodophyta, 44 were Chlorophyta, 44 were Phaeophyceae, and two species were Xanthophyceae. Three species were new records for eastern Canada: Colaconema bonnemaisoniae, C. endophyticum, and Elachista stellaris, all were previously recorded from New England. The flora included eight non-native species of which Colpomenia peregrina and Bonnemaisonia hamifera (both gametophytic and tetrasporophytic stages) were abundant at two or more sites, and the invasive Codium fragile subsp. fragile was recorded based on a single drift specimen. With 150 species and varieties of seaweeds, Brier Island has the highest species richness of a limited area of eastern Canada. The Cheney floristic index at 2.4 is higher than comparable areas, and suggests that many additional brown algae remain to be found.

Keywords: Chlorophyta, *Colaconema*, Bay of Fundy, Brier Island, Phaeophyceae, Rhodophyta, seaweeds

INTRODUCTION

Brier Island, Nova Scotia (44°15'N, 66°22'W) is the most westerly point in Nova Scotia, at the end of Digby Neck and Long Island, in

* We dedicate this paper to three pioneers of the seaweed flora of the Maritime Provinces: Tikvah Edelstein, Constance MacFarlane, Jack McLachlan

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the outer Bay of Fundy. A portion is under management by the Nature Conservancy of Canada as part of an effort to preserve native habitat of the globally endangered *Geum peckii* Pursh[1] (Rosaceae). With its highly exposed location in the Bay of Fundy, a largely undisturbed shoreline, and a diversity of habitats, a baseline study of Brier Island provides a baseline for long-term monitoring of impacts of sea level rise, climate change and invasive organisms. Here we provide a floristic study of the marine macroalgae carried out in 2017.

The marine macroalgal flora of Brier Island was initially investigated by Edelstein *et al*. (1970) as part of a detailed floristic and seasonal study of Digby Neck and adjacent Long and Brier Islands. While the Brier Island flora was not treated separately, the subsequent review of seaweed distributions for the Bay of Fundy by Wilson *et al*. (1979) included 66 species on Brier Island including 30 Rhodophyta, 9 Chlorophyta and 27 Phaeophyceae. No comprehensive account of the algae followed, although more focused observations of individual species and single sites were undertaken as part of more geographically wide-ranging studies. For example, Novaczek and McLachlan (1989) carried out a single transect on Brier Island at North Point as part of transects on rocky intertidal shores of the Maritime provinces, although the results for Brier Island were merged with those of other sites in the outer Bay of Fundy. Further physiological and ecological studies were carried out on *Palmaria palmata* (e.g. Garbary *et al*. 2012), *Prasiola stipitata* (Kang *et al*. 2014); *Ascophyllum nodosum* and *Vertebrata lanosa* (Garbary 2017a); and *Prasiola crispa* (Garbary and Hill 2017). There are complementary floristic studies from the western side of the Bay of Fundy in both Canada and USA. These include South *et al*. (1986) for Passamaquoddy Bay, Bates *et al*. (2009) for coastal New Brunswick, Mathieson et al. (2009) for Cobscook Bay, Maine, and Mathieson (2018) for northeastern ('downeast') Maine. Here we present a list of the seaweeds of Brier Island based on sampling from May to October 2017, and discuss our findings in the context of seaweed distributions in the Maritime Provinces and adjacent northeastern United States. This new species list provides a detailed account for an area that has received little attention for about 50 years.

1 Authorities for species are provided in the text only when they are not included in Appendix 1.

MATERIALS AND METHODS

Brier Island has a circumference of about 24 km (Fig 1). It has a boreal climate, and as a consequence of being surrounded by the cold waters and large tides of the Bay of Fundy, its maritime climate tends to have cooler summers and milder winters than the rest of Nova Scotia. The island is sparsely settled with a single community of Westport (population *ca.* 220), where economic activity focuses on fishing and ecotourism. Much of the terrestrial landscape consists of secondary growth of boreal forest (mostly black spruce) undergoing secondary succession from abandoned agricultural and logging activity. There are extensive peatlands, some of which are inhabited by *Geum peckii*. The western side of the island has a fringe of coastal heaths in which the invasive *Rosa rugosa* Thunberg has become dominant and is outcompeting both herbaceous and shrubby vegetation on the coastal fringe (Garbary *et al.* 2013).

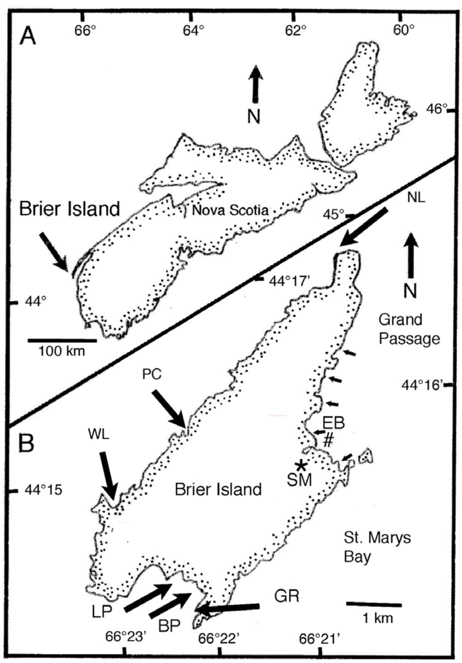


Fig 1 **Map of Nova Scotia (A) and Brier Island (B) indicating primary collection sites. Abbreviations and symbols: NL, Northern Light; PC, Pero Jack Cove; WL, Western Light; LP, Little Pond Cove; BP, Big Pond Beach; GR, Gull Rock Point; SM, salt marsh*; EB, eelgrass bed#; small arrows, Westport Village.**

Table 1 Primary sites on Brier Island sampled for seaweed biodiversity and sampling dates. Primary sites were visited multiple times on low tides. Secondary sites were visited once on poor tide, or by SCUBA. Coordinates indicate approximate midpoint on the shore, taken from Google Earth. Primary sites listed counter-clockwise from Northern Light. See Fig 1 for locations. All sampling times are from 2017.

Site	Latitude (°N)	Longitude (°W)	Dates sampled (day/month)
Primary sites			
Northern Light	44°19.19’	66°20.64’	13/5, 2/6, 23/6, 27/7, 2/9, 6/10
Pero Jack Cove	44°15.97’	66°22.07’	24/6
Western Light	44°14.94’	66°23.46’	1/6, 22/6, 25/7, 7/10
Little Pond Cove	44°14.35’	66°22.71’	11/5, 25/6, 26/7, 28/8, 8/10
Big Pond Cove	44°14.35’	66° 22.28’	12/5, 24/6, 6/10
Gull Rock Point (east side Big Pond Cove)	44°14.15’	66°22.22’	29/7
Grand Passage (Westport)	44°15.90’	66°20.95’	10/5, 21/6, 22/6, 26/6, 23/7, 28/7, 31/8, 8/10
Westport eelgrass*	44°15.62’	66°20.94’	23/7, 27/8#, 29/8#, 7/10
Westport salt marsh*	44°15.56’	66°21.15’	4/6, 22/7, 6/10
Secondary sites			
North of Pero Jack Cove	44°16.30’	66°21.99’	13/5
Westport, floating dock[1]	44°15.50’	66°20.84’	21/6
Hog Cove	44°13.92’	66°22.23’	21/6
Peters Island#	44°15.52’	66°20.19’	27/8
Gull Rock#	44°11.28’	66°25.21’	28/8
Whipple Point#	44°14.38’	66°22.96’	28/8
Gull Rock#	44°12.29’	66°23.90’	28/8
Northwest ledges#	44°21.09’	66°21.77’	29/8
Seal Cove#	44°17.26’	66°20.75’	29/8
Gull Rock (east side)#	44°12.80’	66°23.10’	30/8
Gull Rock (west side)#	44°12.84’	66°23.32’	30/8
North Point (east side)	44°16.90’	66°20.46’	3/9

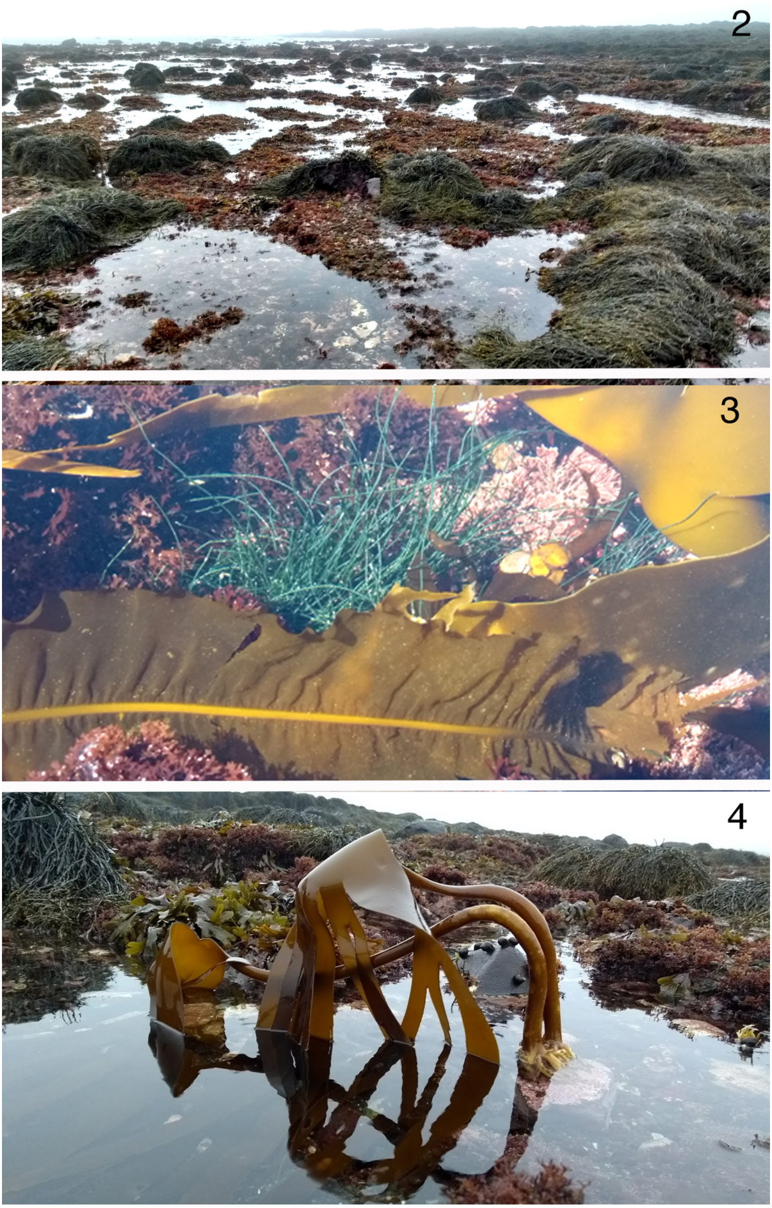
* Coordinates from centre of habitat/site
\# DFO SCUBA sampling
[1] floating dock pulled ashore – unknown provenance

The bedrock is the endpoint of a basalt ridge that extends 200 km along much of the southern shore of the Bay of Fundy (Roland 1982). The intertidal zones (Tables 1, 2) are mostly exposed basalt bedrock and boulder fields (Fig 2) with numerous rock pools (Fig 3). The shores include steep cliffs rising about 10 m above the intertidal zone, gently sloping shores comprising boulder fields, a single sandy beach, and some muddy-gravel shores associated with the village of Westport. A salt marsh (*ca*. 2 ha) on the landward side of the main road at Westport is part of the drainage from the eutrophic Big Meadow

Table 2 Summary of primary physical features of sampling sites. Width of site refers to portion of shore explored. Site length refers to length of intertidal zone.

Site	Width of site (m)	Site length (m)	Primary subtrata	Comments
Northern Light	180	140	Boulder fields, bedrock, tidal pools	Most wave-exposed site
Pero Jack Cove	80	100	Boulder field, bedrock, freshwater inflow	
Western Light	50	75	Boulder field, bedrock	Extensive platform at low water, protected by islets and headlands
Little Pond Cove	100	500	Boulder field, bedrock, numerous shallow pools	Protected by ridges of basalt bedrock
Big Pond Cove	400	NA	Sandy gravel beach with some cobble	Visited for wrack collection
Gull Rock point	200	60	Boulder field with low pools	
Grand Passage (Westport)	1500	50-100 m	Boulder fields, mud, wood pilings, concrete walls, floating dock	Low wave-exposure
Westport eelgrass bed	> 100	NA	Eelgrass in muddy sand	Requires spring tides
Westport salt marsh	100	150	Marsh mud/peat, sides of drainage channel, high pools with floating mats	Limited tidalmarsh exchange via culvert

Bog into the ocean. In addition, two tiny remnants of salt marsh (each *ca*. 20 x 10 m) of *Spartina alterniflora* Loisel. remain on the seaward side where Big Meadow Bog drains into Grand Passage via a culvert. A single bed of *Zostera marina* occurs in the low intertidal and shallow subtidal zone at Westport (Fig 1) and is bounded on the seaward side by an active salmon aquaculture facility. Artificial substrata of concrete at the government wharf and ferry terminal, a floating dock in the main harbour, and numerous pilings associated with the fishing industry wharfs and fish shacks provide extensive wood substrata. Remnant pilings from the destruction caused by the



Figs 2-4 Selected intertidal habitats for macroalgal collections. (2) Shore at Little Pond Cove at low tide with numerous shallow pools. (3) Mid-shore rock pool at Northern Light with diversity of algae including: *Alaria esculenta* (with midrib), *Chaetomorpha melagonium* (green hair), and *Corallina officinalis* (calcified pink alga). (4) Low intertidal rock pool at Northern Light with *Laminaria digitata* and diverse algae in background.

February 2, 1976 Groundhog Day gale are also scattered along the shorefront of Westport.

Marine algae were collected between May and October 2017 around Brier Island (Fig 1, Table 1). The primary sites (i.e., Western Light, Little Pond Cove, Big Pond Cove, Northern Light, Westport shore and eelgrass bed) were visited multiple times. One to three people visited a site on a tide and attempted to collect all of the species present. Field work was carried out such that collections were undertaken during periods that overlapped with spring tides. Many conspicuous algae were simply noted in the field at each site, and general collections were returned to a field laboratory on Brier Island to identify species requiring microscopic evaluation, and to examine large plants for epiphytic and endophytic taxa. Algae were typically processed while fresh, with voucher specimens prepared for deposit in regional herbaria at ACAD and STFX. Microscopic species were prepared as semi-permanent slides in 40% clear corn syrup. Subtidal collections were carried out by snorkeling at low water in July, and some additional collections were made in late August-early September by SCUBA divers from the Department of Fisheries and Oceans collecting at *ca*. 10 m depth (Table 1). We use the floristic index of Cheney [1977; = (#green algae + # red algae) / # brown algae] to compare other regional floras.

Mathieson and Dawes (2017) was the primary resource for keys and descriptions, although Brodie *et al*. (2007) was especially useful for green algae, Bird and McLachlan (1992) for red algae, and Fletcher (1987) for brown algae. Keys in Sears (1998) and Villalard-Bohnsack (2003) were also useful. Authorities for all algal species identified are given Appendix 1.

RESULTS

Over 1,100 identifications of 152 species and varieties of marine and brackish water macroalgae were recorded from Brier Island (Appendix 1). These species included 62 Rhodophyta, 44 Chlorophyta and 44 Phaeophyceae and two species of *Vaucheria* (Xanthophyceae). Of these species, over 35 were new for Digby Neck, 12 were new for the Bay of Fundy, one was new for Nova Scotia, and three were new records for Canada (Table 3).

Table 3 New distribution records for Brier Island and associated geographic areas.

Species	Eastern Canada	Bay of Fundy	Digby Neck	Comment
Chlorophyta				
Blidingia subsalsa?			+	Requires culturing to distinguish from *B. ramifera* (Garbary and Barkhouse 1987)
Capsosiphon fulvescens			+	
Chaetomorpha picquotiana			+	
Chlorochytrium cohnii			+	
Cladophora liniformis		+	+	High marsh pool; new record for Nova Scotia
Codium fragile subsp. fragile		+	+	Single drift specimen
Derbesia marina			+	
Eugomontia sacculata		+	+	
Percursaria percursa			+	
Prasiola crispa		+	+	See Garbary and Hill (2017)
Pseudendoclonium dynamenae			+	
Pseudothrix borealis			+	
Tellamia contorta			+	
Ulothrix laetevirens			+	
Ulothrix subflaccida		+	+	
Ulva torta			+	
Ulvella repens?			+	Endophyte in *Elachista*
fucicola				
Rhodophyta				
Acrochaetium endozoicum		+	+	Endozoic in bryozoan
Acrochaetium humile		+	+	
Acrochaetium luxurians		+	+	
Acrochaetium minimum		+	+	
Acrochaetium parvulum		+	+	
Bonnemaisonia hamifera			+	Abundant gametophytes and tetrasporophytes
Coccotylus hartzii			+	
Colaconema bonnemaisoniae	+	+	+	Common endophyte in *Bonnemaisonia hamifera*
Colaconema endophyticum	+	+	+	Rare endophyte in *Dictyosiphon*
Colaconema daviesii			+	
Erythrotrichia carnea			+	
Lithothamnion glaciale			+	
Pneophyllum fragile			+	
Rhodomela lycopodioides			+	
Rhodophysema georgii			+	
Scagelia pylaisaei			+	

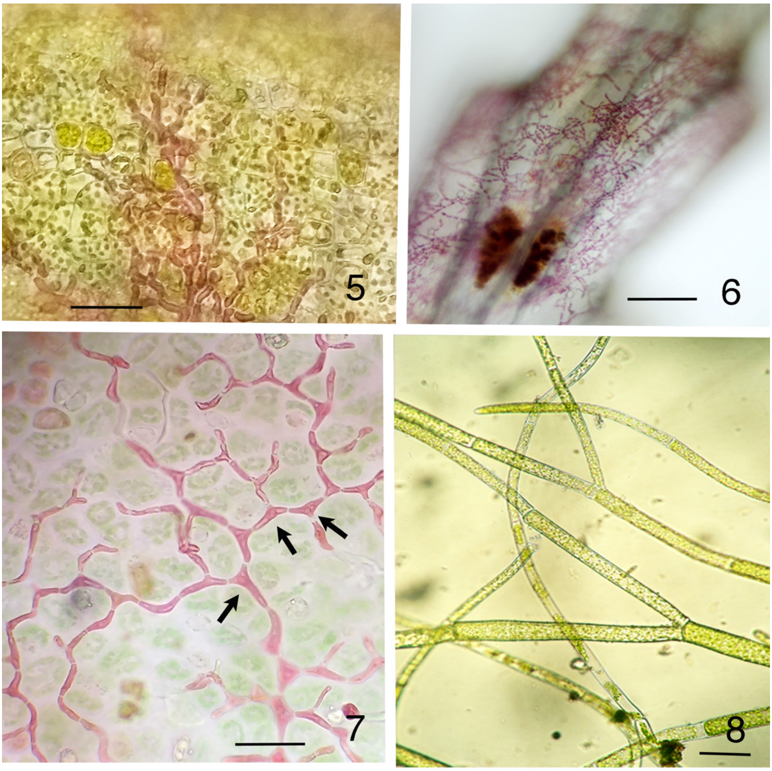
Table 3 cont'd

Table 3 Cont'd

Species	Eastern Canada	Bay of Fundy	Digby Neck	Comment
Phaeophyceae				
Colpomenia peregrina			+	Abundant at several sites
Dictyosiphon eckmannii?			+	
Ectocarpus siliculosus var. *pygmaeus*			+	
Elachista stellaris?	+	+	+	Epiphyte on *Vertebrata lanosa*
Sphacelaria rigidula?			+	
Spongonema tomentosum			+	
Xanthophyceae				
Vaucheria intermedia		+	+	
Vaucheria sp.	?	?	+	Non-reproductive

Three distinct intertidal habitats were explored: 1) the rocky intertidal zone of the west side of the island, 2) the bed of *Zostera* in Grand Passage, and 3) the salt marsh at Westport. The majority of species occurred on the rocky intertidal of the west side (121 species with 69 exclusive species), 38 species (8 exclusive) were found in the eelgrass bed, and 15 species (7 exclusive) were found in the salt marsh (Appendix 1). Two species, *Melanosiphon intestinalis* and *Peyssonnelia rosenvingei* were found only on artificial structures in Westport village; the former was associated with an old piling north of the ferry terminal, and the latter grew on concrete at the ferry terminal.

Following the species concepts in Garbary *et al*. (1982) and Mathieson and Dawes (2017) we indentified two endophytic algae for the first time in eastern Canada: *Colaconema endophyticum* and *C. bonnemaisoniae* (Figs 5, 7). Both species were previously recorded in the northwestern Atlantic Ocean only south of Cape Cod (Mathieson and Dawes 2017). The former species had very small cells (< 10 μm long) and the single parietal chloroplasts were devoid of pyrenoids. The latter species had much larger cells (15-30 μm), each with a single parietal chloroplast and pyrenoid. *C. endophyticum* was found once in *Dictyosiphon foeniculaceus* in the subtidal zone south of Northern Light on the Fundy shore. *C. bonnemaisoniae* was more common and observed ten times in the gametophytic phase of *Bonnemaisonia hamifera*, and was particularly conspicuous in the cell walls of the hooked branches of its host when host tissue was



Figs 5-8 **Photomicrographs of selected endophytic red algae (Figs 5-7) and a free-living green alga. (5) *Colaconema endophytica* in outer cell wall of *Dictyosiphon foeniculaceus*. Scale bar = 20 µm. (6) *Acrochaetium endozoicum* in bryozoan. Scale bar = 100 µm. (7) *Colaconema bonnemaisoniae* endophytic in outer wall of *Bonnemaisonia hamifera*; arrows indicate single pyrenoid in each cell. Scale bar = 25 µm. (8) *Cladophora liniformis* in high salt marsh pool. Scale bar = 100 µm,**

bleached or senescent. While no attempt was made to quantify the occurrence of *C. bonnemaisoniae*, only a few specimens of the host gametophytes were required to find the endophyte. Accordingly, it probably is fairly common. Another endobiotic species is the rare *Acrochaetium endozoicum* (Fig 6). It occurred in a bryozoan epiphytic on *Chaetomorpha melagonium* in a low shore rock pool. This was only the second record of this species in Canada. The single previous Canadian record is from the sublittoral of Halifax County (Edelstein *et al*. 1969).

The identification of *Elachista stellaris* was somewhat problematic as the identification keys are based primarily on host identity.

Our material was a common epiphyte on *Vertebrata lanosa* and was identified seven times in the collections. The thalli were very small relative to *E. fucicola*, and only 1-2 mm high. A single clump of the host sometimes had five or six thalli. In both Europe and North America, *E. stellaris* is reported from a variety of hosts but neither *Ascophyllum* nor *Fucus* which are regarded as the only hosts for *E. fucicola* (Fletcher 1987, Mathieson and Dawes 2017). Host switching of *E. fucicola* onto *V. lanosa* remains a possibility.

Two species of *Vaucheria* were present in the salt marsh: *V. intermedia* and *Vaucheria* sp., which, in the absence of gametangia, could not be identified to species. Its narrow filaments (*ca*. 20 μm) and the absence of reproduction suggest *V. minuta* Blum & Conover, but further collections are needed to confirm this identification (see Mathieson and Dawes 2017).

Cladophora liniformis (Fig 8) formed an extensive floating mat in a high pool in the salt marsh at Westport, where it was the dominant species and mixed with *Ulva torta* (new for Digby Neck). *C. liniformis* was not previously recorded from Nova Scotia, and previous records from eastern Canada were questioned by South (1984).

DISCUSSION

Species richness in the Maritime Provinces and Gulf of Maine

The 152 species and varieties of seaweeds identified on Brier Island in 2017 indicate a relatively diverse flora in a limited geographic area. The Brier Island flora thus represents 60% the 254 species of red, brown and green seaweeds for the Bay of Fundy reported by Wilson *et al*. (1979) for New Brunswick and Nova Scotian shores to Cape Sable Island (Table 4). This difference in species richness is explained by the much larger area and greater diversity of habitats in the Bay of Fundy as a whole. In addition, the Wilson *et al*. inventory included historical collections made over more than 50 years; thus, the greater likelihood of including rare taxa.

A primary objective of this work was to compare the current flora of Brier Island to that detailed by Edelstein *et al*. (1970) based largely on collections from Digby Neck, with only limited sampling undertaken on Brier Island. The species identified in that study and other incidental collections on Brier Island in the ensuing years were mapped by Wilson *et al*. (1979). While the algal distributions

Table 4 Comparison of the seaweed flora of Brier Island with other localized floristic lists in Nova Scotia, New Brunswick and Maine indicating numbers of Chlorophyta (G), Phaeophyceae (P), Rhodophyta (R), and Xanthophyceae. The Cheney (1977) floristic index, (#R + #G) / #P is provided for each flora (see text for discussion).

Flora	Chlorophyta	Phaeophyceae	Rhodophyta	Xanthophyceae	Total	Index
Brier Island	44	44	62	2	152	2.4
Digby Neck[1]	33	61	52		146	1.4
Bay of Fundy[2]	62	93	99		254	1.7
Passamaquoddy Bay[3]	45	58	68		171	1.9
Cobscook Bay[4]	38	46	64		148	2.2
New Brunswick (coast)[5]	16	25	31		72	1.9
Bras d'Or Lake[6]	23	31	31		85	1.7
Pomquet Harbour[7]	39	44	32	5	120	1.6
Prince Edward Island (north shore[8])	19	50	52		131	1.6

[1] Edelstein *et al*. 1970 (duplicate records based on life history phase removed)
[2] Wilson *et al*. 1979
[3] South *et al*. 1988 (numbers based on only summer collections)
[4] Mathieson *et al*. 2010
[5] Bates *et al*. 2009 (numbers based on strictly intertidal observations)
[6] McLachlan and Edelstein 1970
[7] Bird *et al*. 1976
[8] Bird *et al*. 1983

reported by Edelstein *et al*. (1970) for Brier Island (as given in Wilson *et al*. 1979) were clearly limited because of collection intensity, many of those species can reasonably be expected to occur on Brier Island today. This list includes five brown algae: *Punctaria tenuissima* (C.Agardh) Greville [as *Desmotrichum undulatum* (J.Agardh) Reinke], *Entonema polycladum* (Jaasund) Jaasund, *Eudesme virescens* (Carmichael ex Berkeley) J.Agardh, *Microspongium globosum* Reinke, and *Myriotrichia clavaeformis* Harvey (as *M. filiformis* Harvey). A sixth species *Stragularia clavata* (Harvey) Hamel (as *Ralfsia bornetii* Kuckuck) is now considered the sporophytic phase of Scytosiphonaceae (see Mathieson and Dawes 2017). In addition, one green alga, *Ulva rigida* C.Agardh, and three red algae, *Harveyella mirabilis* (Reinsch) F.Schmitz & Reinke, *Hydrolithon farinosum* (J.V.Lamouroux) Penrose and Y.M.Chambelain, and *Leptophytum leave* Adey were listed. Most of these algae could reasonably be expected to occur on Brier Island. Of these, *Hydrolithon farinosum* is typically found as an epiphyte on *Zostera marina* Linnaeus during fall and winter (Mathieson and Dawes 2017), for which we had only limited collections.

South *et al*. (1988) reported 176 species from Passamaquoddy Bay. While this was more than the 150 species we found on Brier Island, theirs was over a collection area at least several orders of magnitude greater, and encompassing habitats (e.g., estuaries) not found on Brier Island. Their study was also based on extensive subtidal sampling via SCUBA with experienced phycologist-divers including a specialist on crustose coralline algae. Moreover, the total for that list included many species that were not found specifically in the study area but were assumed to be present based on reports from the outer Bay of Fundy. While more species might be found on Brier Island with winter collections and more extensive subtidal sampling, our number of summer species is unlikely to be significantly increased.

The bed of *Z. marina* has endured two major environmental impacts since the 1970s that could well have limited species richness. The first was storm damage from the Groundhog Day gale (2/2/1976) that destroyed the waterfront of Westport and sent seawater across 3 km of the island through the low-lying Big Meadow Bog. This would have severely impacted the eelgrass bed. Subsequently, a salmon aquaculture facility was installed adjacent to the *Z. marina* bed, with possible effects on trophic levels. The extensive diatom growth we observed on leaf blades may have limited colonisation of epiphytic macroalgae. Even in its current state, *Z. marina* provided a habitat for 38 species, mostly as leaf epiphytes. The single collection of *Derbesia marina* was an unattached mat from within the eelgrass bed. Should storm action or sea-level rise cause a major breach in the barrier beach at Big Pond Cove, this would create a large area suitable for colonisation by *Z. marina* and its epiphytes.

Some species not recorded for Brier Island relative to the Edelstein *et al*. (1970) inventory may result from algal seasonality. Hence *Porphyra linearis* Greville, *Ulvella parasitica* (Oltmanns) R.Nielsen, C.J.O'Kelly & B.Wysor (as *Acrochaete*), and *Chlorochytrium dermatocolax* Reinke were found only in the winter, and probably explains why these species were not found in the current study.

In Nova Scotia and the southern Gulf of St. Lawrence, three additional species lists of marine algae have been compiled for limited geographic areas: Bras d'Or Lake, Pomquet Harbour, and the north shore of Prince Edward Island (Table 4). All have lower diversity (85 to 131 species) even though Bras d'Or Lake and Prince Edward Island have much greater coastal areas. Only Cobscook Bay in Maine, with a much larger shoreline, has an equivalent species richness to Brier Island (148 vs 152).

The Cheney (1977) index for the floras in Table 4 ranges from 1.6 to 2.4, suggesting that these floras are all boreal, with cold-water affinities. It is of note that Brier Island has the highest value (2.4) with Cobscook Bay close at 2.2. This suggests that the Brier Island flora is underrepresented in brown algae. The inventories of species in Edelstein *et al*. (1970) and Wilson *et al*. (1979) recorded from Digby Neck that were not found in the current study include ten green algae, 24 brown algae, and nine red algae. Should all of these species occur as well on Brier Island it would raise the species number to 184, more than the 176 species from Passamaquoddy Bay on the opposite side of the Bay of Fundy. In addition, it would lower the Cheney index to 1.8, consistent with other regional floras.

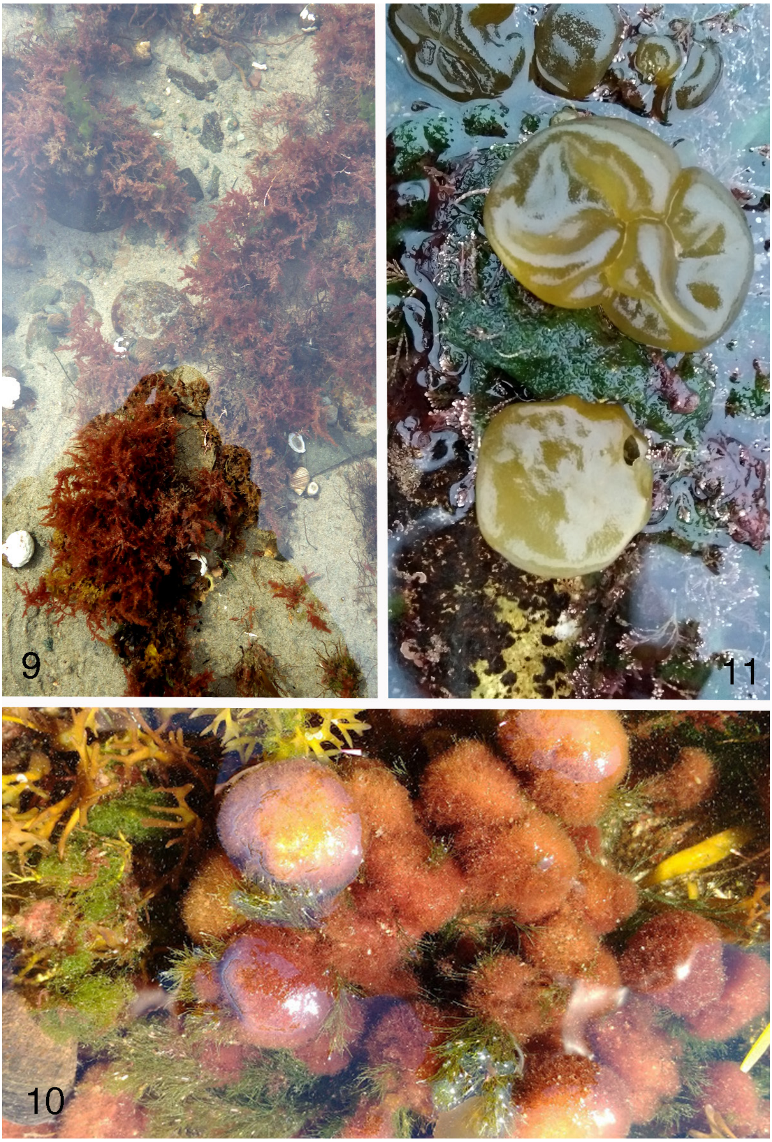
Introduced seaweeds

Mathieson and Dawes (2017) provided a list of 32 introduced species for the northwest Atlantic Ocean. Seven of these were found on Brier Island: *Codium fragile* subsp. *fragile*, *Colpomenia peregrina*, *Melanosiphon intestinalis*, *Ulonema rhizophorum*, *Bonnemaisonia hamifera*, *Ceramium secundatum*, and *Dumontia contorta*. Several of these species appear to be naturalized (e.g., *M. intestinalis*, *U. rhizophorum*, *Ceramium secundatum*, and *D. contorta*) without invasive properties. The non-native, Nova Scotian invasive species, *Fucus serratus* Linnaeus, was not observed. The introduction and spread of *F. serratus* in Nova Scotia were discussed by Edelstein *et al.* (1971-1973), and the closest reported populations are in southwestern Nova Scotia, about 50 km south from Brier Island (Wilson *et al.* 1979).

Bonnemaisonia hamifera

There was an abundance of both the tetrasporophytic and gametophytic phases of the introduced species *Bonnemaisonia hamifera* (Figs 9, 10). Neither life-history stage of this species was recorded by Edelstein *et al.* (1970) or Wilson *et al.* (1979) for Digby Neck, and the nearest recorded populations were in the Yarmouth area, about 75 km south from Brier Island. In 2017, it would have been difficult to avoid these tetrasporophytic plants (i.e., the *Trailliella*-phase) in a general collection from any rocky shore on the island where it formed distinct epiphytic tufts up to several cm wide or occurred as scattered filaments in most rock pools. In subtidal collections, it was associated with kelp holdfasts and diverse red algae. Similarly, the gametophytic stage occurred at every site, and fragments were common in the drift or attached via their hooked branches to other macrophytes. In mid- to low-intertidal rock pools it was abundant and seemingly replaced the expected populations of *Ceramium virgatum*.

Chen *et al.* (1970) described the vegetative development of gametophytic plants directly from the *Trailliella*-phase, and this might account for the abundance of gametophytes on Brier Island. Alternatively, the abundance of the gametophytic phase of *B. hamifera* might also reflect warming of the Bay of Fundy (Hebert *et al.* 2018). Breeman *et al.* (1988) showed that the life history of *B. hamifera* in Europe was regulated by both temperature and daylength. Tetrasporangia formed when water temperatures were over about 11°C and daylength was less than 12 h of light. We suggest that appropriate conditions for tetrasporangial production had been reached in late summer and fall of 2016, and that the resulting tetraspores produced the gametophytes that we observed in 2017. Whereas tetrasporophytes were present in our mid-May collections, the larger gametophytic phase was not noted until late June. That is, the gametophytes that we observed appeared not to have overwintered as large plants, but must have developed in late spring to early summer. This seems inconsistent with the finding of gametophytes in winter along the Atlantic coast of Nova Scotia



Figs 9-11 ***In situ*** **photographs of two non-native species common on Brier Island. (9) Dense population of gametophytic stage of** ***Bonnemaisonia hamifera*** **in low intertidal rock pool (figure courtesy of Roy Gjelstad). (10) Dense population of tetrasporophytic stage (*****Trailiella*****-phase) of** ***Bonnemaisonia hamifera*** **in rock pool; each 'pom-pom' about 2 cm in diameter. (11) Two thalli of** ***Colpomenia peregrina*** **with larger thallus about 10 cm diameter.**

(Chen *et al*. 1969). We saw no thalli with male or female gametangia, or cystocarps, although spermatangia, carpogonia and rudimentary pericarps have been recorded from Nova Scotia (Chen *et al*. 1969, 1970; Bird 1980). In addition, none of the tetrasporophytic thalli we observed had produced tetrasporangia by early October. In view of this, it will be interesting to see if *B. hamifera* gametophytes are as abundant in the future.

Colpomenia peregrina

Colpomenia peregrina (Fig 11) was abundant at two sites on the west side of Brier Island, at Little Pond Cove and Pero Jack Cove. It has been considered rare on the Atlantic coast of Nova Scotia (Bird and Edelstein 1978) where it was found only at a few widely separated locations, in the sublittoral zone down to 3-5 m. It has since then become a regularly occurring species in Halifax County, where it is collected by SCUBA divers (B. Hymes pers. comm.). On Brier Island the species was found in July-August at low water on spring tides, attached to *Mastocarpus stellatus* and *Corallina officinalis,* with many thalli exposed. Thalli were up to 20 cm in diameter. Despite considerable wave exposure on the west side of the island, the two locations were protected from waves by offshore rock outcrops and nearby headlands. Green *et al*. (2012) described the southward extension of *C. peregrina* in the northwest Atlantic Ocean, and it now occurs as far south as Cape Cod. The findings on Brier Island represent an almost 100 km extension of the distribution from previous records in southwestern Nova Scotia. The abundance of *C. peregrina* may suggest aggressive colonization, as the species is considered a potential oyster-thief in Maine (Green *et al*. 2012) and the Mediterranean Sea (Verlaque *et al*. 2015). However, with its general lack of robustness in thallus structure, it is unlikely to become an aggressive invasive species on the exposed shores of Brier Island.

Melanosiphon intestinalis

Melanosiphon intestinalis, first reported by Edelstein *et al*. (1970a, b) as a new record for eastern North America from Digby Neck, is now known from Long Island (New York) to Labrador (Mathieson *et al*. 2008; Mathieson and Dawes 2017). On Brier Island, it was found on a single exposed piling in Westport village, and thalli were 1-2 cm long. One of us (CJB) recalls that this species was previously abundant on the wall of the local ferry terminal (*ca*. 1970).

Extensive searches there and elsewhere on Brier Island failed to locate additional populations. In addition, thalli were mostly less than 1.5 cm long and about 1 mm wide, suggesting that the species may be on the verge of extirpation from environmental or competitive interactions.

Codium fragile* subsp. *fragile

Codium fragile subsp. *fragile* has an extensive distribution along the Atlantic coast of Nova Scotia from Yarmouth to Canso and in the southern Gulf of St. Lawrence (Watanabe *et al*. 2010). These distributions were likely based on independent introductions in Mahone Bay (Bird *et al*. 1993) and Prince Edward Island (Garbary *et al*. 1997, Hubbard and Garbary 2001). We found a single thallus (*ca*. 12 cm high) on the last collecting period in October amongst extensive mounds of seaweed wrack at Big Pond Cove, and none was found in four visits to Big Pond Cove in 2018. This suggests either that it had been transported a long distance as drift, or that a population on Brier Island had only recently been established. The SCUBA diving by DFO in late August/early September at eight locations found no *C. fragile*; if any populations are present, they are likely to be limited. The nearest known populations are in southwestern Nova Scotia (*ca*. 100 km from Brier Island; Watanabe *et al*. 2010). The species is well established in the Gulf of Maine (Mathieson *et al*. 2003), and the thallus on Brier Island may also have arrived via drift from northern Maine where it has been found in Cobscook Bay (Mathieson *et al*. 2010).

CONCLUSIONS

For its size, Brier Island possesses relatively species-rich communities of marine macroalgae in a limited geographic space. The three main community types of rocky intertidal zone, salt marsh and eelgrass beds all contribute unique species to the overall diversity of over 150 species of seaweeds. Given the relative isolation of the western shoreline of the island, and the already protected nature of key adjacent terrestrial habitats, Brier Island warrants consideration for protection of its coastal marine habitats.

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Appendix 1 **List of species of macroalgae and their local distribution on Brier Island in 2017. Note: Eelgrass bed and salt marsh are specific habitats found within Westport which covers the shores along Grand Passage with various natural and built substrates. P = Present.**

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
Chlorophyta					
Acrosiphonia arcta (Dillwyn) Gain	P	P			
Acrosiphonia sonderi (Kützing) Kornmann	P				
Acrosiphonia spinescens (Kützing) Kjellman	P	P			
Blidingia marginata (J.Agardh) J.P.L.Dangeard ex Bliding			P		P
Blidingia minima (Nägeli ex Kützing) Kylin	P	P	P		P
Blidingia subsalsa (Kjellman) Kornmann & Sahling ex Scagel			P		
Bolbocoleon piliferum Pringsheim	P				
Capsosiphon fulvescens (C.Agardh) Setchell & N.L.Gardner					P
Chaetomorpha brachygona Harvey	P			P	
Chaetomorpha ligustica (Kützing) Kützing	P	P	P	P	
Chaetomorpha linum (O.F.Müller) Kützing					
Chaetomorpha melagonium (F.Weber & D.Mohr) Kützing	P	P	P		
Chaetomorpha picquotiana Montagne ex Kützing			P	P	P
Chlorochytrium cohnii E.P.Wright			P		
Cladophora liniformis Kützing					P
Cladophora rupestris (Linnaeus) Kützing	P	P			
Cladophora sericea (Hudson) Kützing	P	P			
Codium fragile (Suringar) Hariot subsp. *fragile*		P			
Derbesia marina (Lyngbye) Solier				P	
Eugomontia sacculata Kornmann		P	P		
Gayralia oxysperma (Kützing) K.L.Vinogradova ex Scagel *et al.*			P	P	

Appendix 1 cont'd

Appendix 1 Cont'd

Species	**Northern Light to Western Light**	**Little Pond Cove to Gull Rock Point**	**Westport**	**Eelgrass bed**	**Salt marsh**
Gomontia polyrhiza (Lagerheim) Bornet & Flahault			P	P	
Monostroma grevillei (Thuret) Wittrock	P	P			
Percursaria percursa (C.Agardh) Rosenvinge					P
Prasiola crispa (Lightfoot) Kützing	P				
Prasiola stipitata Suhr ex Jessen	P	P	P		
Pseudendoclonium dynamenae R.Nielsen	P				
Pseudothrix groenlandica (J.Agardh) Hanic & S.C.Lindstrom	P				
Rhizoclonium riparium (Roth) Harvey			P		P
Spongomorpha aeruginosa (Linnaeus) Hoek	P				
Tellamia contorta Batters		P			
Ulothrix flacca (Dillwyn) Thuret	P		P		
Ulothrix speciosa (Carmichael) Kützing	P				
Ulothrix subflaccida Wille			P		
Ulva compressa Linnaeus			P		
Ulva intestinalis Linnaeus	P	P	P	P	P
Ulva lactuca Linnaeus	P	P	P	P	P
Ulva linza Linnaeus	P	P			
Ulva prolifera O.F.Müller			P		
Ulva torta (Mertens) Trevisan					P
Ulvaria obscura (Kützing) Gayral ex Bliding	P		P	P	
Ulvella repens (Pringsheim) R.Nielsen, C.J.O'Kelley & B.Wysor		P			
Urospora penicilliformis (Roth) Areschoug	P				

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
Rhodophyta					
Acrochaetium endozoicum (Darbishire) Batters	P				
Acrochaetium humile (Rosenvinge) Børgesen		P		P	
Acrochaetium luxurians (J.Agardh ex Kützing) Nägeli				P	
Acrochaetium parvulum (Kylin) Hoyt				P	
Acrochaetium secundatum (Lyngbye) Nägeli	P	P			
Acrochaetium sp.	P				
Ahnfeltia plicata (Hudson) Fries	P	P			
Antithamnionella floccosa (O.F.Müller) Whittick	P	P	P	P	
Bangia atropurpurea (Mertens ex Roth) C.Agardh	P				
Bonnemaisonia hamifera Hariot	P	P	P	P	
Ceramium deslongchampsii Chauvin ex Duby	P	P	P		
Ceramium secundatum Lyngbye	P	P			
Ceramium virgatum Roth	P	P	P	P	
Chondrus crispus Stackhouse	P	P	P		
Choreocolax polysiphoniae Reinsch	P	P			
Choreocolax rabenhorstii Reinsch		P			
Clathromorphum circumscriptum (Strömfelt) Foslie		P			
Coccotylus hartzii (Rosenvinge) LeGall & G.W.Saunders	P	P			
Coccotylus truncatus (Pallas) M.J.Wynne & J.N. Heine	P				
Colaconema bonnemaisoniae Batters	P	P		P	
Colaconema daviesii (Dillwyn) Stegenga	P				
Colaconema endophyticum (Batters) J.T.Harper & G.W.Saunders	P[1]				
Colaconema minimum (Collins) Woelkerling	P				
Corallina officinalis Linnaeus	P	P			

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
Cystoclonium purpureum (Hudson) Batters	P	P			
Devaleraea ramentacea (Linnaeus) Guiry	P	P			
Dumontia contorta (S.G.Gmelin) Ruprecht	P	P	P	P	
Erythrotrichia carnea (Dillwyn) J.Agardh	P	P	P		
Euthora cristata (C.Agardh) J.Agardh	P	P	P		
Fimbrifolium dichotomum (Lepechin) G.I.Hansen	P			P	
Hildenbrandia rubra (Sommerfelt) Meneghini	P	P	P		
Lithothamnion glaciale Kjellman	P	P			
Mastocarpus stellatus (Stackhouse) Guiry	P	P	P	P	
Meiodiscus spetsbergensis (Kjellman) G.W.Saunders & McLachlan		P	P		
Membranoptera fabriciana (Lyngbye) M.J.Wynne & G.W.Saunders	P	P			
Palmaria palmata (Linnaeus) F.Weber & D.Mohr	P	P	P	P	
Peyssonnelia rosenvingei F.Schmitz			P		
Phycodrys rubens (Linnaeus) Batters	P	P			
Phyllophora pseudoceranoides (S.G.Gmelin) Newroth & A.R.A.Taylor ex P.S.Dixon & L.M.Irvine	P	P			
Phymatolithon laevigatum (Foslie) Foslie		P			
Phymatolithon lenormandii (Areschoug) Adey	P	P			
Plumaria plumosa (Hudson) Kuntze	P	P			
Pneophyllum confervicola (Kützing) Y.M.Chamberlain					
Pneophyllum fragile Kützing				P	
Polyides rotundus (Hudson) Gaillon	P	P			
Polysiphonia elongata (Hudson) Sprengel			P		
Polysiphonia flexicaulis (Harvey) Collins			P	P	

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
Polysiphonia stricta (Mertens ex Dillwyn) Greville	P	P		P	
Porphyra umbilicalis Kützing	P	P	P	P	
Ptilota serrata Kützing	P	P			
Pyropia leucosticta (Thuret) Neefus & J.Brodie	P		P		
Rhodochorton purpureum (Lightfoot) Rosenvinge	P		P		
Rhodomela confervoides (Hudson) P.C.Silva	P				
Rhodomela lycopodioides (Linnaeus) C.Agardh		P			
Rhodomela virgata Kjellman	P			P	
Rhodophysema elegans (P.Crouan & H.Crouan ex J.Agardh) P.S.Dixon		P			
Rhodophysema georgei Batters			P	P	
Rubrointrusa membranacea (Magnus) S.L.Clayden & G.W.Saunders	P		P	P	
Scagelia pylaisaei (Montagne) M.J.Wynne	P	P	P	P	
Titanoderma pustulatum (J.V.Lamouroux) Nägeli	P	P			
Vertebrata lanosa (Linnaeus) T.A.Christensen	P	P	P		
Wildemania miniata (C.Agardh) Foslie	P	P			
Unidentified red crust (non calcified)	P[2]				
Phaeophyceae					
Agarum clathratum Dumortier	P	P			
Alaria esculenta (Linnaeus) Greville	P	P			
Ascophyllum nodosum (Linnaeus) LeJolis	P	P	P		
Asperococcus fistulosus (Hudson) W.J.Hooker		P			
Chordaria flagelliformis (O.F.Müller) C.Agardh	P	P	P		
Colpomenia peregrina Sauvageau	P	P			

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
Desmarestia aculeata (Linnaeus) J.V.Lamouroux	P	P		P	
Desmarestia viridis (O.F.Müller) J.V.Lamouroux	P	P			
Dictyosiphon chordaria Areschoug	P				
Dictyosiphon ekmanii Areschoug				P	
Dictyosiphon foeniculaceus (Hudson) Greville	P	P		P	
Ectocarpus fasciculatus Harvey	P				
Ectocarpus siliculosus (Dillwyn) Lyngbye	P	P		P	P
Ectocarpus siliculosus var. *pygmaeus* (Areschoug) Gallardo					P?
Elachista fucicola (Velley) Areschoug	P	P	P		
Elachista stellaris Areschoug	P	P	P		
Entonema polycladum (Jaasund) Jaasund		P			
Fucus distichus Linnaeus subsp. *distichus*	P				
Fucus distichus subsp. *edentatus* (Bachelot de la Pylaie) H.T.Powell	P	P			
Fucus distichus subsp. *evanescens* (C.Agardh) H.T.Powell	P	P			
Fucus spiralis Linnaeus	P	P	P		
Fucus vesiculosus Linnaeus	P	P	P		P
Halosiphon tomentosum (Lyngbye) Jaasund		P			
Isthmoplea sphaerophora (Carmichael) Gobi	P				
Laminaria digitata (Hudson) J.V.Lamouroux	P	P	P		
Leathesia marina (Lyngbye) Decaisne	P	P			
Melanosiphon intestinalis (D. A.Saunders) M.J.Wynne			P		
Microspongium stilophorae (P.Crouan & H.Crouan) Cormaci & G.Furnari		P			
Mikrosyphar polysiphoniae Kuckuck	P				
Myrionema corunnae Sauvageau		P			

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
Myrionema magnusii (Sauvageau) Loiseaux *nom. inval.*				P	
Myrionema strangulans Greville		P			
Petalonia fascia (O.F.Müller) Kuntze	P		P	P	
Planosiphon complanatus (Rosenvinge) McDevit & G.W.Saunders				P	
Planosiphon zosterifolius (Reinke) McDevit & G.W.Saunders				P	
Protohalopteris radicans (Dillwyn) Draisma, Prud'homme & H.Kawai			P		
Punctaria latifolia Greville		P			
Pylaiella littoralis (Linnaeus) Kjellman	P	P	P	P	
Ralfsia fungiformis (Gunnerus) Setchell & N.L.Gardner	P	P			
Ralfsia verrucosa (Areschoug) Areschoug	P	P	P		
Saccharina latissima (Linnaeus) C.E.Lane, C.Mayes, Druehl & G.W.Saunders	P	P	P		
Sacchoriza dermatodea (Bachelot de la Pylaie) J.Agardh	P	P			
Scytosiphon dotyi M.J.Wynne			P		
Scytosiphon lomentaria (Lyngbye) Link	P	P	P		
Sphacelaria rigidula Kützing		P			
Sphacelaria spp.	P	P			
Spongonema tomentosum (Hudson) Kützing	P		P		
Xanthophyceae					
Vaucheria intermedia Nordsted					P
Vaucheria sp.					P

[1] Northwest Ledges
[2] Gull Rock – DFO diving

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TESTING EFFICACY OF BIRD DETERRENTS AT WIND TURBINE FACILITIES: A PILOT STUDY IN NOVA SCOTIA, CANADA

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ABSTRACT

Wind energy has become one of the fastest-growing renewable electricity sources globally, and this trend is expected to continue. However, wind turbines cause avian mortality when birds collide with these structures. Although regulatory agencies in many jurisdictions require post-construction bird mortality monitoring at turbine sites, resulting mortality estimates are often imprecise and under-reported. This uncertainty is often attributed to searcher inefficiencies or scavenger losses. Furthermore, data regarding the effectiveness of active bird mortality mitigation at these facilities are also lacking. This pilot study assessed mitigation effectiveness of visual and audio deterrents, using predator owl deterrent models and bioacoustic alarm and predator calls deployed at a wind turbine facility in Nova Scotia, Canada. These deterrents did not deter birds from wind turbines in statistically significant ways, in comparison to control sites. Whilst results were inconclusive, it would be prudent to continue assessing mitigative options to minimize impacts on birds, considering the expected growth of the wind energy sector in Canada.

Keywords: Wind energy development; Wind turbines; Bird mortality monitoring; Bird deterrents; Bird mortality mitigation.

INTRODUCTION

Wind energy has become one of the fastest-growing renewable electricity sources in over 90 countries (Marques *et al*. 2014; CanWEA 2016), because it is a reliable, affordable, and relatively safe alternative to carbon-based energy sources. Wind energy in Canada continues to grow by 18% annually on average, with an installed capacity of 11,989 MW in 2016 (CanWEA 2016). With annual electricity consumption of 16 megawatt hours (MWh) per capita,

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Canada ranks fourth highest globally, reflecting an important need for energy efficiency, conservation, and renewable energy development (The World Bank Group 2016). Wind energy growth is also continuing in Nova Scotia, which has doubled its wind energy production from 2012 - 2016. As of December 2017, the province was producing 610 MW of wind electricity, meeting 14% of provincial energy needs (CanWEA 2017; Nova Scotia Power 2017). Nova Scotia ranks fourth in total installed capacity in Canada and is on track to meet 40% of its energy needs through renewable sources by 2020 (EGSPA 2007).

Although wind energy continues to provide a clean, reliable source of electricity, it is not without direct and indirect impacts. Wind turbines have significantly lower impacts on birds than traditional energy sources and other man-made structures (e.g., power lines and buildings) (Saidur *et al*. 2011; Calvert *et al*. 2013), but are still responsible for an estimated 0-40 bird mortalities/turbine/year (Sovacool 2013; Zimmerling *et al*. 2013).

However, many proponents are now employing mitigation techniques, and using an understanding of how passerine birds (the most impacted species guild from wind turbines in Atlantic Canada) use different habitats to strategically site turbines away from sensitive areas (Baisner *et al*. 2010). This has led to reductions in avian mortality rates to as low as 0.02-7.36 birds/turbine/year (Wang *et al*. 2015).

In Canada, the Wind Energy Bird and Bat Monitoring Database (WEBBMD) is a joint initiative among Bird Studies Canada, Canadian Wind Energy Association (CanWEA), Environment and Climate Change Canada, and Ontario Ministry of Natural Resources (Bird Studies Canada, 2018). The database is used to understand characteristics of bird and bat mortality at wind farms across Canada. It currently relies heavily on data from Alberta and Ontario, the provinces from which most wind turbine monitoring results are submitted (WEBBMD 2016). Data from Atlantic Canada come from only 2 sites from New Brunswick, 3 in Prince Edward Island, 2 in Newfoundland and Labrador and 1 in Nova Scotia. Consequently, with the current data, researchers are unable to accurately assess mortality rates for Atlantic Canada, particularly Nova Scotia (WEBBMD 2016; Parisé and Walker 2017). In Atlantic Canada, the estimated average mortality rate is 1.17 birds/turbine/year, markedly lower than for Ontario (6.14) and Alberta (2.65) (WEBBMD 2016). Passerines represented the majority of bird mortalities recorded in Atlantic Canada (76.9%), followed by gull mortalities (11.5%). which likely reflects the coastal locations of wind farms for which data were submitted (WEBBMD 2016).

Many mitigation measures have been proposed and tested, ranging from sensory deterrents to turbine modifications. Beston *et al*. (2015) evaluated outcomes of various studies and found that many of these measures had inconclusive results. This is likely due to differences in geography and avian species present at each wind-energy site, highlighting the need for site-specific mitigation measures (Hull *et al*. 2013). It is often difficult to accurately quantify numbers of mortalities from wind turbines, due to error caused by searcher inefficiency, removal of carcasses by scavengers, and inconsistencies in data collection techniques (Smallwood *et al*. 2010; Zimmerling *et al*. 2013; Beston *et al*. 2015; Stenglein *et al*. 2015; Reyes *et al*. 2016). New studies have called for standardized post-construction monitoring techniques to address this (Parisé and Walker, 2017), and Zimerling *et al*. (2013) provide statistical correction factors to reduce error.

Although wind turbines present a lesser threat to birds than do other man-made structures (Calvert *et al*. 2013), the cumulative impacts of human-made structures are largely unknown, and assessing possible impacts to birds requires more research (Schuster *et al*. 2015). In Canada, all bird species are protected under the Migratory Birds Convention Act (MBCA 1994), and those at risk have legal protection under the federal Species at Risk Act (SARA 2002). Wind turbine monitoring can serve as a regulatory tool to support compliance in reducing impacts to species at risk (Dorey and Walker 2018). Further research is required to determine which monitoring protocols effectively reduce bird mortality associated with wind energy developments (Beston *et al*. 2015; May *et al*. 2015; Parisé and Walker 2017). The goal of this pilot study was to test the efficacy of sensory deterrents, including a predator owl model (visual) and bioacoustics calls (audio), for reducing bird mortalities at wind energy facilities.

Predator models have been widely studied for a variety of other uses (e.g. DeHaven 1971; Howard *et al*. 1985; Conover 1985; Knittle and Porter 1988; Rensel and Wilder 2012), but have not been studied at wind turbines. Target species, food types, location, time of day, season, and model used can all influence predator model effectiveness (Marsh *et al*. 1992). Deterrent effects demonstrated were often short-term, because birds habituate to the models due to lack of reinforcement from painful or lethal experiences (Marsh *et al*. 1992). However, introducing deterrents under different circumstances may be effective. Furthermore, if models are effective at deterring bird species even for a short time, they could be useful in reducing collisions when used selectively during periods of high avian activity. Use of predator models at wind turbines requires a different line of inquiry compared to previous studies, reflecting different target species, habitat, and models used. Predator owl deterrents could be more effective at wind turbines than in other situations, because turbine structures do not attract birds with food, as do crops or feeders.

Bioacoustic techniques have been implemented to deter birds in other instances, including landfills (Baxter 2000), airports (Blokpoel 1976), fish-rearing ponds (Andelt *et al*. 1997) and along highways (Conklin *et al*. 2009). Bioacoustic calls are thought to be the most effective audio deterrent for birds, because they invoke a natural fear response (Marsh *et al*. 1992). Sound is socially important to birds, as they can discern details in each sound and differentiate among conspecifics, harmless species, and potential predators (Congdon, 2015). Audio deterrents in the form of predator and alarm calls have been found effective for small areas over short periods of time, and could be used in similar situations to deter birds from wind turbines (May *et al*. 2015). Past research suggests that many species recognize alarm calls of other species, allowing a playback of both predator calls and alarm calls to be more effective by invoking fear from multiple species (Magrath *et al*. 2009), causing the birds to leave the area.

The objective of this study was to test the effectiveness of visual and audio deterrents in deterring birds from areas near wind turbines, by deploying a predator owl model deterrent paired with an audio recording of predator and alarm calls. These bioacoustic calls were intended to draw attention of post-breeding and migrating songbirds to the owl model, helping to identify an immediate threat which could deter these birds from open areas near turbines, where they may be at risk of collision with turbine structures.

METHODS

Study Location and Timing

This study was conducted at a wind farm site located in Halifax Regional Municipality approximately 20 km northwest of Halifax, Nova Scotia, Canada (Fig 1). This wind farm includes 5 turbines with an installed capacity of 10 MW. The turbines are situated linearly,

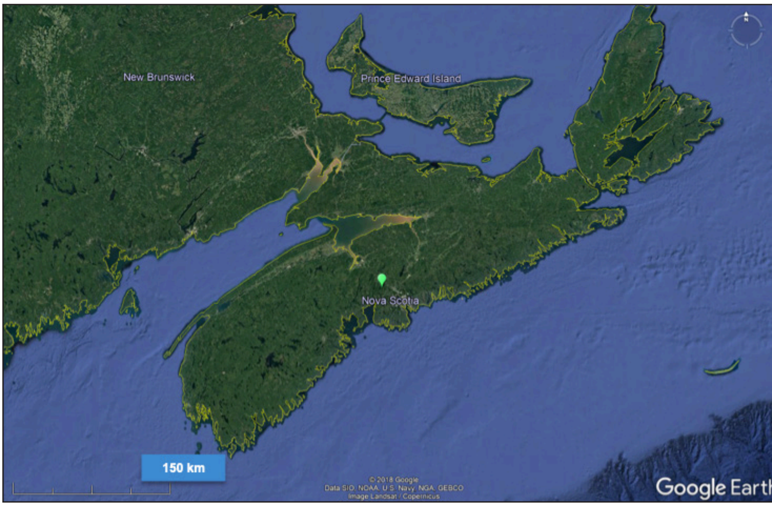

Fig 1 **Study location, showing relative position of the wind farm 20 km northwest of Halifax, Nova Scotia, Canada.**

approximately 400-700 m apart. The site encompasses 282 ha of diverse landscape, including softwood, hardwood and mixed wood forests, a power line corridor, urban areas, clear cuts, roads, dead stands, wetlands, and marshes. The site is located approximately 20km from the Atlantic coast. The elevation of the site is approximately 150m, similar to the surrounding land.

The study was conducted from 22 August to 16 September 2016, during the early fall bird migration period. This period was selected to capture peak bird movements across the site, allowing observation of both migrating and resident birds engaged in a range of behaviours including foraging, high and low flight patterns, and migratory stopover.

Data Collection

Efficacy of model owls and predator calls in deterring birds from the area near wind turbines was assessed by monitoring bird flight paths and the number of bird passes and bird calls, using human observers during four trials. Deterrents and controls were implemented and monitored simultaneously 12 times for each of four turbines. Turbines were monitored three times per week on Monday, Wednesday and Friday. Each turbine was continuously monitored using an observer for 20 min., starting at sunrise. The total survey time was four hours for each deterrent and 16 hours for the entire study.

Date, time, weather, turbine number, and trial type for each trial and turbine were recorded on a field sheet. A table with different bird flight behaviors on the field sheet was used to record whether the bird flew directly over the turbine, stayed within the tree-line, or flew over the turbine pad but changed its flight path. The observer recorded the number of bird passes and flight paths, and whether the bird was flying or calling. The observation area included a 50 m radius from the turbine, with bird movements observed from the entrance to the turbine base.

The four trials used in this study were: Trial #1: Visual deterrent; Trial #2: Visual and audio deterrents; Trail #3: Rotating Control turbine with no deterrent; and Trail #4: Stationary Control turbine with no deterrent. The first trial used a Bird-X Prowler Owl with moving wings, perched on a 2.5 m section of polyvinyl chloride (PVC) pipe within 50 m of the turbine. The second trial included the Prowler Owl paired with predator calls and alarm calls. The predator call was of a Red-tailed Hawk (*Buteo jamaicensis*). Alarm calls were played from Ovenbirds (*Seiurus aurocappilla*) and White-throated Sparrows (*Zonotrichia albicollis*), two of the most common species found during pre- and post-construction monitoring. A mixture of predator calls and alarm calls were used to provide variation and portray a realistic threat. Playback was set up to run 24 h/day for the duration of the study.

The StorMP3 speaker was selected to play calls because it was water-resistant, had internal storage, and was powered by batteries lasting >72 h. This was essential because the speaker was required to operate for a minimum of 48 h between site visits and battery changes. The speaker was placed in a plastic casing with holes cut out so that its sound was not muffled. An audio file was created using version 2.1.2 of the Audacity® recording and editing software (Audacity Team 2016), using the Xeno-canto website to compile various Red-tailed Hawk, Ovenbird, and White-throated Sparrow calls (Cruikshank 2012; 2014; Price 2012; Davis 2014; Marvin 2015; 2014; Grosselet 2016; St. Michel 2016). Multiple calls for each species were used to simulate variety.

As bird numbers in the area of the turbines vary daily during the migration period, all trials occurred on the same dates. Trials rotated among turbines every second monitoring day, to control for different habitat and bird abundances at different turbines, except for the stationary control which remained at the same turbine throughout the study period. This control provided base-line bird counts without interference from bird deterrents, as the habitat at this location was similar to that found over the majority of the wind farm site. This was in contrast to the rotating control which was moved among turbines, to help indicate changes in base-line bird numbers resulting from the effect of deterrents at each turbine location during the previous monitoring day.

Data Analysis

Field sheets were transcribed into Microsoft Excel. Data were separated into total bird observations and calls heard versus birds flying. Data were also analyzed to detect differences in how birds responded to each of the deterrents at each turbine. Data were entered in VassarStats (Lowry 2016). A one-way analysis of variance followed by a Tukey's test was conducted to determine whether differences between trials were significant.

RESULTS

Table 1 describes the number of birds observed during each of the implemented trials. Each total is also separated into those birds that were observed flying and those that were only audible, and the abundance at each individual turbine are presented.

Table 1 Observed and audible bird occurrences and individual turbine bird abundances.

	Observed	Audible	Total	T1 Totals	T2 Totals	T4 Totals
Owl Model Alone	58	43	101	13	62	25
With Bioacoustic Calls	60	23	83	18	34	31
Rotating Control	60	52	112	37	57	18
Stationary Control	47	41	88	NA	NA	NA

No significant difference was found in the number of birds observed during each trial ($F=0.43$, $P=0.73$; Fig 2), nor was there a significant difference between the number of birds observed flying and the number heard ($F=0.11$, $P=0.95$; $F=1.87$, $p=0.15$). However, slightly fewer audible calls were noted when bioacoustic calls were played, compared to the owl deterrent by itself or to the control (Fig 3). This suggests that birds tended to fly, rather than call, when the bio-acoustic calls were played with the owl deterrent, although differences

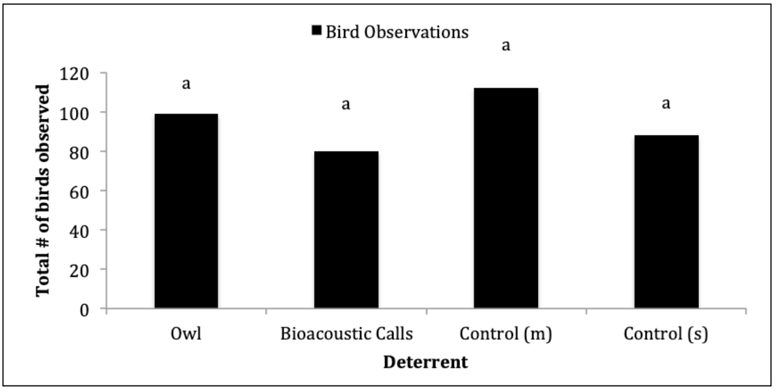

Fig 2 **Effect of deterrent type on the total number of birds observed over 12 sampling events. Differences were tested for significance using a one-way ANOVA, followed by a Tukey's test. Bars with same letters represent data that were not significantly different at the P<0.05 level. Values represent total bird abundance so error bars not included.**

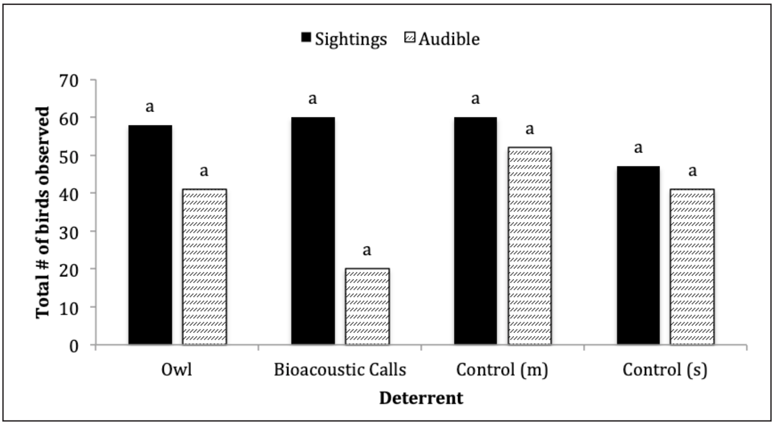

Fig 3 **Effect of deterrent type on the total number of birds observed flying (black bars) and the number only heard calling (horizontally-stippled bars) over 12 sampling events. Differences were tested for significance using a one-way ANOVA, followed by a Tukey's test. Bars with same letters represent data that were not significantly different at the P<0.05 level. Values represent total bird abundance, so error bars not included.**

were not statistically significant (F=2.37, P = 0.12, Fig 3). Abundance of birds observed at each turbine were significantly different, with turbine two showing the highest abundance (F=5.13, p=0.01, Fig 4).

Although this effect was controlled for, low bird abundance was noted on most monitoring days and, with only 12 monitoring days in

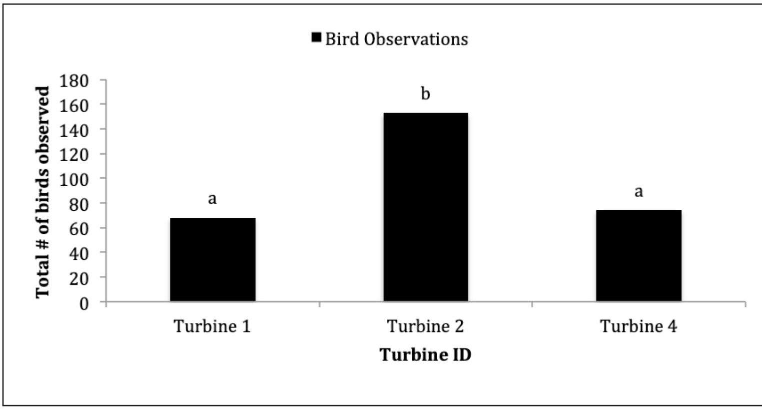

Fig 4 Effect of turbine location on the total number of birds observed over 12 sampling events. Differences were tested for significance using a one-way ANOVA, followed by a Tukey's test. Bars of the same letter represent data that are not significantly different, and bars with different letters represent data that differ significantly at the $P<0.05$ level.

Table 2 Total bird observations for each deterrent on each day for the study period.

	Total Bird Counts for Each Deterrent				
Date	**Owl**	**Predator Call**	**Control (m)**	**Control (s)**	**Total Daily**
Aug-22	18	3	3	1	25
Aug-24	8	4	7	6	25
Aug-26	2	0	2	3	7
Aug-29	1	4	4	5	14
Aug-31	4	8	14	5	31
Sep-02	9	5	23	8	45
Sep-05	19	6	14	9	48
Sep-07	17	15	13	13	58
Sep-09	4	4	4	6	18
12-Sep	6	26	8	16	56
14-Sep	3	0	9	11	23
16-Sep	8	5	11	5	29
Total	99	80	112	88	379
Average	8.25	6.67	9.33	7.33	31.58
Standard Error	1.84	2.09	1.75	1.24	4.77

the study, even one day with high abundance at a deterrent had the potential to skew the data. Total daily observations for each trial are presented in Table 2.

However, though abundance at turbine two was observed to be higher, when bioacoustics calls were played, the abundance of birds

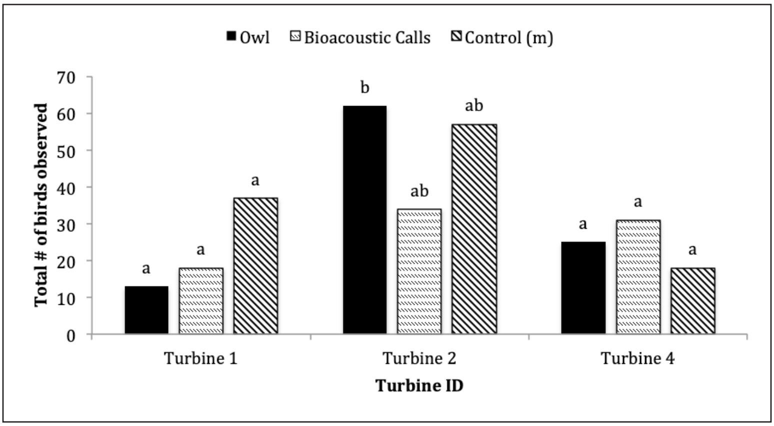

Fig 5 **Effects of each deterrent type at each of three turbine locations over 12 sampling events. Black columns represent the total number of birds observed with the owl deterrent, horizontally-stippled columns represent total birds observed with the predator call deterrent, and diagonally-stippled columns represent total birds observed with no deterrent (control). Differences were tested for significance using a one-way ANOVA, followed by a Tukey's test. Bars of the same letter represent data that are not significantly different, and bars with different letters represent data that differ significantly at the P<0.05 level.**

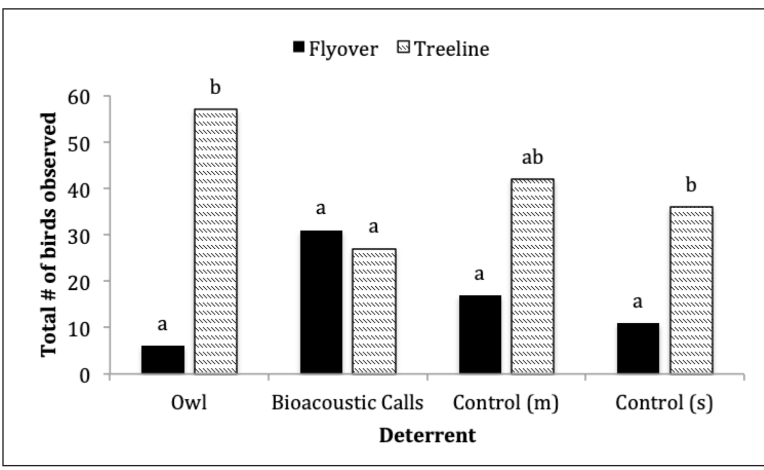

Fig 6 **Effect of deterrent type on flight paths taken by birds, over 12 sampling events. Filled columns represent the total number of birds that flew directly over the turbine base, and hatched columns represent total number of birds that stayed among the tree-line. Differences were tested for significance using a one-way ANOVA, followed by a Tukey's test. Bars of the same letter represent data that are not significantly different, and bars with different letters represent data that differ significantly at the P<0.05 level.**

at turbine two was lower than other trials at this turbine (Fig 5). Significantly more birds stayed among the tree-line than flew over the turbine pad when only the owl was present (F=9.57, P=0.005, Fig 6). The rotating control also had a similar effect of reduced numbers, but the difference was not significant (F=1.9, P=0.18). The numbers of birds observed in the tree-line and over the open turbine pad were not significantly different, nor was an effect observed for bioacoustic calls (F=0.05, P=0.83, Fig 6).

DISCUSSION

Efficacy of Deterrents

The owl deterrent did not significantly deter birds from approaching the wind turbines, when present either on its own or with bioacoustic calls. However, some effects identified suggest that bioacoustic calls may have had some effect. More birds were observed flying compared to calling when bioacoustic calls were paired with an owl deterrent, contradicting other studies which found that passerine birds often gave alarm calls when hawks were present, at frequencies that made it difficult for hawks to locate the calling bird (Marler 1955; Klump 2000). However, alarm calls that were played in the background of the bioacoustic recording could have caused the fleeing effect. Fallow *et al*. (2013) found that all birds fled when a natural or synthetic call of a different species was played. Aerial alarm calls usually represent a flee call identifying a fast-moving threat that requires a prompt response (Bradbury and Vehrencamp 1998). It is possible that alarm calls in the bioacoustic playback caused nearby bird populations to flee or avoid the turbine area, rather than join in alarm-calling, as lower call rates and lower abundance with bioacoustic calls were observed at turbine two. Fallow *et al*. (2013) found a higher probability of birds fleeing when alarm calls were played at a frequency of 9 kHz, which is similar to the frequency of the alarm calls played in the background of predator calls on an audio track. As effects observed in this pilot study were inconclusive, further studies are required to determine whether model owls in combination with bioacoustic calls would be effective at deterring birds from flying over the wind turbine pad.

There was a significant difference in the abundance of birds observed at each turbine, with higher numbers recorded at turbine two. This could be a result of turbine two having the most diverse landscape, including a swamp, a managed reservoir and roadway, and was across from a water treatment facility.

Study Limitations and Future Research Directions

Statistical power was a limitation of this pilot study, but future deterrent monitoring should incorporate more replicates distributed across more turbine sites to allow for improved statistical comparison to determine the effectiveness of these mitigative measures.

Bird species targeted in this study differ from those in studies attempting to deter pest species (e.g. crows, starlings, grackles, gulls) (Conover and Perito 1981; Conover 1979; 1985). Most turbine mortality events impact nocturnally migrating songbirds (WEBBMD 2016), which may react differently than pest species. Therefore, future studies should also be designed to assess impacts on these species.

Implementing the visual and bioacoustic deterrents at several wind energy sites and over entire spring and fall post-construction monitoring periods would provide more data, with the potential to show some of the identified effects as significant. Future studies could also benefit from more effective technology. Although the StorMP3 speaker was easily heard at the level of the turbine pad, it is unknown whether it was always audible at the height of the turbine blades. Birds may be unable to hear playback calls at turbine height when combined with wind and turbine noise. Furthermore, testing different owl perching positions could offer insight into the effects of predator visibility on deterrent effectiveness. Placing the perched owl higher could increase the visibility of the predator to incoming birds as they approach the turbine pad.

During each trial, acoustic monitors also recorded night flight calls to determine differences in bird abundance through the night. However, the SongMeter3 acoustic monitors used could not clearly capture flight calls and could therefore, not be used for the remainder of the study. Even when calls may have been identified on the spectrogram, differentiating it from whistles from the wind or blade was not possible.

Wind developers face similar and larger-scale challenges when implementing mitigation measures and consistently-effective mitigation measures are still to be identified. Many studies found conflicting results, mainly because the effectiveness of mitigation measures is usually species-specific (Conover 1985; Boag and Lewin 1980; Rensel and Wilder 2012).

May *et al*. (2015) suggest implementing measures that are specific to each site and to the bird species present, as different species often react differently near turbines. Relevant data could be gathered during baseline pre-construction data surveys. Although baseline studies must be conducted, further monitoring is needed once mitigation measures are implemented to determine their effectiveness, requiring additional resources. Due to the large investment of resources required to monitor site and species factors, as well as post-implementation monitoring, wind developers would likely prefer to implement measures that are known to be effective. However, effective measures at wind turbine sites are not certain and few studies have conducted research at wind turbines (e.g. Haugan 2014; Laufer Wind Group 2016; Young *et al*. 2003), while many measures are reliant on labratory testing (e.g. Avery *et al*. 1996; Hodos 2003; Poot *et al*. 2008; Long *et al*. 2011).

It is difficult to determine whether measures are effective if actual mortality rates are unknown, due to insufficient data available in the WEBBMD, particularly from the Atlantic region (Parisé and Walker 2017). It is widely reported that mortality rates at wind turbines are underestimated, contributing to a lack of complete understanding of interactions between birds and wind turbines (e.g. Erickson *et al*. 2005; Bernardino *et al*. 2013; Marques *et al*. 2014; Huso and Dalthorp 2014). Parisé and Walker (2017) suggested recently that developers should submit mortality data to WEBBMD for a better understanding of bird mortality rates in Nova Scotia. This could be a regulatory requirement, as these data would help developers make more-informed decisions, by understanding the mortality rates in relation to species, location, geography, number of turbines, and layout of farms.

Further challenges in determining effective measures relate to public acceptance. Communities often have concerns related to sight and sound of turbines and may perceive changing turbine structures negatively. Additionally, noise from operating turbines is often controversial, and implementing audio deterrents may pose additional challenges to turbine acceptance. The bioacoustics approach considered here may blend with natural background sounds. However, other audible avian harassment sources, such as the use of air cannon techniques, may not be well-reviewed by the public.

CONCLUSION

Wind energy is one of the fastest-growing renewable sources of electricity globally, as a clean alternative to fossil fuels. Though beneficial at reducing greenhouse gas emissions, wind turbines are known to cause avian and bat mortality through collisions. Current practice uses strategic planning, such as effective siting and lighting, and an understanding of bird behavior to reduce bird collision rates. However, there is a lack of confidence in the effectiveness of active mitigation measures, such as bird scaring, due to inconsistent monitoring protocols and reporting. With additional research and testing of deterrents and mitigation measures, effective measures may be identified to help reduce environmental harm from the growing wind industry.

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TITUS SMITH JR. AND THE UNITY OF NATURE: ENVIRONMENTAL ADVOCACY IN EARLY 19TH CENTURY NOVA SCOTIA

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The only known portrait of Titus Smith, Jr., circa 1840. The attribution to Maria Morris suggests that she painted it while they were collaborating on the first part of the *Wildflowers of Nova Scotia* published in 1839. Smith holds eyeglasses in his left hand. Although listed in Norman Creighton's estate inventory at the time of his death in 1995, the present whereabouts of the painting is unknown.

ABSTRACT

As scientists try to understand and predict the global consequences of climate change, the early environmental advocacy of Titus Smith Jr. (1768-1850) seems more relevant than ever. Smith's concept that industrial capitalism was disrupting the interlocking associations between humans and nature represented an alternate narrative that characterised the first wave of 19th century environmentalism in Nova Scotia. A study of Smith also enhances our knowledge about the beginnings of preservationist thinking and the environmental movement just prior to the era when science was not yet specialized and a single mind like Smith's could move between disciplines allowing each to inform the other.

Keywords: Titus Smith; ecological succession; environmental advocacy

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INTRODUCTION

The life of Titus Smith Jr. bridged the end of the Enlightenment, the Romantic Era, and the beginnings of the Victorian Age. In the year Smith was born, Captain James Cook left on HMS *Endeavour* for his first voyage to the South Seas launching what Richard Holmes calls the "Age of Wonder," which ended with Charles Darwin's homecoming on HMS *Beagle* in 1836. Commonly regarded as the greatest ever voyage of exploration, the Admiralty ordered Cook to record the Transit of Venus across the face of the sun from Tahiti on 13 April 1769, and to search for the mythical Southern Continent (Gascoigne 2014). While Cook added to the map of the world with detailed surveys of coastal Australia and New Zealand, Joseph Banks, Daniel Parkinson, and other "scientists" (Wootton 2015) packed the storage holds, cabins, and the deck of the *Endeavour* with collections of exotic creatures, plants, and the art of never before encountered human societies. After his return, Banks had a display in his London apartment creating the first museum of Pacific culture combining, in a new way, natural history with human artifacts (Holmes 2009). Darwin would also return from his five-year circumnavigation of the globe with the key insights that underpinned 'natural selection' that became the most controversial theory of the Victorian Age. It changed the way humans saw themselves and their place in the world when he finally published *On the Origin of Species* in 1859.

Between these two celebrated voyages, European discoveries were shrinking the globe and creating new forms of knowledge as, for example, other expeditions led by Alexander von Humboldt to Spanish America from 1799 to 1804, and by Meriwether Lewis and William Clark across the whole of the North American continent between 1804-1806. They disclosed, to an ever-fascinated public, knowledge about wondrous lands, peoples, and bizarre life forms. Eventually, the natural and human-made curiosities collected on these various expeditions, which often indulged the pleasures of the wealthy, and turned room-sized collections into some of the first public museums.

This time was also the age of a new breed of experimentalists who shunned the rigid mathematical world and the mechanistic clockwork universe associated with Newton, Locke, Hooke, and Descartes, giving way to the notion of an infinite and mysterious natural realm waiting to reveal her secrets. The rise of geology and other earth sciences challenged the Christian stranglehold on creation that postulated that the earth and its organisms originated by divine fiat, with humans coming last, until a worldwide flood destroyed almost everything. Startling fossil discoveries, such as the first skeleton of a mammoth shown in the autumn of 1802 by the young American artist Rembrandt Peale at London's Pall Mall (O'Connor 2007), gave tantalizing glimpses of an earth history far older than the literal six-day event recounted in Genesis.

Inspired by discoveries in chemistry and astronomy, the Romantic revolution in science emerged with an imaginative intensity driven by an almost reckless desire to discover the dynamic laws, invisible powers, and cyclical transformations beneath the surface of the living world. This was immortalized, for example, in paintings by Joseph Wright of Derby (1734-1797). In his famous 1766 candlelit scene of "A Philosopher Lecturing on the Orrery," a student dutifully takes notes while two young children joyfully watch the mechanical motion of the planets around the sun. By contrast, Wright's 1768 "An Experiment on a Bird in an Air Pump" is immediate and disturbing. Here not only two young girls, but others watching the experiment, are clearly upset at the sight of the bird, in this case an exotic white cockatoo, convulsing and eventually dying in agony as the air is exhausted from the glass chamber.

While these types of paintings projected a sense of wonder and curiosity about the natural world, especially when confronting the mysteries of untamed nature, they also revealed a darker, more sinister side of science lurking in the Romantic ideal of the brooding genius. As Richard Holmes points out, this is one of the crucial conceptions—or misconceptions—of Romantic science. It was centered around the intuitively inspired moment of discovery that many writers and painters celebrated as either benefiting humankind, or like Mary Shelley, branded as a reckless Faustian idea. (Holmes 2009). Mary Shelley (1797-1851), the controversial muse of the "Age of Wonder," condemned the failure of science to save humankind that crystalized the Romantic conflict between sense and sensibility. In *Frankenstein or the Modern Prometheus* published in 1818 when Mary was only 19, she merged science and fiction to forge a modern creation myth. Frankenstein evoked a scientific theology with man, not God, at life's epicenter.

The point here is that Smith too was a Romantic explorer and experimenter in search of knowledge about the natural world who was admired for his breadth of learning and a formidable memory that allowed him to recall the smallest of details. He packed his life with incessant work and believed that knowledge had to be shared, exchanged, and made available to everyone. However, Smith was also a man of diverse interests. His early life in Nova Scotia was defined by his government sponsored provincial surveys in 1801-1802 for Lieutenant Governor Wentworth to inventory natural resources (Field 2013). However, in the last decades of his life Smith employed his unremittingly natural theology to counter the two emerging giants of the 19th century— capitalism and industrialization—with an alternate environmental narrative. In many respects, Smith's life is a Janus-faced lens that looks two ways at once—back to the origins of the environmental movement—and forward to all those current environmental advocates who echo Smith's preservationist efforts in calling for the conservation and stewardship of nature. They called for conservation and the stewardship of nature. Becoming a fierce opponent of industrial capitalism that exploited nature for profit, Smith was an early naturalist who envisioned the human and natural realms as integrated halves of a single whole. He saw the world as an expression of God's design. For Smith, God was not a separating agent between humanity and nature, but a unifying authority. The primal forces of creation offered an image of both division and connection, a divine bridge between natural and human. Smith, therefore, saw human need and purpose linked to nature. For him, the natural world and an environmental consciousness conditioned human well-being and sustainability.

SMITH IN AMERICA

Titus Jr., was the first child of Reverend Titus Smith and Damaris Nash nee Waite, whom Smith married while he was serving as a pastor in a small church in West Suffield, Connecticut. The younger Titus was born in Granby, Massachusetts on 4 September 1768, one month after Cook departed from Plymouth, England. By age three, Titus exhibited the intellectual powers of eidetic memory often attributed to child prodigies. By age four, the pastor's young son was an adept reader. Even today, such gifted children often receive early education like the young Smith. He was given accelerated enrolment into a private school at New Haven run by Daniel Humphreys, a fellow Yale alumnus of his father (Piers 1938). Here the classic curriculum and disciplined environment sparked the boy's intellectual and imaginative powers. Titus was proficient in Latin by age seven; translating the classics at age 12. By 16, when his father presented his son with a gift of the complete plays of Shakespeare, the teenager apparently not only read the Bard's dramas in one sitting, but thereafter could recite entire scenes.

In the Smith household, intellectual life flourished in the humanist tradition. Reading aloud was proper conduct to instruct children and benefit people unable to learn in other settings. Beyond these practical benefits, recitation was also a mark of civility and cultivated taste that enhanced the mental culture of refined households (Bushman 1993). The young Titus recited Greek and Latin verse, languages also familiar to his three siblings: Rebecca, born in 1771, Sylvester in 1773, and William in 1777. Years later, his brother William told how Titus relished the discourse that inevitably erupted on political, philosophical, and religious subjects when well-read neighbours visited the house. He also remarked that "his earliest desire appeared to be to perfect himself" (Lawson 1972), an aspiration clearly noticeable in Titus' personality.

With the beginning of colonial hostilities against England, the elder Smith's decision to remain loyal to the crown and reaffirm his conscientious objection to violence initiated a period of turmoil for his family. Although Titus sympathized with the rebellious colonies seeking independence, not even an appeal from George Washington to supply gunpowder to his troops changed his views (Lawson 1972). In 1775, after refusing Washington's request, Smith signed a petition outlining Sandemanian religious convictions against any form of opposition to the King's government. Forced to leave New Haven, Titus and his family took refuge with other Loyalists inside the British lines at Bushwick, one of the original six towns comprising Brooklyn, New York, and chartered in 1661. It was here in August 1779, in her 42nd year, that his wife Damaris fell ill and died.

Having four children between the ages of two and 11, Titus quickly married Lydia Barstow, whom Smith was undoubtedly acquainted with as a member of the Sandemanian church. Intermarriage among followers was common. His father's support of the King also led to his sons removal from Humphrey's School in New Haven, and permanently closed the possibility of his entering Yale in his father's footsteps. The 11-year-old's education, that now fell to his father and other knowledgeable adults, apparently did not pause or waver. By his next birthday, Titus was translating the Latin authors and progressing in Greek (Piers 1938). In 1783, Titus and his family departed the newly formed American nation. In the company of his old friend Theophilus Chamberlain, the British evacuated the Loyalists from New York to Nova Scotia. There seven years earlier the Sandemanians among the Boston Loyalist refugees had established a church in Halifax located on the north side of Prince Street between Barrington and Granville. Smith Senior presided as an elder along with John Howe, the father of the reformer Joseph Howe (Beck 1982, Stayner 1951).

By the time the 15-year-old Titus landed on the shores of Nova Scotia, he had witnessed momentous civil and political unrest that fundamentally changed the course of history. Thus, as a teenager, Smith saw the impact of these formative events and learned about civil disobedience and political dissent from his father. These influences emerged later in life when he publically expressed unpopular views about class struggle, materialism, and industrial capitalism.

SMITH IN HALIFAX, PRESTON, AND DUTCH VILLAGE

To a viewer standing on the deck of a ship entering Chebucto Harbour in 1783, three features dominated the Halifax skyline—the wind-whipped pennants flying from the towering signal masts of Citadel Hill, the spire of St. Mathers, and the steeple of St Paul's Anglican Church. These structures symbolized the ability of the Admiralty and Board of Trade and Plantations to project into the wilderness of Nova Scotia a settlement that validated British control over territory granted under the terms of the 1713 Treaty of Utrecht. Although British colonies were not exact replicas of English towns, or of each other, a familiar set of laws, political institutions, and religious belief inextricably linked them to Britain. These institutional faculties were supported by a replicated set of recognizable material traditions and served as the defining backdrop to Britain's imperial ventures, each working harmoniously, to make the world England.

Halifax, once part of a powerfully evocative projection of a far-flung British Empire founded to help secure Britain's destiny in North America, was not a particularly inviting place when the Smiths, their friend Theophilus Chamberlain, and other Loyalists arrived from New York on board the transport *Nancy* in 1783. Many Loyalists, who thought they were going to another Boston, Philadelphia, or New York, albeit smaller in scale, were sorely disappointed at the condition of the colony. For most, however, their dismay was not pressing, owing to the impoverished state in which many found themselves. In a letter written 20 November 1783, Governor Parr wrote, "upwards of 25,000 Loyalists have already arrived in the Province, most of whom, with the exception of those who went to Shelburne, came to Halifax…" (Akins 1973). This sudden influx increased the population of the town by three times. "Typically, the refugees were poor, desperate, and increasingly disillusioned with the prospects facing them in towns such as Halifax" (Fingard, Guildford, and Sutherland 1999). Much of the housing in Halifax dated from its founding, many had low-gabled roofs with dark interiors dominated by massive fireplaces to ward off winter wind and cold. The streets were crowded, food scarce, and crime prevalent. Arriving with few personal belongings, the once productive, respected families, and individuals fell into despair and poverty with only idleness to occupy their days and nights. Although there were enterprising Loyalists who built refined and commodious dwellings by 1791, many moved elsewhere in the Province or returned to England.

The Smiths' were no exception. Within a year of their arrival, they moved to the Township of Preston where 162 Loyalists received lots after Theophilus Chamberlain mapped it in 1784 as deputy surveyor under Charles Morris. The Township contained 56,772 acres with 32,000 acres granted to the Loyalists and the remaining part was reserved for future use. In 1791, Lieutenant John Clarkson, one of the central figures in the abolition of slavery in England and the British Empire at the close of the 18th century, arrived from London. His aim was to help remove black settlers to Sierra Leone. Clarkson, who visited the Smith farm on 12 October, made an entry in his diary about his stopover. He called the elder Smith an "honest gardener," and "excellent botanist," and commented that he used part of his garden for botanical experiments, and that Smith showed him some of the maple trees he had "refined" (Lawson, 1972).

Experimental gardens, like the one first established by the Smiths at Preston, were essential to meet the demands of local gardeners for the vegetable and flowers seeds that would thrive in Nova Scotia's soil and climate. When the Smiths moved to Dutch Village in 1796, father and son continued their Preston efforts to produce viable varieties of vegetable and fruits. By 1830, through advertisements, Titus Jr. made available to farmers, gardeners, and overseas correspondents local seeds of the most common vegetables, along with collections of Nova Scotia's indigenous plants. In a letter written at Windsor on 9 April 1839, the unidentified correspondent asks Smith to send to Three Mile House via Mr. Jordon, the mail coachman, "roots of the Indian plant, called blood root, the potato plant from Newfoundland, and the other blue snap-dragon" (PANS). In another letter from Windsor dated 26 August 1839, Thomas King requests that Smith send to a friend in Europe "all the forest seeds of our trees & shrubs" (PANS). It is unknown if Smith filled Mr. King's large request. Smith also introduced into his own garden, and those of friends, indigenous plants he collected on his journeys. Piers states that as early as 1822, Smith planted a large variety of native trees on his grandfather's property that included Red baneberry (*Actaea rubra*), white Bloodroot (*Sanguinaria canadensis*), and American Spikenard (Piers, 1938).

Titus Smith Jr. continued the long tradition of botanical exchanges between North America and Britain by acting as an agent to supply indigenous and acclimatized plants, and local seeds from Nova Scotia to botanical enthusiasts in England and Scotland. The earliest correspondence dated 30 May 1825 from Mr. Charles Manley thanks Titus for the box of plants forwarded to him by Mr. Franklin (Norman Creighton Fonds). Manley notes several of the specimens took root and thrived considering the season was against them and adds that he would appreciate Smith resending him the plants that perished. Manley also requested that Smith send him some new species and enclosed a list of Latin and common names for over 50 plants, trees, and shrubs including: Mountain Pine, *Diervilla*, Winterberry, *Ilex*, *Pinus nigra*, *Viburnum*, and *Aralia racemosa*.

Smith also exchanged seeds and plant specimens with the Scottish botanist Robert Graham (Norman Creighton Fonds). In a letter dated Edinburgh 29 March 1839, Graham thanks Smith for his sizable contribution of dried plant specimens for his Herbarium. Graham sent Smith a new edition of Persoon`s *Synopsis plantarum,* first published in two volumes between 1805 and 1807. Graham was an M.D. and a botanist appointed in 1820 as the first professor of Botany at Edinburgh University. Although Graham published a number of botanical papers, his *Flora of Great Britain* remained incomplete at the time of his death in 1845. However, he did successfully develop the Edinburgh Botanical Garden, which may be the reason he contacted Smith to obtain plant specimens for both his garden and Herbarium.

Experimental gardens, botanical correspondence, travel narratives, and shipments of seeds and plant specimens all characterized the mediums of exchange between colonial North America and Britain. There was an ever-demanding and curious public seeking knowledge about the natural history of the Atlantic World, which Susan Scott Parrish suggests led to the very birth of modern curiosity itself (Parrish 2006). These interactions helped to establish the reputation of colonial correspondents such as Smith within London's natural and philosophical circles that saw his lecture on "The Natural History of Nova Scotia" published in 1835 in London's *The Magazine of Natural History*.

Two events prompted the elder Smith to sell his Preston farm and move to Dutch Village in 1796. First, all of the elder Smith's children except Titus returned to Connecticut and secondly, over 500 "Maroons," arrived from Jamaica to work on the Halifax fortification. Their arrival in July of that year caused discontent between Governor Wentworth and Colonel W. D. Quarrel of Jamaica who was in charge of the Maroons. Smith Sr. seemingly took advantage of the planned purchase of land in Preston for their settlement and sold much of his Preston farm to Colonel Quarrell on 17 August 1796. Less than two months later, on 22 October, Smith purchased from Martin Wagner a small house, farm, and woodland of 50 acres in Dutch Village. This was originally, lot number 1, granted to Frederick Kohl in 1763. Wagner and Kohl were part of the group of German farmers who wanted to return to Halifax after moving to Lunenburg in 1753, and who successfully petitioned the government for land that stretched along the western slope of Chebucto Basin (now Bedford Basis). On 8 April 1763, The government granted lots of 150 acres to nine settlers, with three more lots added in 1765. In 1768, about fifty Germans had settled in what became Dutch Village (Bell 1961). The farm and gardens purchased by his father would become Titus Jr.'s private retreat from the public world; a place where he conducted his naturalist activities, departed from for his provincial journeys, and where he continued his agricultural trials after his father's death in 1807. Dutch Village was, until his death in 1850, Smith's place of solitude, experiment, and research where he developed his ideas about environmentalism, and manufactured the impressive body of knowledge that earned him the famous title of "the Rural Philosopher of Dutch Village" from Joseph Howe in 1828.

SMITH AND THE HALIFAX MECHANICS' INSTITUTE

The proposal to establish a Mechanics' Institute, put forth as early as 1827 by the editors of "The Colonial Patriot," the "Novascotian," and the "Acadian Recorder," was intended to educate the populace and prepare artisans and journeymen for the uncertainties posed by industrialization through public instruction in the mechanical and applied sciences (Fergusson 1960). When Joseph Howe rose to deliver his inaugural address to the members of the newly formed Halifax Mechanics' Institute on Wednesday evening, 11 January 1832 he stated, "In forming this Institute, its members were not unmindful …how much the body-politic might be facilitated or retarded by the intelligence or ignorance of the handicraftsmen" (Howe 1832).

On 5 March 1834, Smith presented the first of two lectures before the Halifax Mechanics' Institute where for the first time he outlined his ideas about recurring changes in nature. In the first talk on "Mineralogy," he told his audience that the earth's landscapes formed from a sequence of previous landscapes. "From all I have observed, I am compelled to believe that we have no proof that any mass of rocks have existed in this province in its present state since creation. I believe that we have fertile lands formed from materials which were once rock; that we have masses of rock which were once earth; that there have been changes within the rocks as well as on the surface; and that these changes will continue till they are brought to a conclusion by the last great change" (Smith 1834).

Smith's observations about these recurring changes in the landscape were aligned with early 19th century principles of "natural theology," particularly the views expressed by William Paley (1743-1805) in his bestselling *Natural Theology: or, Evidences of the Existence and Attributes of the Deity, collected from the Appearances of Nature* first published in 1809. Paley's suggestion that divinely appointed forces guided the growth of bodies and the formation of matter did not undermine the idea of secondary changes that occurred in nature over time from first cause (Genesis) to final cause (Revelations).

Less than one year later on the evening of 14 January 1835, Smith presented to the members of the Halifax Mechanics' Institute his second and most important lecture. Titled "The Natural History of Nova Scotia," it was subsequently published in the December issue of London's *The Magazine of Natural History,* as "Conclusions on the results of the Vegetation of Nova Scotia and on vegetation in general, and on man in general, of certain Natural and Artificial Causes deemed to actuate and Affect them." This lecture seemingly comprised two opposite concepts that were in fact, for Smith, halves of the same whole. The first outlined Smith's Theory of Ecological Succession that Evile Gorham, who resurrected Smith's theory in 1955, appraised as one of the first major contributions to plant ecology in North America (Gorham, 1955). The second questioned the wisdom of a society abandoning its agrarian economy for one built around machines and mechanization. Smith objected not only to the sense of power conveyed by machines of industry over nature, but also to the creation of a working class dependent on others for their livelihood and not on the products of their own labours.

As if to assure his audience that God was still at the helm of his ideas, Smith began his lecture before his Institute audience on that January evening by conjuring the God of Creation. "For, rough and rude as our forests appear, they form a portion of the 'garden of God.' In all their various productions, there is nothing superfluous or out of place" (Smith, 1835). In doing so, Smith was reaffirming for his listeners the hierarchical structure of the Great Chain of Being (*scala naturae*), derived by the Medieval Christian church from the classical thought of Plato and Aristotle. They ranked all life from its primal elements to God. Smith knew from his own observations, however, that the interrelationships between species in nature were much more complex. Beginning during his provincial surveys, Smith began to notice that disruptions of ecological communities caused by natural or human events resulted in new associations between species within a given ecosystem. Nature was not, as thought, a divinely passive hierarchical system, but a world where living organisms influenced one another in surprising ways, which Smith revealed to his audience in meticulous detail by explaining that within any ecosystem every species has a set of environmental conditions under which they will thrive and reproduce most optimally.

What mostly concerned Smith, however, was secondary ecological succession caused by human harvesting, colonization, and industrialization that violently and unnaturally disrupted the balanced composition of ecological communities. For Smith, this was the point. Machines gave humans, as the dominant species, unchecked power over any ecosystem to harness nature as an industrial resource. The consequence of this union between "man and machine" was not only causing social and environmental imbalances but also humanity's abandonment of their role as stewards of nature. Smith also understood that generating an environmental discourse over resource exploitation could not take place without debate about capitalism and industrialization. Thus Smith ended his lecture with a series of searing comments. It was as if Smith finally had had enough. Clearly vexed, he publically judged those responsible. ["A] constantly increasing evil is to be found in habits of unbounded luxury and extravagance, which have turned the labour of multitudes from producing the necessities of life, to furnishing articles of luxury for a few very rich individuals" (Smith 1835). Smith further stated, "In every part of Europe manufactories appear to be increasing. The business is overdone; markets cannot be found sufficient to absorb the immense quantities of goods. The motive appears to be found in the great fortunes that some capitalists have acquired" (Smith 1835).

Smith pressed on with remarks that clearly foreground modern concerns about the increasing inability of the planet to feed the world's population. "There is a general complaint of the great and increasing distress of a superabundant population, who cannot find employment by which they can support themselves. This distress has reached such a height…that opposite parties are predicting a *bellum servile*, or war of the servants against the masters; and it has seriously been proposed to enact laws to prevent a portion of the labouring class from marrying…who seem to fear that [the earth] may fail to produce sufficient food for its inhabitants" (Smith 1835). This view reflects Thomas Malthus' famous treatise *An Essay on the Principle of Population* first published in 1798, where he stated that unchecked population growth increases in a geometrical ratio while the power of the earth to produce subsistence increases only arithmetically. Prophetically, Smith concludes his remarks by stating, "The necessities of life are drawn principally from the culture of the earth. Money, or what we call wealth, is the power of commanding this labour, but this power is not always wisely applied. From habit, men sometimes continue the business, which formally was profitable" (Smith 1835). For Smith, the idea that machines and mechanization would foster human progress and lead to greater happiness and improvements in society was an illusion. Smith chose instead to infuse his remarks with a sense of dismay at the loss of the dignity, freedom, and independence that comes from the products of one's own labour.

We will never know how Smith's views were received. Did he use his reputation as a naturalist and philosopher to present his irreverent ideas before an Institute audience he knew would include wealthy merchants and politicians, some of whom represented the pinnacle of 19th century Nova Scotian society? After all, his comments represented a deep defiance of established economic and political policies and drove forward his argument that ignoring our obligation as stewards of nature would have dire consequences, which he summarized. He summarized in one of his more famous statements near the end of his lecture: "Whenever man neglects the dictates of nature, he is sure to suffer" (Smith 1835).

Smith's final lecture to the Halifax Mechanics' Institute on "Painting" coincided with his collaboration with Maria Miller to produce the first Nova Scotia Florilegium. Although Smith would live for another 14 years, what distinguished the writings that emerged from this period centered on his continuing advocacy for agricultural improvement. This involved his work with the Central Board of Agriculture after becoming secretary in 1841, at age 72. In that capacity, Smith contributed weekly articles to *The Acadian Recorder* on farming practices until his death in 1850. As Terry Punch stated, his physical energy and intellectual abilities involved him in so many public activities they are difficult to recount. "He selected and planted the original rectangle of trees which surround Province House…wrote petitions, served as road overseer…was active in the Horticultural Society… gave evidence before the Durham Commission, and lectured at the Mechanics' Institute" (Punch 1978). All this while farming, surveying, experimenting with seeds, and raising fourteen children. Despite his success, however, Smith's contemporaries thought his life difficult.

Throughout his involvement with the Mechanics' Institute as well as the Halifax Scientific and Literary Society, Smith clearly supported the education of the populace and democratic notions about a people's science. For Smith, it seems only useful knowledge, not profit, material gain, or inherited privileges supplied an individual and a nation with true power. On 13 February 1836, the *Acadian Recorder* reprinted Smith's lecture on "Education" read before the Institute on 11 February clearly outlining his egalitarian attitude toward education, the working class, and a nation's prosperity. "If all the inhabitants of a country were taught reading, writing, and the first rules of arithmetic, and then permitted access to books containing nearly all the useful knowledge which man has acquired, they must necessarily be more prosperous than the inhabitants of a country possessing equal advantages of nature, but closing the sources of knowledge to the greater part of its population" (Smith 1836a).

It is interesting that Smith equates knowledge with the power to make great nations, citing England and America as examples, but only if the "greatest portion of useful knowledge is…made most accessible to all" (Smith 1836a). In other comments, that reflect his own self-education, he shuns college-based learning. "But if all are taught to read and works containing the most useful knowledge placed within their reach, they who are qualified by nature…will, without other assistance, acquire more knowledge than the majority of those who are sent to colleges" (Smith 1836a). Later he states that the poor who have access to the power of knowledge in libraries, and are gifted with superior natural abilities, can acquire as much information about art and science as they would have done in college. These comments are indeed surprising coming from a man who was educated in the humanist tradition and who mastered Greek and Latin at a young age. That is, until one considers the fact that his father's opposition to the American Revolution and loyalty to the Crown lost his son the opportunity to attend Yale. As a result, all of his life Smith carried the label of being "self-taught."

What made Smith so different from his provincial counterparts was his fluid mind and an interdisciplinary approach that informed his ability to grasp the importance of humanity's interconnectedness to nature. This is one reason why Smith objected so passionately to the exploitation of people and the natural world for profit. Believing that industrial development and capitalism turned the environment into a site of conflict between mind and nature that led to the oppression of a nation's people, Smith also advocated for universal education particularly for the poor. He also encouraged the purchase, growing, and manufacture of local products rather than relying on imported manufactured goods.

"We are, during our long winters at Halifax, burthened [sic] with a great number of poor people, able and willing to work at any rate of wages, but who can find no employment. Yet we purchase palmetto hats from our neighbours, instead of importing the leaves and making them, as they do—we use a great number of nets, but ought to import the hemp only, and make them here. We lack heads in proportion to our hands…." (Smith 1836a).

Smith hoped that the goals of the Institute to bring science to the people, would succeed beyond the limits of Halifax, and spread a larger portion of useful knowledge through the province. Indeed, it did. Mechanic' Institutes established in other Nova Scotian towns from the mid-1830's included Sydney (1837), Antigonish (1840), Liverpool (1841), and Windsor and Dartmouth (1842). In Pictou, however, because of the early influence and work of Rev. Thomas McCulloch, a subscription library was founded in 1822, that like the Halifax Mechanics' Institute, fostered scientific pursuits through a variety of public lectures and demonstrations.

THE UNITY OF NATURE

Romanticism emerged from enlightenment rationalism with a desperate sense of alienation from nature. For the romantics, nature could only be understood by turning inward. English romantics such as Samuel Taylor Coleridge and American Transcendentalists such as Ralph Waldo Emerson declared that humankind had once been one with nature (Wulf 2015). While some romantic natural philosophers believed in the importance of close observation, classification, rigid measuring, and data collection, they also embraced individual perception and imagination as being equally important.

Here is the event horizon between the Age of Reason with its rigid model of predetermined cosmic order from which humanity cannot escape, and the Romantic Era that saw nature as the antithesis of a hierarchical society rooted in institutionalized practices of thought. No poet better epitomized this mystical relationship than William Wordsworth did. These Romantic sensibilities were part of a Wordsworthian tradition identified with individual consciousness and contemplation where nature provoked a state of imagination that led to a higher self-awareness. This is what Scott Hess calls the *ecology of authorship* associated with a radically profound, and highly personalized relationship with nature (Hess 2012). The ecology of authorship disconnected the individual from specific places and environments. Leisurely travelers experienced nature through detachment and sensual immersion, or as Scott Hess explains, "the ability to transcend [ones] own flesh and blood into a kind of disembodied aesthetic consciousness" (Hess 2012).

Smith's environmentalism, however, was a tangible, earth under the fingernails *ecology of community* where people experienced nature through connection and direct engagement with their local environment. While echoing Michael McGinnis's (1999) bioregional view that an ecology of community is a place where the environment is shared through participative human practices of localized material, political, and economic systems (Hess 2012), there was, however, an added dimension to Smith`s ecology of community. Humans needed to submit to God's authoritativeness by uniting communitarianism with humanities duty to protect the bounty of nature for the long-term welfare and survival of humankind.

What Smith sought was what Ralph Waldo Emerson called an "apocalypse of mind" (Walls 2009) that folded nature back into the mind of God as creator, and then into human consciousness as part of that creation. In many respects, Smith's views represented a form of pantheism that integrated the divine and humankind in nature. Smith constantly uses a language in his lectures and articles to impress upon his audience the importance of this link which was often dismissed because of its fundamental Christian overtones. However, one wonders if his comments were any different from those Romantic writers who similarly recognized in nature the majesty, power, and perfections of the creator?

Clearly, Smith's ideas about the interconnectedness of humans and nature, brushed against the grain of prevailing opinions. His views were neither brooding, dark, or reckless but imaginative and objective, grounded in two realities both bound by moral authority — one resided in God, the other in human consciousness. He understood that, as agents of free will, humans often chose to ignore what they knew was morally right and acted in opposition to natural and human law. In these instances, self-preservation often overrules acts of kindness and obligation to others resulting in antisocial behaviour towards those less fortunate. For Smith, the worst examples of this were profit-driven economic and political systems that increased the opportunities for individuals to forget themselves. Based on false notions of status, the power of moral example diminished as people turned from the products of their own soil and industry to a form of individuality which was marked by unrestrained acquisitiveness, driven by desires for material wealth and status.

The idea that the sacred pervaded all of nature also informed every aspect of Smith's life. There was a beautiful harmony to

Smith's world determined by "the Great Cutivator. His ecological advocacy was not only about connection but also about knowledge. Without knowledge, there was no understanding of humankind's sacred obligation to maintain the ecological integrity of the planet. In Smith's lecture on "Biology" to the Halifax Mechanics' Institute reprinted in the 20 February 1836 *Acadian Recorder*, he stated that humankind did not understand the workings of the natural world and its importance to the future of humanity. "The Operations of Life, the animating principles of all organized bodies, are perpetually before our eyes, yet there is nothing that we less understand" (Smith 1836b).

Importantly, Smith's ideas were not isolated from the mainstream environmental thought of his day. His concerns about the growing conflict between humans and nature paralleled the thinking of other naturalists during the 19th century. They deplored the tragic destruction of forests and the exploitation of natural resources to meet the demands of industry. One of those individuals was Alexander von Humboldt (1769-1859), who like Smith believed "to scar the face of nature is to scar the people it nourishes" (Walls 2009). For Humboldt, the external world and the internal world of feeling were inextricably linked (Wulf 2015). There is no evidence to indicate that Smith was familiar with Humboldt or his writings, although they were available in some of the newly established subscription libraries in Halifax. Humboldt's *Personal Narrative of Travels to the Equinoctial Regions of the New Continent, During the Years 1799-1804* published between 1814 and 1829 was listed in the 1831 catalogue of the Halifax Library to which Smith was a subscriber. The 1835 catalogue of books for the Cambridge Military (Garrison) Library also listed this book in their collection as well as Humboldt's extraordinary English edition of his two volume *Researches concerning the institutions and monuments of the ancient inhabitants of America: with descriptions & views of some of the most striking scenes in the Cordilleras* published in 1814.

Laura Dassow Walls sees Humboldt as standing at the head of today's ecological movement, established by such figures as Henry David Thoreau, George Perkins Marsh, and John Muir. "He succeeded in bringing into being a discourse, a way of speaking, about nature that we now call 'environmental': namely, a planetary interactive causal network operating across multiple scale levels, temporal and spatial, individual to social to natural, scientific to aesthetic to spiritual" (Walls, 2009). Humbolt was born one year after Smith in 1769. When in (1801-1802) Smith carried out his provincial surveys for Wentworth, Humboldt was already two years into his five-year expedition (1799-1804) to Spanish America. Both men also saw, during their lifetime, how nature was being remade by colonial imperialism, global capitalism, and the beginnings of the industrial revolution. Eventually what began as a dialogue about nature and humankind's relationship to it became in 1866 the science of ecology, a word first coined by Ernst Haeckel.

There are parallels in the thinking of both Smith and Humboldt. In particular, both men were concerned by deforestation caused by agricultural and industrial development. "Humboldt was the first to explain the fundamental functions of the forest for the ecosystem and climate: the trees' ability to store water and to enrich the atmosphere with moisture, their protection of the soil, and their cooling effect. He also talked about the impact of trees on the climate through their release of oxygen. Humboldt insisted that the effects of the human species' intervention were already 'incalculable,' and could become catastrophic if they continued to disturb the world so brutally" (Wulf 2015). As Gorham points out, Smith too was equally concerned about the destruction of trees and forests by human actions and by the fires necessary to clear the land for the increasing number of human inhabitants. (Gorham 1955).

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

There is little question that Smith attempted to create for the first time in Nova Scotia an environmental discourse about the relentless pace of industrial and agricultural progress. This was based on his belief that nature was not just a background for human development but essential to humanity's well-being. Such sentiments were clearly counter-intuitive to early 19th century ideas about humans dominating nature. Humankind, after all, was divinely destined to make the natural world better by civilizing the wilderness through cultivation and improvement to create orderly fields, cleared forests, neat villages, and productive landscapes. During Smith's lifetime, human progress depended on nature being "conquered," not defended.

CONCLUSION

With biodiversity in crisis everywhere, recovering Smith`s vision of a natural world that was no less than the collective phenomena of nature and humankind, where a violation in one recoiled in the other, deepens our knowledge about the history of early environmental advocacy in Nova Scotia. Smith's views on the environment are not old-fashioned— since everything for Smith was about connection. He clearly perceived in nature a deeper reality that for him represented the face of a higher truth. Without it, Smith saw the world adrift in soulless materialism. As Gorham claimed, Smith's science was truthful and founded on measurable observations and inductive reasoning. This also grounded his environmental and social thinking. Thus, when Smith mapped out his theory of ecological succession, he clearly implied that the process of adaptation and disruption also applied to human communities. Clearly, in his writings, Smith linked the human causes of ecological change—namely capitalism and industrialization— to the upheavals he witnessed in society. They were laying the groundwork for a society dominated by an evolving breed of entrepreneurs, industrialists, and financiers.

Smith knowingly participated in the practice of acquiring knowledge in which experiment, observation, and classification provided the basis for a holistic system of explanation that increasingly marked the shift to modern ways of looking at the world. For Smith, humans needed to listen to the voice of nature to ensure the survival of their community through commitment and interconnectedness. Communities stripped of this affiliation due to their excesses against nature or their extravagant reliance on worldly goods, whose ownership glorified the individual over the duties we owe to each other, were relegated to failure. Just as Smith forewarned, the specter of humankinds accumulated transgressions against nature haunt the twenty-first century (Doyle 2014). We are witnessing the complete collapse of ecosystems that go back thousands of years, as irrevocable economic and industrial consequences overwhelm the environmental integrity of the planet. Ironically, Smith's ideas about unity in diversity and the interconnectedness of all living things being critical to the survival of humans and nature, seem almost as radical today in the minds of some politicians and company CEO's as they were during his lifetime.

Smith, like his father suffered from a liver ailment, experienced an attack of "jaundice" in the fall of 1849. It is likely that father and son suffered not from Jaundice, that is caused by bile pigments accumulate in tissues, resulting in yellowing skin, but from Hemochromatosis. The latter is one of the most commonly inherited diseases in America among people of Western European descent. It is caused by an accumulation of iron in the liver. The symptoms include joint pain, fatigue, weight loss, abdominal pain, and a "bronzing" of the skin, the latter being the reason why in the nineteenth century this disease was often misdiagnosed as jaundice. Smith took more than the usual amount of exercise to ward off the condition and hide the symptoms from his family. Despite his efforts, and generally strong constitution his liver failed.

Titus Smith Jr. died at the age of 81 on January 4, 1850, on the anniversary of his marriage to his beloved Sarah 47 years earlier. He was interred in a small family burying-ground overlooking Bedford Basin, where his father, stepmother, and some of the early Dutch Village German settlers were also allowed to bury their dead. Sometime after 1866, someone erected a six-and-a-half-foot grey granite obelisk simply carved with his name, the date of his death, and his age.

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IN SEARCH OF A CLIMATE CHANGE SIGNAL IN NOVA SCOTIA: THE ALEXANDER MACKAY DATA, 1901-1923

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ABSTRACT

Our objective in this work is to model First Appearance Time (FAT) of flowering in five species of plants in Nova Scotia, Canada, as a function of climatic variables (such as temperatures) and geographical factors (such as latitude). Dr. Alexander H. MacKay was the superintendent of public schools in Nova Scotia from 1891-1926. Beginning in 1896 MacKay instructed all the school teachers of Nova Scotia to have their students collect data on the first appearances of numerous plants, animals, and seasonal events, and then summarized the data himself. The summaries of the phenological data collected in this massive citizen science project were then published in the *Proceedings of the Nova Scotian Institute of Science* in a consistent fashion over the period 1901-1923. We analyze five species from the summary MacKay data for Nova Scotia, producing a model for First Appearance Time of flowering for each, as a function of latitude, longitude, mean monthly temperatures for many months, and sea ice off the coast of Newfoundland in winter months. Our model produces good agreement between predicted FATs and those FATs we find in the literature.

Key Words: 1901-1923, Alexander MacKay, First Appearance Time (FAT), flowering, latitude, longitude, mean monthly temperatures, Nova Scotia, sea ice.

INTRODUCTION

"Seasonal timing of biological events, phenology, is one of the strongest bio-indicators of climate change." (CaraDonna *et al.* 2014) Our purpose is to use phenological data collected and summarized by Dr. Alexander MacKay to model First Arrival Time (FAT) of flowering of several species of plants in the early 1900s in Nova

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Scotia. Having obtained a model, we use it to predict a change in FAT based on climatic variables (e.g. temperatures, sea ice), suggesting that a consequence of climate change is phenological change, and allowing us to guess how further changes in climate will affect the phenology of these flowering species of plants. We also use our model to compare our predictions to data and models on FATs from the late 20th century and early 21st century. Studies showing signs of changes in the four seasons in response to climatic change are becoming quite common (Garbary 2018; Santor, et al. 2018); this is our contribution.

This paper is certainly an homage to Dr. Alexander MacKay, to whom we are indebted for our data. He was a beloved member of the Nova Scotian Academy of Sciences and a brilliant scientist in his own right. Appointed Superintendent of Education for Nova Scotia on November 4th, 1891, he retired nearly 35 years later, on July 31st, 1926. He left an indelible mark on Nova Scotia's public educational system. "Under his able administration not only the [Pictou] Academy, but the whole province, was coordinated into one efficient system of education, in imitation of Ontario and American models." (Wood 1994) "Under Principal MacKay's strong administration the Academy made rapid strides. It became celebrated throughout the province and far beyond its limits. Students flocked in from all quarters until there was not room enough to receive." (MacPhie 1914) Perhaps MacKay's disposition had something to do with his popularity: "Only once did I hear him speak with unwonted warmth or perhaps anger, and that was when an educated man seemingly tried to demonstrate to a large audience that the world might be flat!" (Piers 1930) We include a photograph of MacKay (Fig 1), a photo favored by Harry Piers, author of MacKay's "scientific obituary" (ibid).

MacKay himself described the history of the phenological work in Canada, and presented the state of affairs in 1897, when the contributions of his students began to appear in the summaries:

> *In 1890, Section IV of the Royal Society of Canada passed the following resolution: 'That the various Natural History and Scientific Societies affiliated with the Royal Society be requested by it to obtain accurate records in their individual localities of meteorological phenomena, dates of the first appearance of birds, of the leafing and flowering of certain plants, and of any events of scientific interest for collation and publication in the Transactions of the Society.'... By 1897 the idea was extensively*

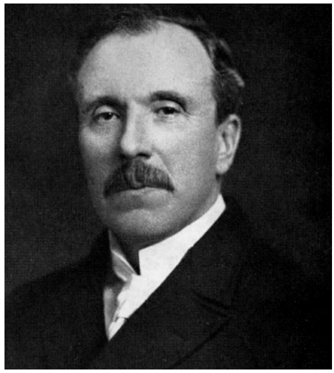

Fig 1 This photograph, chosen by the author of MacKay's "scientific obituary" (Henry Piers), is one personally sent to him with MacKay's handwritten inscription ("Yours very truly").

> *taken up in the public Schools of the province of Nova Scotia, the pupils of a whole school section or district being the observers, under the direction and criticism of the teacher. The observations were a part of the prescribed 'Nature Studies' in all schools, although the recording of them in the Phenological Records of the locality and the sending of a duplicate of the observations to the Inspector to be transmitted to the Education Office, were entirely voluntary. While the schedule of the Botanical Club had a list of about sixty objects for the observation of their first occurrence each season, the schedule of the public schools had over one hundred objects on its list, with instructions and a column for the observation of (1) the first occurrence and (2) when each began to be common. Over two hundred fairly well filled schedules were sent in from as many localities throughout the province.* (MacKay 1902a)

MacKay gave us our marching orders from across the years:

> *...we may consider a phenological date to be a sort of mathematical function of variables, several of which are already being very systematically and accurately observed and recorded by the meteorological departments of most countries, such as the variations of temperature, of atmospheric pressure, sunshine, precipitation. Then there are local constants, such as latitude, elevation, slope, proximity of bodies of water, and character of the soil. All of these influences affect the phenological date,*

and conversely the date may be considered as a summation or integration of all these and other more or less unknown elements. (ibid, p. 76).

Note that MacKay mentions only latitude: we discover here that longitude is nearly as important. Otherwise, his suggestions are spot-on: if we had the information he suggests at our fingertips, we would include it. As it was, we used what was available.

His observations of discrepancies in phenochrons can be considered a second charge to us:

An interesting irregularity in the phenochrons of the different counties is shown in nearly every part of this table. Their order is not parallel in the different counties. Very often it is reversed. As the phenochrons are averages of ten observations, it cannot be laid altogether to the charge of defective observation. The rarity of certain species in certain counties, or in the districts in which the observations were made, tends to make the phenochron later, for the plants may be in flower several days before they may be met with. But the character of the soil, the elevation, the slope, etc., must have had some influence. And, then, may it not be possible that the same species may develop a tendency to an earlier or later maturing in different regions? These are questions that careful future observations may help to answer. (ibid, p. 81).

It is fascinating to hear his mature scientific voice in his concern for using averages to arrive at stable estimates; in his theorizing about the influence of low sampling, and environmental influences; and in proposing that he and his students would be laying the groundwork for future scientists.

MacKay presented his phenological study strategy in his 1901 report on the phenology of Nova Scotia (MacKay 1903):

I present herewith a summary of the phenological observations made in about 450 of the public schools of the Province of Nova Scotia, each county being represented by a greater or less proportion of observers.... The observers are specially directed to the determination of two dates (phenochrons) – one for the first appearance of the event (leafing, flowering, ripening of fruit, etc.), the other for the date when it may be said to be 'becoming common.'

For the years 1901 to 1923 (with the exception of 1910 for which we were unable to find the data), we found and digitized published summaries of the observations made by the public school children of Nova Scotia from the *Proceedings of the Nova Scotian Institute of Science*. The printed form the teachers and students used in individual schools was published in 1902 (MacKay 1902b), along with a report (ibid, pp. 58-63) on difficulties associated with compiling those regional reports of the raw data into Nova Scotian summaries in the case of 1901.

As for MacKay's scientific legacy, those who indexed the *Proceedings of the Nova Scotian Institute of Scienc*e report that "[t]he phenological data, collected over 31 years by Dr. A.H. MacKay, are a major contribution to Canadian science...." (Nova Scotian Institute of Science 1992, p. 150). MacKay collected data Canada-wide in the early reports, from a handful of observers across the Commonwealth. The value of his work was recognized in his own time: The President of the Nova Scotian Institute of Science said in his address of March 14, 1898 that MacKay's phenological observations "...may lead to some important generalizations regarding the relation of organized life to latitude and other climatic conditions." (MacKay 1899, p. ii) Note again the emphasis on latitude only – we will find that longitude is perhaps equally important.

Our primary objective here, however, is to prove the President correct in his assessment: MacKay's observations do lead to important generalizations regarding the relation of life to climate.

MATERIALS AND METHODS

Data collection and processing

The data were obtained from summaries of MacKay's phenological data published in the *Proceedings of the Nova Scotian Institute of Scienc*e (MacKay 1903), and every year thereafter until 1923, with the exception of 1910. We analyze five species from the summary data for Nova Scotia from the period 1901-1923, species chosen for special consideration by MacKay himself. After an initial cleaning we imputed missing values (using a method we describe), after which some regions were combined (described below). Once the data were deemed clean, we proceeded to the modeling step.

The original raw data were collected by school teachers of the more than 1400 schools which MacKay oversaw as superintendent of public schools in Nova Scotia. This was one of the earliest and largest citizen science projects ever created. Not every school participated every year, but MacKay strongly encouraged it, and for more than 25 years MacKay oversaw not just the collection, but also the analysis of the data. His summaries were published every year from 1901 to 1923 (with the exception of 1910); his summaries were based on the summaries of colleagues from each of the 9-11 regions of Nova Scotia (the number of these districts varied over time).

Descriptions of the difficulties encountered in the regional summarization and the process of data collection itself (including the forms the teachers used) were published in the Journal of Education (MacKay 1902c). MacKay and his collaborators were very concerned about accuracy, stating:

> *[C]are must be exercised in selecting schedules, the observations of which appear to have been carefully made, neglecting any which give reason for doubt, when selecting for summation on the form within. Great care must also be exercised in copying the figures and entering them, so that no slip may occur. Every entry must be checked. One slip may spoil the effect of all the accurate numbers entering into the summation. In like manner, great care has to be taken in adding and averaging the figures; and for this purpose every sum should be done twice in reverse order, so as to give absolute confidence in the accuracy of the work.* (MacKay 1903, p. 490).

While we had access to the school-level raw data (digitized by Fenech, et al. 2005) from the data publicly archived in ledgers in the Nova Scotia Museum of Natural History, Nova Scotia (Austen 2000), we chose to limit ourselves to the summary data published by MacKay. Clearly there were issues with the raw data which were thoroughly and carefully addressed by MacKay's regional compilers; and while we had access to over 100 variables featured on the summary reports, we chose a small subset to work with. MacKay and his collaborators also carefully chose a subset of the data, that being of good quality, and we know that they made a conscious culling of the data to avoid including data poorly or improperly collected, fabricated, or otherwise suspect:

> *The various points for consideration in choosing Schedules are a fair distribution of the Stations over the Belt, the number and accuracy of the observations, the sex and temperament of the observer, the neatness of the work, the method of stating dates*

and in some cases the Compiler's personal knowledge of the observer. (MacKay 1902c, p. 59).

The compilers of the data from each of the regions often gave informative (and sometimes amusing) examples of the trials and tribulations of data collection and reporting (ibid, pp. 60-63). By using the summary data, carefully scrutinized and cleaned by reliable colleagues of MacKay, we avoid some of the noise associated with the raw data. Nonetheless it is certain that we inherit some of the data problems of citizen science. Some interesting and/or amusing examples from individual compilers follow (many more can be found in that reference):

It would appear in many cases that the observer has given the date of his first seeing a plant instead of the actual date of its first appearances in a locality. Frequently the date 'when becoming common' is given the same as 'when first seen'. In such cases the former is probably the correct one.

- *One or two observations are obviously guesses. I strongly suspect that they were all filled out about the close of the term, possibly from memory or aided by the pupils.*
- *G. is very early with 55, 57, 60, in Musquodoboit Harbor, but as Rev. Mr. Rosborough is there and instructs the teachers often in Botany, I accept them.*
- *Unusually early dates are often given, based upon plants growing in exceptionally favourable situation.*

We ourselves found instances for which the "when common" date was earlier than the "first seen" date. We found other values which appeared to be outliers, perhaps of the sort described above (values occurring early for the wrong reasons – some teacher wanting to be first, or basing the date on a plant growing in exceptional circumstances). We managed to handle these problems with what we felt were reasonable strategies. For example, sometimes an outlying data value appeared suspiciously similar to a value in a column or row nearby (perhaps an error at the time of printing). In that case, we could use the averages (which were also frequently given) to check: if the data didn't give the proper average, we could assume that an error had been made in that suspicious position, and fix it.

Data Subsetting

In his 1901 report (MacKay 1903), MacKay presents a graphic (we'll call it "the 1901 graphic", Fig 2) of the first appearances of

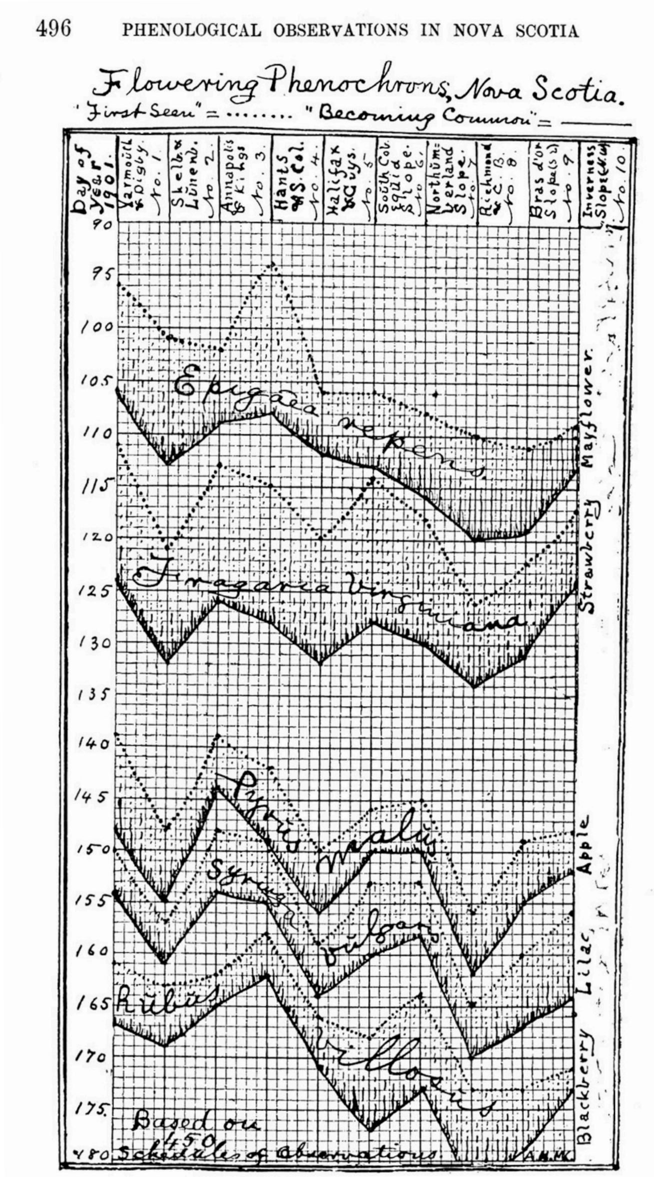

Fig 2 In his 1901 report (MacKay 1903), MacKay presents this graphic of the first appearances of mayflower, strawberry, apple, lilac, and blackberry (summary data rows 3, 13, 51, 57, and 30, as noted in the report (p. 495).

mayflower, strawberry, apple, lilac, and blackberry (summary data rows 3, 13, 51, 57, and 30, as noted in the report, p. 495). The report includes it along with this remark:

> *A plate of graphs showing the relation between the flowering phenochrons in each region of the province of Nova Scotia for the dates 'when first seen' and 'when becoming common' is given on page 496. 'When becoming common' must always be a matter of personal judgement; so that the general conformity of the five pairs of curves for the flowering of the Mayflower, Strawberry, Apple, Lilac, and Blackberry, on the said plate is very interesting.*

In the Report from 1900, MacKay noted:

> *...the curves for the three years are to a great extent conformable, which demonstrates the important effect of the position of each county. The variations from conformability, are probably due to the differences in the winds and sunshine.* (MacKay 1901).

This graphic was obtained from the summary data, a subset of 450 of the more than 500 data sets submitted by his many teachers that year. The regions are sorted by latitude: MacKay's evident supposition was that first appearances would come later the more northerly a locality. We wonder if he chose those variables because they spanned the season, and don't generally overlap – so that the distinction between each of the species will be (generally) clear. We haven't been able to find an explanation for his choice. However, given that MacKay felt that these five species are important enough to focus on, we too decided to focus on them. They are well-represented across the years (with minor exceptions). It may be that he suspected that they would show the most dramatic results, or that they were easiest for his students to identify (so were likely to be the most accurately represented). At any rate, the analyses in this paper pertain only to five species that MacKay chose for the 1901 graphic: mayflower, strawberry, apple, lilac, and blackberry.

Combining Regions

Another important problem that we confronted was that, over the years, some regions were split up, and others were joined together: MacKay's regions ("phenochrons" – Fig 3) varied over time. For example, some years combined regions 9 and 10 to create one data point. In other years, region 6 was split into two separate parts, 6A and 6B. These inconsistencies lead to problems when it comes to

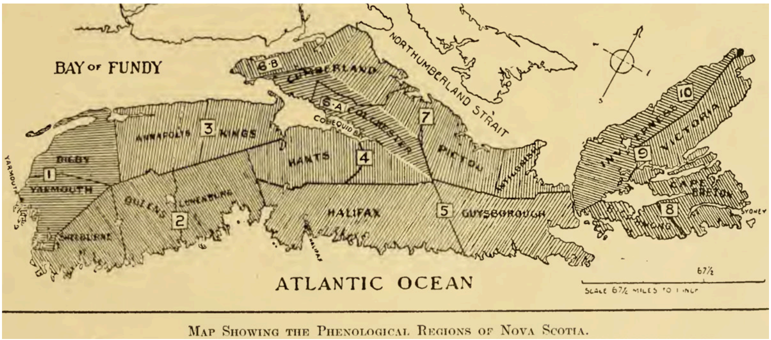

Fig 3 From the Phenology Report of 1909: "Each province may be divided into its main climatic slopes or regions which may often not be coterminous with the boundaries of counties. Slopes, especially those to the coast, should be subdivided into belts such as (a) the coast belt, (b) the low inland belt, and (c) the high inland belt."

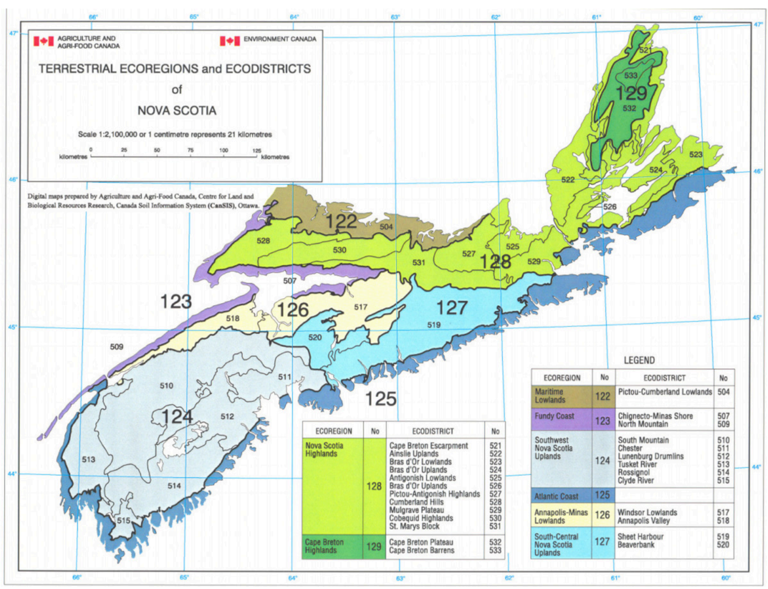

Fig 4 Map of the Terrestrial Ecosystems and Ecodistricts of Nova Scotia (Webb and Marshall 1999), obtained from http://sis.agr.gc.ca/cansis/publications/surveys/ns/nsee/index.html.

data analysis. We elected to create a standard set of nine regions to utilize for analysis. Regions 1-5 and 7-8 are identical to those created by MacKay. Region "6" is identical to MacKay's region 6 in most cases. Where there is a 6A and 6B in MacKay's original data set, our region "6" is a combination of 6A and 6B. In all cases, regions 9 and 10 were combined to create one region. In the cases where MacKay combined regions 9 and 10, this last region is identical to the original. The configuration of the final data set used is shown in Table 1, and we describe in that table how the regions were averaged together.

Modern day analysis (Webb and Marshall 1999) suggests that the ecosystems of Nova Scotia should look more like the subdivisions of Fig 4.

Data Imputation Using the Singular Value Decomposition (SVD)

The summary data we study consists of five species, reported in nine regions, over 23 years. We can think of each year's data as a matrix: five rows for the five species, and nine columns for the nine regions. Data from 1910 was "accidentally misplaced" (MacKay 1911), and MacKay's report from that time period is discouraging (MacKay 1909). It appeared for a time that the phenological reporting might cease; however, it recommenced in 1911, and continued unabated from then until 1923.

Missing or Corrupt Data in a Matrix

One small challenge was a dozen or so missing data values: several years were missing values for one or more species. For that, we required a method of imputation (estimation), and we chose a method based on the Singular Value Decomposition (SVD). A glance at the 1901 graphic strongly suggests that the five species' FATs are synchronized; they are in lockstep, to a certain degree. Clearly there is some underlying similarity in the graphics: as MacKay remarked, "...the general conformity of the five pairs of curves for the flowering of the Mayflower, Strawberry, Apple, Lilac, and Blackberry, on the said plate is very interesting." (MacKay 1903).

We suspect that the similarity is a consequence of species' relatively similar response to their geographical location (longitude and latitude). There is a certain one-dimensional commonality to their behavior, and the SVD is a good tool for identifying this one-dimensional commonality. In what follows we turn this idea on its head, however, and use the requirement of commonality to estimate the missing values using the SVD.

Table 1 This table lays out how regions were combined: 1) "Original" means that the new region is identical to the one created by MacKay. For 6A and 6B, it means that the regions were not originally split into two parts. For regions 9 and 10, this means that the regions were combined by MacKay, and were therefore not changed for the final data set. 2) In cases where we had to combine regions, the weighted ratios are given. 2a) If the ratio is "given," we were able to find the number of reports for each region and use that ratio to weight the data points. For example, in 1917, there were six reports from 6A and fifteen reports from 6B. Therefore, to create a region "6," A was weighted by six and B was weighted by fifteen. 2b) If the ratio is "estimated," there was no information given on the number of reports from each region. In order to create a ratio to use, we used the total ratio of reports from the years in which a ratio was given. For regions 6A and 6B, the ratio is combination of the years 1913-1919. For regions 9 and 10, the ratio is a combination of the years 1903, 1906, and 1918. In some cases, the data points given for regions were the same, so the regions ended up being given equal weight.

Year	Regions 6A and 6B	Regions 9 and 10
1901	Original	Weighted 14/27—estimated
1902	Original	Weighted 14/27—estimated
1903	Original	Weighted 4/12—given
1904	Original	Weighted 14/27—estimated
1905	Original	Weighted 14/27—estimated
1906	Original	Weighted 1/6—given
1907	Original	Original
1908	Original	Original
1909	Original	Original
1910		
1911	Original	Weighted 14/27—estimated
1912	Original	Original
1913	Original	Original
1914	Original	All same—weighted equally
1915	Original	Same except strawberry—weighted 14/27
1916	Original	Original
1917	Weighted 6A/15B--given	Original
1918	Weighted 5A/13B--given	Original
1919	Original	Original
1920	Weighted 3A/7B--estimated	Original
1921	Weighted 3A/7B--estimated	Original
1922	All same—equal weight	Original
1923	Weighted 3A/7B--estimated	Original

The SVD Theorem: Decomposing Matrices

Our strategy in this paper owes its starting point to a powerful tool in linear algebra – the Singular Value Decomposition (SVD) – and to strategies based on it and explored by one of the authors in his dissertation (Long, 1994) and in a subsequent publication (Long and Long, 2001). The latter publication introduced a strategy for interpolating (or estimating) a matrix that was described as "skinning the matrix, even though we are putting a skin on rather than taking one off." The authors emphasized the flexibility of their skinning scheme, which allowed for an unlimited number of different skins. Each choice of one-dimensional interpolators gives rise to a different skin, with characteristics derived from the one-dimensional interpolators. Long in his dissertation explored the generalization of the SVD to tensors. In this paper, we explore the generalization of the SVD to tensors, but "skin the tensor" as well. In particular, we take advantage of the flexibility of the interpolation scheme to explore one-dimensional linear regressors to create the skin for the tensor. One could then use the error bounds of the regressors to deduce error bounds for the tensor.

The Singular Value Decomposition theorem has been called "The Fundamental Theorem of Linear Algebra" by one of the masters of the subject (Strang 1993). It states that a real matrix can be decomposed into a product of orthogonal matrices and a diagonal matrix, $A = U\Lambda V^T$ where Λ is diagonal with positive entries $\lambda_1, \cdots, \lambda_n$; these are called the singular values, ordered from largest to smallest (with possible ties and zero values), and U and V are orthonormal (have columns mutually orthogonal and of unit length).

Another way of representing the "decomposition" is as a sum of outer products: this is the important representation of that we will focus on. The SVD says that

$$A = \lambda_1 \underline{u}_1 \underline{v}_1^T + \cdots + \lambda_m \underline{u}_m \underline{v}_m^T$$

where $\underline{u}_i$ *and* $\underline{v}_i$ the columns of U and V. The terms $\lambda_\kappa \underline{u}_\kappa \underline{v}_\kappa^T$ are the skeletons of the "skins" mentioned above. As before, we may "throw away" some of the outer-products (generally those corresponding to the smallest singular values) and write

$$A \approx A^* \equiv \lambda_1 \underline{u}_1 \underline{v}_1^\prime + \cdots + \lambda_k \underline{u}_k \underline{v}_k^\prime,$$

where $k<m$. We then model A with A^* (having removed what we construe as noise). A number of imputation methods are based on this SVD technique of ignoring the "noise" of all but the most important singular values (Arciniegas-Alarcon, et al. 2014). We use an imputation technique that fits into this class of algorithms. We choose missing values so that the first singular value λ_1 is as

large as possible relative to the other singular values. In particular, we maximize .

$$\frac{\lambda_1}{\sqrt{{\lambda_1}^2+\cdots+{\lambda_n}^2}}.$$

MODEL BUILDING

MacKay gave us some help in our modeling process. He was a thorough scientist, whose preliminary analysis and speculation provided us some direction (MacKay 1901). He speaks to the importance of altitude, the proximity to the Atlantic, to the general SW to NE trend, to differences in sampling patterns; concluding:

> *[t]he manner in which the other curves intersect each other have also their explanations. But we are not yet in a position to be able to state them.*
>
> *The general trend is seen in the later flowering as the counties lie north and east. There is a general conformity in this trend between the eight plants which fall into four groups, the Mayflower averaging 113.01 (24th April), the Dandelion and Strawberry 137 + (18th May), the Wild Cherry, Blueberry, Buttercup and Apple 154 + (4th June), and the Lilac 165 + (15th June).*
>
> *A general trend is also seen in passing from Guysboro in the east back to Cumberland in the west; although moving on the whole northward, the flowering becomes earlier. A similar change takes place in passing from Richmond to Cape Breton. This latter is more remarkable, for Cape Breton is not only north but also east of Richmond. This seems to suggest that the observers in Guysboro and particularly in Richmond, might not have been so keen in the search for the first flowering as those in Cumberland and Cape Breton. The small number of observers in these counties also suggests such a possibility. But by reference to the table, it will be seen, that as a rule, in counties where the observation stations are so numerous that ten could be selected from the coast, ten from the low inlands, and ten from the high inlands, the earliest flowering is on the low inlands, then on the coast, and latest on the highlands. It must be remembered, that there is a very great difference in the altitudes of what are called the low and high inlands in the different counties.*

From such considerations, it is proposed in future to divide the Province into meteorological districts and subdistricts, instead of counties – the subdistricts being the coast belt, low inland belt and highland belt of each district; each district including a simple meteorological region or geographic slope.

Among the peculiarities shown by these curves are, for instance, the lateness of the Strawberry as compared with the Dandelion in Shelburne, Queens and Guysboro; and its advanced appearance in Kings, Cumberland, Inverness and Victoria. Does the breath of the Atlantic retard the flowering of the Strawberry as compared with the Dandelion?

It also appears that the southern and sea surrounded Yarmouth is favorable to the early flowering of the Mayflower, but comparatively not so favorable to the Lilac. The manner in which the other curves intersect each other have also their explanations. But we are not yet in a position to be able to state them.

The stations of observations are, necessarily, not the same in each county each year. It is therefore possible that the phenochrons might be affected by a change in the relative number of coastal, inland and highland stations.

As all these observations are bound carefully into a large volume for each year, anyone having the time can use the facts recorded in any combination promising the most useful results. The present selection of ten plants, and the comparison of their flowering phenochrons in each county is merely a sort of preliminary or provisional testing of the possibilities and probably value of such observations – sufficient to interest the observers while they are developing accuracy – and a record of facts for future generalization.

....

In the meantime we can make no mistake in recording and preserving as many accurate local phenological facts as possible. In a few years we shall be better able to estimate their value for many purposes.

THE SINGULAR VALUE DECOMPOSITION (REPRISE)

Tilted Geographical Coordinates

The SVD is useful for separating out the three dimensions of our data tensor: the species, the region, and the year. At the outset we did an analysis of FAT of each species by region, year after year, as a function of latitude and longitude. As mentioned previously, we expected the latitudinal component to be significant, representing as it does the northerliness of a region. We were surprised to discover, however that as often as not longitude played a role. A glance at Fig 4 shows a couple of reasons for why this might be:

1. Longitude is a proxy for latitude: the further east one goes, the further north one goes. So the two measures are confounded.
2. Longitude represents how far the province juts out into the Atlantic Ocean. Ocean currents vary about Nova Scotia (Wu and Tang 2011), and there are several different major bodies of water that impact the province. Hence, longitude may play a more complex role.

However, the first of the two issues impelled us to try rotating the coordinates to align one along the major axis of Nova Scotia (thinking of it as an ellipsoid) and the other along the minor axis. These tilted longitude/latitude coordinates were then used for further modeling, and we found that we were far more likely to achieve significant results using them. Table 2 illustrates a case for which neither geographical coordinate was significant on its own, but for which the tilted coordinates produced a significant and useful model.

A Tensor Version of the SVD

A precise analogue for the SVD does not exist for the tensor case (Kolda and Bader 2009). However, we can directly extend one method for constructing the SVD to tensors, leading to the method we call the TSVD – Tensor SVD.

One method for constructing the SVD of $m \times n$ matrix A of rank r entails maximizing the scalar product

$$\underline{u}^T A \underline{v}$$

over all unit vectors $\underline{u}$ and $\underline{v}$. This will succeed because we are maximizing this product over a closed and bounded set (the cross-product of spheres in m and n dimensions, respectively).

Table 2 **This example regression illustrates a case for which neither geographical coordinate was significant on its own, but for which the tilted coordinates produced a significant and useful model. Tilted longitude is significant, as is the intercept term. The issue is that latitude, which we along with MacKay suspected would be the primary determinant of climate, is confounded by longitude. More northerly parts of Nova Scotia are more easterly, and vice versa.**

Parameter	**Estimate**	**Std. Error**	**t-value**	**Pr(>|t|))**
(Intercept)	55.568	291.197	0.191	0.855
Latitude	2.978	4.244	0.702	0.509
Longitude	1.365	1.699	0.804	0.452
Tilted Parameter	**Estimate**	**Std. Error**	**t-value**	**Pr(>|t|))**
(Intercept)	97.1914	2.4968	38.926	1.92e-08
Tilted Latitude	2.3314	4.5091	0.517	0.6236
Tilted Longitude	2.3017	0.7507	3.066	0.0221

Once we compute $\underline{u}_1$ and $\underline{v}_1$ for the maximum value λ_1 of $\underline{u}^T A \underline{v}$,

$$\lambda_1 = \underline{u}_1^T A \underline{v}_1$$

we remove that weighted outer-product

$$A_1 = A - \lambda_1 \underline{u}_1 \underline{v}_1^T$$

and then repeat the process on matrix A_1. We continue recursively removing these weighted outer-products where λ_κ is the maximum value of $\underline{u}^T A_{\kappa-1} \underline{v}$ over all possible vectors $\underline{u}$ and $\underline{v}$. Unit vectors $\underline{u}_\kappa$, $\underline{v}_\kappa$ are the ones that realize this maximum value

$$\lambda_k = \underline{u}_k^T A_{k-1} \underline{v}_k$$

Once we have found λ_κ, $\underline{u}_\kappa$, $\underline{v}_\kappa$, we use them to construct a lower rank matrix.

$$A_k = A_{k-1} - \lambda_k \underline{u}_k \underline{v}_k^T$$

Because each subtraction reduces the rank by one, eventually the resulting matrix is the zero matrix, so

$$A = \sum_{k=1}^{r} \lambda_k \underline{u}_k \underline{v}_k^T$$

This is just a different representation of the singular value decomposition theorem, in the form of a method.

We can carry out this same method in the more general tensor case. In our case we have a 3-tensor given by the three-dimensional data set of (*species, region, year*).

$$T = \sum_{k=1}^{16} \lambda_k \; \underline{s}_k \otimes \underline{r}_k \otimes \underline{y}_k$$

where the tensor product ⊗ is this same outer product. In the tensor case the value of *N* is not as well defined as in the matrix case, and there are other important distinctions between the decompositions in the tensor and matrix cases.

THE FINAL TENSOR MODEL

Having written our data tensor *T* as a sum of 16 such terms,

$$T = \sum_{k=1}^{16} \lambda_k \; \underline{s}_k \otimes \underline{r}_k \otimes \underline{y}_k$$

we proceeded to model the different dimensions (species, region, year) in three different ways.

The species vectors were left as is: we didn't do any modelling for those. Our efforts were focused on the other two dimensions, region and time. We used linear regression to model the regions vectors as functions of tilted longitude and latitude (*tlong* and *tlat*), whereas the time series (year) vectors were modelled as functions of climate variables (notably average monthly temperatures up to a year prior to flowering, and sea ice off the coast of Newfoundland).

Whereas the climate variables were included only linearly, we allowed quadratic terms for the region model (*tlat* and *tlong* variables). We assumed that we might have coastal effects: and since the *tlat* and *tlong* coordinates run along the "major axis" and "minor axis" of Nova Scotia, we felt that a linear model would not be appropriate – a planar model of FATs across Nova Scotia – but a parabolic model would allow for one value along the coasts on opposite sides of the "heights of Nova Scotia", and a different value for the heights themselves. Fig 5 shows how one quadratic model appears in the province.

Having modelled both these two dimensions, we arrive at a model of that we represent schematically as

$$\underline{T}_a(tlong, tlat, climate) = \sum_{k=1}^{16} \lambda_{i(j)} \underline{s}_{i(j)} r_{i(j)}(tlong, tlat) y_{i(j)}(climate)$$

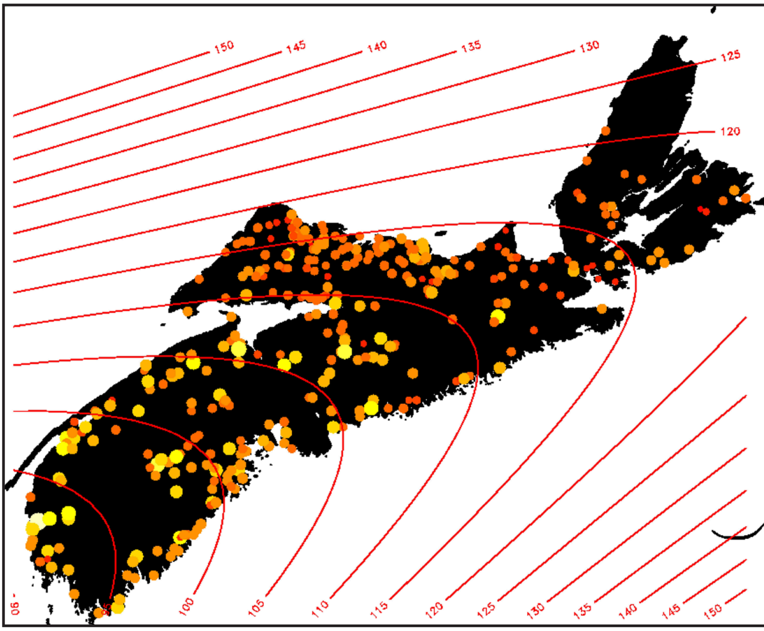

Fig 5 **This illustrates our projections of First Arrival Time for Mayflower for the year 1901. Numbers represent day since beginning of the year. One can see the advantage of the quadratic FAT model over a linear model: the isoFATs bend over the highlands of Nova Scotia and wrap from coast to coast.**

where time is embedded in the climate variables. Details of the modeling procedure are provided in an appendix.

RESULTS

Because we now have a continuous model of species as a function of location and time, our model can be used to forecast FATs for any year for which we have the same climate data, at any location.

How the Model Performs

Model predictions for the FATs of the original data are given in the succession of small multiples shown in Fig 6. The data and model fits are available for visual comparison for all five species across all 23 years.

As one can plainly see, some species are better reconstructed generally than others. For example, it is clear that mayflower is better reconstructed than blackberry, as a rule. That being said, in

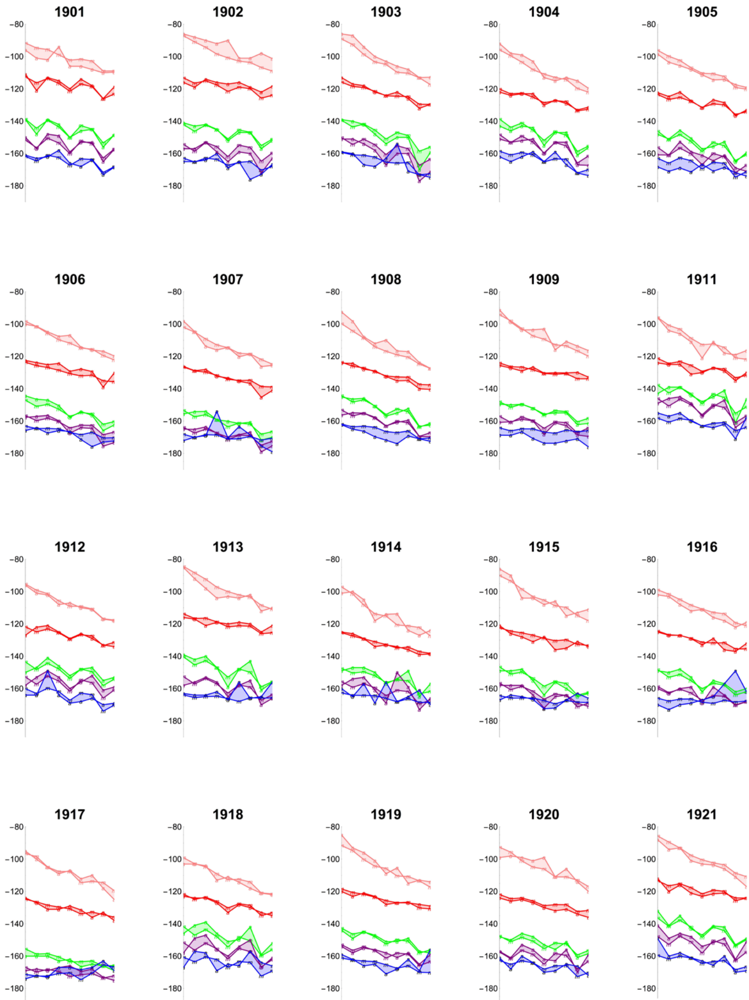

Fig 6 **Model results (comparison with data) for the FATs from 1901-1923. We use Tufte's "small multiples" (Tufte 2004) to help us gauge the effectiveness of our model over the entire span of the data.**

some years, blackberry may be better predicted than mayflower, etc. Average error in a species prediction, by region, is a reasonable "diagnostic" to provide for using model predictions in the future. The average error across the entire data set is 2.7 days.

Year, region, and species means of absolute errors across the years are given in Tables 3, 4, and 5. As one can see, strawberry is best reconstructed, and blackberry worst. Among regions, all are roughly similar, although the combined regions (4 and 5 in the original data) have the largest mean absolute deviation: 3.11 days.

Comparison with Predictions of Others

A recent paper in the *Proceedings* (Hill and Garbary 2013) caught our eye, entitled "Early spring flowering in Nova Scotia: an extreme spring is reflected in advanced flowering". It features data on many species of flowering plants, but in particular it included recent data (2012) on two of our species: mayflower and strawberry. They provided coordinates for their search (latitude and longitude), so we were able to generate predictions of first flowering of those two species. Our predictions were within five days in each of the cases (see Table 6), and biased toward predicting earlier FATs, rather than later ones. Hill and Garbary note that "...since all of these records were based on opportunistic sampling across a wide geographic area (northern Cape Breton to the Annapolis Valley), we do not claim that the dates represent first flowering of the species." The implication is that the observed dates should be later than the actual FAT. For that reason,

Table 3 Error by region (in days).

Region	Average Error (Days)
Yarmouth and Digby	2.77
Shelburne, Queens, and Lunenburg	2.45
Annapolis and Kings	2.37
Hants and Colchester	2.44
Halifax and Guysboro	2.81
Cobequid Slope	2.76
Northumberland Straits Slope	2.71
Richmond and Cape Breton	2.75
Bras d'Or and Inverness Slopes	3.11

Table 4 Error by species (in days).

Species	Average Error (Days)
Mayflower	3.02
Strawberry	1.88
Apple	2.22
Lilac	2.67
Blackberry	3.64

Table 5 **Error by year (in days). 1918, 1914, 1922, 1903, and 1923 were the most poorly reconstructed. The run from 1904-1913 was fairly well reconstructed.**

Year	Average Error (Days)
1901	2.17
1902	3.04
1903	3.29
1904	2.17
1905	2.59
1906	2.50
1907	2.46
1908	2.08
1909	2.65
1911	2.69
1912	2.43
1913	2.64
1914	3.19
1915	2.59
1916	2.82
1917	2.30
1918	3.11
1919	2.34
1920	2.55
1921	2.50
1922	3.24
1923	3.76

Table 6 **Predictions against data (Hill and Garbary 2013), including predictions for 2012 (for which "temperatures for the late winter and spring of 2012 in Nova Scotia were considerably elevated relative to climate normal") and for the years adjacent to 2012. As one can see, our predictions suggest that 2012 was, indeed, anomalous, and that flowering should have occurred about six days earlier due to the warmer temperatures.**

Location	Species	2012 Prediction	2012 Observation	2011 Prediction	2013 Prediction
Antigonish	Mayflower	April 10	April 15	April 16	April 17
Antigonish	Strawberry	April 25	April 28	May 1	May 2
Annapolis	Strawberry	April 17	April 16	April 21	April 23

the bias in our results towards earlier dates (in Antigonish, at least) is encouraging.

A publication referenced in the Hill and Garbary paper, entitled "Spring-flowering herbaceous plant species of the deciduous forests of eastern Canada and 20th century climate warming" (Houle 2007) performed regressions of flowering times of 18 different plants from eastern Canada, from 1900 to 2000. "...Results show a 2-6 days advance in flowering date over 100 years, depending on the region considered (corresponding to a 2-3 days advance per 1°C); these values are somewhat lower than those published in other studies, but still support the increasing body of literature on the effects of climate warming on plant phenology."

We highlight the predictions of Houle's work, which are in exact accord with our own conclusions: 2-6 days advance per century (Figs 7 & 8). He proceeded by regressing on data; we proceeded by regressing on model predictions. Although we used different species, our general agreement is satisfying.

DISCUSSION

We have produced a model that predicts First Appearance Times (FATs) of flowering of five plant species, in Nova Scotia, Canada. The model is a function of average monthly temperatures and winter/spring ice coverage in Newfoundland.

The model was generated by fitting a tensor model to the tensor of data with three dimensions: species, region of Nova Scotia, and year, with five species, nine regions, and 22 years of data. The data were first cleaned and a few values imputed using a technique based on the Singular Value Decomposition (SVD).

The data tensor was decomposed into a sum of rank-one tensors, each of which is an outer-product of three vectors (one in each dimension – species, region, and year). For each rank-one tensor, a model was constructed using linear regression on two of the dimensions: region and year. The region model was a function of longitude and latitude; the year model was a function of average monthly temperatures and winter/spring ice coverage in Newfoundland. The rank-one tensors were then replaced with a vector of five functions, each of which represented one species. When summed in the same fashion as the rank-one tensor decomposition, we produced a set of five functions, each of which predicts FAT based on these geographic and climatic variables.

CONCLUSIONS

Our models as shown in Figs 7 and 8 suggest that climate change over the past 100 years (increasing temperatures, in particular) are causing some plants to come into flower earlier (2-6 days earlier,

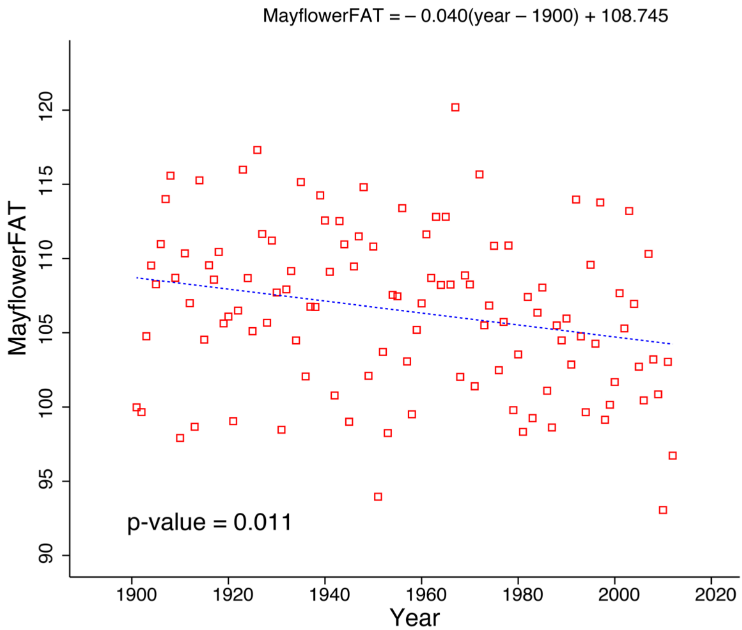

Fig 7 **Model projections for Mayflower for one hundred years, showing a significantly earlier flowering time (about 4 days/year).**

with all five plants that we studied showing a significant trend to earlier flowering).

FUTURE WORK

Moving forward, we will:

Use a simpler and faster alternative method of tensor decomposition than the one we used here, to see how results compare.

Add additional summary data from MacKay's published reports. In addition, we plan to add two species which overlap with the Hill and Garbary paper (Hill and Garbary 2013), and are well-represented in the MacKay data, to see if our predictions continue to hold up well.

Include comparisons of our model predictions with other data in the literature, including Plant-Watch data (Liette Vasseur 2001), and even MacKay's own data (we did not include his summaries prior to 1901, because they were not completely formulated in terms of his citizen science project prior to 1901).

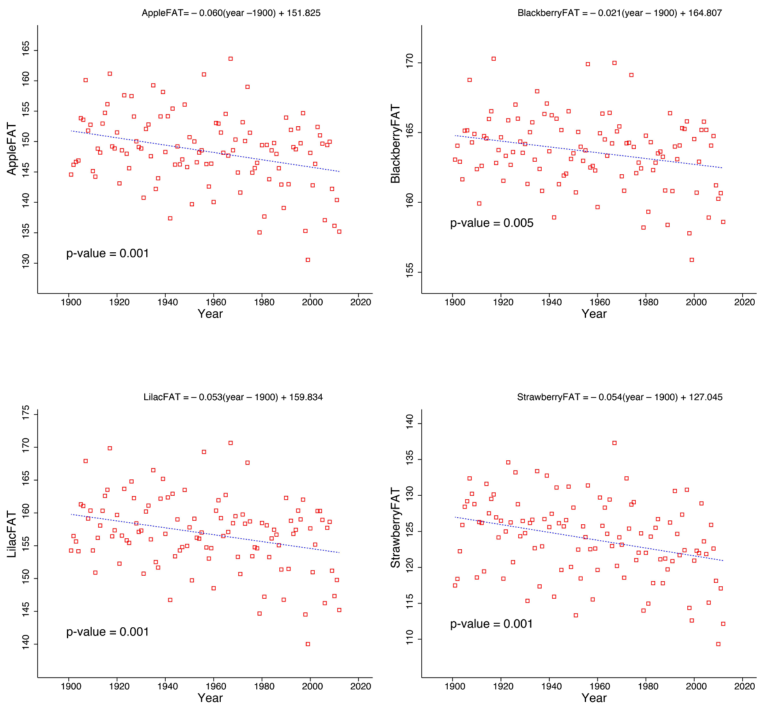

Fig 8 **The other four species also showed significantly earlier flowering over the 100 years.**

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APPENDIX A: DATA TREATMENT AND ANALYSIS DETAILS

MODEL DETAILS

1. We begin with the data tensor, which we can envision as a three-dimensional stack of first arrival times (FATs) for five species, nine regions, and 22 years.
2. From T we create the "anomaly tensor" T_a, by subtracting off from each year the mean matrix of the time series of the five species and nine regions (Table 7):

$$T_a = T - M_{5\times 9} \otimes \underline{1}_{22}$$

Table 7 The mean matrix *M*, of mean FATs of the time series of FATs for the five different species of plants over the nine regions (moving generally southwest to northeast, hence illustrating the general trend toward later flowering along that axis).

mayflower	strawberry	apple	lilac	blackberry
94.4	121.5	145.8	156.4	163.7
98.6	123.8	146.9	156.5	164.4
102.2	123.4	145.0	154.2	163.4
106.2	125.9	149.5	157.5	164.9
108.3	128.4	155.8	163.9	167.7
111.9	127.2	152.5	159.3	166.6
112.7	129.0	151.0	158.3	166.0
116.4	133.0	161.9	169.2	168.4
117.9	131.8	158.3	165.5	167.5

The matrix crossed with the one-vector of length 22 represents a tensor where each slice along the temporal dimension is the same – containing the mean FATs for each species in each region. Thus, T_α represents not FATs, but rather the difference in FAT from the mean FAT for that species in that region. As a consequence, the mean of each temporal column of anomaly tensor T_α is 0.

Our objective is to model *T* by modeling the anomaly tensor T_α and the matrix *M* separately: *M* as a function solely of latitude and longitude, and T_α as a function of latitude, longitude, and climate variables.

3. Latitude and longitude are "tilted" to align with the shape of Nova Scotia, which runs generally southwest to northeast (discussed in the text). So our regressions use "tlong" and "tlat", defined as

   tlong=cos(20) (*longitude*+65.8094)-sin(20)(*latitude*-41.1496)
   tlat=sin(20) (*longitude*+65.8094)+cos(20)(*latitude*-44.1496)

   The choice of a 20-degree tilt was made by visual examination; the centroid was simply chosen to lie within Nova Scotia, along what we perceived to be the major and minor axes.

4. To model *M* we first decompose *M* using the SVD, producing the usual rank five decomposition

$$M = U\Lambda V^T = \sum_{i=1}^{5} \lambda_i \, \underline{u}_i \otimes \underline{v}_i$$

   The $\underline{u}_i$ we may construe as species-related, and we do not model those; the $\underline{v}_i$ are region-related, and we model by regression on latitude, longitude, and their squares.

   The first three singular products contained $\underline{v}_i$ which produced a significant $p<.05$ model, whereas the last two did not. Therefore, the first three outer products only were used to create the vector function of latitude and longitude (a mean surface, or rather a set of five of them – one for each species). We give below an explicit representation of M as a vector model, composed of a sum of three pieces, each comprised of the product of a singular value weighting a dot product of two vectors, all of which scales the vector of species weights $\underline{u}_i$ on that outer-product pair:

$$\underline{M}(tlong, tlat)$$

$$= 967.6(-0.318 - 0.022tlat^2 + 0.00696tlat$$

$$- 0.00511tlong)\,\langle -0.334, -0.394, -0.471, -0.497, -0.514\rangle$$

$$+16.96(-0.571 - 0.0149tlat^2 + 0.379tlat$$

$$+ 0.251tlong)\,\langle 0.844, 0.0229, 0.0905, -0.148, -0.506\rangle$$

$$+7.064(0.0966 - 0.786tlat)\,\langle -0.314, -0.206, 0.506, 0.505, -0.590\rangle$$

5. The model for the anomaly tensor T_α is a little more complicated. We decomposed it, using the procedure described in the text, to obtain

$$T_\alpha = \sum_{i=1}^{16} \lambda_i \underline{s}_i \otimes \underline{r}_i \otimes \underline{y}_i$$

where $\underline{s}_i$, $\underline{r}_i$, and $\underline{y}_i$, are the i^{th} species, region, and year vectors, respectively. They are essentially singular vectors of a tensor version of the singular value decomposition.

We reduced our study to just the first sixteen products by considering only those outer-products that showed some dependence on climate or region variables. However, not all of the first sixteen showed dependence on both climate and region: twelve of the sixteen products produced models that were simultaneously significant for $\underline{r}_i$ and $\underline{y}_i$ (otherwise a particular outer-product in the sum is replaced by the 0 tensor, which is the null model – these were products 6, 9, 10, and 11 – ordered by their relative importance in the decomposition).

The vector model form FAT anomaly thus becomes a sum of twelve vector functions,

$$T_\alpha = \sum_{i=1}^{16} \lambda_i \; \underline{s}_i \otimes \underline{r}_i \otimes \underline{y}_i$$

where the models for region vectors (and their weights), obtained by linear regression, are given in Tables 8 and 9 below; the particular values of λ used are given in Table 10. Table 11 contains the weights on each outer-product by species. *i(j)* represents the j^{th} retained index skipping the four listed in Table 10 as insignificant. "Climate" is used here as shorthand, by which we mean temperature and sea ice extent values, which were obtained using relevant data from the years over which the FAT dates were collected. Temperature records were obtained from Environment Canada for Parrsboro, Halifax, Sydney, and Yarmouth, and then averaged to obtain an estimate for Nova Scotia generally. These locations had the longest records contemporaneous with our FAT data, with some few missing values. Newfoundland ice values were obtained from Brian T. Hill, formerly of Environment Canada, "an estimation of the sea ice extent in the winter months off the east coast of Newfoundland and over the Grand Banks." (Hill, personal communication)

6. In the end, then, the vector model for T (FAT itself, for the five species as a function of location and climate variables) is obtained simply as the sum of two length-five vector models:

$$\underline{T}(tlong, tlat, climate) = \underline{M}(tlong, tlat) + \underline{T}_{\alpha}(tlong, tlat, climate)$$

Table 8 Results of backward-stepwise regressions for the 12 significant region vector models. The model $r_{i(j)}$ *(tlong, tlat)* is obtained by taking the inner-product of the vector given by (1, *tlat,* tlong, *tlat*^{2}*, tlong2*) and the vector given by the coefficients listed below (missing coefficients are 0). Note the absence of any linear dependence on the square of the tilted latitude in the anomaly tensor (although the mean surface contains it as a predictor).

j	outer-product index *i(j)*	intercept	*tlat*	*tlong*	*tlat*^{2}	*tlong*^{2}
1	1	0.316	0.112			
2	2	0.331				
3	3	0.215				-0.0271
4	4	0.326		-0.131		
5	5	-0.0175				
6	7	-0.479		0.0687		
7	8	-0.114	0.759			
8	12	-0.0109				
9	13	0.0295				
10	14	0.114	-0.730			
11	15	0.503		-0.505		0.0734
12	16	-0.0230				

Table 9 **Results of backward-stepwise regressions for the 12 significant year vector models. July and September temperatures which occur in the models are for the year prior. The model $y_{i(j)}$ *(climate)* is determined by taking the inner-product of the two vectors indicated below, which creates a scalar function of the chosen climatic variables.**

Outer-product index			**Predictors** Coefficients				
1	*1* 0.751	*Apr Ice* 2.896E-7	*Jan Temp* 8.526E-3	*Mar Temp* –5.350E-2	*Apr Temp* –8.155E-2	*May Temp* –0.142	*Sep Temp* 4.461E-2
2			*1* –0.767	*Apr Temp* –0.102	*May Temp* 0.131		
3			*1* –0.757	*Mar Ice* –1.109E-6	*Apr Ice* 1.123E-6	*May Temp* 9.731E-2	
4	*1* 1.26	*Jan/Feb Ice* 1.517E-6	*Mar Ice* –1.883E-6	*Feb Temp* 1.290E-6	*Mar Temp* 9.865E-2	*Apr Temp* –0.111	*Jul Temp* –9.307E-2
5				*1* –1.86	*Jun Temp* 0.144		
7				*1* 0.401	*Jan/Feb Ice* –1.389E-6		
8	*1* –3.00	*Jan/Feb Ice* 9.872E-7	*Mar Ice* –2.212E-6	*Feb Temp* –8.615E-2	*Mar Temp* –5.168E-2	*Apr Temp* 7.938E-2	*Jul Temp* 0.152
12		*1* 2.10	*Apr Ice* 1.052E-6	*Jul Temp* –0.141			
13			*1* –1.33	*Jun Temp* 0.103			
14		*1* –0.189	*Jan Temp* –5.205E-2	*Mar Temp* 5.658E-2			
15		*1* 0.518	*Mar Temp* 7.20E-2	*Apr Temp* –0.117			
16			*1* –0.344	*Jan/Feb Ice* 1.191E-6			

Table 10 **Singular values, and those that we included based on their simultaneous dependence on both place and climate.**

Outer-product index	Singular Value	Used (Y/N)
1	124.419	Y
2	73.0337	Y
3	40.7310	Y
4	32.0933	Y
5	31.4943	Y
6	28.3814	N
7	26.9661	Y
8	26.5059	Y
9	20.8977	N
10	20.7605	N
11	18.4311	N
12	18.2133	Y
13	17.3022	Y
14	16.9779	Y
15	15.4649	Y
16	14.9188	Y

Table 11 **Species weights for each of the twelve outer-products used in the model. These might be studied to interpret the outer-product pairs biologically, as one would do in a factor analysis.**

mayflower	strawberry	apple	lilac	blackberry
0.482	0.492	0.526	0.459	0.195
0.667	0.300	-0.334	-0.504	-0.315
-6.301E-2	-0.113	-0.188	-0.284	-0.931
-0.440	-0.161	-0.647	-0.594	-9.621E-2
0.224	9.209E-2	-1.057E-2	-0.168	-0.955
-0.677	0.616	0.173	-0.172	-0.321
-0.520	-0.414	-0.348	-0.366	-0.550
0.440	0.123	0.236	0.184	-0.838
0.552	0.205	-0.267	-0.720	-0.252
-0.865	-9.634E-2	-0.125	0.476	2.309E-2
-0.817	-8.398E-2	0.537	0.194	-7.051E-3
-0.406	-0.424	-0.416	-0.471	-0.511

DATA MANIPULATION

- Implementations of our SVD imputation is available in three different programming languages—Mathematica, Python, and R: www.nku.edu/~wilkinson/links/MacKay/software/
- Our original data set of FATs of the five chosen species transcribed from the Proceedings, 1901-1923, is contained in this csv file of First Arrival Times: norsemathology.org/laura/DatesofArrival.csv
- Our final data set of FATs is (following cleaning, region combining, and data imputation) is contained in this csv file of First Arrival Times: norsemathology.org/laura/DatesofFAT.csv

ADDITIONAL CODE FOR REPLICATING RESULTS

- Mathematica file containing graphics of SVD factors: norsemathology.org/laura/SVDCoefficientsUpdate.nb

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BIODIVERSITY SURVEY METHOD FOR DETECTING SPECIES OF CONSERVATION CONCERN IN NOVA SCOTIA PROTECTED WILDERNESS AREAS AND NATURE RESERVES

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ABSTRACT

Biodiversity transect surveys have been undertaken in protected Wilderness Areas and Nature Reserves in Nova Scotia, Canada since 2002. They document plant communities as well as plant and animal species of conservation concern. The Protected Areas Branch wished to have an assessment of the value of these surveys. Fourteen years of sampling data in 80 Wilderness Areas and Nature Reserves were used to determine detectability, density and distribution of species of conservation concern. Two hundred and twenty-two occurrences of species of interest were recorded. Nine bird species and 19 plant and lichen species were recorded 2 or more times. Densities for bird species ranged from 0.023 individuals per km of transect (± 0.012) for the Boreal Chickadee to 0.727-km (± 0.007) for the Eastern Wood Pewee. Plants densities ranged from 0.02 individuals per km (± 0.01) for the Round-Leaved Orchid to 27.1 individuals per km (± 10.4) for the Bulblet Bladder Fern. Most of the species of conservation concern were rare with 66% being found only once. The method used for the current biodiversity transect surveys appears to be adequate for the more common species of conservation concern when a single protected area is examined. However, less than half the species analyzed had a 95% confidence of being detected within the mean sample length of the transect (4.5 km). All species analyzed were within the sample length when all protected areas were combined suggesting that the present methodology is more useful as a system wide survey rather than for individual protected areas. Twenty-eight of eighty-three species of conservation concern detected during the survey occurred frequently enough for density calculations. Methods that might increase the value of the surveys include grouping species, using species richness measures, using occupancy or accepting lower confidence intervals and confidence limits.

Keywords: biodiversity survey, species of conservation concern, species at risk, protected areas

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INTRODUCTION

The primary purpose of Wilderness Areas and Nature Reserves in Nova Scotia is the protection of biodiversity (Wilderness Areas Protection Act 1998, Special Places Act 1989). In some cases, this means protection of areas or habitats for species of conservation concern such as the Atlantic Coastal Plain Flora or Canada Lynx. The areas or reserves also protect rare or at risk ecosystems, e.g. old growth forest or rich floodplain forest (Cameron 2004). In both cases, specialized surveys are required to document the characteristics of the biodiversity which the area was intended to protect.

The largest area of Wilderness Areas and Nature Reserves, were established to protect biodiversity as a whole, including species, ecosystems and ecological processes. The protected areas program achieves this type of biodiversity protection through the protection of representative ecosystems in Natural Landscapes. The premise is that if a variety of ecosystems are captured, most of the biodiversity will be preserved (Cameron & Williams 2011).

Ecosystems that form the Natural Landscapes in Nova Scotia have been mapped using a Geographical Information System (GIS) that includes remotely sensed data (Cameron & Williams 2011). These data provide a low-resolution surrogate assessment of spatial distribution of biodiversity. To ensure that the remotely sensed data are capturing the predicted range of biodiversity, field surveys of all newly proposed protected areas are undertaken. The surveys were designed to be rapid, repeatable and scientifically rigorous.[1] The advantages of a basic field inventory are that it gives planners an indication that what is being proposed for protection actually occurs on the ground. It also serves as a check on the predictability of the remotely derived GIS data as well as a benchmark for measuring impacts such as climate change. It can also be a resource for planning recreational developments.

It is impractical to measure all biodiversity in a field survey and therefore the Protected Areas Branch chose to use plants and plant communities as surrogates to assess overall biodiversity. Transects which bisect the variety of mapped ecosystems are traversed and vegetation plots established to measure plant community composition and structure. In addition, any animal species of conservation

[1] Authorities for species are provided in the text only when they are not included in Appendix 1.

interest, heard or seen and any plant species of conservation concern seen while traversing the transects were also recorded. The primary purpose of recording such species is so that planners were aware of their presence when planning for developments. In addition, ecologists have a list of the species within surveyed protected areas. Since the transects are a stratified systematic sampling, they are statistically valid. The Protected Areas Branch wanted to know how well this sampling methodology captures species of conservation concern and whether this method could be used to calculate population density estimates with reasonable confidence intervals (CI).

METHODS

Field Sampling

Methods for plot selection were designed using the Ecological Society of America Guidelines "Describing Associations and Alliances of the U.S. National Vegetation Classification" (Jennings *et al*. 2004). Topographic features and dominant plant communities were identified in the area to be surveyed using Nova Scotia Environment GIS Ecosystem Classification (Cameron & Williams 2011). Transects were placed within each area such that it traversed the variety of topographical features and dominant plant communities of each landscape. The mean transect length was 4.5 km and it was navigated once. Plots measuring 20 m x 20 m were established along or near transects in areas that represented a relatively homogenous vegetation community. New plots were set out each time a different vegetation community was encountered. The presence and cover class of each plant species at 5 vertical layers (canopy, sub-canopy, shrub, herb, moss-lichen) was recorded in each plot following standards set out by the Ecological Society of America (Jennings *et al*. 2004).

Any plant species of conservation concern within 3 m of either side of the transect were recorded with a GPS location. Songs or calls heard and sightings of bird species of conservation concern were also recorded. The species of conservation concern that were recorded on transects were those listed by COSEWIC as endangered, threatened or of Special Concern as part of the federal Species at Risk Act, and those listed under the provincial Endangered Species Act as endangered, threatened or vulnerable. Furthermore, any species that is listed as S1, S2 or S3 by the Atlantic Canada Conservation Data Centre were recorded. This inventory did not include sightings of species of conservation concern seen while walking to or from the transect. The inventory also did not use information from specialized surveys undertaken by staff to examine, for example the Atlantic coastal plain flora or cyanolichens. Nomenclature for plants follows Brouillet et al. (2017). Nomenclature for birds follows American Ornithological Society Checklist latest supplement (Chesser et al. 2017).

Statistical Analysis

Fourteen years of transect data were used to determine the sample sizes needed for a 5% chance of type 2 error and 95% confidence intervals for density measures.

Green and Young (1993) suggested sample size given a chosen level of type 2 error can be calculated using the following:

$$N = -(1/D)\log\beta \qquad (1)$$

Where N is sample size, D is the known density and β is the type 2 error. This equation assumes a Poisson distribution. Green and Young (1993) concluded from their study that for most situations a Poisson distribution would be adequate and even if the species are not randomly distributed the Poisson distribution will be adequate if the mean density is very low and the spatial distribution is not highly aggregated. This equation is adequate for quadrat sampling. If the assumption is that the transect is a series of connecting quadrats (Stehman & Salzer 2000), equation (1) can be adopted for this purpose. A maximum type 2 error of 0.05 was used.

Density D can be calculated as (Buckland *et al*. 1993):

$$D = Y/A = \Sigma^{N}_{u=1}Y_u/\Sigma^{N}_{u=1}a_u \qquad (2)$$

Where Y = total number of objects in the population and A is the total area of study; Y_u is the number of objects in the transect and a_u is area of transect u. $\Sigma_{u=1}^{N}$ is the summation over all transects N.

Standard error can be calculated by first calculating the variance, denoted V'(D') (Thompson 1992):

$$V'(D') = 1/\bar{a}^2(N\text{-}n/N)S_e^{2}/n \qquad (3)$$

Where $S_e^{2} = \Sigma_s(y_u - D'a_u)^2/(n\text{-}1)$. The standard error is the square root of the variance V'(D') (Buckland *et al*. 1993).

Buckland *et al*. (1993) provided the equation for calculating sample size for transect sampling given a specified confidence level:

$$L = (b/(cv_t(D')^2)(L_0/n_0) \quad (4)$$

Where L is transect length, $cv_t(D')$ is the coefficient of variation for given density D', L_0 is the length of the survey transect and n_0 is the number of objects detected. The variable b can be estimated as $b' = n_0(cv_t(D')^2$ (Burnham *et al*. 1980). A coefficient of variation of 0.10 was used in this analysis.

To determine if species were distributed randomly across the transects, a chi-square test goodness of fit of a Poisson distribution was used for all birds combined and all plants combined and for each species individually. The Chi square test using a Poisson distribution is suitable for samples with a small mean (ideally around 1) (Zar 1996). Zar (1996, page 575) also indicated that if a population has random distribution then $\sigma^2 = \mu$ and $\sigma^2/\mu = 1$. In a uniformly distributed population $\sigma^2/\mu < 1$ and clustered population $\sigma^2/\mu > 1$.

For plants that occurred in large numbers (>100 stems), local populations were estimated. Mosses and lichens were enumerated by number of colonies. For calculation of densities, transects were stratified for each species to capture broad categories of suitable habitat. For example, only aquatic transects were used for Common Loon analysis, transects that traversed mature deciduous and mixed wood were used for Eastern Wood Pewee and only transects within Windsor Geological Group were used for Yellow Lady's Slipper.

RESULTS

Between 2002 and 2016, 361 km of transect in 80 existing and proposed Wilderness Areas and Nature Reserve were traversed and occurrences of species of conservation concern were recorded. The mean transect length for protected area was 4.51 km. Two hundred and twenty-two occurrences of species of conservation concern were recorded during the transects. Fifty-nine species of plants and lichens (Table 1) and twenty-five species of vertebrates (Table 2) were observed. Species of conservation concern occurred at a density of one per 614 m.

The results showed that species were not distributed randomly across transects for all plants combined (P<0.001) or for all birds

Table 1 **Plant and lichen species of conservation of concern tallied within 80 protected area on transects between 2004 and 2016.**

Scientific Name	Common Name	Number of Times Encountered
Anemone quinquefolia	Wood Anemone	1
Asplenium trichomanes	Maidenhair Spleenwort	1
Asplenium trichomanes-ramosum	Green Spleenwort	1
Atrichum crispum	Atrichum Moss	1
Atrichum undulatum	Common Smooth-Cap Moss	2
Betula michauxii	Michaux's Dwarf Birch	4
Buxbaumia aphylla	Brown Shield Moss	1
Caltha palustris	Yellow Marsh Marigold	1
Carex swanii	Swan's Sedge	1
Caulophyllum thalictroides	Blue Cohosh	2
Cladina stygia	Black-footed Reindeer Lichen	2
Collema nigrescens	Blistered Tarpaper Lichen	1
Cornus suecica	Swedish Bunchberry	1
Cypripedium parviflorum	Yellow Lady's-Slipper	8
Cystopteris bulbifera	Bulblet Bladder Fern	8
Degelia plumbea	Blue Felt Lichen	1
Dryopteris fragrans	Fragrant Wood Fern	1
Empetrum eamesii	Pink Crowberry	1
Equisetum hyemale	Common Scouring-Rush	1
Equisetum scirpoides	Dwarf Scouring-Rush	2
Equisetum variegatum	Variegated Horsetail	1
Erigeron hyssopifolius	Hyssop-leaved Fleabane	2
Fuscopannaria leucosticta	White-Rimmed Shingle Lichen	1
Fraxinus nigra	Black Ash	5
Galium kamtschaticum	Northern Wild Licorice	1
Goodyera oblongifolia	Menzies' Rattlesnake-Plantain	1
Goodyera repens	Lesser Rattlesnake-Plantain	3
Goodyera tesselata	Checkered Rattlesnake-Plantain	5
Hudsonia ericoides	Pinebarren Golden Heather	1
Lachnanthes caroliniana	Redroot	1
Lilium canadense	Canada Lily	3
Listera australis	Southern Twayblade	1
Minuartia groenlandica	Greenland Stitchwort	1
Packera paupercula	Balsam Groundsel	1
Panax trifolius	Dwarf Ginseng	6
Platanthera macrophylla	Large Round-Leaved Orchid	1
Platanthera orbiculate	Small Round-Leaved Orchid	3
Polygonum scandens	Climbing False Buckwheat	1
Polystichum braunii	Braun's Holly Fern	1
Rhamnus alnifolia	Alder-leaved Buckthorn	1
Rhodobryum ontariense	Ontario Rose Moss	1
Sanguinaria canadensis	Bloodroot	4
Schizaea pusilla	Little Curlygrass Fern	1
Sclerophora peronella	Frosted Glass-Whiskers	2
Shepherdia canadensis	Soapberry	2
Smilax rotundifolia (Atlantic pop.)	Round-leaved Greenbrier	1
Solidago multiradiata	Multi-rayed Goldenrod	1

Table 1 cont'd

Table 1 Cont'd

Scientific Name	Common Name	Number of Times Encountered
Solorina saccata	Gypsum Lichen	1
Sphagnum quinquefarium	Five-ranked Peat Moss	1
Sphagnum torreyanum	Torrey's Peatmoss	1
Sphagnum wulfianum	Wulf's Peat Moss	9
Sticta fuliginosa	Peppered Moon Lichen	1
Tiarella cordifolia	Heart-leaved Foamflower	1
Timmia megapolitana	Metropolitan Timmia Moss	1
Triosteum aurantiacum	Orange-fruited Tinker's Weed	1
Vaccinium boreale	Northern Blueberry	1
Vaccinium uliginosum	Alpine Bilberry	3
Viola labradorica	Labrador Violet	1
Woodwardia areolate	Netted Chain Fern	1

Table 2 Vertebrate species of conservation concern tallied within 80 protected area on transects between 2004 and 2016.

Scientific Name	Common Name	Number of Times Encountered
Accipiter gentilis	Northern Goshawk (B)	3
Actitis macularius	Spotted Sandpiper (B)	1
Alca torda	Razorbill (B)	1
Alces americanus	Mainland Moose (M)	1
Calidris pusilla	Semipalmated Sandpiper (B)	1
Charadrius vociferus	Killdeer (B)	1
Chelydra serpentina	Snapping Turtle (R)	1
Chordeiles minor	Common Nighthawk (B)	5
Contopus cooperi	Olive-sided Flycatcher (B)	11
Contopus virens	Eastern Wood-Pewee (B)	14
Empidonax flaviventris	Yellow-bellied Flycatcher (B)	3
Gavia immer	Common Loon (B)	8
Glyptemys insculpta	Wood Turtle (R)	1
Hirundo rustica	Barn Swallow (B)	1
Passerculus sandwichensis	Savanah Sparrow (B)	1
Perisoreus canadensis	Gray Jay (B)	2
Petrochelidon pyrrhonota	Cliff Swallow (B)	1
Phalacrocorax carbo	Great Cormorant (B)	1
Picoides arcticus	Black-backed Woodpecker (B)	1
Poecile hudsonica	Boreal Chickadee (B)	2
Sterna hirundo	Common Tern (B)	1
Thamnophis sauritus	Eastern Ribbonsnake (R)	1
Tringa semipalmata	Willet (B)	1
Wilsonia canadensis	Canada Warbler (B)	4

combined ($P<0.001$). None of the tests for individual species indicated random distribution ($P<0.05$). Plant distribution for all plants combined may be clustered because $\sigma 2/\mu$ is much greater than one (205.167). However, $\sigma 2/\mu$ for Bloodroot (0.85) and Wulf's Moss

(0.89) were less than one suggesting that these species have a more uniform distribution. All other plants species had σ2/μ greater than one suggesting they each have a clustered distribution. Bird species distribution for all birds combined may be more uniform because σ2/μ = 0.730. However, for most bird species individually, σ2/μ was greater than one, suggesting clustered distributions. Only Common Loon (0.62) and Gray Jay (0.85) had σ2/μ less than one.

Nine bird species and 19 plant and lichen species were recorded 2 or more times (Table 3). Densities for bird species ranged from

Table 3 Density of vertebrates, plants and lichens tallied two or more times in transects including confidence intervals (Standard Error), sample size required to be 95% confident of detecting a species and sample size required to sample a population with a confidence interval of 0.1 or 10%.

Species (number	Density to be 95% per km)	Sample size required to confident of detecting a species (km)	Sample size required to sample a population with a confidence interval of 0.1 or 10% (km)
Alpine Bilberry	2.37 ± 6.40	0.5	52.7
Black Ash	0.22 ± 0.03	6.0	46.4
Black-Footed Reindeer Lichen	0.18 ± 0.02	6.9	16.0
Bloodroot	0.10 ± 0.01	13.5	62.3
Blue Cohosh	5.36 ± 0.13	0.2	3.4
Boreal Chickadee	0.02 ± 0.01	55.7	171.3
Bulbet Bladder Fern	27.10 ± 10.40	0.1	45.2
Canada Lily	0.13 ± 0.04	10.1	62.3
Canada Warbler	0.30 ± 0.03	4.3	26.7
Checkered Rattlesnake Plantain	0.04 ± 0.01	35.5	163.8
Common Loon	0.10 ± 0.12	13.5	83.2
Common Nighthawk	0.04 ± 0.03	32.0	197.1
Common Smooth-Cap Moss	3.32 ± 1.52	0.3	60.3
Dwarf Ginseng	0.32 ± 0.20	4.2	93.8
Dwarf Scouring-Rush	1.00 ± 0.54	1.0	45.2
Eastern Wood Pewee	0.73 ± 0.01	1.8	44.0
Frosted Glass Whiskers	3.02 ± 0.04	0.4	15.9
Gray Jay	0.04 ± 0.01	37.1	171.3
Hyssop's Fleabane	0.42 ± 0.21	3.1	45.2
Lesser Rattlesnake Plantain	0.09 ± 0.06	14.8	171.3
Michaux's Dwarf Birch	3.32 ± 9.80	0.4	52.7
Northern Goshawk	0.24 ± 0.01	5.5	25.4
Olive-Sided Flycatcher	0.19 ± 0.06	7.3	134.3
Small Round-Leaved Orchid	0.02 ± 0.01	56.9	175.1
Soapberry	3.32 ± 1.66	0.4	45.2
Wulf's Moss	0.05 ± 0.01	25.6	177.6
Yellow Lady Slipper	0.11 ± 0.05	11.7	45.2
Yellow-Bellied Flycatcher	0.119 ± 0.08	10.9	50.3

0.023 individuals per km (± 0.012) for Boreal Chickadee to 0.727 individuals per km (± 0.007) for Eastern Wood Pewee. Plants densities ranged from 0.02 individuals per km (± 0.01) for Round-Leaved Orchid to 27.1 individuals per km (± 10.4) for Bulblet Bladder Fern. Vascular plants tended to have higher densities than other groups. More than 40% of vascular plant species in this study had densities greater than 1, while no bird species had density more than 1. Lichens and mosses each had only 2 species recorded; both with one species density greater than 3 (Common Smooth-Cap Moss, Frosted Glass Whiskers) and one species with density less than 1 (Wulf's Moss, Black-Footed Reindeer Lichen). The range of densities found in plants was much greater (0.02 - 27.10) than for birds (0.02 - 0.73).

DISCUSSION

Most of the species of conservation concern sampled in this study were rare. Indeed, 66% of species were found only once. For most ecological communities, a few species are common but the greater majority are rare (MacArthur & Wilson 1967, Gaston 1994). Those species that are of greatest conservation concern are most often rare (Meffe & Carroll 1997, Fagan *et al*. 2002, Hartley & Kunin 2003). This may be, in part, because smaller populations are more susceptible to stochastic events (Cunningham & Lindemayer 2005).

Density estimates from this study are comparable to many densities for the same species in other studies in Nova Scotia despite differing methodologies. COSEWIC (2008) report densities of Canada Warbler between 0.001 individuals per ha, to 0.250 individuals per ha in Nova Scotia. Estimates from this study are between this range at 0.005 individuals per ha. COSEWIC (2012) provided an estimate of 30,000 individuals of Eastern Wood Pewee for Nova Scotia and when divided by the total area of hardwood and mixed wood forest (preferred habitat) in the province (Nova Scotia Department of Natural Resources 2017) provide an overall provincial estimate of 0.0195 individuals per ha. The estimate from this study is only slightly less at 0.012 individuals per ha. Other density estimates for birds from this study are less similar to other studies. The estimate for Yellow-Bellied Flycatcher (0.001 individuals per ha) is much lower than the 1.0 to 18.0 pairs per ha reported for Fundy National Park in New Brunswick (Freedman and Johnson 1999). However, the density estimate for Northern Goshawk (0.004 individuals per ha) is much higher than reported for Pennsylvania (0.00012 individuals per ha) and western North America (0.00107 individuals per ha) (Squires and Kennedy 2006).

Plants show much greater variation between studies. Oberndorfer and Lundholm (2008) found Northern Blueberry only once in their plots along 500 m transects in 6 coastal heathland sites. Northern Blueberry was also only found once in this study suggesting the rarity of this species. Oberndorfer and Lundholm (2008) also found 0.417 colonies per ha of Black-Footed Reindeer Lichen, which is much higher than the 0.003 colonies per hectare found in this study. Taylor and Tam (2012) report over 34 Orange-fruited Tinker's Weed stems per km of transect in their study sites in Nova Scotia, which was found only once in this study.

Although several other studies reported rare plant abundances in Nova Scotia, direct comparisons of abundance are not possible because of differences in methodology. Hill and Garbary (2011) measured abundances of four rare forest herbs also found in this study. Blue Cohosh, Bloodroot, Orange-fruited Tinker's Weed and Canada Lily were restricted to floodplain habitats and not found in adjacent upland forests in their study and this was the case for this study. Neily et al. (2011) likely has the most comprehensive assessment of plant abundances in their 1456 forest vegetation plots. They report Bloodroot in only 12 plots and while Blue Cohosh and Canada Lily are mentioned, they are not reported in their plot data. Neily et al. (2011) report Bulblet Bladder Fern from only 2 plots in their study. Yellow Lady's Slipper is mentioned but not reported in their plot data. Although direct comparison of abundances is not possible, these studies indicate the rarity of these plants within the landscape in Nova Scotia.

Ability to Detect Species of Conservation Concern

The rarity of species of conservation concern leaves ecologists with the challenge of designing statistically valid surveys that are able to detect small populations over large areas. The method described in the current study was designed to cover large areas and acquire data rapidly. However, it may only be an adequate sampling design for the more common species of concern when examining single protected areas alone. For example, only twelve of twenty-eight species analyzed (2 bird, 10 plant species) had a 95% confidence of being detected within the mean survey length of a protected area (4.5 km).

If, however, the objective is to detect species of conservation concern within the protected areas network across the province, then the methodology may be more useful. The sample size required for 95% confidence of detecting all 28 analyzed species was well within the 361 km of total survey length. It is important to note that most species of conservation concern were only detected once using the approach described above. Sixty-three percent of vertebrates and sixty-eight percent of plants and lichens were only detected once. There are also likely to be species of conservation concern present in the protected areas that were not detected.

Distribution of Species

The clustered distribution of plants suggests that with the detection of one species of conservation concern, others will also be present in the same area. When this occurs, more focussed surveys may be warranted. Clustering of plant species often occurs because of particular habitat characteristics; for example, species that require calcareous soil are often found together (Zinck 1998). Similarly, many floodplain inhabiting plants such as Blue Cohosh, Canada Lily and Bloodroot are found together (Hill & Garbary 2011).

The more even distribution of bird species of conservation concern may reflect the fact that many of the bird species detected are territorial songbirds. Therefore, they are more likely to be spread out, at least within suitable habitat. Sherry and Holmes (1985) found 4 of 7 songbirds had an even distribution in northern hardwood forests in New Hampshire. Some inferences can be made; for example, the Boreal Chickadee and Gray Jay can be useful indicators of species at the southern extent of their range and an important indicator of the rate of climate change.

Ability to Determine Density

The ability to determine density (number of individuals per length of transect) can be helpful for protected areas managers. It can aid in long-term monitoring to determine outcomes of management intervention or the impact of human use. Population density can be used as a benchmark to compare against the working landscape and this can, in turn, help ecologists determine causes of population declines.

Only 28 of 83 species of conservation concern detected in surveys were recorded frequently enough for analysis. However, because plants appear to have a clustered distribution it may be possible to use some species as proxies for rarer species that have abundances too low for density calculations. For example, changes in populations of the four calcareous soil associated plant species, Bulblet Bladder Fern, Hyssop's Fleabane, Soapberry and Yellow Lady's Slipper, may reflect issues with the karst or limestone ecosystems. These species may predict the occurrence of rarer and endangered species such as the Ram's-Head Lady's Slipper that is sometimes found with them (Neily et al. 2011). Monitoring population levels of floodplain associated species such as Blue Cohosh, Canada Lily or Bloodroot, and may also provide information on changes within that community.

Both Alpine Bilberry and Michuax's Dwarf Birch had confidence intervals greater than actual densities. This was likely due to the high degree of variation in population counts between sites. Although arctic-alpine plants were found distributed in a clumped pattern, species were not often found together. Abundances could be very high in some areas and very low in others. Cameron and Bondrup-Nielsen (2013) found a similar pattern in their study of heathlands in Nova Scotia.

Suitability of Method for Sampling Species of Conservation Concern

Although only some species of conservation concern were detected and have density determined by the data analysis, there may be different approaches or ways the data could be used. Nichols *et al*. (2000) suggested one approach for bird species is to group *a priori* different species with a similar predicted variation in detection probability (e.g. easy or difficult to detect). This approach can be tested *a posteriori*. In order for this approach to have some biological meaning, it may be necessary to additionally group species with similar population dynamics (MacKenzie *et al*. 2005) and habitat requirements.

The purpose of the survey needs to also be considered. For example, if one is interested in the effects of sugar maple decline on bird species it would be necessary to group species associated with sugar maple forests. Since one of the purposes of protected areas in Nova Scotia is to provide habitat for birds requiring large interior forest, this kind of grouping may be helpful. Another potentially useful grouping may be boreal forest birds. This grouping may lead to a better understanding of the effects of climate change in the hemi-boreal forests of Nova Scotia.

Another approach to using rare species data is to examine species richness (MacKenzie *et al.* 2005). This may be useful when examining community level questions and as a way to make use of data on rare species that might otherwise not lend itself to analysis. Because not all species are likely to be detected in a plot, estimates need to be calculated and a number of methods have been proposed (Bunge & Fitzpatrick 1993). For territorial rare species, MacKenzie *et al.* (2005) suggested occupancy rather than abundance as an alternative measure. As with species richness, there is the problem of imperfect detectability. MacKenzie *et al.* (2005) provides examples to address imperfect detectability by repeated sampling during a single or several seasons. Probabilistic arguments are then applied to form a model likelihood that can be used to obtain parameter estimates. Forest birds monitored in this study may be a group to which this method could be usefully applied.

One approach not addressed by MacKenzie *et al.* (2005) in their review, is accepting larger confidence intervals for some species. Another consideration is making adjustments to acceptable levels of confidence or survey length which can yield improvements in detectability. For example, adjusting the confidence to 80% means 16 species are likely to be detected within the mean survey length instead of the current 12 species. If the average survey length was doubled the number of species likely to be detected with 95% confidence is 16 or 23 with 80% confidence. However, accepting these kinds of adjustments will make it more difficult to detect change and there will be less certainty comparing areas. The risk is that impacts will be well underway before a change is detected. This risk needs to be evaluated by species to determine if some other measure or intensive sampling is warranted.

Protected Areas Ability to Capture Species of Conservation Concern

Protected areas not designed to capture species of conservation concern may not be adequate for protecting vulnerable species. Only about 8% of the vascular plant species of conservation concern known to occur in the province, and about 7% of non-vascular flora, were captured in this study. Birds fared better with about 19% of species captured. Three of the four reptiles of conservation concern were found during the surveys and one of thirteen mammals. It should be noted that the protected areas assessed were not designed to protect specifically species of conservation concern, but rather to protect representative ecosystems. Other protected areas in the network are designed for species at risk (Cameron & Williams 2011) such as the 23,000 ha of nature reserves versus the 496,000 ha of wilderness area primarily focused on ecosystem representation (Nova Scotia Department of Environment 2018). The results of this study support the need to have protected areas specifically for species of conservation concern because protected areas designed to capture representative ecosystems may not capture the rare species of conservation concern. There are also likely species of concern that occur in the study areas but were not captured by the survey.

CONCLUSION

The method described in this study is suitable for detecting and determining density for many species of conservation concern within the protected areas network in Nova Scotia. Modification of the analysis used in the present study, as suggested in the discussion, could yield useful results for individual protected areas or for some of the more rare species of conservation concern.

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BOOK REVIEW

The Future of Ocean Governance and Capacity Development: Essays in Honor of Elisabeth Mann Borgese (1918-2002). **Edited by International Ocean Institute-Canada: D. Werle, P.R. Boudreau, M.R. Brooks, M.J.A. Butler, A. Charles, S. Coffen-Smout, D. Griffiths, I. McAllister, M.L. McConnell, I. Porter, S.J. Rolston, & P.G. Wells. Eds. Brill Nijhoff, Leiden and Boston. 562 pp.**

This collection of over eighty essays, organized and edited by the International Ocean Institute (IOI) – Canada, aims to honor, update, and advance the contributions of Elizabeth Mann Borgese to ocean governance on the centenary of her birth. It is both a homage to Elizabeth's influence and legacy, and a reflection on the IOI's influence and global reach via its training programs, which she initiated. Elizabeth Mann Borgese (1918-2002) was a daughter of the Nobel-Prize writer Thomas Mann; she went into exile with her family during World War II to escape Nazi Germany, first to Switzerland and then the United States. She was heavily involved in the development of the Third United Nations Conference on the Law of the Sea (UNCLOS III), including leading a project and conference on *Pacem in Maribus* (Peace in the Oceans) in the run-up to the UNCLOS negotiations. The *Pacem in Maribus* conferences continued on from 1970-2013, organized by the IOI; they focused on international ocean affairs topics ranging from arms control, monitoring and surveillance, to management and conservation of marine resources, concerns related to ocean shipping and ocean development, and emerging issues including climate change, coastal cities, and ocean-related hazards.[1]

Elizabeth set up the IOI in 1972, initially at the University of Malta where she worked closely with Dr. Arvid Pardo (1914-1999). Pardo was the Maltese Ambassador to the United Nations and considered the father of the "common heritage of mankind" concept, i.e., that the seabed beyond national jurisdiction and its resources are a "commons" that should be kept in trust for future generations, in contrast to the outdated open-access approach of "freedom of the seas" espoused by Hugo Grotius (1583-1645). Elizabeth subsequently moved to Canada and launched the first training program of the IOI in 1981, hosted

[1] IOI website, Pacem in Maribus (PIM) Conferences: www.ioinst.org/about-1/ioi-story/pacem-in-maribus-pim-conferences/ [Accessed 11 December 2018].

at Dalhousie University. She remained in Canada for the rest of her life, engaged in the training program at IOI-Canada.

Given that background and context, this volume of 82 short essays, plus introductory and concluding pieces, provides a valuable perspective on the many issues of ocean governance and capacity development. It connects the current state of the field with Elizabeth's legacy, as well as with the contributions of the IOI training program that address these issues. The book is organized around ten parts, each of which includes several essays on a range of relevant topics, with contributions from academics, regulators, consultants, and other experts.

The first part, Perspectives on Ocean Governance, sets the scene and includes essays addressing fragmentation, trans-disciplinarity, partnerships, ethical dimensions, and participation, including NGOs and First Nations. The second part, on Capacity Development, goes into some detail on the contributions of the IOI training program, including alumni reflections, an interesting and novel inclusion in a volume like this. The third part, on the Law of the Sea and Principled Ocean Governance, addresses the past, present, and future of UNCLOS, connecting Elizabeth's contributions to ongoing areas of tension such as mining the deep sea floor, managing the Arctic, and settling maritime boundaries. The fourth section, on Ocean Sciences, provides an overview of the health of the oceans and current crises, including ocean acidification, as well as new technologies to measure ecological change and support management. The fifth section, on Integrated Coastal and Ocean Management, addresses a range of relevant topics related to coastal management approaches, such as marine spatial planning, the role of information at the science-policy interface, marine protected areas, marine noise, and economic concerns, including sustainable tourism.

Fisheries and Aquaculture is covered in the sixth section, connecting fisheries science and management approaches, including market approaches, enforcement and compliance approaches, regional fisheries management organizations and small island developing state perspectives on management. The seventh section, on Ocean Energy, addresses marine renewable energy in Canada and issues related to oil and gas exploration. The eighth section, on Maritime Safety and Security, includes themes related to espionage, piracy, refugees, disaster response and, interestingly, connections between ecological resilience and the role of women and communities. The ninth section, on Maritime Transportation, addresses shipping policies and the growth of the industry, as well as port state control, seafarer's human rights, and maritime emergency preparedness, while also examining newer issues such as the international ballast water regime, Arctic shipping risks, and autonomous vessel technology.

The final section focuses on Communication and Negotiation and includes an array of topics, ranging from poetry to journalism, the origin of Ocean Day, and the importance and influence of social media and ocean literacy, including a case study of cetaceans in the media, focused on right whales. The last essay in the volume addresses ocean peace, a nice full-circle compliment to Elizabeth's *Pacem in Maribus*.

The editors, all associated with IOI-Canada, conclude the volume by synthesizing the essays' contributions into four broad categories, which they explore in a forward-thinking manner. These include: (1) major environmental problems and population pressures; (2) institutional responses to these problems and pressures; (3) the role of technological challenges and opportunities; and (4) the future of ocean governance. While no single book can address every relevant topic in the oceans, this volume does a good job of highlighting key ocean issues of the past, present and future, and provides viewpoints from a range of perspectives.

This book will be of interest not only to ocean governance practitioners/regulators and students/scholars, but also to engaged members of the public. All readers will learn a great deal about the issues facing our oceans today and how we are addressing them, as well as noting the impressive legacy of Elizabeth Mann Borgese and the IOI's contributions to date.

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Volume 50, Part 1, pp. 185-186

BOOK REVIEW

***The Rise and Fall of the Dinosaurs – A New History of a Lost World*. S. Brusatte. 2018. William Morrow Harper Collins, New York, NY. 404 pp.**

I was planting trees in northern Ontario the first time I read "Wonderful Life" by Stephen Jay Gould (1989). Exhausted from the intense work of tree-planting, I spent my evenings reading to avoid the swarms of mosquitoes that hummed outside my tent. Gould's book captivated my imagination, and inspired me to learn more about deep time, evolution, natural history, and to recognize the importance of the history of science.

Gould was a prolific and masterful writer. He described 'his writing style recipe' in the preface of his penultimate volume of essays (Gould 2000, pp. 4), "*to encapsulate, in the unforgiving form of an essay, the essence of both a person (as expressed in the controlling idea of his scientific life) and a concept (through the quintessentially human device of displaying its development in an individual life*". It was this linkage of scientific concepts and biographies of real people that struggled with real questions that inspired me (and many others) to study and pursue research in natural sciences.

Today, I find a similar linkage of science and biography in Steve Brusatte's new book, the *Rise and Fall of the Dinosaurs - A New History of a Lost World*. This engaging and accessible book provides personal stories of discovery and collaboration that Brusatte has shared with the current generation of dinosaur paleontologists around world.

This *New History of a Lost World* provides a summary of our current knowledge of dinosaur biology and evolution, as well as the stories of hardship and discovery of the people behind the science. It includes stories of recent graduate students conducting research projects that continue to open new chapters of evolution's grand narrative, and stories of international collaborations and modern technology applied to ancient dinosaur fossils.

By its nature, paleontology is a strongly historical science. After being discovered and collected, fossil specimens are carefully stored in museums to be examined by new researchers and modern approaches. Brusatte conveys the important relationship between modern discoveries and the history of science, tracing the understanding of dinosaurs through time. At the same time, he conveys how modern students and researchers continue to shine light on an ancient lost world in exciting new ways.

In my own research, I've had the great pleasure to meet and work with several of the inspiring people mentioned in this book. I can attest to the excitement and intensity of the "Rat Pack" of new scientists such as Sterling Nesbitt and Jessica Whiteside, while working with Paul Olsen in the Bay of Fundy. This new generation of researchers continue to make exciting new discoveries.

Brusatte is an accomplished public science writer. His experiences writing articles for Scientific America and online sources provide him with a clear and compelling style. If you are interested in glimpsing into the culture of dinosaur research, what it's like to discover new species in exotic places around the globe, this book is for you. If you are an undergraduate student, this book may inspire you to come up with your own questions and conduct your own research projects.

For those so inspired, I also recommend reading the Notes of the book. Brusatte provides a running summary and suggestions for additional reading for the topics of dinosaur science discussed. These notes also provide another layer in which to see the weaving of personal biographies and burning questions that have inspired and challenged the scientists.

Stating the obvious, dinosaurs remain a hugely popular topic. We cannot seem to learn enough about these 'terrible lizards' of the ancient past. Engaging and effective popular science writing is surely one of the reasons for the growing interest in dinosaur paleontology. Books like those written by Stephen Jay Gould and Steve Brusatte convey the human interest and struggle that continues in new scientific research. Thankfully, one might predict that a new generation of scientists, including paleontologists, will be inspired by this new dawn of popular science writing.

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Proceedings of the Nova Scotian Institute of Science (2018)
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NSIS COUNCIL

Reports from the Annual General Meeting, May 2018

AGENDA

157TH ANNUAL GENERAL MEETING

5 pm - 7 May 2018

The Great Hall, University Club
Dalhousie University, Halifax, NS

1. Minutes of 156th AGM, 2017
2. President's Report 2017-2018 (Sherry Niven)
3. Treasurer's Report 2017-2018 (Angelica Silva)
4. Editor's Report 2018 (Peter Wells)
5. Librarian's Report 2017-2018 (Michelle Paon)
6. Webmaster's Report 2018 (Suzette Soomai)
7. Student Science Writing Competition 2018 (Hank Bird)
8. NSIS Excursions 2018 (Hank Bird)
9. NSIS 2018-2019 Public Lectures (Tana Worcester)
10. Nominations for NSIS Council 2018-2019 (Sherry Niven)
11. Any Other Business
12. Adjournment

NOVA SCOTIAN INSTITUTE OF SCIENCE

MINUTES OF THE 156TH ANNUAL GENERAL MEETING

1 May, 2017
Dalhousie University Faculty Club

Council Members present: Sherry Niven (President), Patrick Ryall (Past President), Tamara Franz-Odendaal (Vice-President), Michelle Paon (Librarian), Angelica Silva (Treasurer), Linda Marks (Secretary), Nicole LeBlanc (Publicity Officer), Dylan Miller (Membership Officer), Richard Singer

Members present: Carol Morrison, David Richardson, Robert Cook, David McCorquodale, Tana Worcester, David Richey, Matthew Richey, Paivi Torkkeli, Alan Ruffman

Regrets (Council Members): Suzette Soomai (Webmaster), Hank Bird (Excursions and Student Science Writing Competition Coordinator), Peter Wells (Editor), Victoria Turpin, Ron MacKay, Zoe Kirste (Student Representative)

The President welcomed members and called the 156th Annual General Meeting (AGM) to order. It was noted 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 155th Annual General Meeting of 1 May, 2016:**
   Motion to accept the minutes of the 155th AGM
   Moved: Patrick Ryall
   Seconded: Richard Singer
   All in favour: Carried

2. **President's Annual Report (Sherry Niven):**
   The President thanked the 2016-2017 Council for their work and support and noted that it was an honour to serve as President of one of the oldest learned societies in Canada, especially as the country enters its 150th year.

   The President described a successful series of public lectures in 2016-2017 and thanked the speakers, the Lecture Committee and lecture hosting venues (Museum of Natural Science, Agricultural

Campus of Dalhousie University in Truro, Mount Saint Vincent University and the Dalhousie's University Club).

The President reported that Council organized several successful excursions in 2016-2017 and thanked Hank Bird, Michelle Paon and Ron MacKay for leading the events. Other successful events included the sponsorship of a reception following the Dalhousie University Huntsman lecture; a student poster contest at the annual Fisherman and Scientists Research Society Conference; regional science fairs and awards to the NSIS Student Writing Contest. As well, Dr. Alan Taylor's bequest was distributed to nine Nova Scotia Regional Libraries.

The President was pleased to report that an Honorary NSIS Membership was granted to Nobel Laureate Dr. Arthur MacDonald. The membership was presented to Dr. MacDonald at the October 2016 ceremony where he was invested into the Order of Nova Scotia.

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

3. **Treasurer's Annual Report (Angelica Silva):**

The Treasurer noted that her reporting period was 1 April 2016 – 31 March 2017 and reported that the NSIS has 79 regular, 12 life, 9 student and 16 institutional members. The Treasurer hoped that with the help of Membership Officer, Dylan Miller, memberships will be increased.

As of 31 March 2017, the net worth of the NSIS was $59,383.28 with $22,993.44 in cash ($10,665.91 was very recently moved from an investment to cash) and $36,389.84 in savings and investments. The Treasurer noted that again expenditures ($15,998.86) exceeded revenue ($4,945.24) due to increased expenses and $5K from Dr. Alan Taylor's bequest is being distributed to Nova Scotia libraries (payment is based on population with the largest payment going to the Halifax libraries).

Revenue included memberships, sales of publications and a royalty payment from Access Copyright. Expenditures incurred to support science fairs, the writing competition and lectures/conference sponsorships; printing of the Proceedings, lecture posters and the brochures and postage.

Maturing investments (May 2017 and February 2018) will earn a lower rate of interest than currently received.

The Treasurer's report included a budget projection for 2017-2018 which identified greater expenses and lower revenue. Several items were identified for correction.

The President noted that she had earlier neglected introducing Membership Officer, Dylan Miller, who joined Council in October 2016 following the resignation of the officer elected at the May 2016 AGM.

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

Associate Editor David Richardson invited members to submit papers to the Proceedings and noted that articles from speakers at the NSIS public lectures were needed. David Richardson reported that, following the meeting, Vol. 49 (1) will be available to those with paid memberships and as a bonus, a 1975 issue of the Proceedings, Vol. 27, suppl. 2, The Ipswich Sparrow by Ian McLaren and Wayne Stobo, will be available for free.

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

Michelle Paon described her role as Librarian.

The Librarian reported that in 2016-2017, sales of the Proceedings yielded $675.00 with 18 copies of the Flora of Nova Scotia sold. The Flora continues to sell well and with only 18-19 issues remaining the publication will be reprinted. The Birds of Brier Island (Vol. 46 Proceedings 2011 Special Issue) is now available on-line so the selling cost has been reduced from $25 to $15 and Council has agreed that a free copy be given with each new membership.

The Librarian reported that Dalhousie University's Killam Library, which stores the Institute's unsold issues of the Proceedings, is currently experiencing a shortage of space. To ease the shortage the inventory of the Proceedings, which is over 5000 issues, needs to be reduced. The Librarian reported that she will prepare a plan to address the issue.

David Richardson suggested contacting various institutions to see if they need if they need specific issues of the Proceedings to complete their collections. The Librarian noted that the issues would be free but mailing costs would need to be paid.

The Librarian reported that the NSIS has 16 institutional members and 84 exchange partners. Last year 126 publications from around the world were received from the exchange partners. The Librarian thanked the Killam Library staff and Carol Richardson for ensuring that these materials are available on the library shelves.

The Librarian reported that the 2015 repertoire payment from Access Copyright was $369.24 and noted that royalties have declined due to fewer sales of the Proceedings and the availability of issues digitally. The payment is projected to further decline as Access Copyright licensing revenues also decrease. Editor Peter Wells has signed a new Access Copyright agreement which reflects the online presence of the Proceedings.

Alan Ruffman noted that Access Copyright repertoire payment, mentioned by the Librarian, was not reflected in the Treasurer's proposed budget and the lower sales of Proceedings. Angelica Silva noted the differences and reported that she took into account presales of approximately $700 for the Sable Island edition of the Proceedings.

6. Lecture Program for 2017-2018 – Report of the organizing committee (Tamara Franz-Odendaal):

The Vice-President presented the report of the Lecture Committee. The lectures for 2017-2018 cover a variety of topics of interest in Canada's 150th year and, to accommodate an anticipated larger audience, two lectures will be held at the Halifax Central Library. In recent years the Council has been endeavouring to increase the profile of the NSIS outside the Halifax area and in that light the December lecture will be held at Acadia University in Wolfville. Brochures are available.

2 October 2017	**Stephen Locke,** Dalhousie University – 175th Anniversary of the Geological Survey of Canada
6 November 2017	**Dave Risk,** Saint Francis Xavier University – Mapping methane emissions
4 December 2017	**Donna Crossland,** Parks Canada – Forest management
8 January 2018	**Tim Fedak,** Fundy Geological Museum – 150 years of Canadian dinosaurs

5 February 2018	**Angie Birt,** Mount Saint Vincent University – Memory
5 March 2018	**Marcos Zentilli,** Dalhousie University – Climate change in the Arctic
9 April 2018	**Sarah Stewart-Clark,** Faculty of Agriculture, Dalhousie University - Aquatic invasive species
7 May 2018	**Anna Redden,** Acadia University – Tidal energy and marine life

7. Proposed Excursions for 2017-2018 (Hank Bird):

Hank Bird reported that four successful excursions took place in 2016-2017:

– Natural History of McNab's Island
– Annapolis Royal Historic Gardens
– The Science and Art of Making Beer
– Burke-Gaffney Observatory

Following a survey of the membership five excursions were selected for 2017-2018:

- Petroglyphs and Nature Hike, Kejimkujik National Park, to be organized by Peter Wells
- Halifax Planetarium, Dalhousie University, to be organized by Hank Bird
- Joggins Fossil Cliffs, to be organized by Patrick Ryall
- Shubenacadie Canal, Dartmouth, to be organized by Kara MacPhee
- Bedford Institute of Oceanography (part of the BIO Open House) to be organized by Sherry Niven

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

Hank Bird reported two winning papers and one honourable mention were selected from 16 manuscripts. Awards were presented at the 3 April 2017 NSIS public lecture. Hank Bird thanked the panel of five who helped him with the judging and the Publicity Officer, Nicole LeBlanc, for her design and promotional work.

9. Publicity Report (Nicole LeBlanc):

The Publicity Officer reported that the 2017-2018 brochure has been redesigned to include a Facebook icon and a separate membership form. The Institute's presence and promotion of events on Facebook and EventBrite will target more students.

The Publicity Officer noted that she will continue to work with other members of Council to promote the Student Writing Contest, lectures, other events and enhance membership.

The Publicity Officer recommended that the NSIS logo should be updated. A new logo along with a "pop-up" banner will improve the visibility of the NSIS at events.

Carol Morrison asked that members be given an opportunity to vote on the new logo. The Publicity Officer suggested that a survey could be sent to members.

The President thanked Nicole LeBlanc for bringing new energy and ideas to Council.

10. Webmaster's Report (Suzuette Soomai):

The Webmaster reported that she continues to provide general maintenance and updates to the website, including the posting of monthly lectures, but the website requires a redesign which will require regular technical support to maintain and enhance its functions and update its security. The Webmaster reported that a new Webmaster should be sought once the redesign has been completed. In March 2017 Council approved the expenditure to hire a web designer and a notice was distributed.

Motion to accept the Annual Reports:
Moved: Tamara Franz-Odendaal
Seconded: Michelle Paon
All in favour: Carried

11. Report of the Nominating Committee for the 2017-2018 Council (Sherry Niven):

Sherry Niven reported that she has agreed to stay for a second term as President in 2017-2018 as Vice-President Tamara Franz-Odendaal will be unable to accept the position but has agreed to stay on Council. Tana Worcester will join Council as Vice-President and Patrick Ryall has agreed to stay as Past-President.

The President, as Chair of the Nominating Committee, asked the AGM to elect the following to NSIS Council for 2017-2018:

President	Sherry Niven
Vice-President	Tana Worcester
Past-President	Patrick Ryall
Secretary	Linda Marks
Treasurer	Angelica Silva
Publicity Officer	Nicole LeBlanc
Membership Officer	Dylan Miller
Librarian	Michelle Paon
Editor	Peter Wells
Webmaster	Suzuette Soomai
Councillor	Tamara Franz-Odendaal
Councillor	Hank Bird
Councillor	Donald Stoltz
Councillor	Richard Singer
Student Representative	Alexa Kirste

Observers:

Discovery Centre	Kara MacPhee
Nova Scotia Museum	Laura Bennet

There was a call for additional nominations from the floor, including two vacant positions for Councillors. There were no other nominations.

Motion to accept the Nominations
Moved: David Richardson
Seconded: Richard Singer
All in favour: Carried

12. Any Other Business:
Sherry Niven invited all present to enjoy the public lecture at 7:30 PM, following the dinner.
There was no other business.

13. Adjournment:
Motion by Michelle Paon to adjourn the 156th Annual General Meeting of the NSIS at 6:12 PM.

Respectfully submitted
Linda Marks
Secretary

PRESIDENT'S REPORT 2017-2018

Welcome to the Annual General Meeting for the 157th year of the Nova Scotian Institute of Science! I would like to start the meeting by thanking the 2017-18 Council:

Officers: Patrick Ryall (Past-President); Tana Worcester (Vice-President); Linda Marks (Secretary); Angelica Silva (Treasurer); Nicole LeBlanc (Publicity Officer); Dylan Miller (Membership Officer); Michelle Paon (Librarian); Peter Wells (Editor); and Suzuette Soomai (Webmaster)

Councillors: Hank Bird (lead for Excursions and the Student Science Writing Competition); Tamara Franz-Odendaal; Richard Singer; and Donald Stoltz.

Observers: Alexa Kirste (Student Representative) and Kara MacPhee (Discovery Centre)

It has been another busy year for me at work and I very much appreciate Council's understanding and support!

Public Lectures

We had a very successful public lecture series this year. A sincere thank-you to Tamara Franz-Odendaal for organizing the series – and to all the speakers for their contribution to the Institute's goal of communicating and celebrating science in Nova Scotia:

Oct 2, 2017: Stephen Locke (Geological Survey of Canada, Natural Resources Canada) *A proud history of the Geological Survey of Canada: On the 175th anniversary*

Nov 6, 2017: David Risk (St. FX University) *In Pursuit of "the other" Greenhouse Gas: Mapping Methane Emissions across the Canadian Energy Sector*

Dec 4, 2017: Donna Crossland (Parks Canada) *A "clear-cut" Perspective about "science-based" forest management in NS*

Jan 8, 2018: Tim Fedak (Nova Scotia Museum of Natural History) *150 Years of Canadian Dinosaurs and other Major Fossil Discoveries*

Feb 5, 2018: Graham Daborn (Emeritus Professor, Acadia Centre for Estuarine Research/Acadia Tidal Energy Institute) *Reflections on the Bay of Fundy: Past, Present and Future*

March 5, 2018: Marcos Zentilli (Emeritus Professor, Dalhousie University) *The rise of mountains and climate changes in the Canadian Arctic Archipelago*

April 9, 2018: Sarah Stewart-Clark (Dalhousie University) *Aquatic Invasive Species in Nova Scotia; Are they spreading disease to our native species?*

May 7, 2018: Anna Redden (Acadia Centre for Estuarine Research/ Acadia University) *Tidal energy and marine life: Pro-testing,not protesting*

May 7, 2018: Anna Redden (Acadia Centre for Estuarine Research/ Acadia University) *Tidal energy and marine life: Pro-testing,not protesting*

Special thanks to Graham Daborn for stepping in at the last minute to provide February lecture! Council extends thanks as well to the Museum of Natural History for hosting the October, November, February, and March lectures; the Halifax Central Library for hosting the January and April lectures; Acadia University for hosting the November lecture; and Dalhousie's University Club for hosting the AGM lecture and dinner.

The Institute also co-hosted a public lecture with the Ocean Frontier Institute on Nov 29th 2017 at Dalhousie University by the 2017 recipient of the A.G. Huntsman Medal for Excellence in Marine Sciences, Dr. Jeffrey Hutchings (Dalhousie University). (Recovering Canada's Marine Fish and Fisheries: the Roles of Science, Policy and Societal Will)

The Library, Dalhousie, and Acadia University lectures provided great opportunities for out-reach and to distribute lecture brochures and complimentary copies of old Proceedings

Other Activities

Information on other activities during the year (excursions, the Proceedings, the student writing contest, website, publicity, and sponsorships) are detailed in other reports. My thanks to all members who have contributed to the success of these activities.

Looking to the Future

Council is planning a visioning and strategic planning session this summer. Stay tuned for information!

Respectfully submitted,
Sherry Niven
2017-18 NSIS President

TREASURER'S REPORT

NOVA SCOTIAN INSTITUTE OF SCIENCE

April 1, 2017 - March 31, 2018

ASSETS as March 31, 2018	
Bank Account BMO (as of March 31, 2018)	12,529.08
Investments (as of March 31, 2018)	37,125.73
TOTAL ASSETS:	**$49,654.81**

INVESTMENTS (as of March 31, 2018)	
Renaissance High Interest Savings Account (March 29, 2018) @1.0%	9,090.31
Equitable Bank GTD Investment Cert CA @ 1.81% due June 15, 2018	7,000.00
Equitable Bank GTD Investment Cert CA @ 2.46% due March 09, 2020	10,015.99
Equitable Bank GTD investment Cert CA @ 2.72% due May 08, 2021	11,019.43
TOTAL INVESTMENTS as of March 31, 2018	**$37,125.73****

REVENUES AND EXPENDITURES 2017-2018

REVENUE as of March 31, 2018	
Membership dues Regular	$ 1,800.00
Membership Life	300.00
Membership Students	50.00
Membership Institutions	420.00
AGM Dinner (May 2017)	855.00
Sales NSIS Proceedings, Birds of Brier Island, Flora NS	1,219.68
Donations	10.00
Income/Royalties ACCESS Copyright Royalty	337.03
Field trip/Excursion	359.950
Postage	16.00
TOTAL REVENUE	**$ 5,367.66**

EXPENSES as of March 31, 2018	
Proceedings printing/ layout PNSIS	$ 4,126.63
NSIS Flora Reprint	1,258.10
NSIS Annual Brochure, Monthly Lectures	1,127.13
Mail PNSIS to members, NSIS postage	371.93
AGM Dinner (2017) venue, dinner	1,242.68
NSIS Dr. Taylor's bequest contribution to NS Regional libraries	4,999.99
Lecture Sponsorships	500.00
Nova Scotia Regional Science Fairs contributions	400.00
NSIS Writing Competition (Undergraduate/Graduate)	1,250.00
Rent Halifax Regional Library - lecture	92.00
Supplies office	93.00
Field trip/ excursion	334.95
Bank charges	36.60
TOTAL EXPENSES	**$ 15,832.02**

Finances

The net worth of NSIS is $49,654.81 as of March 31, 2018 from a total of $12,529.08 at BMO account plus current Investments of $37,125.73.

For this past 2017-2018 period, NSIS had a total income of $ 5,367.66 that resulted from Membership regular, students, and institutions ($2,570); revenue from AGM dinner ($855), Sales of Proceedings PNSIS, Flora of Nova Scotia, Birds of Brier Island ($1,219.68), donations ($10), Royalties ACCESS ($337.03), NSIS Excursions ($359.95) and paid postage for $16.

Total expenditures of $15,832.02 did result from costs associated to Printing of Proceedings of Nova Scotian Institute of Science (PNSIS) ($4,126.63), re-printing of NSIS Flora of Nova Scotia ($1258.10) plus expenses related to communications and publicity that included Annual NSIS Brochures, Monthly posters, Bookplates for NS regional libraries ($1,127.13), mailing costs of PNSIS to members ($371.93), AGM venue and dinner ($1,242.68), 2nd year (2017) of NSIS Dr. Taylor's bequest to NS Regional Libraries ($4,999), Lecture Sponsorships ($500), Regional Science Fairs ($400), NSIS Student Writing Competition (Molly LeBlanc $750 and Zachary T. Sherker $500), Lecture space at Halifax Regional Library ($92), Office Supplies ($ 93), Field trip/excursion ($334.95), Bank charges ($36.60).

Membership 2017/2018 and Projected Budget 2018/2019

2017/2018: NSIS had a total of 78 paid members (n= 60 regular members; n=5 student members and n=13 Life Members) and 14 Institutional members. NSIS also has numerous Honorary Members.

The Nova Scotian Institute of Science continues to dedicate all its resources towards communication of scientific issues relevant to all Nova Scotians and it has supported lectures, conferences, student competitions, printing of the Proceedings of the Nova Scotian Institute of Science, Regional Science Fairs and more recently Field excursions to NSIS members. The upcoming year 2018/2019 will be the 3rd and last year of support to Nova Scotia Regional libraries as per Dr. Alan Taylor's bequest to NSIS.

Projected Revenues are expected to increase in 2018/2019 with promotion of new memberships. Projected Expenses will be similar to this year ~ $15,000 will include costs of printing and production of The Proceedings of the Nova Scotian Institute of Science (PNSIS); NSIS writing Awards to University Undergraduate and Graduate Students ($1,250), Regional Science Fairs (n=10 x $200- $2000); contributions to Science Lectures and Conferences in the Province; costs associated with publicity of Annual NSIS Brochure with lectures and Membership form; publicity costs of Monthly NSIS lecture posters; Mailing costs to Institutions and NSIS members. Updates to website will be included at ~$1,500.

It is recommended that investments are maintained by renewing investments at time of maturity to maintain a minimum of $25,000 or greater level of savings.

Respectfully submitted to NSIS AGM 2017-2018 on May 7th, 2018

Angelica Silva PhD
NSIS Treasurer
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EDITOR'S REPORT 2018

Prepared for AGM May 1, 2018

The 2018 issue of the PNSIS (Volume 49, Part 2) has been published and is available in hard copy (limited printing) and on the websites of the NSIS and Dalhousie University. As with the previous issue, it has an Editorial, Commentaries, Articles, and for this issue, one book review.

Input is continuing for the next two issues of the Proceedings - Volume 50(1) will be a special issue on marine polychaetes, and Volume 50(2) will be a regular issue, with a number of contributed papers already received and in review.

We have revisited and strengthened the Instructions to Authors; they are printed in the recent issue. This is meant to reduce the time required at the final editing and proofing stage of production. Producing this journal is largely a volunteer operation; it is hoped that the contributing authors will follow the new instructions and reduce the time commitment of the editors.

As stated last year, we need more contributions that reflect the annual NSIS lecture program, and the work and concerns of members of the NSIS. The Proceedings are a voice piece of the Society; it would be nice to receive feedback from members and interested members of the public who attend the monthly lectures.

Finally, we would like to thank everyone involved in this enterprise - the authors, the Editorial Board, and especially Gail LeBlanc, Production and Layout Editor, for a job well done once again for the Proceedings of the NSIS.

Respectfully submitted by:
Peter G. Wells, Dalhousie University, Editor
May 3, 2018

LIBRARIAN'S REPORT 2017-2018

Prepared for AGM May 7, 2018

In my role as NSIS Librarian, I communicate with NSIS journal exchange partners from around the world and oversee the receipt of partner journals. I also work with Killam Library staff members who prepare these journals for the shelves and facilitate access to the online *Proceedings of the Nova Scotian Institute of Science*.

Proceedings of the Nova Scotian Institute of Science

During 2017/2018, sales of the Proceedings from the Killam Library's Reference & Research Services office generated $500 in revenue (see Appendix A). Of note, NSIS sold 11 copies of the Flora of Nova Scotia to university students in a summer course. In July, NSIS Council replenished the stock of this publication by reprinting 50 copies of the Flora.

Distribution of Overstock Issues of the Proceedings

During the year, NSIS distributed 779 complimentary copies of the Proceedings (see Table 1) from the overstock inventory stored in the Killam Library. Recipients included NSIS members, lecture attendees, library patrons, science teachers, and visitors to the BIO Expo event in Dartmouth. Many lecture attendees were intrigued by issues published in the late 19th and early 20th centuries. Graduate students were also happy to discover the free copies, with some surprised to recognize their supervisors' names as the authors of articles in the *Proceedings*. NSIS will continue to give away overstock copies of the journal during the upcoming lecture season. This initiative has been a great success!

Access Copyright

In July 2017, the NSIS Librarian submitted the required forms to Access Copyright for the 2017 repertoire payment to publishers. NSIS subsequently received a payment of $337.03 (This was lower than the 2016 payment of $369.24).

Table 1 Distribution of Complimentary Copies of the Proceedings (August 2017 – February 2018)

Date (2017-18)	Event / Message	Number of copies distributed
Aug.	Message re. "free copies" sent via email to NSIS councillors and members, and posted to NSIS website and Facebook.	285
Sept. 18-23	Science Literacy Week display tables - Killam Library	154
Sept. 20-24	Bedford Institute of Oceanography Expo, Dartmouth, NS	65
Oct. 27	Atlantic Science Teachers' In-service Day, Halifax, NS.	100
Nov. 29	Huntsman Award Lecture, Dalhousie University	47
Dec. 4	NSIS Lecture, Acadia University, Wolfville, NS.	39
January 8th	NSIS Lecture, Central Library, Halifax, NS.	59
February 21st	Royal NS Historical Society lecture, Halifax, NS.	30
	Total distributed during August 2017 to February 2018	779

Copyright-Related Requests

On November 6th, NSIS granted permission to Biodiversity Heritage Library (BHL), based at Harvard University, to redigitize the Proceedings of the NSIS. When BHL loads these files to its online platform, it will provide researchers around the world with additional options and ways to search the contents of the *Proceedings*.

On November 16th, Warren Reed requested permission to reprint an NSIS publication in combination with primary source material from the Nova Scotia Archives. Entitled *Titus Smith: "The Dutch Village Philosopher", Pioneer Naturalist of Nova Scotia, 1768-1850*, the booklet was published in 1938. As the author Harry Piers died 78 years ago, the text is now in the public domain, and no permission was required from NSIS.

Institutional Members and Exchange Partners

Renewal notices were sent to institutional members in March 2018. There are currently 16 institutional members and 86 NSIS exchange partners.

NSIS Exchange Journal Collection

NSIS receives journal issues from exchange partners around the world. As an example, from April 2017 to March 2018, 110 journal issues and society publications were delivered to the Killam Library from the Institute's exchange partners. These items have been processed and added to the NSIS collection in the Killam Library.

On behalf of NSIS, I would like to thank the Killam Library's Administrative Assistant Carol Richardson and the staff of the library's Serials Department who process the exchange journals and make them shelf-ready. In fact Carol graciously finds time to assist NSIS in many ways. She responds to NSIS councillor requests, collects NSIS mail, locates copies of exchange journals for document delivery requests, sells copies of the *Flora* to students, prepares mail-outs, tallies the AGM dinner registrations, and generally provides the NSIS Librarian with much-valued support. We are very fortunate and thankful to have her! Looking back on this year, Carol expressed satisfaction with the popularity of the free giveaways (NSIS *Proceedings*), an initiative that is helping to free up much-needed space in the Killam Library basement.

Respectfully submitted by:
Michelle Paon
NSIS Librarian
May 3, 2018

APPENDIX A

Proceedings sold by Killam Library Reference & Research Services Office
April 2017 – March 2018

Date (2017)	**Volume/Issue of *Proceedings of the Nova Scotian Institute of Science***	**# Sold**	**Price**	**Amount Received ($)**
April	Flora of Nova Scotia	1	$35.00	$ 35.00
May	Birds of Brier Island	2	$15.00	$ 30.00
May	v. 34, pt. 3/4	1	$10.00	$ 10.00
May	v. 31, pt. 1	1	$10.00	$ 10.00
July	Flora of Nova Scotia	11	$35.00	$385.00
Nov.	v. 48, pt. 2	1	$15.00	$ 15.00
Dec.	v. 49, pt. 1	1	$15.00	$ 15.00
Totals		18	-------	$500.00

WEBMASTER'S REPORT
AGM MAY 2018

General maintenance of the NSIS website was kept up for the 2018/2019 year, including regular posting of news items and information on the lecture series.

This is my last report as NSIS Webmaster, as mentioned in my April 2018 report. I was unable to find an appropriate replacement for a new Webmaster to continue for the 2018/2019 NSIS year.

A meeting is proposed with the President and Vice-President of the NSIS to discuss the future of the website management. I am also suggesting that a member of the Council continue the routine management of the website, in the interim, while seeking a Webmaster and a web designer for the proposed redesign of the website. I will provide the username and password for the NSIS website and provide a brief description of how the site is organized.

The new Webmaster should be able to continuously monitor the site given the proposed interactive design (e.g., photograph, video, links to NSIS social media, and Paypal). The new Webmaster will also coordinate the hiring of a web-designer to enable the NSIS website to support these new functions.

Action requested: NSIS President and/or Vice-President to advise on an appropriate time to meet to discuss handing over responsibilities for future maintenance of the website.

Submitted by
Suzuette Soomai, Webmaster

STUDENT SCIENCE WRITING COMPETITION 2018

May 2018 Report for the AGM

This year 15 students (4 undergrad, 11 postgrad) expressed interest in participating, and 7 students (2 undergrad, 5 postgrad) submitted manuscripts. This was fewer than in recent years, so we will take steps to increase participation next year.

In March the seven judges assessed the manuscripts and selected the following:

Undergrad Winner:
No paper qualified as a winner this year.

Undergrad Hon. Mention:
Bronwen Schryver (MSVU) for the paper *"Childhood-Onset Schizophrenia: Trajectories of Gray and White Matter Development and Associations with Clinical Outcomes"* .

Postgrad Winner:
Loay Jabre (Dal) for the paper *"Deciphering the Scent of Phytoplankton Around Sable Island, Nova Scotia"*. ($750 Prize)

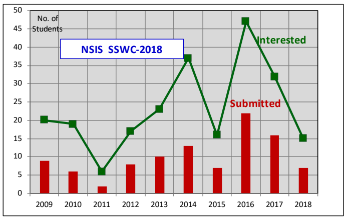
Postgrad Hon. Mention:
Casey Jones (Dal) for the paper *"A Quantified Society: How Genetics Is Changing the Way We Do Healthcare"*.

Certificates and cheques were awarded at the beginning of the April 3rd NSIS public lecture.

The judges also discussed constructive feedback which was given to each contestant, and ways to improve the competition in future years. Thanks to Tom Rand, John Rutherford, Pat Ryall, Rick Singer and Don Stoltz for their hard work.

Univ.	Interest	Submitted
Acadia	0	0
CBU	0	0
Dalhousie	12	5
MSVU	1	1
SFX	0	0
SMU	2	1
Total =	15	7

Year	Interest	Submitted
2009	20	9
2010	19	6
2011	6	2
2012	17	8
2013	23	10
2014	37	13
2015	16	7
2016	47	22
2017	32	16
2018	15	7



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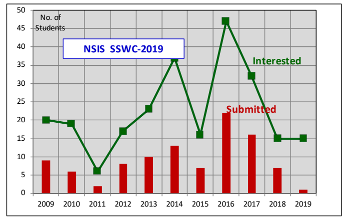
2014	37	13
2015	16	7
2016	47	22
2017	32	16
2018	15	7
2019	15	1



Hank Bird
SSWC Coordinator

NSIS EXCURSIONS 2018
REPORT FOR AGM, MAY 2018

We did three excursions in late 2016:

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

And in 2017 there were the following five:

- Burke-Gaffney Observatory
- Joggins Fossil Cliffs
- Shubenacadie Canal
- Bedford Institute of Oceanography
- Dalhousie Planetarium

Based on a survey of the membership, we selected 3 of the more popular excursions (from a list of 10) to do in the Spring, Summer and Fall of this year. They are:

- Labrador Castle Hike (East River) Pat Ryall
- Otter Ponds Demonstration Forest (Shubie Park) Hank Bird
- Petroglyphs and Guided Nature Hike (Kejimkujik) Peter Wells

The following has been added and will take place on June 2nd:

- Habitats & Habits of NS Birds (Brooklyn) Hank Bird

We may also arrange a repeat of The Art and Science of Making Beer, or arrange an excursion to a vinyard.

Thanks to Linda Marks and Nicole LeBlanc for canvassing the membership and the student community.

Each excursion is being set up and organized separately by the person listed. Announcements and details should begin to appear soon.

Hank Bird
Excursions Coordinator

NSIS 2018-2019 PUBLIC LECTURES

The lecture series committee proposes the following line-up for the 2018-19 series. Titles and abstracts will be available by the end of May.

Oct 1, 2018
Jeff Hutchings (Professor and Killam Chair in Fish, Fisheries and Oceans, Dalhousie University). Distinction between Advice and Advocacy in Science.

Nov 5, 2018
Shelley Adamo (Department of Psychology and Neuroscience, Dalhousie University). Zombies in the natural world: how a parasitic wasp hijacks the brain of its caterpillar host.

Dec 3, 2018
Bruce Ewert (L'Acadie Vineyards). The Science of Sparkling Wine in Nova Scotia.

Jan 7, 2017
Noni MacDonald (Department of Pediatrics, Dalhousie University). MicroResearch in the Nova Scotian Context: how approaches used successfully in Uganda may help to address health issues in Nova Scotia.

Feb 4, 2017
Zoe Lucas (Sable Island Green Horse Society) on Sable Island.

March 4, 2017
Bruce Hatcher (Director of the Bras d'Or Institute and Chair in Marine Ecosystem Research, Cape Breton University). Bras d'Or Lakes Biosphere.

April 1, 2017 (TBC)
Shelley Denny or alternate (Director of Aquatic Research and Stewardship, Unama'ki Institute of Natural Resources). Use of Science and Two-eyed Seeing to Address Aquatic Issues of Importance in Cape Breton.

May 6, 2017 (TBC)
Ross Firth or Peter Green (Nova Scotia Nature Trust). 100 Wild Islands on the Eastern Shore, NS.

Tana Worcester
Chair of 2018-19 NSIS Lecture Committee
Vice President, NSIS

NOMINATIONS FOR NSIS COUNCIL 2018/2019

President	Tana Worcester
Vice-President	Darlene Smith
Past-President	Sherry Niven
Secretary	Lorraine Hamilton
Treasurer	Angelica Silva
Publicity Officer	Nicole LeBlanc
Membership Officer	Dylan Miller
Librarian	Michelle Paon
Editor	Peter Wells
Webmaster	TBA
Councillor	Tamara Franz-Odendaal
Councillor	Hank Bird
Councillor	Donald Stoltz
Councillor	Richard Singer
Councillor	Carol Morrison

NOVA SCOTIAN INSTITUTE OF SCIENCE MEMBERSHIP FORM 2019-2020

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Memberships (please check one):

Regular member $30 _____

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Life membership $300 _____

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

Voluntary Donation (Tax receipt will be issued): ___________

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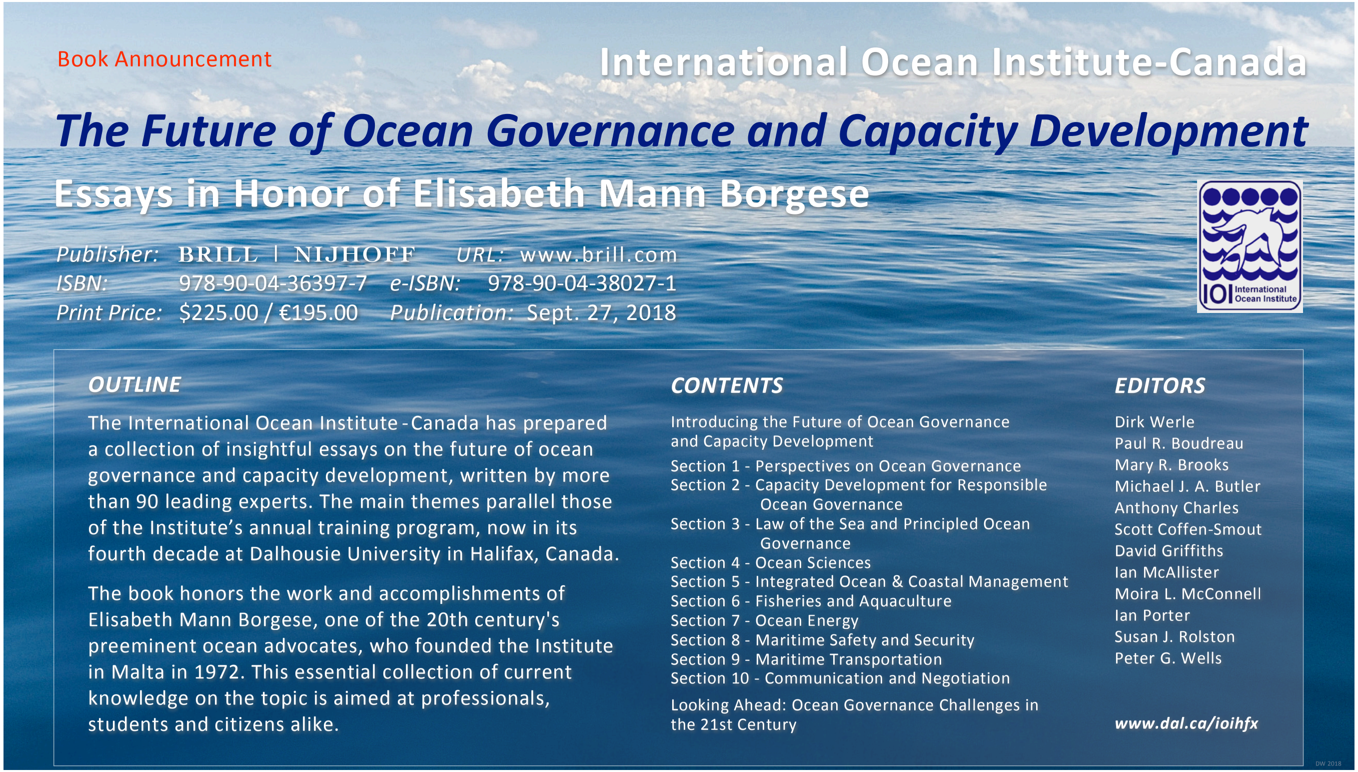
c/o Reference and Research Services
Killam Memorial Library | 6225 University Avenue
PO Box 15000 | Halifax, NS Canada B3H 4R2


Book Announcement
International Ocean Institute-Canada
The Future of Ocean Governance and Capacity Development
Essays in Honor of Elisabeth Mann Borgese
Publisher: BRILL | NIJHOFF URL: www.brill.com
ISBN: 978-90-04-36397-7 e-ISBN: 978-90-04-38027-1
Print Price: $225.00 / €195.00 Publication: Sept. 27, 2018
IOI International Ocean Institute
OUTLINE
The International Ocean Institute - Canada has prepared a collection of insightful essays on the future of ocean governance and capacity development, written by more than 90 leading experts. The main themes parallel those of the Institute's annual training program, now in its fourth decade at Dalhousie University in Halifax, Canada.
The book honors the work and accomplishments of Elisabeth Mann Borgese, one of the 20th century's preeminent ocean advocates, who founded the Institute in Malta in 1972. This essential collection of current knowledge on the topic is aimed at professionals, students and citizens alike.
CONTENTS
Introducing the Future of Ocean Governance and Capacity Development
Section 1 - Perspectives on Ocean Governance
Section 2 - Capacity Development for Responsible Ocean Governance
Section 3 - Law of the Sea and Principled Ocean Governance
Section 4 - Ocean Sciences
Section 5 - Integrated Ocean & Coastal Management
Section 6 - Fisheries and Aquaculture
Section 7 - Ocean Energy
Section 8 - Maritime Safety and Security
Section 9 - Maritime Transportation
Section 10 - Communication and Negotiation
Looking Ahead: Ocean Governance Challenges in the 21st Century
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The Proceedings accept original research papers, commentaries, reviews of important areas of science and science history, student award papers, and book reviews.

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

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

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

For the **general layout of papers**, refer to recent issues of the Journal. Pages of the submitted WORD document should be numbered. Provide a running head for the paper.

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

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

As appropriate, **sections within the paper** entitled Introduction, Methods, Results, Discussion, Conclusions, and References should follow. Canadian spelling and SI units should be used wherever possible. References cited in the text in brackets should be separated by commas and personal communications should be as follows: Smith A.J. (2001, pers. comm.). *Latin* or *scientific* names should be in italics, as well as abbreviations such as *et al*. **Please spell check the entire paper before submitting.**

All **tables, figures, photographs** and **other illustrations** should be numbered and have a self-explanatory caption. **They are be attached to the submission as separate high resolution files and not embedded in the working WORD document.** Authors should indicate where each item might be placed in the manuscript.

Authors are encouraged to submit **figures, photographs** and **illustrations** in colour. Colour versions will be placed on the NSIS website and in the PDFs provided to authors. Black and white versions will be in the print copies, unless color output is otherwise requested. There will be a charge ($25 per page) containing color in the printed papers.

References are to be in alphabetical order – name first, followed by initials, with no space between initials. For cited papers, give the full title of the journal (in italics), volume and issue numbers where appropriate. Examples of formatted references, covering monographs, chapters in monographs and papers, and with close attention to spacing, follow:

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

Website Citation should follow this pattern: Author (year) title, URL and date accessed. An example follows:

Graymont Western Canada Inc. (2015). Giscome Quarry and Lime Plant Project Application for an Environmental Assessment Certificate. Environmental Assessment Office. projects.eao.gov.bc.ca/p/giscome-quarry-and-lime-plant/docs (Accessed Dec. 18, 2017).

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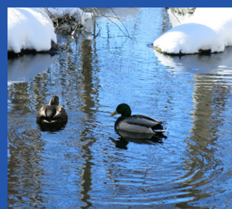

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