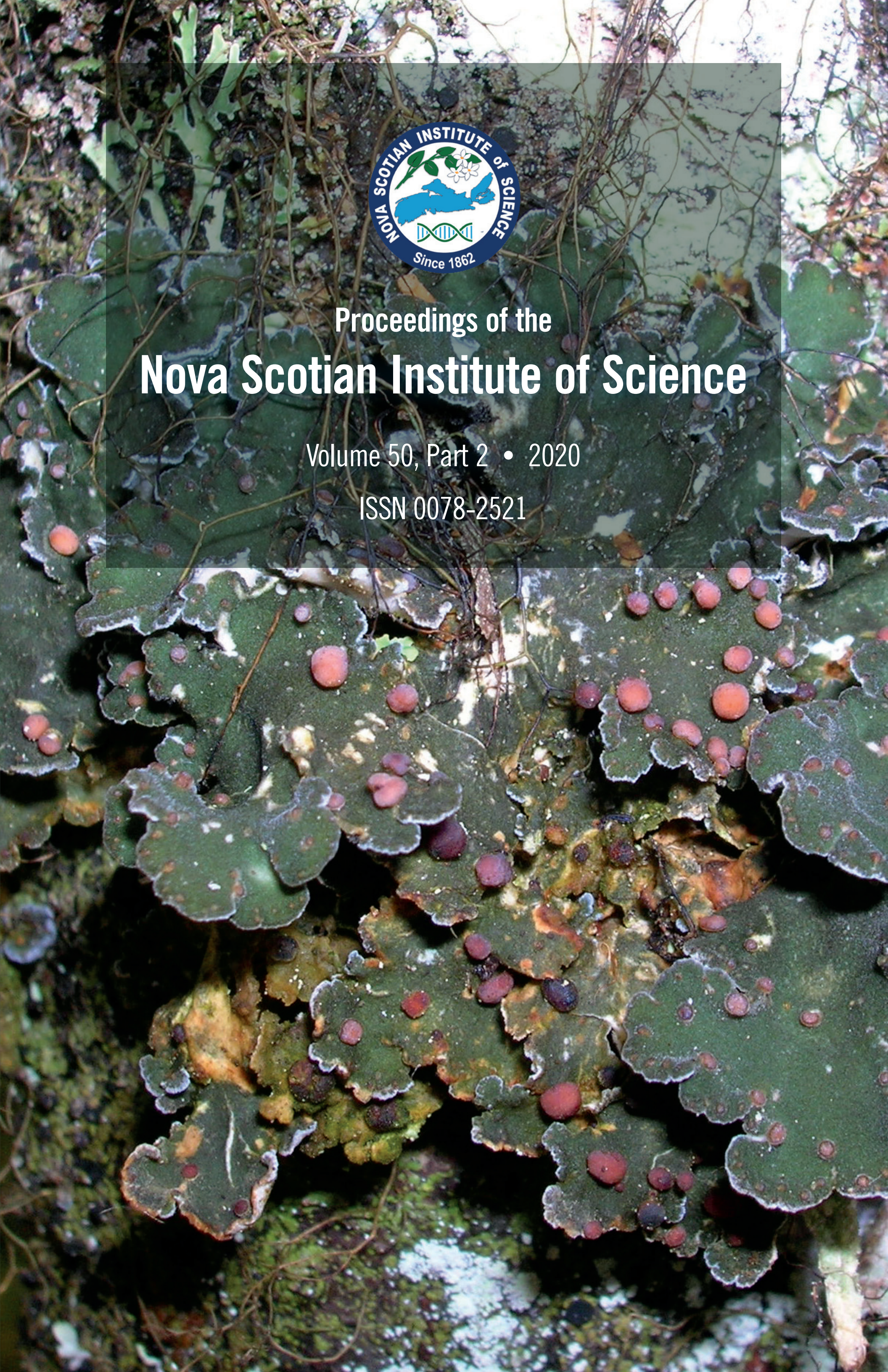

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Cover photo credit: Robert Cameron, *Boreal felt lichen*.

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EDITORIAL

Reflecting on the importance of scientific anniversaries - the SS *Arrow* oil spill in Chedabucto Bay, NS, in 1970

Scientific anniversaries are times of appreciation and reflection – appreciation of the significance of a discovery, event or process, the persons or people involved, and reflection of its longer significance to human-kind. For example, last year (2019) was the 50th anniversary of the Apollo landing on the moon on July 20th, 1969 (Berg 2019), the first time humans had exited the Earth to land on another planetary body; the 75th anniversary of Erwin Schrodinger's prescient book "What is Life" (Schrödinger 1944), which stimulated several advancements in molecular biology and structural chemistry that led to the discovery of the structure and role of DNA; the 150th anniversary of the Periodic Table of the Chemical Elements, a landmark achievement in chemistry by the Russian scientist Dmitri Mendeleev (Szuromi 2019); and the 500th anniversary of Leonardo da Vinci's death in 1519 (Wikipedia), whose many outstanding contributions to the sciences and arts were celebrated worldwide. These anniversaries make us pause and reflect on advancements in science that are important stepping stones of progress in our scientific knowledge and practice.

Closer to home in Nova Scotia, NSIS recognized its 150th anniversary in 2012 and the contribution of the Institute to scientific dialogue in Nova Scotia and the Maritimes. That year was also the 50th anniversary of the publication of *Silent Spring*, by the American author and marine scientist Rachel Carson. This remarkable book galvanized recognition of the harm being done to ecosystems by persistent toxic chemicals and that led to the world-wide environmental movement. The environment is at the heart of this editorial, drawing attention to the anniversary in 2020 of an event in eastern Canada that helped shape an important aspect of marine environmental research in Canada and beyond.

Fifty years ago, on Feb. 4th, 1970, the Liberian tanker SS *Arrow* ran aground on Cerberus Rock in Chedabucto Bay, on the east coast of Nova Scotia (Gordon *et al*. 2014; pers. observ.). Carrying 14,700 tons (108,000 barrels) of Bunker C fuel oil, the broken ship released about two-thirds of its cargo into the bay, much of it ending up on the bay's northern rocky coastline. Some of it emulsified into the water column and was transported away in ocean currents or consumed by zooplankton. Remaining oil was recovered from the wreck at the time by an emergency response program called Operation Oil, and biological surveys were initiated (Operation Oil 1970). More recently, as a result of the appearance of oil slicks, an additional several thousand litres of oil have been removed from the sunken ship (CBC News, Oct 27th, 2015). However, despite the activities by Transport Canada and the Coast Guard, oil is still present in the sediments in some coastal locations (Yang *et al*. 2018, Lane, D., pers.comm.).

The legacy of this spill to Canadian marine science, and Canada's capacity to respond to such events, is enormous and worth noting. In the years following the accident, studies ranging from the development of chemical methods (e.g., dispersant use, bioremediation) to the marine ecotoxicology of petroleum hydrocarbons were initiated (Gordon *et al.* 2014). Research programs were established to assess the fate and effects of oil in cold temperate and northern waters (Gordon *et al.* 2014), especially oil-sediment-biotic interactions. The Bedford Institute of Oceanography (BIO) became a center for such research, continuing to this day. One of NSIS's previous Presidents, Dr. James Stewart, contributed to this research through studies of the microbial degradation of oil in cold waters (Mulkins-Phillips and Stewart 1974). Emergency response capabilities to ship-based spills were gradually improved through research by the Canadian federal government and the oil industry, especially through programs at BIO. These proved invaluable for later Maritime spills, such as the one from the *Kurdistan* in Cabot Strait in 1979. Due to concerns about hydrocarbon effects on fisheries, especially on the juvenile stages, new techniques for aquatic and marine ecotoxicology were developed (e.g., Blaise *et al.* 1988; Wells *et al.* 1998). To ameliorate the impact of spills, a major program to test the efficacy and toxicity of oil spill dispersants was established at BIO (Doe *et al*. 1978; Wells 1984), a program that continues to this day (King, T., and Lee, K, per.comm.). Dispersant use guidelines were drawn up for Canada (EC 1984), with input from local scientists. Above all, the *Arrow* spill led to increased general public awareness of the threats of spilled oil to coastal water and sediment quality, the fisheries and marine wildlife (e.g. seabirds), and the need for enhanced protection and response.

Fifty years later, work continues periodically at the site of the *Arrow* spill, improving our understanding of the persistence of oil constituents, such as PAHs (polycyclic aromatic hydrocarbons), in littoral and sub-littoral coastal sediments (e.g., Lee *et al*. 2003, Yang *et al*. 2018). The research emphasis at BIO on dispersant efficacy and bioremediation approaches for cold water environments is important as many studies have shown that components of spilled oil persist for decades in coastal environments, especially low energy shallow water ones. The field of marine environmental risk assessment has also benefited from the questions posed by such spill incidents. In particular, from what has been learned in Nova Scotia, there are implications for spill preparedness in Arctic waters, given current and future increases in ship traffic. In summary, the legacy of the *Arrow* spill event is huge and should be noted.

Many benefits emerge from noting anniversaries of scientific events or issues that have led to the application of new science. Reflecting on these anniversaries, knowing the history of local events, and making known the various key scientific discoveries is an important role for the NSIS. Too often we forget past events, their significance or the efforts of previous investigators. In general, “it is probably easier to look back and weigh the importance of a particular scientific achievement of the past than to predict how science will influence the future” (Adelman 2019). Recalling the legacy of the *Arrow* spill is important. Hopefully, it will ensure that the NSIS, amongst other organizations, will continue to commemorate such markers of our scientific progress.

To conclude, it would be remiss to overlook three other anniversaries. The year 2019 was the 100th birthday of Dr. James Lovelock, the outstanding British scientist whose chemical expertise led to the detection of chlorofluorocarbons (CFCs) that still threaten the Earth’s ozone layer, though banned decades ago. Further, his insights contributed to seeing planet Earth as a whole self-regulating system, the GAIA Principle. The NSIS acknowledges his remarkable life and achievements, an anniversary indeed, and offers its best wishes! 2019 was also the 150th anniversary of the seminal journal *Nature*, an historic milestone in scientific communication. Finally, closer to home, 2020 is the 50th anniversary of the epic voyage (1969-70) of the oceanographic research vessel CSS *Hudson*, when she circumnavigated North and South America, making numerous marine discoveries enroute. Stay tuned for much more on this story as this year (2020) progresses!

Acknowledgements The author is grateful for the comments by Michael Butler, Donald Gordon, Ken Lee and David Richardson during preparation of this article.

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ETHNOBIOLOGY OF NORTHEASTERN TURTLE ISLAND FOOD & MEDICINE: SUMMARY OF AN NSIS LECTURE[1]

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ABSTRACT

Food, medicine, and material culture are related topics. Securing access requires a respect for the natural laws of the environment. With examples from the Mississaugas of the Credit First Nation (in Ontario), Mi’kmaq First Nation, and global indigenous nations, we observe that indigenous peoples are natural leaders for achieving an ecological balance with our oral stories that document our traditional observations for millennia. Indigenous spirituality and ecological ways of knowing provide solutions for dealing with climate change, local food, medicine, and material security.

With ethnobiology, we awaken native linguistic knowledge, traditions in medicine and foods, and discover designs that were laid dormant by colonization. Native languages and verbal traditions in science carefully described a holistic role that applies to the land, while acknowledging all our relationships with water, plants, medicines, fish, flyers and crawlers, emphasizing their importance to all.

SUMMARY OF LECTURE

Dr. Ferrier began his story by recognizing that we are in Mi’kma’ki, the country and home of the Mi’kmaw and the home that provides food, medicines and material wealth for all inhabitants, which also inspires the Mi’kmaq language. The Proceedings of the NSIS was also where he published his first scientific paper. He has published three papers in the journal during his career (see References). These publications are valuable contributions to the botany in Nova Scotia (Mi’kma’ki) and demonstrate the value of the Proceedings for Nova Scotian science.

1 This was an NSIS Public Lecture on Monday, November 4, 2019. A drumming ceremony was performed by Jonathan and Kirsten Edwards prior to the start of the lecture.

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Also see www.researchgate.net/profile/Jonathan_Ferrier

In February, he began his new role as Assistant Professor at Dalhousie University. He has been busy writing and editing a biology textbook, as well as setting up his new lab that focuses on applications of metabolomics, ethnobotany and indigenous studies. During his presentation, Jonathan summarized his work using Nuclear Magnetic Resonance (NMR) to study metabolic processes in local medicinal plants, especially those of his native roots from the Mississaugas of the Credit First Nation. He has been examining blueberry (also called "miinan") extracts that may have potential applications for treating preeclampsia ("a pregnancy complication characterized by high blood pressure and signs of damage to another organ system, most often the liver and kidneys" - Mayo Clinic website).

Dr. Ferrier offered a reframing of science by providing an overview of colonial history. Another aspect of his research focuses on ancestral migration landscapes of Mississauga of the Credit First Nation along the Credit River (Missinnihe "the Trusting Creek") to Eramosa township ("Animoshag" "Group of Dogs") and the Grand River, both in Ontario. A study of colonial history revealed a move away from Anishinaabek migration life history and the sustainable balanced relationships with the natural environment.

The reframing of colonial history provides much to reflect upon, including the destruction caused by saw-mills in the 19th century, and problematic relationships of indentured indigenous workers his family on farms in the territory of the Mississauaga of the Credit First Nation. Dr. Ferrier offered insights about how the indigenous languages and names of regions within Mi'kma'ki offer more of these descriptions of ecological knowledge. The indigenous languages are a blueprint for solving many climate issues. Respecting indigenous languages in indigenous countries inhabited by Canada give us another set of solutions, previously not considered by the dominant culture.

Through application of modern techniques, including LIDAR, digital census records, Nuclear Magnetic Resonance (NMR) metabolomics and other molecular techniques, Dr Ferrier has focused on ethnobotany topics. He is bringing attention to important topics and issues as we move toward decolonization in order to speak the truth and reconcile our history.

Fig 1 Dr. Tana Worcester (NSIS President) introduces Dr. Jonathan Ferrier during his public lecture.

Fig 2 Dr. Jonathan Ferrier points to areas in his family and kin's ancestral lands around the Credit River Valley.

Note: Tana Worcester, NSIS President, stated after the presentation that *"We should continue to find ways to facilitate this dialogue between science practiced by western and indigenous people, and the ways we talk about the issues that we face – how they came to be and how we can work together to solve them. That is two-eyed seeing - eduaptmunk"*

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IDENTIFYING LICHEN-RICH AREAS IN NOVA SCOTIA

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Nova Scotia supports an exceptionally high diversity of lichen species. The province's geographic position in the North Atlantic, and high coastline length in relation to area ratio, ensure a cool wet climate that is conducive to lichens and the development of lichen habitats, particularly in coastal forests (Clayden *et al.* 2011). Furthermore, Nova Scotia transcends the boundary between boreal and temperate forests, and therefore is colonized by lichen species either on the northern or southern limits of their geographic distribution (Davis and Browne 1996). Some examples include Boreal Felt Lichen, an endangered lichen at the southern extent of its range in North America and Vole Ears, an endangered lichen at the northern extent of its global range (Maass & Yetman 2002, Cameron *et al.* 2011).

Many lichen species which are relatively common in Nova Scotia are rare and declining in the northeastern USA, and these are listed by Hinds & Hinds (2007). Our province has a disproportionately high number of nationally listed lichen species. Nine of the of 24 lichen species listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in Canada occur in Nova Scotia (COSEWIC 2019). Furthermore, roughly 10 percent of all the wildlife species listed provincially as At-Risk are lichens (Nova Scotia Department of Lands and Forestry 2019).

Like many other organisms, the distribution of lichens is neither random nor even across the landscape in Nova Scotia. Most of the at-risk, rare or uncommon lichens in NS occur in specific habitats in association with other at-risk lichen species in spatially discrete localities (Cameron & Richardson 2006, Cameron & Neily 2008, McMullin *et al.* 2008). Lichens such as the Boreal Felt Lichen, tend be clustered, with some clusters having high populations (Cameron & Neily 2008, Cameron *et al.* 2013).

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Given the diversity and number of rare lichens in the province, the Nova Scotia Lichen Recovery Team recognized the importance of identifying the specific areas with the highest lichen-richness. The intent was to identify these areas and direct efforts towards their conservation. Protection of these areas should ensure a more efficient conservation and protection of important lichen ecosystems, so helping to preserve the at-risk species.

A small team met in November 2016 and April 2017 to review lichen distribution data for Nova Scotia and identify Lichen-Rich Areas in the province. The team was aware that large parts of the province have not been searched for lichens. Thus this assessment reflects what has been achieved with the available data and using the personal knowledge of the team of expert lichenologists. We recognize that other Lichen-Rich Areas may occur which have not been as yet identified. Data sources used included the Atlantic Canada Conservation Data Centre (AC CDC), the Mersey Tobeatic Research Institute and the knowledge provided by expert lichenologists.

The initial approach was to develop and apply a set of criteria that captured the most significant Lichen-Rich Areas of the province. The following criteria were proposed and used to select the Lichen-Rich Areas:

Must have all of the following:

1. Treed swamps, bogs, fens, riparian swamps and floodplains and their associated critical function zones as defined in the Voles Ears Recovery Strategy (Environment Canada 2014);
2. Historical continuity of forest cover as determined using historical satellite imagery, aerial photographs, forest cover Geographical Information System (GIS) data from Department of Lands and Forestry and field observations from lichenologists;
3. Low to zero anthropogenic disturbance prior to discovery of the site as revealed by a lack of human disturbance observed during field surveys;

And two or more of the following features:

4. Three or more records of lichen species that are rare, uncommon or At-Risk in Nova Scotia as defined by a status of S1, S2 or S3 by the AC CDC;
5. Three or more records of lichen species that are rare and declining elsewhere in Northeastern North America as indicated by Hinds

& Hinds (2007) such as *Fuscopannaria leucosticta, Heterdermia leucomela* and *Pannaria lurida* or Goward *et al.* (1999) such as *Leptogium corticola, Letogium subtile* and *Everniatsrum catawbeinse*;

6. Two or more thalli of a species listed as Endangered or Threatened under provincial or federal legislation.

Lichen Concentration Area Boundaries

Recent research on Boreal Felt Lichen indicates forestry and other activities within 500m can be a factor in mortality (Cameron *et al.* 2013). This 500m zone of influence is reflected in the Special Management Practices for Crown Land adopted by the Nova Scotia Department of Lands and Forestry (2018) and recommended by the Nova Scotia Lichen Recovery Team. For sites where the Boreal Felt Lichen has been found, the boundaries were set to a 500 m radius zone. For all other species which are known to be sensitive to disturbance but for which less research exists, a 200m radius boundary was adopted.

RESULTS AND CONCLUSIONS

Twenty-five Lichen-Rich Areas were identified and mapped using GIS. These Areas occur in 8 counties in NS (Fig 1). The total area for the 25 was calculated as 5482 ha. Most Lichen-Rich Areas lie along the Atlantic Coast from Shelburne to Cape Breton County although one Area was identified in Digby County and another in Cumberland County. Shelburne County had more Lichen-Rich Areas than any other county with nine being identified in this county alone. Although all Areas have remarkably rich lichen floras, one Area in Shelburne County is exceptional as it contained *Leptogium hibernicum*, which is extremely rare in North America, and the Endangered Boreal Felt Lichen and Endangered Vole Ears in addition to several other At-Risk lichens. The Richmond County Areas were notable for the high populations of Boreal Felt Lichen while an area in Digby County contained the only occurrence of *Heterodermia leucomela* in the province in addition to *L. hiburnicum* and many other At-Risk lichens.

The Lichen-Rich Areas identified in this study require extremely careful management and conservation. Clear-cutting in or near these areas must be avoided if we are to retain these Lichen-Rich Areas. We recommend that these Areas be left undisturbed by human activity.

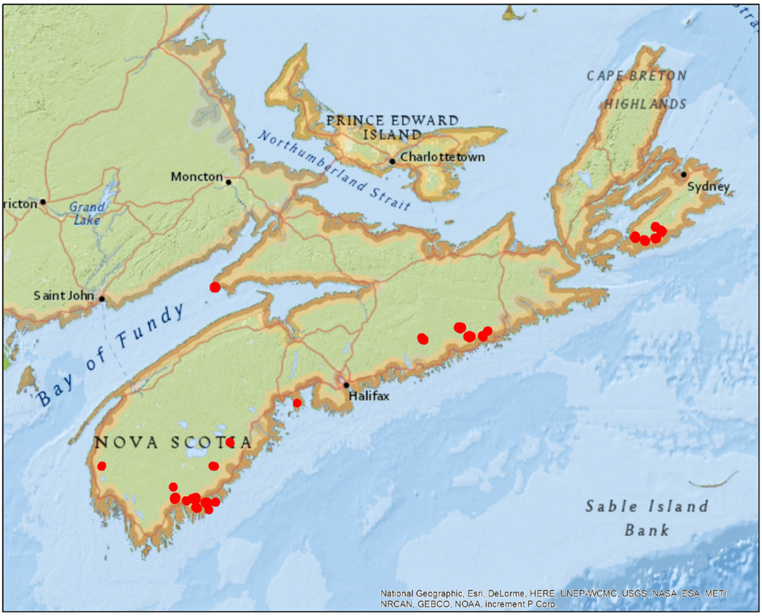

Fig 1 Approximate locations of twenty-five Lichen-rich Areas identified by lichenologists in Nova Scotia, using six criteria.

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THE CITY NATURE CHALLENGE 2020

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In April 2020, six areas in the Maritimes will participate in the international City Nature Challenge (CNC). This citizen science event sponsored by the Natural History Museum of Los Angeles and the California Academy of Sciences is organized locally by a number of keen naturalists and outdoor enthusiasts. The local objectives are simply to encourage people to get outdoors; to explore; to observe nature; to share observations; and to have fun.

Local activities and promotional information such as the Maritime CNC2020 poster (Fig 1) will be accessible on the Facebook page of CityNatureChallengeMaritimes.

The first CNC took place in 2016 in California with just two cities involved. It has grown exponentially since then, with 159 cities including the Halifax Regional Municipality competing in 2019. It is expected that over 250 cities from around the world will compete in 2020 to see who can make the most observations of nature, find the most species, and engage the most people.

The CNC competition takes place in two parts over the course of 10 days. First, nature observations (photos of wild plants and animals) are recorded. This is followed by a short period for these observations to be uploaded and identified by the iNaturalist community as best as possible before the challenge ends. The final numbers across three categories (total observations, total species, and total participants) are counted for each competing city/area project and winners are announced. The dates for 2020 are as follows: April 24-27 observation/collection period; April 28 - May 3 final upload and identification period; May 4 winners announced.

The platform for sharing observations of wild flora and fauna is iNaturalist. In Canada, iNaturalist.ca is led by the Canadian Wildlife Federation, along with Parks Canada, NatureServe Canada, and the Royal Ontario Museum, all collaborating with iNaturalist.org. iNaturalist is a joint initiative of the California Academy of Sciences and the National Geographic Society.

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Fig 1 The CNC2020 poster for the six Maritime areas.

Registering the Maritimes to participate in the CNC is a simple way to introduce our community to iNaturalist. The timing of the event, April, may not be a prime time to assess the biodiversity of our region. It does, however, occur on the weekend following the 50th anniversary of Earth Day, April 22nd. This is an excellent opportunity for everyone to get outdoors after a long winter and record information about the natural history in our area. Observations at this time of year may highlight the fact that spring has arrived or is on its way.

Maritimers across the region are concerned about climate change. Sharing observations with iNaturalist is one simple method to compile information required to understand and manage our resources, and to document environmental change. These observations will help verify species distribution or help fill temporal/spatial coverage. The City Nature Challenge 2020 is an excellent opportunity to learn how you can contribute, as a citizen scientist. Members of the NSIS are encouraged to participate, and also to ask their friends and colleagues to become involved too. Given the environmental challenges of climate change and other stresses, every recorded observation counts!

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RESPONDING TO THE CALL FOR CLIMATE ACTION

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ABSTRACT

Global calls for action on climate change have become more urgent in recent years. However, how to act to achieve climate sustainability remains elusive. The evidence is clear that governmental initiatives – global, national, and provincial – have not been able to coalesce into a meaningful strategy for climate sustainability. What is required is a shift in climate responsibility from governments to individuals and communities who think globally but are best able to act locally. To encourage the citizenry to act requires a science-based information and education whereby climate action is clearly defined along with the consequences of actions (or inaction). Education must include a climate curriculum as a mainstream subject in our schools. Using this approach, local community baselines of climate information, vulnerability, and adaptive capacity can be established. In enhancing their climate roles, governments' need to shift from carrying out mandates for climate response, to becoming auditors of carbon use in which citizens and businesses are given incentives to reduce carbon footprints. Finally, increased investments need to be directed to communities so that they can take more responsibility and be more prepared to live with climate change impacts. Governments also need to engage the community in participatory strategic long-term planning for adaptation to the changing climate.

Keywords: climate action, climate responsibility, institutional arrangements, science-based information, education legacy, strategic planning, community investment

INTRODUCTION

On September 23, 2019, led by a 16-year-old Swede, Greta Thunberg, *Time* magazine's Person of the Year 2019, massive demonstrations took place all around the world for climate change action in concert with the United Nations Climate Action Summit in New York City and the

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Global Climate Strike (United Nations 2019). These recent worldwide protests[1] led by the youth of the world called for immediate global action on climate change (Global Climate Strike 2019). Evidently, it is not acceptable simply to acknowledge climate change, rather it is imperative that we do something about it and soon.

'Ay, there lies the rub' (from *Hamlet*). But what do we DO? How do we ACT? We may be willing to act, and we may even be willing to incur "abrupt and disruptive" change as many climate change activists insist (National Research Council 2013). However, the problem is twofold: (1) by default, climate action directives come from global institutions and national governments which have taken on the responsibility to act on our behalf; and (2) we have very little idea of the consequences of "mandated actions", nor do we know and understand the suite of appropriate actions or how to determine and evaluate them. More likely, "action" is interpreted as a tax paid to our governments that provide others with some undetermined and unclear capability to act. Under these circumstances, how can we be expected, as individual citizens, to know what to do? Global protests calling for "government action" only complicate the vague idea of doing the 'right thing'.

It has taken years to arrive at the current climate crisis situation. Temperature change associated with global warming is referred to with respect to "pre-industrial levels"[2] which, in turn, refers to the '1850 to 1900 baseline period' (King *et al.* 2017). This time period predates all those alive today. Similarly, our strategic forecasts to the end of the 21st century are beyond the lifetimes of nearly every adult person now alive. Thus, whatever actions we take now, the proponents of those actions will not be in a position to observe the associated impacts. As such, we are behaving as proxies for future generations who must live with the consequences of our actions today.

[1] There have been several global climate demonstrations in recent years - 2009 (Mobilization for Copenhagen), 2014 (People's Climate March), 2015 (Global Climate March), 2017 (People's Climate March), and the 2019 Global Climate Strike (Wikipedia 2019).

[2] Paris Accord commitment, Article 2(a): "Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (UNFCCC 2015).

Current approaches do not work. It can be argued that decisions made now are inconsequential to current citizens or constituents. This may be the reason why governments, led by politicians on finite mandates, are not capable of addressing the strategic consequences of climate change. Top-down government-led global initiatives are not able to overcome the political difficulties of achieving change to our existing systems that would alter our economic status quo and cause prolonged hardship. In response to yet another impressive mobilization of global demonstrations on climate, *The Economist* (2019) recently reported:

> "The [September 2019 New York United Nations Climate Action] Summit concluded with a torrent of announcements. There was a commitment by 65 countries and the European Union to reach zero-net carbon emissions by 2050… Some announcements were promises of future announcements. Fully 59 countries said they would shortly be unveiling more ambitious commitments under the Paris agreement… Even if all the pledges are acted on, though, the gap between what the summit promised and what needs to be done remains a chasm… Between 1988 and 2015, 71% of greenhouse-gas emissions came from fossil fuels sold by 100 energy giants… including Exxon-Mobil, Royal Dutch Shell and BP. The firms vowed to limit methane emissions and highlighted their investment into carbon capture and sequestration. But they also explained that they were continuing to develop new oil and gas fields… They are unlikely to stop unless demand drops off." (pp. 56-57)

Meanwhile, it is widely reported that the December 2019 negotiations at COP25, the Madrid Summit (previously the Chile Summit), broke down and the meetings ended without an agreement on the global carbon market rules designed to maintain the targets of the 2015 Paris Agreement (Keating 2019).

In the face of the damning and ever-mounting climate change evidence (UNEP 2019, IPCC 2019, 2018), we nevertheless appear unable to take actions that will enable us to adapt and have improved climate sustainability. Klein (2014) asks the question: "What is wrong with us?" and further suggests that we need an overhaul of our capitalist economy in favour of a more equitable green plan (Klein 2019).

All indicators show that Canada is a poor performer with respect to greenhouse gas (GHG) emissions and among the highest of all nations in emissions per capita (GERMANWATCH 2019).

In December 2015, enthusiasm was high in Canada when the new Minister of Environment and Climate Change returned from COP21 after the Paris Accord was signed. With a new federal government in place, Canada embarked on an ambitious program of convincing its provinces to take up a federally devised carbon pricing scheme and targeted emissions reductions. However, from the outset, opposition among some provinces to the federal nation-wide carbon tax proposal scheme, and designated emissions targets, signaled that the anticipated national program would not happen. The recent Canadian federal election (October 2019) solidified regional disparities and highlighted difficulties in arriving at national unity on issues of climate policy hand-in-hand with the planned expansion of new pipelines for Canada's oil distribution.

In Nova Scotia, renewal is promised on Climate Action but initiatives like the Municipal Climate Change Action Plan (MCCAP, Nova Scotia 2013) are now outdated. Efforts are underway to rewrite *The Environmental Goals and Sustainable Prosperity Act* with renewed targets for reduced emissions, and investments in efficient sources of renewable energy (Nova Scotia 2019). However, when these targets will be approved or how this will encourage "action" by Nova Scotia citizens or companies is not at all clear.

DISCUSSION

Shift the responsibility. The message we must take away from our ineffectiveness to date, is that governmental initiatives – global, national, provincial – simply do not work. The many historical, socioeconomic, and cultural differences negate all opportunities for global agreements to bring about "abrupt and disruptive" action on climate change.

According to Konrad and Thum (2014) the role of governments in climate change is defined as:

> "Firstly, the government has to help in improving our knowledge… Secondly, the government has to provide the regulatory framework for insurance markets… and to induce citizens to the appropriate amount of self-protection, insurance premiums have to be differentiated according to local disaster risks. Thirdly, fostering growth helps coping with the consequences of climate change and facilitates adaptation."

This role recognizes governments as facilitators to its citizenry - not as sole leaders and doers. There is an implied shift of responsibility from government departments (that claim responsibility for managing adaptation to climate change) to "citizens" and communities. It is up to the citizenry to act, e.g., by learning the risks to our families and communities. They need to understand the options, and then agree to pay the real cost of counteracting the risks. Actions by citizens are an important means of answering Klein's (2014) "civilizational wake-up call" that is realized with the engagement and empowerment of our communities which should, by necessity, "think globally, but act locally".

Governments work best when they provide incentives for the population to act, and when they facilitate actions by companies, communities, and individuals. Before we consider answers, we need to ask the question: Who is responsible for acting on climate change? The answer acknowledges that we, the citizenry, are all responsible for human-induced climate change and as a consequence, we are all obligated to act. Assuming carbon is the culprit, we are all responsible daily for our decisions to emit carbon. Yet, most of us do not know the consequences of decisions to drive our cars, take a plane trip, or operate our barbeques. In order to know how to act, we need to be made more clearly aware of these consequences.

Establish an education legacy. It is important for groups like the NSIS to invest in developing education programs to inform people of the impacts of our carbon use as citizens of a globally leading country in per capita GHG emissions. We need to understand how we generate, use and measure carbon before we can begin to make decisions as to how we can reduce our use and curb our emissions (Wells 2018, 2019). Climate change is no longer a discipline reserved for meteorologists, climatologists, and natural scientists. Rather, there is an increasing need for interdisciplinary analysis that embraces all disciplines in a manner that can be measured and easily understood by the general public. Only this will lead to actions and consequences that result in reducing carbon emissions.

In Nova Scotia, *The Environmental Goals and Sustainable Prosperity Act* should recognize and expand educational efforts to disseminate climate change issues to primary, secondary, and post secondary NS education institutions. Nova Scotia school curricula embedded in the

Grade 4 and Grade 11 provincial "Oceans 11" course should include extensive discussion on the science of climate change and climate action, and become mainstream – not optional.

The Role of Governments – 'I think I'd better think it out again!' (Fagin from the musical *Oliver*). Enlightened understanding, spurred by education based on science, stimulates the ways and means to act. In 2007, Gore (2007) argued in *Inconvenient Truth* that if appropriate 'actions' were taken soon, the effects of global warming can be successfully reversed by releasing less CO_2 and planting more vegetation to consume existing CO_2. Gore calls on individuals to help combat global warming by: recycling, speaking up in your community, buying a hybrid vehicle and encouraging everyone to watch his movie. While collectively, these actions by individuals are important, they are hardly "abrupt and disruptive". Surely, today, the urgency now exists that compels us to do much more than this. Herein lies the role of governments – to compel us as individuals to act.

Much needed actions include:

1. Audit Individuals' Carbon Footprints

As a first step in improved understanding, governments should implicate the citizenry by developing a carbon audit and an associated user pay tax based on our carbon footprints (Berners-Lee 2010). To do so requires a "carbon calculator" that would determine the total amount of greenhouse gases generated by our actions that include improving energy efficiency construction in homes and businesses, reducing heating energy costs, efficient lighting and appliances use, reduced water consumption, and enhanced composting and recycling practices[3]. The example of the Government of Newfoundland and Labrador, Department of Municipal Affairs and Environment's

[3] "A carbon footprint is the total amount of greenhouse gases (including carbon dioxide and methane) that are generated by our actions. The average carbon footprint for a person in the United States [as well as Canada] is 16 tons, one of the highest rates in the world. Globally, the average is closer to 4 tons. To have the best chance of avoiding a 2°C rise in global temperatures, the average global carbon footprint per year needs to drop under 2 tons by 2050. Lowering individual carbon footprints from 16 tons to 2 tons doesn't happen overnight! By making small changes to our actions, like eating less meat, taking less connecting flights and line drying our clothes, we can start making a big difference." (Nature Trust 2019)

carbon calculator "Turn back the tide" (Newfoundland and Labrador 2016) provides an excellent template for a more refined household audit framework that could be adopted by Nova Scotia, and indeed other provinces, as a key element of the new *Environmental Goals and Sustainable Prosperity Act*.

2. Establish new institutional arrangements

In support of the carbon use auditing role, governments need to prioritize climate change and develop new institutional arrangements that define committed strategic financing to prioritize the future. This should go beyond political mandates and provide incentives that would encourage individuals, communities, and businesses to act (Lane *et al.* 2015).

In Nova Scotia, the proposed revision of *The Environmental Goals and Sustainable Prosperity Act* should declare itself as a policy specifically associated with Nova Scotia's Action Plan on climate change. The *Act* should establish a new institutional arrangement with dedicated funding directed at informing, facilitating, promoting, and financing action by its citizens on climate change. In recognition of its importance, a new provincial department should be established that is elevated to be of the same importance as the Federal Department of Environment & Climate Change from the current secondary designation within the Department of Environment – Climate Change Unit.

3. Be prepared and Plan Strategically

A key role of the new institution would be to define community preparedness measures that take into account the uncertainties of climate emergency events and their physical, socioeconomic and cultural human impacts. Preparedness indicators include regularly exercising Emergency Operations Centre (EOC) personnel in sessions that simulate the community's response to climate emergency events that would engage and improve awareness of members of the community. Clearly specified community indicators and objectives reflect the environmental, socioeconomic, cultural, and institutional priorities of the community. These objectives are measurable indicators to be monitored and tracked as a sign of community action (Chung 2014).

The institution should take on the role of evaluator of alternative adaptation measures for the information of its citizenry, e.g., new designs for family housing with solar heating and improved insulation. Such proposals should be backed by the scientific method of problem solving, and the institution should support recommendations for climate action through the evaluation of proposed strategy options for analysis and review. The problem solving tools associated with adaptive management in conjunction with simulation and system dynamics are fundamental to strategic evaluation over the long term (Lane, *et al.* 2017).

4. Invest in Communities

With the assistance of community stakeholders, the institution should focus on improving the communities' information baselines. This information includes identifying and profiling community vulnerability, recognizing and evaluating community resilience, and community adaptive capacity. The exercise of profiling community status is preliminary to identifying community priorities, especially in the face of stochastic climate changes (Lane *et al.* 2013, Lane *et al.* 2017).

Governments need to assign responsibility for engagement and collaboration among multiple community partners by ceding authority to local communities, municipal and local authorities. Local authority and responsibility requires participatory, traditional, indigenous and direct communication that will inform, sensitize, and create ownership within the local population (Lane *et al.* 2013, Klein 2014).

Finally, municipal governments need to assert their place in climate change by forming participatory institutions to support the MCCAP programs. The Regional Municipality of Halifax (HRM) now has a climate adaptation plan (MCCAP, Nova Scotia 2013 but one which is dated). It has a template that should be used by all Nova Scotia municipalities. The MCCAP is a strategic, forward looking plan that aims to address all aspects of the climate problem for households and companies. The MCCAP also associates problems and challenges with the evaluation of adaptations and solutions to protect, retreat, and accommodate, using e.g., nature-based approaches for coastal communities facing subsidence, sea-level rise, and storm surge impacts *(*Dal News 2019). Finally, the MCCAP should ensure that we no longer simply replace existing and failing infrastructure (e.g., for water, sewage, roads, power) without planning strategically to take account of any increases in loading due to climate change or an anticipated demand for services with greater capacity into the future.

Let's hope Gore (2007) is right when he suggests that if appropriate 'actions' are taken soon by all citizens, the effects of global warming may be successfully mitigated. In order to achieve this, Nova Scotia can become national leaders whereby its citizenry are induced to act based on a strong and clearly understood foundation in science, led by groups like the NSIS, via an improved information baseline on the repercussions of climate impacts and the consequences of inaction, financed by incentives supported by our governments which should act as auditors and facilitators in our ongoing daily adaptation climate decisions and actions. We cannot fail to act in the pursuit of climate adaptation for sustainability. If we do not take up the call to action now, the consequences will be paid by our children, grandchildren, and future generations. If we do not move forward now, they will never understand why we did not act sooner.

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GENETICALLY ENGINEERED GENES: WHEN HAVE WE GONE TOO FAR?

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DNA is the code for what we call GENES, genes are the holder of all our personality traits like our hair colour, eye colour, how tall or short we are, etc. We have of thousands of genes. David Suzuki has talked a lot about genes, and how some genes carry illnesses (Suzuki, 2019), like different forms of cancer, cystic fibrosis, sickle cell anemia and many more illnesses that doctors struggle to find cures for. Now scientists think they have found a way to eliminate these illnesses forever. They have developed a strategy called CRISPR; it is a scientific method to place genes back into cells. This basically means they can extract one bad gene (a gene that carries an illness or disease), and then modify it and put it back. Like if you were to need a new battery for your phone, first they open it up, find the problem, remove the problem, replace with a new "battery" and close the phone back up and it's ready to go. Problem solved, easy as that. CRISPR is the remove, fix and replace method scientists have discovered to help cure that "bad" gene that makes faulty proteins that is killing hundreds of thousands of people every year.

Not only have scientists discovered that they can remove, fix and replace parts of genes in living humans, they have also discovered that they can use CRISPR to potentially create what we call "designer babies". Designer Babies are basically totally customized humans. You could pick everything from hair and eye colour to personality traits like being artistic or athletic. The real question is should scientists be doing these things, just because they could with a little more technology and understanding how genes work. Is there really a need for totally customized babies. CRISPR can be used to edit the genes in body cells, that can ultimately be used for curing illnesses and diseases. Or it can be used to edit genes in germ line cells, to prevent diseases. Germ cell editing can be inherited, so if they are changed a gene, then the edited gene will be passed along to the next

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generation. The problem is that we don't know what we don't know. There could be many errors but at this time we have no idea what they are and when they will appear.

There is a group of people going by the name biohackers! These people are attempting to engineer their own genes in the comfort of their own homes, which can be extremely dangerous.

What are we willing to allow and what are we not? When have scientists gone too far? In fact, the US FBI thinks of CRISPR as a weapon of possible mass destruction. Canada has a law against using CRISPR for customizing living things (which includes pets, humans, other animals or plants). Canada was smart to make strict rules before they were even needed. Many people including qualified scientists and doctors are attempting to bend the laws in order to invent and create the future generation of designer babies. Although I'm not quite sure we're ready for this, it's happening whether we like it or not.

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ABSENCE OF RECOVERY IN A DEGRADED EELGRASS (*ZOSTERA MARINA*) BED IN NOVA SCOTIA, CANADA: RESULTS FROM A TRANSPLANT STUDY

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ABSTRACT

By the early 2000s, the invasion of the European green crab (*Carcinus maenas*) had caused a severe decline of eelgrass (*Zostera marina*) beds in eastern Canada. The formerly lush eelgrass bed in Benoit Cove, Nova Scotia, was extirpated by 2009 and has subsequently failed to recover. The objective of our study was to establish if Benoit Cove (BC) has reached a new equilibrium in which eelgrass cannot recolonize. From July 3 - August 29, 2018, we transplanted eelgrass using frames and monitored eelgrass growth and survival relative to the nearby donor (control) site in Tracadie West Arm (TWA) that had an extensive eelgrass meadow with over 95% cover. Transplant survival was 91.6% and 15.4% for TWA and BC, respectively ($P < 0.001$). Above-ground growth declined at both sites, and could be associated with high summer water temperatures and/or extreme epiphytism. Sediments at both sites had high silt composition (> 28%), and the absence of a macrophyte canopy lead to increased light attenuation in BC in moderate wind and tidal currents. The low density of green crabs in both BC and TWA (0.01 m^{-2} and 0.08 m^{-2}, respectively), and the apparently healthy eelgrass bed in TWA, suggest that green crabs are not having a negative effect on eelgrass in this system and are not responsible for the lack of recolonization of eelgrass in BC.

Keywords: Atlantic Canada; eelgrass bed; European green crab; transplant; *Zostera marina*

INTRODUCTION

Zostera marina, commonly known as eelgrass, is a vascular marine macrophyte that forms extensive perennial beds in subtidal and intertidal habitats (Green and Short 2003, Vandermeulen *et al*. 2012). Eelgrass beds occur along all three Canadian ocean coastlines

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but are most abundant in Atlantic Canada (Vandermeulen *et al.* 2012). Eelgrass is the dominant macrophyte in shallow estuaries in the southern Gulf of St. Lawrence of all three Maritime Provinces. In addition to their physical structuring of these environments and their primary production, eelgrass beds provide shelter and support for an abundance of aquatic animal and plant communities as well as waterfowl species (Burkholder and Doheny 1968, Seymour *et al.* 2002). The combination of a unique rooting system and elongated blades help eelgrass baffle wave energy, prevent coastal erosion, maintain water quality and clarity, facilitate nutrient cycling, and absorb carbon dioxide (Davis and Short 1997, Malyshev and Quijón 2011, Orth and McGlathery 2012, Neckles 2015). In the early 1930s, eelgrass beds in North America experienced a decline of over 90% which brought attention to its major contribution to marine food webs (Bertness 2007). The extreme die-off of eelgrass was caused by 'wasting disease', an infection of the slime mold pathogen *Labyrinthula zosterae* (Muehlstein *et al.* 1991), and it took 30–40 years for these areas to recover (Short and Short 2003).

On a global scale, seagrass cover has declined 7% each year since the 1990s (Waycott *et al.* 2009). Over the last two decades, direct and indirect anthropogenic impacts have been responsible for nearly 18% of the globally reported seagrass decline (Duarte *et al.* 2004). In eastern North America, current eelgrass decline is often a result of pollution and physical disturbance caused by increased human population along the coast (Short and Burdick 1996).

An indirect anthropogenic impact known to influence the distribution and health of eelgrass beds is the introduction of invasive species. Since the early 2000s, the invasion by and settlement of the European green crab (*Carcinus maenas*) has contributed to a severe decline in eelgrass beds in estuarine habitats in Atlantic Canada (Seymour *et al.* 2002, Malyshev and Quijón 2011, Garbary *et al.* 2014). From 2001 to 2002, 13 estuaries along the southern Gulf of St. Lawrence had a mean above-ground biomass decline of nearly 40% (Hanson 2004). In Newfoundland, a Before-After-Control-Impact (BACI) study showed that eelgrass habitats with green crabs experienced a 50% decline in biomass since 1998 and up to 100% loss for sites that have had large populations of green crabs for an extended period (Matheson *et al.* 2016). In Antigonish Harbour, Nova Scotia, eelgrass beds underwent a 95% loss of biomass in one year, which caused a 50%

decline in the number of migrating geese and duck species that depend on those beds (Seymour *et al.* 2002). The removal of eelgrass shoots is caused by the green crabs' natural behaviour. In soft-sediment habitats, adult and juvenile green crabs dig pits into the substrate for food and shelter which leads to the uprooting of eelgrass shoots (Malyshev and Quijón 2011, Garbary *et al.* 2014).

RESEARCH PURPOSE AND OBJECTIVES

Tracadie Harbour (TH), in St. Georges Bay on the north shore of Nova Scotia facing the Gulf of St. Lawrence (Fig. 1), was heavily impacted by the green crab invasion. While nearby habitats such as Antigonish Harbour and Pomquet Harbour have largely recovered over the years, the small inlet of Benoit Cove, appears to have entered a new stable state in which eelgrass has been unable to recover. In 2002, roughly 50,000 m^2 of Benoit Cove's (BC) total area (68,400 m^2) comprised a dense bed of *Z. marina* (Garbary *et al.* 2014). From July to September 2002 eelgrass density declined from 175 shoots m^{-2} to less than 50 shoots m^{-2}, and this decline was associated with green crab foraging (Garbary *et al.* 2014). Subsequently, the decline continued, and by 2009 eelgrass was extirpated (Garbary *et al.* 2014). The benthos of the cove in 2018 comprised unvegetated (i.e. no macrophytes) sediment with a microalgal and bacterial biofilm, with snails (periwinkles and mud snails) and rare crabs (mudcrab and green crabs) being the conspicuous fauna.

The aim of this study was to determine whether BC has transitioned from a healthy eelgrass habitat to one in which the species can no longer survive. In other words, has the cove entered a new stable state devoid of eelgrass? We examined this question by transplanting eelgrass into BC from a nearby control site in Tracadie West Arm (TWA) with a healthy eelgrass bed, and carried out the equivalent transplantation within the bed at TWA. Our hypothesis was that BC had reached a state in which the habitat could not support the return of eelgrass based on transplantation of whole plants.

Findings from this study could help fill in the research gaps on eelgrass habitat recovery in eastern Canada. This is important because high density eelgrass beds in the Atlantic Coastal region of Nova Scotia are now considered as Ecologically and Biologically Significant Areas (EBSA; Hastings *et al.* 2014).

Fig 1 **Map of study area showing locations of control site, Tracadie West Arm (TWA); and test site, Benoit Cove (BC), and site of culvert (arrow) joining Tracadie Harbour with TWA.**

STUDY SITES

Benoit Cove (BC) in Tracadie Harbour (TH; 6.65 km^2; Fig 1) was the experimental site. The donor control site, Tracadie West Arm (TWA), connects to the larger basin through a small culvert. The control site was in a small, sheltered area of TWA (45°63.82′N; 61°66.05′W). Beside the eelgrass bed is a salt marsh bed (*ca.* 25,000 m^2) dominated by *Spartina alterniflora*. We selected TWA as the control site because it has an easily accessible, extensive eelgrass bed, that has been resilient following two decades of disturbance by green crabs and has seawater exchange with TH.

BC (45°37.92′N; 61°37.67′W) is a small, sheltered cove, which feeds into the larger basin of TH through a narrow passage with a sandbar that is exposed at low tide. A small freshwater stream runs into the head of the cove. BC has been devoid of eelgrass since at least 2009, and the benthos is comprised of soft sediment covered by fine flocculent material. On the south side of the cove, the intertidal zone has conspicuous populations of oysters (*Crassostrea virginica*) and scattered *Fucus vesiculosus* and *Ulva intestinalis*. On the north side, trees and shrubs shade a large portion of the cove. On the south side is a band (> 5 m wide) of grass and shrub vegetation adjacent to a large hayfield.

FIELD METHODS AND OBSERVATIONS

Eelgrass Transplant The transplant procedure was initiated during the first week of July 2018. The experimental design was similar to the 'Transplanting Eelgrass Remotely with Frames' method, or TERFS (Short *et al.* 2002). We used a modified frames technique described by Leschen *et al.* (2010) using PVC pipe (Fig 2). Each frame was 0.25 x 0.25 m and constructed of PVC pipe (1.5 cm internal diameter) and stiff plastic webbing (mesh size 3 × 3 cm). Every second column of the webbing was removed to prevent the mesh from blocking growth. Both sites had 12 frames with nine non-reproductive shoots per frame. As per Zhou *et al.* (2014), harvested eelgrass shoots had a rhizome length of 2–3 cm with roots. Collected shoots were stored in a cooler in seawater until attached to the frames.

Rhizome and leaf blade lengths were measured and the number of blades per shoot counted for each transplant. Shoot length was measured from the base of the sheath to the tip of the longest leaf blade. Rhizomes were fastened to the bottom of the webbing using 2.5 mm wide cable ties and were spaced 5 cm apart. This allowed us to plant the rhizome horizontally into the sediment at a depth of 1 to 2 cm (as per Short *et al.* 2002). A snorkeler secured the frames to the substratum using two 30-cm tent pegs. Both TWA and BC had three subsites (A, B, and C) at which four frames were transplanted into each subsite. At BC, we systematically placed the frames in a square formation separated by 1 m. Frame placement in TWA differed from BC because of the high density of eelgrass. Therefore, each frame was placed in a bare patch without eelgrass.

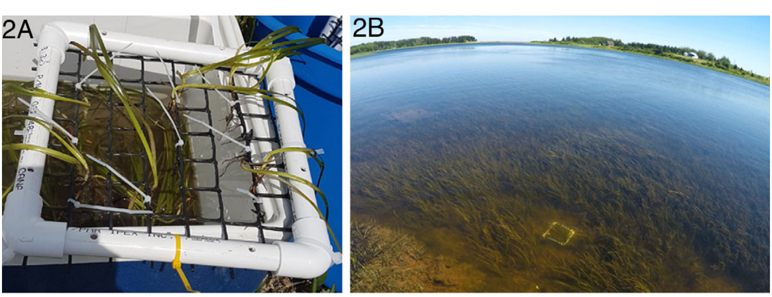

Fig 2 Eelgrass transplant procedure showing (A) a constructed PVC frame (0.25 m²) with nine eelgrass shoots attached and ready for transplant, and (B) *in situ* in Tracadie West Arm.

We visited sites bi-weekly until the end of August. At each visit, we recorded the length of the longest blade per transplant and the number of dead missing shoots per frame. Transplants with only the rhizome portion remaining were considered dead. Eelgrass transplants that had slipped out of the cable ties were considered as missing and these plants were omitted from the initial population size. After 8 weeks, we removed the frames with the remaining eelgrass transplants attached. Final blade and rhizome lengths and the number of blades per shoot were recorded. Canopy height was calculated using the mean of the longest two-thirds of the plants present in each frame (similar to Hansen and Reidenbach 2013).

Abiotic Conditions Water temperature and salinity were recorded throughout the experiment. During each visit, nine water samples were collected: three near the surface, three at half depth, and three near the bottom at each subsite. Water temperature was measured using a glass alcohol thermometer to the nearest 0.5°C. Salinity was measured to nearest 0.5‰ using a Portable Refractometer (Aqueous Lab, Las Vegas, Nevada, USA).

Sediment samples were collected using a 10-cm-diameter homemade coring device to a depth of 10–15 cm. In BC and TWA, nine sediment samples were taken. We used 1-L Imhoff Settling Cones (Wheaton 06340-02, Vernon Hills, Illinois, USA) to estimate sediment composition. Sediment settling after 1 min (sand), 1 h (silt), and 1 d (clay) were recorded (Hossain *et al.* 2014).

Green Crab Count

In both BC and TWA, we estimated green crab abundance. Counting was done every two weeks by a snorkeler at each transplant site (*ca.* 8 m^2 each). This was repeated at each biweekly visit.

Species Richness

Macrofauna and macroflora at BC and TWA were surveyed. A six-category abundance scale based on frequency was used: absent, low, low–moderate, moderate, moderate–high, or high. Changes in epiphyte cover were observed and noted throughout the study. Using snorkeling and underwater photos, we established a visual estimate of epiphytic and drift algal percent cover on the eelgrass blades and on the frames. Algal cover was considered in five categories: absent (0%), low (1%–25%), moderate (25%–50%), high (50%–75%), and intense (75%–100%).

Data Analysis

Using Minitab 18, transplant survival and canopy height from TWA and BC were compared using a nested ANOVA with Tukey's Honest Significant Difference Test (Tukey HSD test). The nested ANOVA was carried out because each measured parameter fell under multiple subgroups belonging to a specific group (Zar 2010). Other statistical tests were conducted using SPSS 25 and Microsoft Excel Data Analysis Package. Sediment composition was assessed using a Student's *t*-test.

RESULTS

Eelgrass Transplant – Survival and Growth

The transplant experiment occurred from 03 July to 29 August 2018. During the experiment, four shoots became reproductive, 22 individual shoots went missing and three frames were not found due to intense macroalgal cover or loss due to wave action. As a result, the initial eelgrass transplant populations for TWA and BC (108 each) were reduced to 72 and 91 transplants, respectively. Final survival and mean canopy height data for the missing frames were replaced using the mean imputation method in which the overall means from the other frames provided an estimate for the missing data (Zar 2010). This method was used only for the nested ANOVAs because of a requirement for equal sample sizes.

After the first 2 weeks, eelgrass transplant survival rate differed between TWA and BC (Fig 3). Tracadie Harbour had a final plant survivorship rate of 91.6% with six shoot mortalities. The three subsites ranged from 83.0% ± 0.0% (subsite A) to 96.3% ± 6.4% (subsite B). After 8 weeks, BC had a transplant survival of 15.4% and 77 shoot mortalities. Subsite survival ranged from 4.17% ± 8.3% to 24.8% ± 8.9%. Transplant survival rates after 8 weeks significantly differed in TWA and BC ($F = 122.025$, $P < 0.001$). The Tukey HSD test revealed that there was no significant difference between subsites in TWA, but subsites A and B in BC were statistically different.

Rhizome length was recorded before and after transplantation. There were no significant changes in length at either site ($P > 0.9$). In TWA, rhizome length was 7.1 ± 4.4 cm and 7.2 ± 4.4 cm at the start and end of the experiment, respectively. BC rhizome length was 7.1 ± 3.4 cm and 7.0 ± 3.8 cm at the start and end, respectively.

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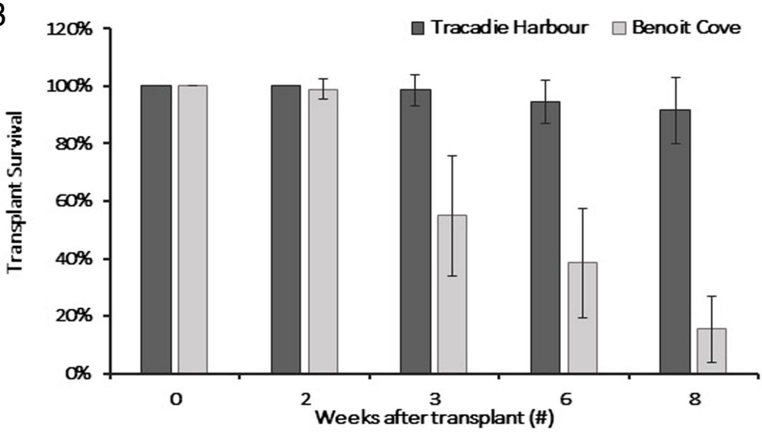

Fig 3 **Transplant survival (± s) over 8 weeks following transplantation into Tracadie West Arm and Benoit Cove.**

For both sites, a declining trend occurred in all above-ground growth variables (Table 1). The initial five blades per shoot declined to 2.6 blades after 8 weeks (Student's *t*-test, $P < 0.001$). In addition, there was no significant difference in the number of blades per shoot between TWA and BC ($P = 0.78$).

Canopy height in BC declined faster than in TWA (Fig 4). In the first two weeks, both sites maintained a canopy height > 31 cm. After 8 weeks, canopy height declined to 3.8 ± 5.4 cm and 24.6 ± 4.1 cm in BC and TWA, respectively ($P < 0.001$).

Temperature, Salinity and Sediment Composition

TWA and BC had similar water temperature trends over the summer with means of 25.4 ± 1.1°C and 24.9 ± 1.1°C in TWA and BC, respectively, with temperature extremes of 23°C to 27°C. Salinity

Table 1 **Summary of transplant above-ground growth characteristics. Values for blades per shoot, blade length (cm), and canopy height (cm) are means ± *s*.**

	Tracadie West Arm		Benoit Cove	
Plant Characteristics	**Initial**	**Final**	**Initial**	**Final**
Number of shoots	72	66	91	14
Number of blades	388	173	579	38
Blades per shoot	5.0 ± 1.2	2.6 ± 1.2	5.4 ± 1.6	2.6 ± 0.8
Blade length (cm)	27.5 ± 8.1	20.9 ± 8.5	29.8 ± 8.3	13.2 ± 6.1
Canopy height (cm)	32.0 ± 5.0	24.5 ± 4.1	34.8 ± 3.9	3.8 ± 5.4

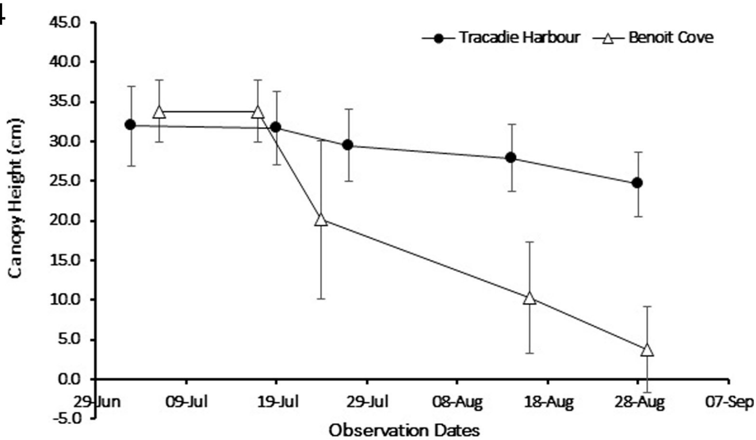

Fig 4 **Canopy height (± *s*) between July and August 2018 in Tracadie West Arm (TWA) and Benoit Cove (BC).**

was also similar at 26.2 ± 2.6‰ and 26.4 ± 2.4‰ for BC and TWA, respectively.

Sediment in TWA and BC was composed mainly of silt and mud with extremely fine particulate matter (Table 2). Mean percent silt composition was 34.1% ± 12.8% in TWA and 28.3% ± 4.4% in BC, which revealed that there was no significant difference between the two sites (Student's *t*-test, P > 0.15). Similarly, there were no statistcal differences in clay composition (P = 0.64). TWA had a mean sand composition of 0.80% ± 0.00% which was significantly different than BC's mean sand composition of 2.08% ± 0.01% (P < 0.001).

European Green Crab Abundance

Green crabs occurred at both sites but at different frequencies. Crab number per visit was significantly greater in TWA (24 and 62 per visit) than in BC (4 and 8 per visit, significant at P = 0.0086). In TWA, crabs also occurred near the transplant frames but did not

Table 2 **Sediment composition at study sites in Benoit Cove and Tracadie West Arm; values are means ± *s*.**

	Site	
Sediment Component	**Tracadie West Arm**	**Benoit Cove**
Sand	0.80% ± 0.00%	2.08% ± 0.01%
Silt	34.10% ± 0.13%	28.33% ± 0.04%
Clay	0.59% ± 0.00%	0.54% ± 0.00%

seem to use the frames as often as the crabs in BC where most crabs were found beside or in the transplant frames along with several crab carapaces, legs, and empty shells. When macroalgal loading was high, crabs often hid under the algal mats covering the frames.

Species Richness

In addition to eelgrass, 40 species were observed that included algae, invertebrates and fish. TWA had 92.5% of these species and BC had 52.5%. The most abundant animals in TWA were fish and grazers (Amphipoda, Tanaidacea, Isopoda). In BC, fish and grazers had low abundance or were absent. Of animal species in BC, 38.5% were molluscs. The most abundant included the Eastern mudsnail (*Tritia obsoleta*), Common slipper limpet (*Crepidula fornicata*), and Eastern oyster (*Crassostrea virginica*). These species were either absent in TWA or in lower abundance than in BC.

At both sites, the dominant seaweed was the red alga *Polysiphonia subtilissima*. In BC, *P. subtilissima* was found attached to rocks at low water and as drift thalli on the transplant frames. These frames also had drift fronds of sea lettuce (*Ulva lactuca*). In TWA, large floating algal mats were often observed on the water surface and throughout the eelgrass bed. These mats were composed primarily of *P. subtilissima* and large fragments of other species including *Ulva prolifera*, *Cladophora* sp., and *Chaetomorpha picquotiana*. At both sites, algal loading increased during the experiment, but cover was greater in TWA. In TWA, *P. subtilissima* covered the eelgrass both as an epiphyte and as drift, whereas cover in BC was strictly as drift. After 8 weeks, the eelgrass in TWA had dense cover of both epiphytic and drift algae (75%–100%) and BC was moderately to highly covered (50%–75%).

DISCUSSION

Eelgrass transplant results from this study are consistent with our initial hypothesis. As expected, the control site (TWA) outperformed the test site (BC) in terms of eelgrass survival (92% vs 15%, respectively). The two sites had the same salinity and temperature regimes and similar sediment with high silt (>28%). With the complete absence of eelgrass in BC, the biota was substantially different, with much lower species richness in BC (Appendix A).

The presence and density of seagrass meadows can substantially influence the severity of sediment resuspension and turbidity (Hansen and Reidenbach 2013). Sediment resuspension and hydrodynamic conditions have caused local regime shifts in habitats that once supported a dense eelgrass bed, and complicate eelgrass recovery both naturally and through restoration efforts (Moksnes *et al.* 2018). This was confirmed during our field work in that BC had many days when turbidity precluded observation of transplants, whereas this did not occur in TWA. The transplants in TWA were surrounded by a dense eelgrass bed which limited sediment being raised into the water column. In BC, without vegetation to stabilize the sediment and reduce impact of wind and currents, sediment resuspension and turbidity were often high. We suggest that increased sediment resuspension and turbidity in BC impeded transplant survival by reducing light availability (indirect) and covering or burying the eelgrass blades (direct). We conclude that BC has entered a new stable state in which it is unlikely to return to its previous condition without large human intervention. In addition, there was an increase in epiphytic and drift algal cover which may have played a role. Eelgrass mortality and reduced growth are common responses to increased loading of algae because of decreased light available for photosynthesis (Vandermeulen 2005). TWA had a higher accumulation of epiphytic algae than BC and still maintained a significantly greater transplant survival. High eelgrass mortality in BC occurred because the site had too many environmental stressors which prevented transplants from establishing.

A limitation of this study was the season when eelgrass shoots were transplanted. Transplanting eelgrass during the summer is not recommended because there is a higher chance of large-scale mortality (CCE 2011). Additional physiological stress is put on plants during the summer because of increasing water temperature and decreasing light levels caused by epiphytic and drift algae (Park and Lee 2007, CCE 2011). Since eelgrass stops growing at water temperatures above 20°C and can lose shoot weight at 25–30°C (Touchette *et al.* 2003; Moreno-Marín *et al.* 2018), plant growth was not an accurate measurement of transplant success for this experiment. Therefore, conducting this study during fall or spring may have facilitated better establishment and growth.

There was no evidence that green crabs impacted transplant survival at either site. Furthermore, BC had a mean green crab count of 0.01 crabs m^{-2}, which was even lower than in TWA (0.08 crabs m^{-2}). Without eelgrass, sufficient prey for the crabs is absent in BC. Following the disappearance of eelgrass in the 1930s, the Woods Hole area lost approximately one third of its species (Burkholder and Doheny 1968). In 2013, BC was depauperate in benthic invertebrates (Garbary *et al.* 2014).

Our sites may have had similar habitat characteristics prior to the green crab disturbance, but this is no longer the case. Eelgrass habitats, including TWA, have a higher abundance of species and are typically more diverse than unvegetated habitats like BC (McCullough *et al.* 2005). Following the assessment of biota in BC, species richness did not meet what would be expected for seagrass habitat in the region. Only a few invertebrates dominated the site, and these were not the species that are usually abundant in eelgrass beds.

We were unsuccessful at re-establishing eelgrass in BC. This cove seems to have entered a new stable state in which eelgrass is not colonizing naturally because of the recurring suspension of fine sediments and turbidity. These conditions also make eelgrass restoration difficult (Unsworth *et al.* 2015). Further work will be required to determine if restoration is possible with more substantial efforts. For instance, previous studies have found that transplant survival increases with an increase in planting unit size (Sheridan *et al.* 1998, van Keulen *et al.* 2003). Perhaps increasing the size and number of frames would allow denser patches of eelgrass transplants to become established, thus helping with sediment stabilization in areas like Benoit Cove. Regardless, the low density of green crabs in TWA is two orders of magnitude lower than crab numbers associated with eelgrass decimation (4.4 crabs m^{-2}, Garbary *et al.* 2014). This suggests that they have reached an equilibrium with their environment and are not a current threat to eelgrass at this site.

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APPENDICES: SPECIES ABUNDANCE

Table A.1 Abundance of species in Tracadie West Arm from 3 July to 28 August, 2018.

Taxon	Abundance Level
Marine Algae	
Ulva lactuca (Sea lettuce)	Low
Ulva intestinalis (Gutweed)	Moderate
Ulva prolifera	Moderate–high
Cladophora sp.	High
Chaetomorpha picquotiana	High
Ulothrix flacca	Moderate
Gomontia polyrhiza	Low–moderate
Gracilaria sp.	Low–moderate
Polysiphonia subtilissima	High
Ceramium diaphanum	Moderate–high
Pylaiella littoralis (Angel hair)	Low
Fucus vesiculosus (Bladder wrack)	Low
Invertebrates	
Carcinus maenas (European green crab)	High
Rhithropanopeus harrisii (Harris mud crab)	Low–moderate
Pagurus sp. (Hermit crab)	Low
Crangon septemspinosa (Sand shrimp)	Moderate
Palaemonetes vulgaris (Grass shrimp)	Low–moderate
Idotea balthica (Baltic isopod)	Moderate–high
Littorina littorea (Periwinkle snail)	Low
Tritia obsoleta (Eastern mudsnail)	Low
Crassostrea virginica (Eastern oyster)	Moderate
Mercenaria mercenaria (Northern quahog)	Low–moderate
Mytilus edulis (Blue mussel)	Low
Hediste diversicolor (Ragworm)	Low–moderate
Capitella sp. (Polychaete)	Moderate
Chordates	
Anguilla rostrata (American eel)	Low
Gasterosteus aculeatus (Three-spined stickleback)	High
Fundulus heteroclitus (Mummichog)	High
Fundulus diaphanous (Killifish)	High
Menidia menidia (Atlantic silverside)	High

Table A.2 Abundance of species in Benoit Cove, from 6 July to 29 August, 2018.

Taxon	Abundance Level
Marine Algae	
Ulva lactuca (Sea lettuce)	Moderate–high
Ulva intestinalis (Gutweed)	Low-moderate
Ulva prolifera	Moderate
Cladophora sp.	Low–moderate
Polysiphonia subtilissima	High
Stylonema alsidii	Low
Fucus vesiculosus (Bladder wrack)	Moderate
Chorda filum (Sea lace)	Low
Invertebrates	
Carcinus maenas (European green crab)	Moderate
Rhithropanopeus harrisii (Harris mud crab)	Moderate
Crangon septemspinosa (Sand shrimp)	Low
Littorina littorea (Periwinkle snail)	Low–moderate
Tritia obsoleta (Eastern mudsnail)	High
Crassostrea virginica (Eastern oyster)	High
Crepidula fornicata (Common slipper limpet)	High
Mercenaria mercenaria (Northern quahog)	Low
Hediste diversicolor (Ragworm)	Moderate–high
Capitella sp. (Polychaete)	Moderate–high
Chordates	
Gasterosteus aculeatus (Three-spined stickleback)	Low

Table A.3 Abundance of species from the orders Amphipoda and Tanaidacea, in Benoit Cove and Tracadie West Arm; A, absent.

Species	Tracadie West Arm	Benoit Cove
Amphipoda		
Corophium volutator	High	A
Corophium sp.	High	Low
Gammarus mucronatus	Moderate	A
Gammarus finmarchicus	Low	A
Gammarus sp.	High	Low
Tanaidacea		
Chondrochelia sp.	Moderate	A
Leptochelia sp.	Low-moderate	A

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EVALUATING OUT-PLANTING SUCCESS AND MYCORRHIZAL STATUS OF ENDANGERED *GEUM PECKII* PURSH (ROSACEAE), THE EASTERN MOUNTAIN AVENS, IN NOVA SCOTIA

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ABSTRACT

Geum peckii (Rosaceae), the Eastern Mountain Avens, is a small herbaceous plant that is listed as endangered federally and provincially. In Canada, this species is found in bogs on Brier Island and Harris Lake, Digby County, Nova Scotia. The only other population outside of Canada is in New Hampshire (USA). To enhance conservation research of this species, a seed sample from the native species seed bank at Acadia University was used to establish a plant tissue culture of *G. peckii* plants. Survival of out-planted material was then assessed in both the greenhouse and the field. The field test site was within 20km of the existing plant populations in Digby County. Our study also revealed that *G. peckii* grows in association with arbuscular mycorrhizal fungi (AMF). During out-planting, plants received a mycorrhizal inoculum with the goal of enhancing survival. We used either a commercial mycorrhizal inoculum, or a native inoculum. Control plants were left untreated. Survival was 97-100 % among all the treatments by the end of the 2016 planting season. The results to date underscore the potential value of seed banking for protection of endangered native plant species. This study marks the first time in Nova Scotia that an endangered plant species has been successfully retrieved from seed bank storage, propagated by tissue culture, and out-planted back into a natural habitat.

Keywords: Conservation, endangered native species, *Geum peckii,* tissue culture propagation

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INTRODUCTION

Geum peckii Pursh (Rosaceae), the Eastern Mountain Avens, is a small herbaceous plant listed as endangered federally and provincially (COSEWIC, 2010; Environment Canada, 2010). In Canada, this species is only found in bogs near sea level on Brier Island, and near Harris Lake on Digby Neck, both sites being in Digby County, Nova Scotia (Fig 1). Globally, the only other population is found in the White Mountains of New Hampshire, USA (COSEWIC, 2010; Environment Canada, 2010; LaRue, 2016a). A comprehensive count of the Brier Island population in 2012 and 2013 estimated the number of plants to be 6000 (LaRue, 2016a). Population counts since 1986 have shown a declining trend, although differences in counting methods have made determining exact numbers challenging (LaRue, 2016a). The largest Brier Island population in Big Meadow Bog has declined due to hydrological changes from a ditching attempt during the 1950's (COSEWIC, 2010; LaRue, 2016a). As the bog dried, sea gull nests and shrub encroachment have become threats contributing to the decline of this species (COSEWIC, 2010; LaRue, 2016a).

Global biodiversity is threatened in the current age of the Anthropocene, and seed banks are considered one of the most effective methods for *ex situ* conservation to help mitigate losses of plant biodiversity and prevent species extinctions (Maunder *et al.*, 2004;

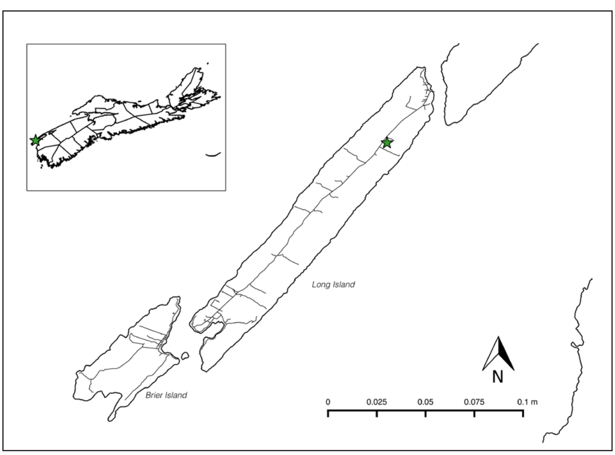

Fig 1 **The field trial location on Long Island is indicated with a green star on the map. Native populations of *G. peckii* are found on Brier Island and at Harris Lake, the two landmasses on either side of Long Island, Nova Scotia.**

Bunn *et al.,* 2007). The K.C. Irving Environmental Science Centre at Acadia University, Wolfville, Nova Scotia, is a research scale seed bank with the mandate to protect and preserve native species found in the Acadian Forest Region of Canada. *Geum peckii* is currently one species of interest. In 2014, seed was collected from the Big Meadow population on Brier Island (under NS DLF permit) and is currently stored in the seed bank.

The restoration efforts undertaken in this study for *G. peckii* are consistent with the Global Strategy for Plant Conservation targets for *ex situ* conservation of native endangered plants and align with the endorsed use of tissue culture techniques for conservation of endangered species (Convention on Biological Diversity, 2012; Rowntree *et al.*, 2011). This provides the opportunity for producing large numbers of plants from a single seed for subsequent testing in conservation programs (Pence, 2011; Ayuso *et al.*, 2019). However, tissue cultures lack the fungal and bacterial associates as sterile conditions are necessary (Kumar and Rao, 2012). The need for aseptic conditions leads to challenges when out-planting from tissue cultures (Chandra *et al.*, 2010).

Arbuscular mycorrhizal fungi (AMF) are a group of obligate symbiotic fungi that form mutualistic associations with roots of over 80% of land plants (Smith and Read, 2008), but are not normally present under tissue culture conditions. AMF aid in survival and growth by providing water and nutrients to the plants in exchange for carbon (Smith and Read, 2008; Neuenkamp *et al.*, 2018). It was hypothesized that the inoculation of AMF to the roots of tissue culture derived plantlets of *G. peckii* would improve out-planting success.

METHODS

Stage 1: Establishment of a plant tissue culture population for testing

To develop the tissue culture population for an out-planting study, a series of trials were completed using agar filled Petri Dishes to find appropriate seed sterilization and micro-propagation methods for this species (Adams 2016; Fancy, 2017) (data not shown). Tissue culture plants were maintained on media made by adding 2.2g/L Murashige and Skoog nutrients (Caisson Labs), 5.8g/L agar (Fisher Scientific) and 20g sucrose in reverse osmosis water with pH adjusted to 5.8. Media was autoclaved for 15 minutes at 121°C at 15PSI and 45mL of molten media was poured into a sterile culture jar (Sigma Aldrich). Preliminary trials were done by adding activated biochar (Novagreen Inc) at a rate of 250mg/L to the standard media recipe before autoclaving (Moland *et al.*, 2018). Visually, the use of activated biochar promoted more rapid growth of *G. peckii in vitro* (Fig 2). All plants used in the trial were grown in biochar amended media before transitioning out of tissue culture. The specific culture population used for the out-planting study was increased by dividing the plants monthly as their growth allowed. Plants were subsequently divided, and ID numbers were assigned, to allow the ability to trace the original parent seed.

Stage 2: Plant hardening and AMF inoculum introduction

Plant Hardening

Seventy-two of the most robust plants were chosen from the established tissue culture population for the field and greenhouse out-planting trials. The plants were split into two groups of 30, with 12 extra in case of initial die off. Twenty-two different parent seeds were represented in the field trial population and 18 in the greenhouse population. Subgroups for different treatments were then created, again based on evenly distributing plants from the same parent seed. There were three experimental groups tested in both the greenhouse and field trials. The first had a prepared native inoculum added (see below under AMF treatment), the second was a commercial inoculum (MykePro WP powder obtained from Premier Tech Biotechnologies, Riviere de Loup, Quebec), and the third control group was left untreated.

Fig 2 **Tissue cultured *Geum peckii* in jar vessels shown with typical growth media (water agar, sucrose, MS nutrients) on the left and the same media with added activated biochar on the right. Visually, the biochar amended growth media provided increased plant vigor. All plants were grown in biochar amended media before transitioning out of tissue culture.**

For acclimatization of tissue culture plantlets to the greenhouse and field conditions, plantlets were first removed from culture medium and out-planted into 4cm x 4cm x 4cm plastic germination cells with thoroughly wetted LP15 ProMix™ on 24 June 2016. Cells were placed into clear 30cm x 35cm plastic boxes with drilled holes to allow some air exchange and water drainage. One box was used per treatment (prepared inoculum, commercial inoculum and untreated control) (Fig 3). These boxes were initially kept in the greenhouse at 20°C, with average relative humidity near 70%. No artificial lights were used to control photoperiod. After the hardening off period, plants were moved into the greenhouse trial on 11 July 2016, or the field trial on 18 July 2016.

AMF Treatments

Native AMF inoculum was produced using a modified trap pot method (Morton *et al.*, 1993) by mixing 250g of Brier Island soil collected from under *G. peckii* with sterilized sand (1 hour at 121^{o}C and 15 psi) in 2L trap pots. Ten *Zea mays* (corn) seeds were sown and then thinned to 4 host plants per pot. Host plants were grown to flower in greenhouse conditions, watering as needed. After approximately 8 weeks of growth watering was stopped. Once the plants dried out, the above ground biomass was removed and the soil along with the below ground biomass was kept as native AMF inoculum.

Fig 3 **A *G. peckii* outplanting box filled with 24 4cm X 4cm cells containing the plants of one treatment. Two other similar boxes were made for the other treatments.**

Presence of AMF in roots of the host plant was confirmed via root clearing and staining (data not shown).

The commercial MykePro WP powder contained *Glomus intraradices* at a minimum concentration of 500 viable propagules per gram of powdered product. The concentration used was 0.6g of powder per 200mL of R.O. water. Three drops from a disposable glass pipette were put into each soil filled cell immediately before the plant was inserted. Concentrations of inocula used were adapted from Moland *et al.* (2018). The application rate of the prepared native inoculum was 10g of homogenized trap soil per plant. A master mix was made by adding 250g of soil from the trap pot to 267g of LP15 ProMix™. This mixture was used to fill the 24 cells in the prepared inoculum box. Plants were kept moist by misting with R.O. water and time without the lids on boxes was gradually increased until permanent removal at two weeks.

AMF Confirmation

A trial was done to confirm that *G. peckii* can form associations with mycorrhizal fungi. Roots were examined from three *ex situ* plants grown in the K.C. Irving Centre Experimental Gardens at Acadia University. They were collected and analyzed for presence of AMF under a compound light microscope following the ink-vinegar staining method of Vierheilig *et al.* (1998). These plants originated from seed obtained from a Brier Island population, as part of preliminary germination tests conducted by LaRue (2016b).

Stage 3: Out-planting trials

Greenhouse Out-planting

The greenhouse trial was completed in a controlled environment phytotron room at the K.C. Irving Centre, Acadia University. After hardening off, plants were transferred to plastic greenhouse pots (10cm x 10cm x 9cm) filled with moist LP15 ProMix™. All the substratum in the original cells was transferred to the larger pots. Thirty plants were transferred to the greenhouse trial: 10 treated with native AMF inoculum, 10 with commercial AMF inoculum and 10 with no AMF inoculum. Plants were watered regularly with R.O. water and rotated on the bench daily to account for differences in light intensity, temperature gradients and air flow. No fertilizer was added to be consistent with the field population and the plants remained vigorous. Between July 11 and September 23, the greenhouse minimum temperature was 17°C and the maximum was 20°C, with average relative humidity near 70% using natural day/night lighting.

Field Out-planting

The field trial was established in the Balancing Rock Bog on July 18, 2016, 19T 0720358N, 4916242E within 20 km of the native *G. peckii* populations (Fig 1). The Balancing Rock Bog is on Long Island, Digby County, Nova Scotia and has similar habitat characteristics in terms of hydrology and plant species to the populations on Brier Island (Dr. Nick Hill, personal communication, June 11, 2016). *Geum peckii* is not known to occur naturally on Long Island (COSEWIC, 2010). This location was chosen in accordance with NS DLF to avoid any potential risk to the existing natural populations of *G. peckii* on Brier Island. A permit was granted by NS DLF to proceed with the trial. A 2m x 2m plot was marked off with 36 30cm x 30 cm cells (Fig 4). Plants were randomized when planting into the grid. Any substrate that did not come out with the plug was first placed into the hole made in the sphagnum layer before the plant was added. A total of 30 plants were transferred to the field, 10 treated with native AMF inoculum, 10 with commercial AMF inoculum and 10 with no AMF inoculum.

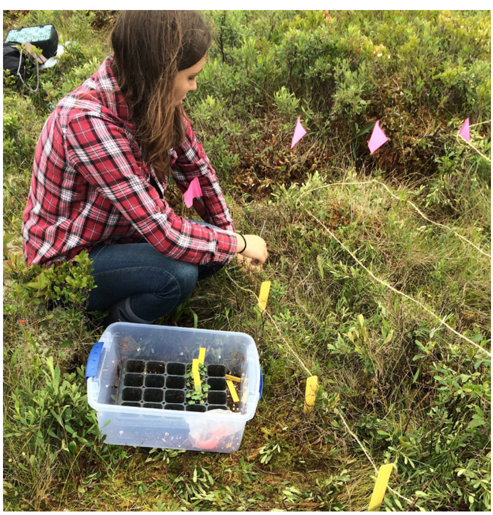

Fig 4 The author transplanting *G. peckii* into the grid in the Balancing Rock Bog on Long Island, Nova Scotia.

Stage 4: Growth monitoring and analysis

Plant Growth

For nine weeks after planting, weekly observations were made on both the greenhouse and field populations. These observations included: number of brown leaves, number of green leaves, length of longest petiole, largest leaf length by width, and degree of leaf reddening. Leaf reddening was used as a visual parameter of stress level. The redness of leaves was ranked with scores from 1 (no redness) to 5 (over 95% of leaf surface red tinged). At the end of the growth period, roots from five *G. peckii* plants within the greenhouse population were sampled to determine of AMF colonization. Field plants were not sampled to avoid stressing the population. Prepared roots were observed with a compound light microscope on slides with equidistant horizontal lines. Presence/absence counts were done at each root-line intersection. To determine percent AMF root colonization, 100 crosses were analyzed per sample (Giovanetti and Mosse, 1980).

Statistical Analyses

GraphPad Prism version 7.0 was used for all statistical analyses. Data from observations of field and greenhouse plants were examined by two-way repeated measures ANOVA to assess differences among mycorrhizal treatments at two timepoints ($p=0.05$). Two-way repeated measures ANOVA was also completed to assess differences in out-plant success in relation to the parent seed. A t-test ($p=0.05$) was done to show statistical differences among plant growth in the greenhouse and field environments.

RESULTS AND DISCUSSION

Plant survival following out-planting

From July 18 to September 17, 2016, all plants (30) in the field and 29 in the greenhouse survived. The greenhouse plants grew larger than the field counterparts, possibly due to differences in temperature, moisture conditions and light intensity (Fig 5). On average, the length by width of leaves, and petiole length, was 57% and 61% larger in the greenhouse plants at the end of data collection. During the dry part of the summer, depth to water table was recorded as 78cm below the bog surface; this level characterized the bog as a dry bog for *G. peckii* habitat (Poirier, 2016). Plants in the field were subject to herbivory over the summer. From August to September 2016, 18 of 30 plants showed signs of herbivory, although never more than 5 leaves per plant were involved (data not shown). Herbivory did not appear to correlate with a decrease in plant vigor.

The out-plant survival rates in this study were high compared to previous greenhouse out-plant trials with this species (Fancy, 2017). Factors such as size of plants at out-planting and duration in tissue culture under nutrient rich conditions may have been involved and merit further attention. The plantlets in the current study were grown in the presence of activated biochar in tissue culture, which may have exerted a beneficial effect (Moland *et al.*, 2018). No significant differences were found between the parent seed and the vigor of any individual plant at p = 0.05. The success of a plant appeared have no correlation with the parent seed from which it originated (data not shown).

Plant Growth and AMF Associations

Plants in the greenhouse and field populations grew very well during their first season. There was an increase in the number of leaves, length and width of the largest leaf, and petiole length over the course of the nine week observations. The plants in the greenhouse grew larger than the field counterparts, with some individual leaves reaching length by width of 80mm x 62mm, while in the field the maximum was 40mm x 30mm. The difference in growth among the field and greenhouse grown plants was statistically significant when length and width of largest leaves and the petiole length were considered (Fig 5). In addition to size differences, the majority of field plants had various degrees of reddening, but none of the greenhouse plants showed reddening at the end of the trial. The most vigorous greenhouse plants increased their leaf width by more than 50mm over the growth season. The size of *G. peckii* leaves in this trial fall within the range found in native populations where the width of the largest leaf on a single rosette varied from 15mm to 150mm (LaRue, unpublished data, 2016).

Two-way repeated measures ANOVAs were completed on only the first and last day of observations in both the field and greenhouse population to minimize the variable effect of individual plant growth. Results of the two-way repeated measure ANOVAs of the first and last day parameters are displayed in Fig 6 for the greenhouse

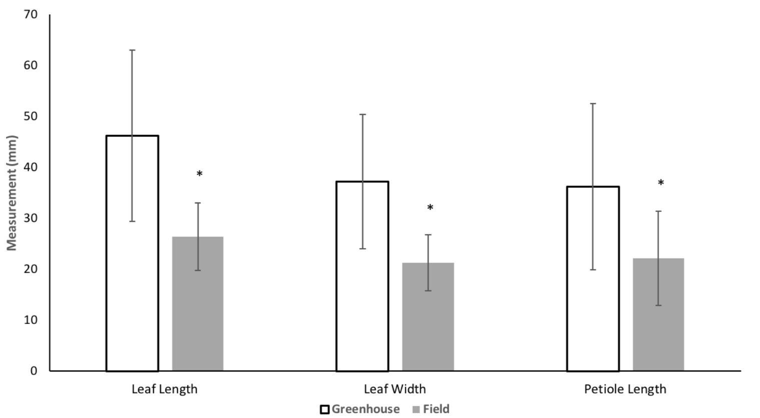

Fig 5 **Growth was significantly different on the last day of observations with the greenhouse plants outperforming the field plants in terms of leaf size and petiole length. * denotes statistical significance among the greenhouse and field populations at p=0.05.**

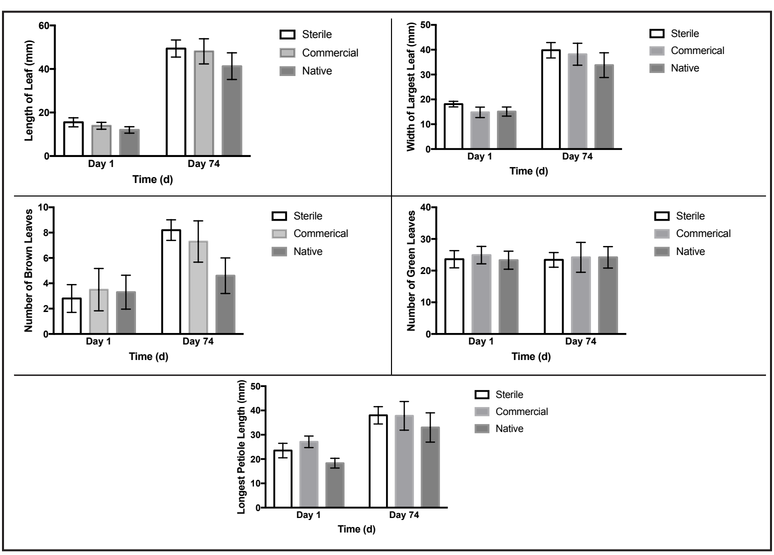

Fig 6 **Results of two way repeated measure ANOVAs from all tested parameters on the first and last day of the greenhouse trial observations at the K.C. Irving Centre. Error bars depict the standard error of the mean. Three mycorrhizal treatments were tested: sterile, a native prepared inocula of Brier Island soil and a commercial inocula (MykePro WP). Redness scores were not included because the greenhouse plants did not display any signs of reddening over the course of the trial.**

population and Fig 7 for the field population. No significant difference was found among measured characteristics of plants for the native inoculum, commercial inoculum, or sterile treatments.

Roots from *G. peckii* plants growing in the K.C. Irving Centre Experimental Gardens at Acadia University were colonized by AMF. To our knowledge, this is the first time that AMF associations have been confirmed for *G. peckii*. Root colonization rates were low, at 20%, but the sample size was just 100 root segments from four plants and the garden conditions were significantly different from the bog habitat on Brier Island.

AMF colonization rates of *G. peckii* plants on Brier Island are undetermined at this time, but are currently being assessed. A native AMF inoculum was produced in this study by using soil collected from under *G. peckii* on Brier Island, confirming that AMF are present in the natural substrate. The five greenhouse grown plants tested at the end of the growth season did not show any AMF when examined

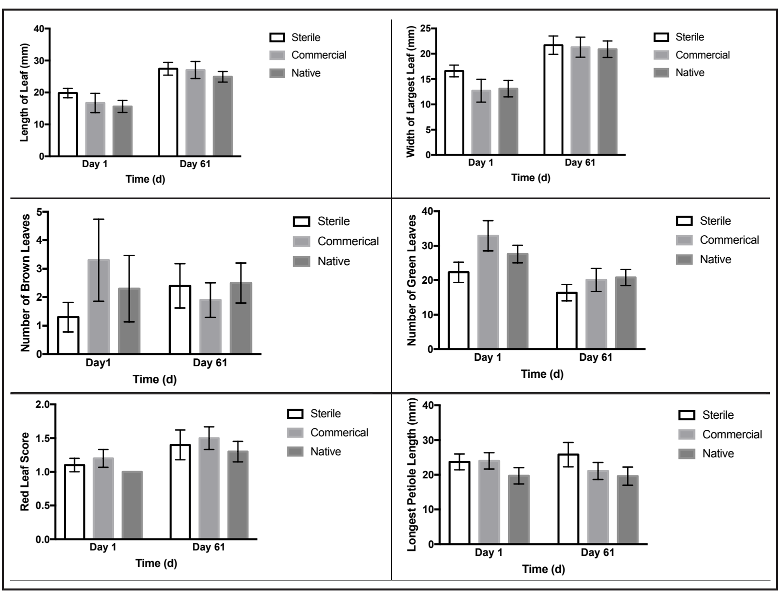

Fig 7 **Results from two way repeated measure ANOVAs of all tested parameters on the first and last day of the *G. peckii* field trial observations. Error bars depict the standard error of the mean. Three mycorrhizal treatments were tested: sterile, a native prepared inocula of Brier Island soil and a commercial inoculum (MykePro WP). The red score native inoculum treatment does not have an error bar because all plants were given a ranking of one (little redness) on the first day of the 74 day trial.**

microscopically following staining. It is possible that the inoculation treatment was not effective for AMF colonization during the trial period. The low stress environment and nutrient availability in the greenhouse substrate could have negated the need for plants to form association with AMF (Smith and Read, 2008; Neuenkamp *et al.*, 2018). Future evaluation of survival and testing for AMF colonization among the field plants is warranted. Based on the results from the first growing season, the hypothesis that introducing AMF inocula would aid in out-planting survival is not supported.

CONCLUSIONS

The Acadia University seed bank currently seeks to establish preservation, propagation and restoration strategies for eleven rare and endangered native Maritime plant species (Fancy, 2017). Results from the present study have confirmed that *G. peckii* seed can be retrieved from low temperature seed bank storage, germinated, multiplied through tissue culture and successfully out-planted under greenhouse and field conditions. Over the 2016 growth season, 100% of field trial *G. peckii* survived and 97% of the greenhouse plants also survived. This is also the first time that *G. peckii* arbuscular mycorrhizal fungal associations have been confirmed.

Observation and monitoring of the field trial have continued in 2017-2019. With time and future studies, more insight can be expected with respect to *G. peckii* AMF associations. This may impact the methods used for the preparation of inocula and treatment of tissue culture plantlets at out-planting. This approach using seed banks and tissue culture could increase habitat reintroductions as part of an overall strategy for plant conservation and protected area management, and in the context of maintaining global biodiversity (Maunder, 1992; Maunder *et al.,* 2004; Ayuso *et al.*, 2019).

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DIVERSITY, ABUNDANCE AND SIZE STRUCTURE OF FISHES AND INVERTEBRATES CAPTURED BY AN INTERTIDAL FISHING WEIR AT BRAMBER, MINAS BASIN, NOVA SCOTIA

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ABSTRACT

Capturing fish using a weir or trap on the intertidal flats of the Bay of Fundy was developed by native Mi'kamaq who later taught the method to the European settlers. Between 1800-1910 fish weirs were a significant part of the important American shad fishery in the inner Bay of Fundy before the collapse of the northwest Atlantic population from pollution and damming of major spawning rivers in the United States. Weirs remain an important segment of the Minas Basin fisheries but now the largest commercial catches consist of Atlantic herring, gaspereau and flounders. Studies on the fishes captured in Minas Basin weirs were published in 1852, 1924, 1984 and 2014, but all lacked a sampling intensity which would fully describe the diversity, abundance and size structure of the catch. An intertidal weir at Bramber, Minas Basin was surveyed during April-July, 2017 where catches were examined at each low tide. The weir was constructed on the intertidal flat during early April after Minas Basin cleared of drift ice. During the study period mean daily tide range was 10.46 m with a maximum spring tide range of 13.72 m. A total of eight neap and eight spring tide cycles were observed. Daily water temperature of Minas Basin was 8.0 C° during late May and increased to a maximum of 21.4 C° in late July. Fish and invertebrate collections began on April 10 and continued daily until July 22 when water temperatures in the trap became too warm for by-catch species to survive (+25 C°). During the study period an estimated total of 674,402 fishes consisting of 45 species were captured and of these 57,950 were measured. The most abundant fishes observed were gaspereau (alewife and blueback herring 51.9%), rainbow smelt (13.9%), Atlantic herring (13.0%) and tomcod (10.1%). Other commonly captured fishes were American shad, skate (little and winter), winter flounder, windowpane flounder, striped

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bass, mackerel and Atlantic sturgeon. A total of 18,511 invertebrates were captured and counted. The most abundant were long-fin squid (13.8%) and crustaceans (rock crab, lady crab; 84.0%).

Keywords: Bay of Fundy; Canada; Clupeidae; commercial fishing; temperatures; tides

INTRODUCTION

The fisheries of the inner Bay of Fundy and Minas Basin began with the native Mi'kmaq. They used intertidal weirs and spears to capture fishes for sustenance and trade (Gordon 1993). The dominant species taken were sturgeon, herring, gaspereau, shad, salmon, smelt, and tomcod, but they probably also utilized any other fishes they captured. When the Acadian settlers arrived during the early 1600's the Mi'kmaq taught them how to use weirs to catch fish for their survival and the methods were passed onto other settlers who followed later. By the 1800's the fishery developed into a major commercial enterprise with exports of American shad to the United States of up to 1,000 metric tonnes (*t*) annually (Perley 1852; Dadswell *et al.* 1984a).

Intertidal fishing weirs are constructed during spring of spruce stakes driven into the intertidal substrate in a V-shape with the tip of the V pointed offshore and then covered with interwoven brush or nets (Gordon 1993). At high tide the weir is underwater. As the tide ebbs fishes are guided into the weir trap which is then fished at low water. In the past horse drawn wagons were used to land the catch. Some weirs in Minas Basin were serviced with horses until the 1980's but all are now are fished with trucks or all-terrain vehicles (Dadswell; pers. obs.).

Intertidal weirs have remained one of the main fisheries methods used in Minas Basin to the present day. During the 1800's hundreds of weirs lined the shores of Minas Basin (Perley 1852). The American shad captured were so important to the economy of Nova Scotia that a Special Act of the Nova Scotia Legislature was passed in 1840 for its regulation, one of the first in Canada. Today weirs are few and the dominant catch is gaspereau (the collective French name for alewife and blueback herring) which are mainly used as bait in the lobster fishery. Other species commonly captured now or in the past are Atlantic sturgeon, Atlantic salmon, Atlantic herring, striped bass, winter flounder, Atlantic mackerel and longfin squid (Dadswell *et al.*1984b).

Biological studies on the fishes captured in Bay of Fundy intertidal weirs began with Perley (1852) who surveyed weirs in Cumberland

and Minas Basins. Liem (1924) conducted in depth weir surveys from 1919-1923 for the Royal Commission established to determine the cause of the collapse of the American shad fishery in the inner Bay of Fundy. His findings concerning the diversity and abundance of fishes caught in weirs were confirmed by Dadswell *et al.* (1984b) in a study of Minas Basin weirs during 1982-1983. A total of 44 fish species were identified from weir catches during these two studies.

The Fundy Ocean Research Centre for Energy (FORCE) recently conducted a study in which Minas Basin fishing weirs were monitored from April-August, 2013 (Baker *et al.* 2014). Sampling was conducted once weekly during daytime low tides at weirs near Five Islands and Bramber, Nova Scotia (Fig 1) and during day and night tides for commercial species and weight at the Bramber weir from mid-July to the first week of August. Their study documented 28 species of fish overall and 24 species at the Bramber site and addressed abundance and size of selected fishes during the monitored period. Sampling, however, was not intense enough to document the

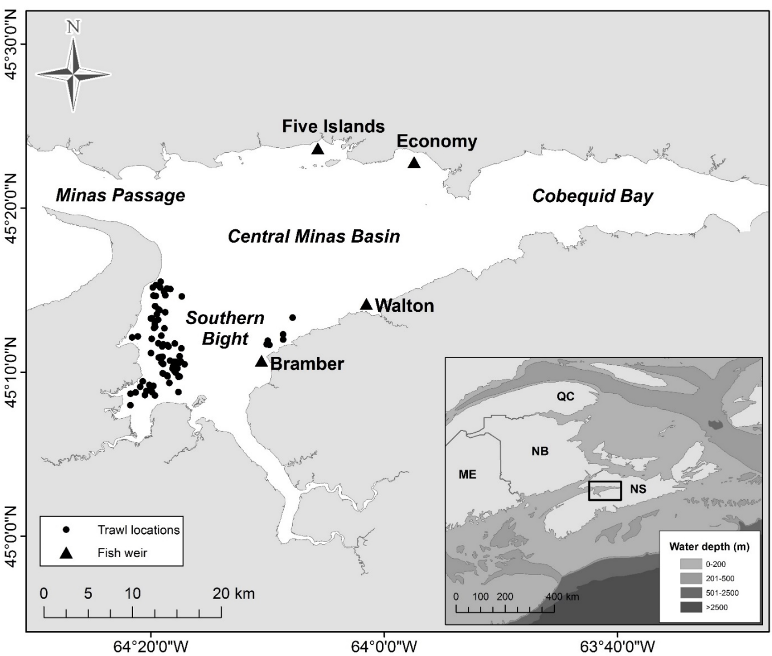

Fig 1 **Minas Basin, Nova Scotia, depicting sites of some present and former intertidal fish weirs. Trawl locations depicted were part of another study on the fishes of Minas Basin (Wehrell 2005).**

potential total diversity, abundance and size structure of fishes captured. As part of the final report FORCE stated: ‘intertidal weirs are useful sampling platforms for assessing general patterns in the presence and abundance of fishes in the Minas Basin and can strengthen on-going environmental monitoring near tidal energy development sites’. Unfortunately, this statement could not be supported by a study that only sampled the catch one day a week during daylight tides. Consequently, on June 14, 2016, in a memo posted to their website, the Department of Fisheries and Oceans (DFO) recommended that further evaluation of the potential use of intertidal weirs to gather additional seasonal baseline information on fish assemblages and habitat use in the vicinity of the tidal energy projects should be undertaken.

In 2017, the commercial fishers of Minas Basin, in conjunction with Big Moon Power Canada agreed to undertake a joint project to monitor diversity, seasonal abundance trends and size structure of resident and migratory fishes. The objective was to establish a comprehensive baseline for fish assemblages in the Minas Basin, as well as an updated species index. This study was conducted as a fisher would work their weir with sampling conducted during every low tide night and day from April to July. Fishers had criticized earlier weir studies based on the fact that sampling was not intense enough to accurately demonstrate the actual diversity, abundance and size structure of Minas Basin fishes in weir catches and this was justified by DFO’s 2016 critique of the FORCE study.

As the selected sampling station, the Bramber weir was designed to create an easily replicated model for scientific purposes. Technical aspects of the weir were modified to keep the maximum number of controllable variables constant. To conduct this study with maximum efficiency, a team was assembled, consisting of experienced fishers, students and scientists. The study, by approach and design, is anticipated to be a relationship-builder that will combine the existing knowledge from local, traditional and academic groups, with cooperative industries.

METHODS

Environmental Sampling

A daily record of moon cycle and tide range was maintained from the Department of Fisheries and Oceans website

Fig 2 The Bramber intertidal fish weir used during the 2017 study at low tide in Minas Basin. The V-shape is described by the weir wings which lead the fish into the trap at the near end during ebb tide. Fishers and their vehicles are clustered around the trap. The channel and heart-shaped structure in the lower portion of the picture is a live holding pond into which non- commercial fishes and invertebrates prohibited for take were released so they could escape unharmed.

(www.dfo-mpo.gc.ca/index-eng.htm/waterlevels). Three temperature data loggers were deployed at the weir. One on the inshore (short) wing, one on the offshore (long wing) and one in the trap (Fig 2). Temperatures were logged every 15 minutes and averaged on each hour from May 26 until July 31, 2017.

Weir Survey

The intertidal fishing weir at Bramber (Fig 1; 45° 12'N, 64° 09'W) was constructed of spruce poles driven into the intertidal substrate and covered with 2.5 cm square mesh nylon at the trap and progressively larger mesh (max. 4.0 cm square) to the wing ends to facilitate release of smaller fishes (Fig 2). The weir walls were 2.2 m in height until half way to the trap when they were increased to 3 m. The wings were approximately 700 m in length. The V-shaped weir walls ended in a trap 3 m in height that was also roofed to prevent fish from leaving the trap at high tide and birds from preying on the captured fishes

(Fig 2). At low tide the trap was emptied in stages through a sluice gate to maintain water in the trap and alleviate stress on bycatch species. Fish and invertebrates were netted at the trap sluice gate and transferred onto sorting tables for counting and measuring. Large fishes such as sturgeon and striped bass were removed from the trap by hand or dip net and taken directly to the live holding pond seaward of the trap after counting, measuring and/or tagging (Fig 2). Fish that were reluctant to leave the trap (flounders, eels, etc.) were captured by hand or with a dip net and retained as commercial catch or transferred to the holding pond after processing.

Commercial catch was sorted into wharf boxes and a subsample taken for measurement. By catch was counted and all or a subsample measured. If the commercial and/or by-catch species represented less than ~60 individuals, all were measured. Total catch of commercial species which were too abundant to count directly was estimated by determining an average weight in the catch for the fish concerned on that tide and dividing it into the total weight of landed catch of that species caught during that low tide.

The weir survey consisted of twice daily sampling of commercial catch and bycatch from April 10 until July 22 when the weir was closed because rising temperatures were endangering the survival of bycatch species. Fishes were measured for fork length (L_F) and/or total length (L_T) depending on the species. Species with forked tails (sturgeon, herring, gaspereau, shad, smelt and striped bass) were measured for L_F. Fishes with rounded tails (eel, tomcod, flounder, etc.) were measured for L_T. Commercial species were landed to sell and by-catch species were released into the live pond to await the rising tide (Fig 2). A portion of the captured Atlantic sturgeon, striped bass, and skate were tagged with external Floy dart tags provided by researchers studying these fishes.

RESULTS AND DISCUSSION

Environmental Characteristics

Minas Basin has the largest tide range in the world (max 17+ m). The characteristic result from such large tides is that Minas Basin has extensive intertidal flats which range from 1-5 km wide when exposed at low tide (Parker *et al.* 2007). The intertidal flats consist of sand, silt, mud and bedrock with little exposed rock and a very low abundance of intertidal seaweed because of winter ice scour. The intertidal flat at Bramber was a mixture of sand and mud with rocks and boulders of various sizes strewn over the surface (Fig 2). The rocks are the result of ice rafting during winter depositing the rocks during the spring melt (Sanderson and Redden 2015).

Mean daily range at the Bramber weir during the study period was 10.46 m with the maximum spring tide range of 13.72 m on April 28, 2017. A total of eight neap and eight spring tide cycles were observed during weir operation with the largest tides occurring in April and May. Daily water temperature of Minas Basin at the Bramber site was 8.0 C° during late May when data loggers were deployed and increased to a maximum of 21.4 C° on July 14. Trap temperatures during low tide were similar to the ambient Basin temperature until July when solar insolation caused trap temperatures to increase quickly during the low-tide fishing period, often becoming >25.0 C°.

The summer fishing period during 2017 was significantly warmer than during the 2013 FORCE study. During 2013 summer surface water temperature never exceeded 19 C° and the Bramber weir remained operational until mid-August (Baker *et al.* 2014).

Weir Catches

An estimated total of 674,402 fishes were captured by the Bramber weir during April 10 to July 22, 2017. The catch consisted of 45 species of fish (Table 1). Gaspereau, consisting of blueback herring and alewife, were the most abundant fish representing an estimated 350,343 of those captured or 51.9% of the total catch. Rainbow smelt were the second most abundant catch (13.9%) followed by Atlantic herring at 13.0%. An estimated 68,212 tomcod were captured (10.1%) and the three abundant species of flounder made up 7.3% of the total catch. Other important contributors to the catch were American shad (1.0%), hakes (1.0%) and skates (0.4%). Other species were rare and often only one specimen was captured during the entire fishing season (spotted hake, striped searobin, etc.). A total of 57,950 fishes were measured.

The fish community captured in Minas Basin weirs can be characterized into four assemblages. There was an assemblage of mainly smaller fish species that live, reproduce in and occupy the Basin year around. This grouping consists of tomcod, rainbow smelt, Atlantic silversides, smooth flounder, windowpane flounder, mummichog, skates, striped bass, sea raven and sticklebacks (Dadswell *et al.* 1984b). A second

Table 1 Fishes captured in the Bramber intertidal fish weir during 2017. Species were counted as a group because they were difficult to separate taxonomically on site: *[1] - skate; *[2] - gaspereau; *[3] - hake.

Common name	Genus and Species	Catch	% Total
Sea lamprey	*Petromyzon marinus*	4	-
Spiny dogfish shark	*Squalus acanthias*	10	-
Little skate, Winter skate*[1]	*Leucoraja erinacea, L. ocellata*	2,874	0.41
Atlantic sturgeon	*Acipenser oxyrinchus*	247	0.03
American eel	*Anguilla rostrata*	44	-
American shad	*Alosa sapidissima*	7,176	1.06
Alewife, Blueback herring*[2]	*A. pseudoharengus, A. aestivalis*	350,343#	51.95
Atlantic herring	*Clupea harengus*	87,587#	12.98
Atlantic menhaden	*Brevoortia tyrannus*	1	-
Atlantic salmon	*Salmo salar*	6	-
Brown trout	*Salmo trutta*	9	-
Brook trout	*Salvelinus fontinalis*	1	-
Rainbow smelt	*Osmerus mordax*	93,976#	13.94
Three-spine stickleback	*Gasterosteus aculeatus*	4	-
Monkfish	*Lophius americanus*	4	-
Atlantic cod	*Gadus morhua*	6	-
Tomcod	*Microgadus tomcod*	68,212#	10.11
Haddock	*Melanogrammus aeglefinus*	6	-
Silver Hake	*Merluccius bilinearis*	384	-
White hake, Red hake*[3]	*Urophycis tenuis, U. chuss*	7,214	1.06
Spotted hake	*Urophycis regia*	1	-
Longfin hake	*Urophycis chesteri*	1	-
Pollack	*Pollachius virens*	1	-
Mummichog	*Fundulus heteroclitus*	2	-
Atlantic silversides	*Menidia menidia*	2,063	0.31
Northern pipefish	*Syngnathus fuscus*	7	-
Striped bass	*Morone saxatilis*	1,388	0.20
White perch	*Morone americana*	12	-
Cunner	*Tautogolabus adsperus*	51	-
Sea raven	*Hemitripterus americanus*	643	0.09
Shorthorn sculpin	*Myoxocephalus scorpius*	4	-
Longhorn sculpin	*Myoxocephalus octodecemspinous*	705	0.10
Ocean pout	*Macrozoarces americana*	1	-
Rock gunnel	*Pholis gunnellus*	5	-
Butterfish	*Peprilus triacanthus*	536	0.08
Atlantic mackerel	*Scomber scombrus*	1,820	0.27
Striped searobin	*Prionotus evolans*	1	-
Summer flounder	*Paralichthyes dentatus*	2	-
Winter flounder	*Pseudopleuronectes americanus*	24,214#	3.59
Smooth flounder	*Liopsetta putnami*	5,841	0.86
Windowpane	*Scophthalmus aquosus*	18,860	2.82
Halibut	*Hippoglossus hippoglossus*	2	-
	Total catch	**674,402#**	

count estimated

assemblage consists of summer migrants into Minas Basin many of which are diadromous species that reproduce in the streams around the Basin. This group consisted of sea lamprey, spiny dogfish shark, Atlantic sturgeon, American eel, Atlantic herring, American shad, gaspereau, Atlantic salmon, Atlantic mackerel and winter flounder. They are the dominant community that supports the commercial fishery (Dadswell *et al.* 1984b). A cold-water assemblage enters the Basin in early spring and departs when water temperatures surpass 10 C^{o}. Atlantic cod, haddock, pollock and halibut are representatives (Bleakney and McAllister 1973). Rare coldwater and/or offshore species among this grouping that were caught at Bramber during 2017 were ocean pout, spotted hake and longfin hake. The final assemblage consists of warm-water migrants that arrive from the south when Basin water temperatures reached their annual maximum (Scott and Scott 1988). During the summer of 2017 this group was represented by butterfish, summer flounder and striped searobin.

A total of 18,511 large invertebrates captured were counted (Table 2). The most abundant invertebrate was the lady crab which

Table 2 Large invertebrates captured at the Bramber weir during the summer of 2017.

Common name	Taxon	Catch	% Total
	Cnidaria		
Lion's Mane Jellyfish	*Cyanea capillata*	128	0.07
	Ctenopora		
Sea Gooseberry	*Pleurobranchia pileus*	rare	-
	Mollusca	2,560	13.8
Longfin squid	*Doryteuthis pealei*		
	Arthropoda		
Shrimp	*Dichelopandalus leptocerus*	1	-
Sand shrimp	*Crangon septemspinosa*	uncounted	very abundant
American lobster	*Homarus americanus*	36	0.02
Rock crab	*Cancer irroratus*	1,626	8.77
Green crab	*Carcinus maenas*	158	0.08
Lady crab	*Ovalipes ocellatus*	13,997	75.57
Toad crabs	*Hyas araneus*	uncounted	very abundant
	Libinia emarginata	5	-
Hermit crabs	*Pagurus acadianus*	uncounted	abundant
	Pagurus longicarpus	uncounted	rare
	Total catch counted	**18,511**	

made up 75.6% of the total counted catch. Longfin squid, the only invertebrate that contributed to the commercial catch, made up 13.8% of the counted catch followed by rock crabs at 8.8%. Other invertebrates were either rare, small, very abundant and/or difficult to identify and were not counted.

CHARACTERISTICS OF CAPTURED FISHES

Data collected from fishes captured during April-July, 2017 consisted of number and length of species captured during each low tide. We summarize the fishes captured below.

Sea lamprey

The total catch of sea lamprey in the Bramber weir during 2017 was only four individuals (Table 1). Low catch was probably an interaction between morphology, biology and migration of this species. Lamprey morphology is eel-like rendering them capable of escaping through all but the smallest net mesh sizes. Sea lamprey are an anadromous species which remains offshore as juveniles feeding on the blood of other fishes (Scott and Scott 1988). Adults return to their natal stream during spring (May-July) to spawn and then die. No lamprey were captured during the FORCE study (Baker *et al.* 2014).

Spiny dogfish shark

A total of ten spiny dogfish shark were captured during late May, 2017. All were adults ranging in length from 750-940 mm L_T.

This species is both demersal and pelagic but apparently remains offshore and away from the intertidal zone resulting in low weir catches (Moore 1998). Also the dogfish stock has been at a low ebb for the past decade (Campana *et al.* 2008) and are no longer abundant in Minas Basin as they were during the 1980's (Dadswell *et al.* 1984b).

Other sharks taken in Minas Basin weirs include great white shark and sand tiger shark. A great white shark was captured in an Economy weir during 2011 and the same weir captured a sand tiger shark in 2017 (Fig 1; W. Linkletter, pers. comm.).

Skates

Two species of skate were captured during 2017, little skate and winter skate (Table 1). They were considered together because they are difficult to identify at the weir (Whidden 2015). A total of 2,874

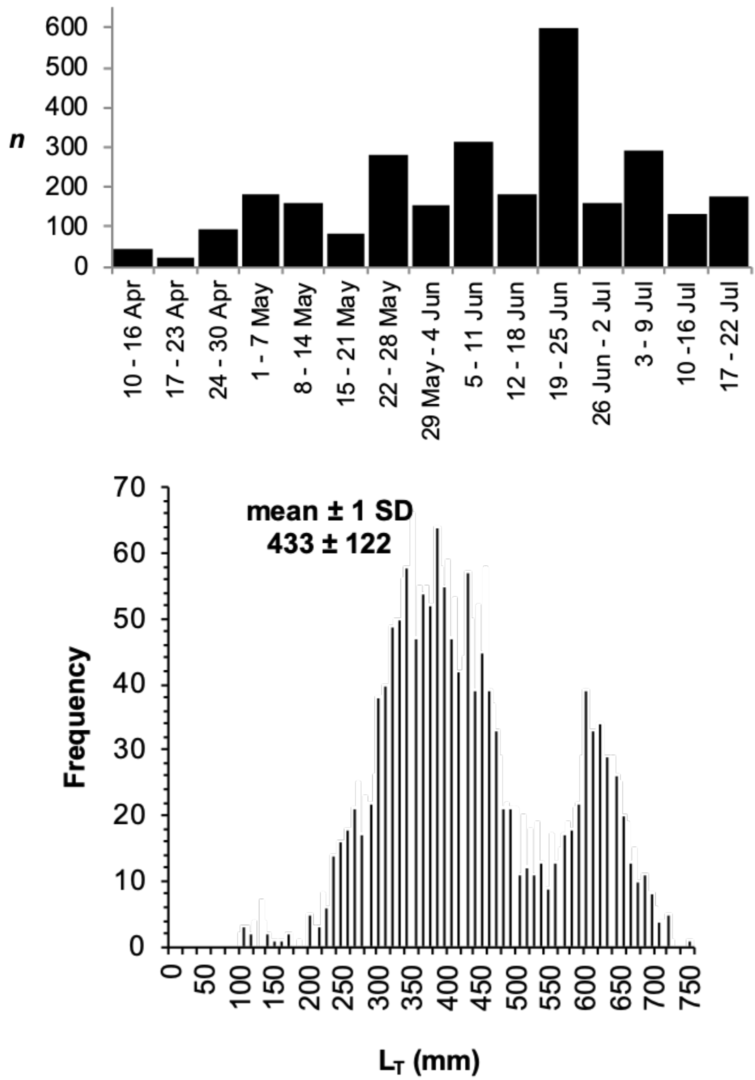

Fig 3 **(Top) Weekly catches (*n*) of skate captured in the Bramber weir from April 10-July 22, 2017; (Bottom) Total length (mm) frequency of skate captured in the Bramber weir during April 10 to July 22, 2017. Lengths are grouped in 5 mm bins.**

skate were captured. Catches were greatest during late May to early July. Their weekly abundance in the weir catches ranged from 15-600 individuals (Fig 3) which was similar to the abundance found by Whidden (2015) during 2012-2014.

Length frequency distribution of skate ranged from 100-750 mm L_T (Fig 3). There was an obvious bimodal distribution in lengths (peaks at 350-400 and 600-650 L_T) perhaps caused by considering the two species together. Winter skate adults are larger than little skate adults (Whidden 2015). The overall mean length ± 1 S.D. of captured skates was 433 ± 122 mm L_T.

American eel

A total of 44 American eel were captured during 2017 (Table 1). Individuals were yellow eel of 500-600 mm $L_{T.}$ This catch was probably an underestimate of eel abundance at Bramber because eels are exceptionally adapt at finding escape routes from nets and traps because of their small diameter and mucus covered skin (Scott and Scott 1988). No American eel were reported captured during the FORCE study (Baker *et al.* 2014).

Atlantic sturgeon

A total of 247 Atlantic sturgeon were captured from late April until the weir was closed (Fig 4). Weekly catches during this period varied between one to 50 sturgeons. Maximum daily catches ranged from 2-3 fish during April-May to 6-12 sturgeon in June-July. The largest catches came during late June to July as the annual aggregation of feeding sturgeon in Minas Basin migrated into the Southern Bight (Dadswell *et al.* 2016).

Atlantic sturgeon were the largest fish species captured by the Bramber weir during 2017. Sturgeon ranged from 52.3 cm to 239.5 cm L_T (Fig 4). The mean length ± 1 SD of the catch was 147.4 ± 31.3 cm L_T which was consistent with the annual mean length of the summer aggregation during previous years (Baker *et al.* 2014; Dadswell *et al.* 2016). The major portion of the annual feeding aggregation which runs through Minas Basin each summer are juvenile Atlantic sturgeon of 10-25 years of age and 110-170 cm L_T from the Saint John R., NB and the Kennebec R., ME (Wirgin *et al.* 2012).

Sturgeon feed on the benthic marine invertebrates found in the Minas Basin intertidal flats (McLean *et al.* 2013). It is during their feeding forays onto the tide flats at high tide that they are captured in the weirs. Atlantic sturgeon have anadromous populations which occur along the east coast of North America from Florida to Quebec and which migrate annually along the Atlantic coast (Dadswell 2006).

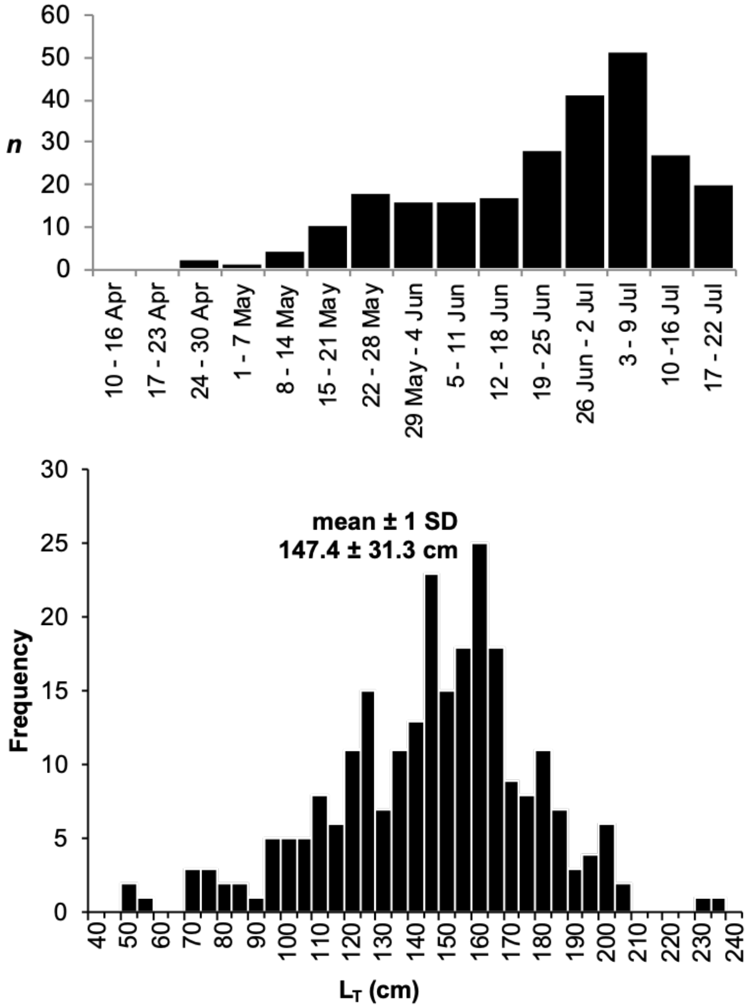

Fig 4 **(Top) Weekly catch (*n*) of Atlantic sturgeon at the Bramber weir during April to July, 2017. Total catch was 251 fish. (Bottom) Fork length (mm) frequency distribution (5-cm bins) of Atlantic sturgeon captured in the Bramber weir April to July, 2017. Unmeasured fork lengths (*n* = 1) were extrapolated based on the following fork to total length relationship (L_T= 1.1026L_F+37.609; r^2 = 0.99; *n* = 246).**

Sturgeon tagged in Minas Basin have been captured as far south as New Jersey and north to the Gaspe Peninsula (Dadswell *et al.* 2016).

Atlantic sturgeon no longer constitute a legal commercial catch in Minas Basin although they were an important component of the commercial catch in some Minas Basin weirs in the past. The commercial take of Atlantic sturgeon in marine waters of Canada was closed by DFO in 2002 in order to facilitate the management of the spawning stocks in natal rivers such as the Saint John R., NB (Dadswell *et al.* 2017).

A total of 74 sturgeon were tagged during 2017 with external, FLOY dart tags supplied by Acadia University and a total of ten recaptures of externally tagged sturgeon were taken in the Bramber weir. Seven of these were from sturgeon tagged in Minas Basin in previous years, two of which were tagged in the Bramber weir during 2013. Three were tagged in previous years by researchers in the Saint John River, NB.

Clupeidae

A total of five species of the family Clupeidae (herring-like fishes) were captured. These were American shad, alewife, blueback herring, Atlantic herring and menhaden (Table 1). Herring catches were lower than in previous years but gaspereau catches were larger (D. Porter, pers. obs.). Based on the way these pelagic species school it is difficult to conclude if the difference in abundance among years represents a real change in abundance or the chance, random movement of large schools intercepted by the weir.

American shad

A total of 7,176 American shad were captured from early April until the weir was closed in July (Table 1). Weekly catches varied from a few to 2000 (Fig 5). Largest catches were in July as the annual shad migration through Minas Basin reached the Southern Bight (Fig 1; Dadswell *et al.* 1984a).

Lengths of captured American shad were from 43 mm to 652 mm L_F (Fig 5) which was similar in range to catches during 2013 (Baker *et al.* 2014). Smaller shad, in the length range of 100-200 mm $L_{F,}$ were the most common. These were age-1 shad possibly from the local spawning populations in Minas Basin. Adult shad of 350-550 mm L_F were the second most common group. These fish were age-3 to age-5 and probably consisted of shad from rivers all along the Atlantic coast (Dadswell *et al.* 1987). Weir catches of adult shad at Bramber during 2017 were low compared to weir catches in Minas Basin during the 1980’s (Dadswell *et al.* 1984a) but similar to catches during 2013 (Baker *et al.* 2014).

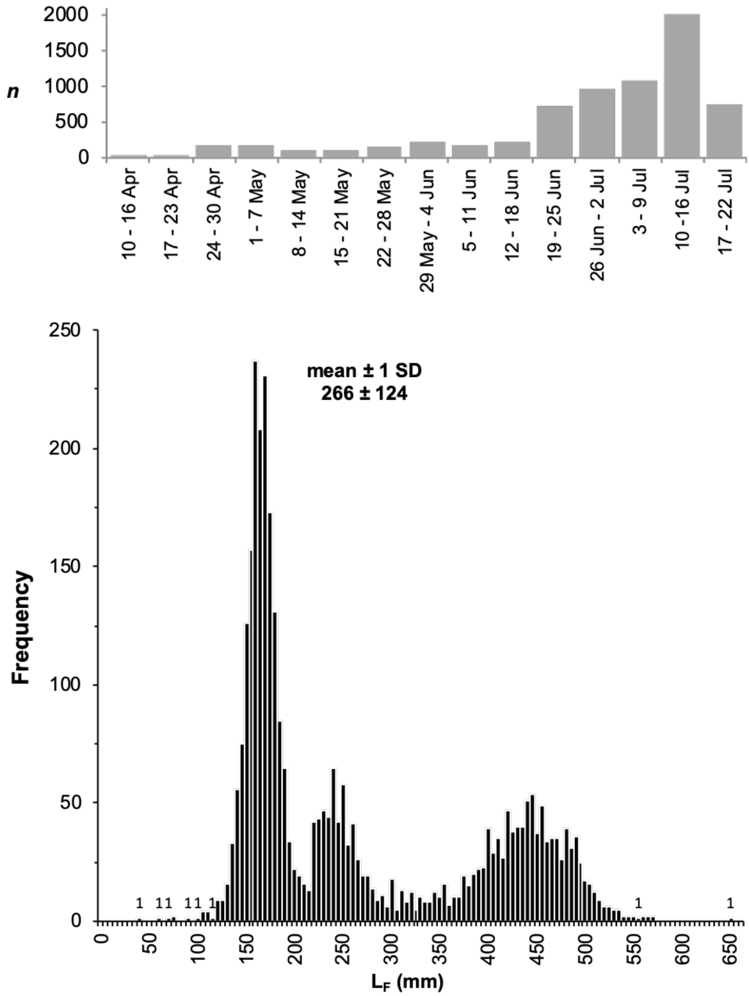

Fig 5 **(Top) Weekly catches (*n*) of American shad captured in the Bramber weir during April to July 2017. Total catch was 7,176 shad. (Bottom) Fork length (mm) frequency of American shad captured at the Bramber weir during April-July, 2017. Lengths are grouped in 5 mm bins. Ones (1) above x-axis indicate a catch of a single shad in that bin.**

Shad are an anadromous, pelagic species which have river spawning populations from Florida to Labrador and migrate annually along the Atlantic coast of North America. Shad tagged in Minas Basin have been captured as far south as Florida and as far north as Labrador (Dadswell *et al.* 1987).

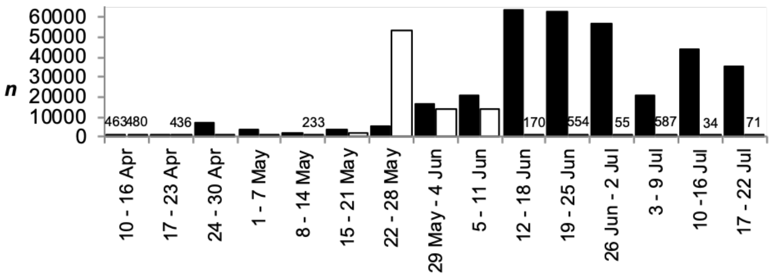

Fig 6 **Weekly estimated catches (*n*) of gaspereau (solid bars, n = 350,343) and Atlantic herring (open bars, n = 87,587) captured in the Bramber weir during April to July 2017. Weekly estimated catches of less than 1,000 individuals are indicated with numbers on the x-axis.**

Gaspereau

An estimated total of 350,343 gaspereau (*Alosa pseudoharengus* and *A. aestivalis*) were captured during April to July (Table 1). This catch represented 51.9% of all the fishes examined during 2017. Weekly catches ranged from 233-60,000 fish and abundance was consistently high throughout the period of weir operation (Fig 6).

The length range of captured gaspereau was 38-282 mm L_F (Fig 7) which represented fish from age-0 to age-3 (Stone 1985). Fish of 200-280 mm L_F (age-3) were the most abundant. Age-3 gaspereau were equally represented by males and females. Males were a mean ± 1 SD of 241 ± 19 mm L_F; females, 253 ± 17 mm L_F. The lack of larger (+300 mm L_F) and older gaspereau (age-4 and age-5) in the catches was probably because mature fish would have been spawning in local streams during April to July (Gibson and Daborn 1997).

Gaspereau are another anadromous, pelagic species which have spawning populations in rivers from Florida to Quebec and migrate annually along the east coast of North America (Scott and Scott 1988). Gaspereau tagged in Minas Basin have been captured as far south as North Carolina (Rulifson *et al.* 1987).

Atlantic Herring

An estimated 87,587 Atlantic herring were captured during 2017 which represented 13.0% of the total weir catch (Table 1). Herring catches were largest from early May to June. Weekly catches ranged from 34-50,000 fish with the highest catches during late May (Fig 6).

Atlantic herring captured during 2017 ranged from 32-350 mm L_F (Fig 8). Virtually all herring captured were mature fish from

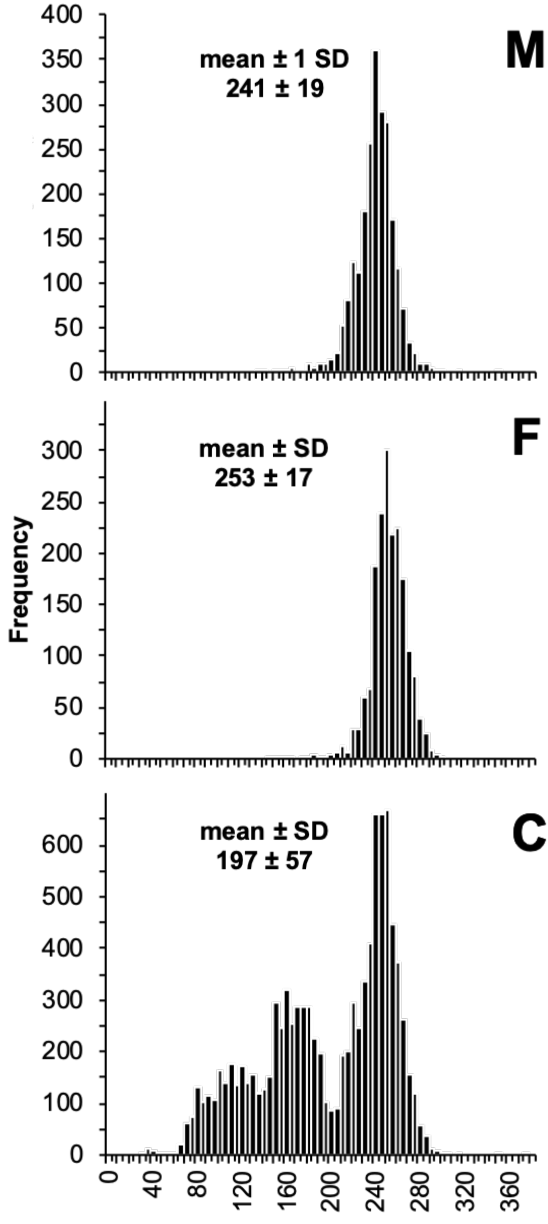

Fig 7. Fork length (mm) frequency of gaspereau captured in the Bramber weir, April-July 2017. Top (M = males), center (F = females), bottom (C = total individuals). Lengths grouped in 5 mm bins.

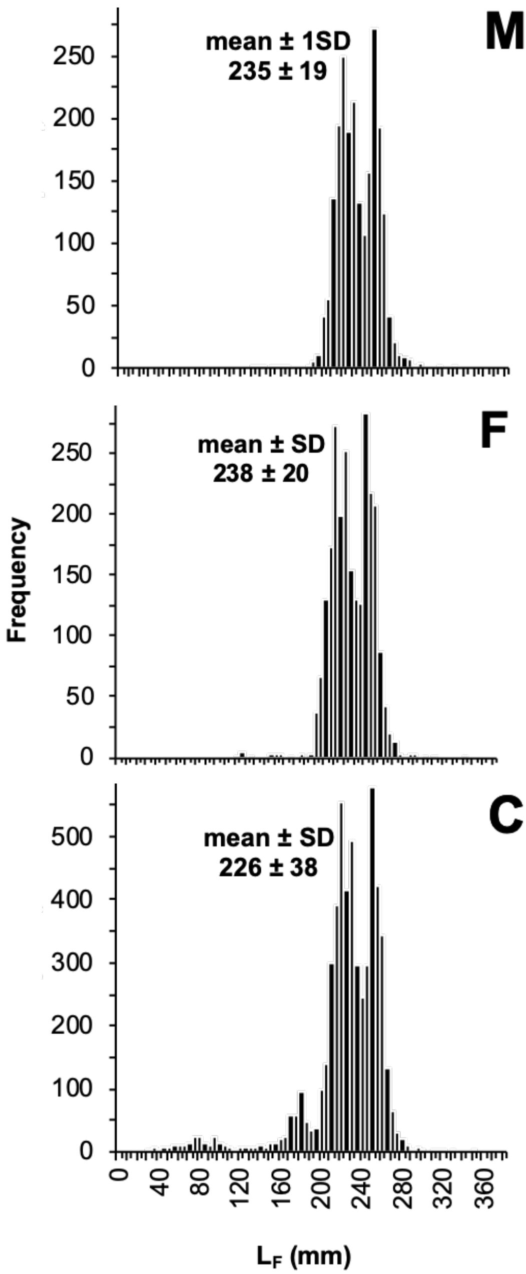

Fig 8 **Fork length (mm, grouped in 5 mm bins) frequency distribution of Atlantic herring captured in the Bramber weir during April to July, 2017. Top (M) males, middle (F) females, bottom (C), all individuals.**

200-290 mm L_F. Males averaged 235 ± 19 mm L_F, (range 130-330 mm L_F, *n* = 2,185); females, 238 ± 20 mm L_F (range 124-350 mm L_F, *n* = 2,438).

Minas Basin has a small, spring spawning stock of Atlantic herring estimated at ~100 *t* (Bradford and Iles 1993). They are captured in Minas Basin by weirs and by intertidal set gill nets during their spawning migration through the Basin.

Atlantic menhaden

Only one Atlantic menhaden was captured in the Bramber weir during 2017 (Table 1). In most years the catch of menhaden is larger (10-100 fish; D. Porter, per. obs.) but they are seldom caught in large numbers in Minas Basin (Dadswell *et al.* 1984b). A small spawning stock of menhaden exists in Minas Basin that spawns during late June in the vicinity of Burntcoat Head (Dadswell and Rulifson, in press).

Salmonidae

A total of four species of the Salmonidae (salmon-like fishes) were captured in the Bramber weir during 2017 (Table 1). These included Atlantic salmon (6 individuals), brown trout (9 individuals), brook trout (1 fish) and rainbow smelt. Atlantic salmon were represented by both post-smolts and adults. Brown trout and brook trout were adult fish probably from local streams. Only brook trout were reported captured in the weirs during 2013 (Baker *et al.* 2014).

Rainbow smelt

The estimated catch of rainbow smelt during 2017 was 93,976 fish (Table 1). Smelt were abundant throughout the fishing period representing 13.9% of the total catch with weekly catches ranging from 1000-12,000 fish (Fig 9). Largest catches were in July probably because the anadromous adults were in local streams spawning during April and May (Scott and Scott 1988). Catches of smelt were strongly correlated to daytime tides (Fig 9; $P < 0.05$). Daytime catches ranged from 10's to 1000's of individuals whereas nighttime catches seldom exceeded ten fish. This observation was not identified by the 2013 FORCE study (Baker *et al.* 2014) which sampled only daylight low tides and would have been undocumented without the consistent fishing of every tide during 2017.

Length distribution of rainbow smelt during April-July, 2017 ranged from 32 – 344 mm L_F (n = 3,954; Fig 10). The mean length ± 1 SD of the catch was 149 ± 42 mm L_F. Captured smelt ranged from age-1 to

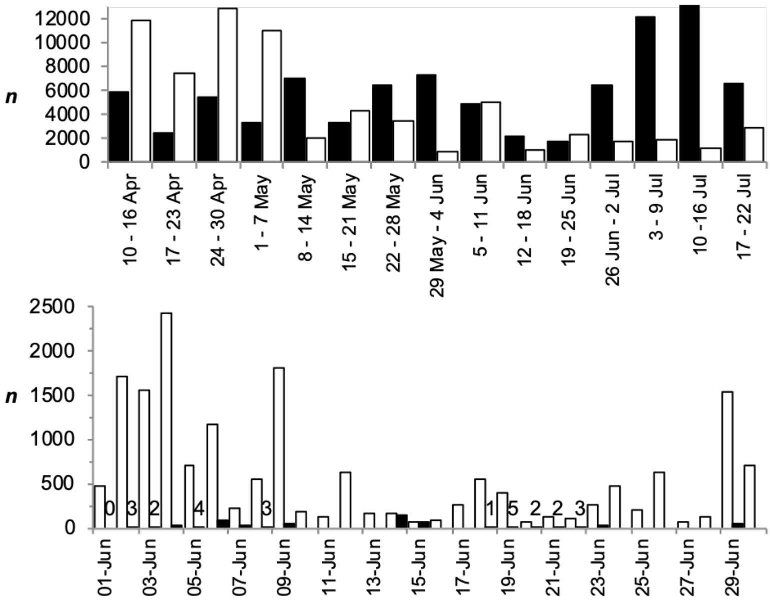

Fig 9 **(Top) Weekly estimated catches (*n*) of rainbow smelt (solid bars, *n* = 93,976) and Atlantic tomcod (open bars, *n* = 68,212) captured in the Bramber weir during April to July, 2017; and (bottom) estimated and enumerated catches (*n*) of rainbow smelt at the Bramber weir in June, 2017 during daytime (open bars) and at night (solid bars and numbers). Catches of less than 10 individuals are represented by numbers along the x-axis. Day-night catch difference was significant (P < 0.05).**

age-5 and the longest captured was near the maximum size reported for Maritime coastal waters (356 mm L_F; Scott and Scott 1988). The L_F frequency distribution peaked at 100-120 mm, 140-150 mm and 180-200 mm which represented age-1, age-2 and age-3 smelt, respectively (Scott and Scott 1988)

Gadoids

A total of nine species of gadoid (cod-like) fishes were captured in the Bramber weir during 2017 (Table 1). Most of the species were captured during the spring, cold water period and occurred rarely. Atlantic cod (six individuals), haddock (six) and pollock (one) represented commercial species captured. The capture of spotted hake (one) and long-fin hake (one) represented off-shore, deep water species and their capture was the first recorded in Minas Basin (Dadswell *et al.* 1984b; Scott and Scott 1988). Only pollock were recorded during the 2013 weir study (Baker *et al.* 2014).

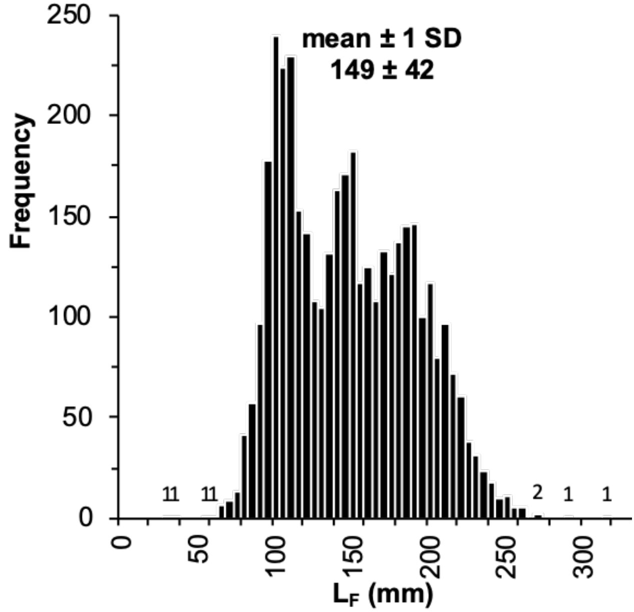

Fig 10 **Fork length (mm) frequency histograms of rainbow smelt sampled at the Bramber weir, during April to July, 2017. Unmeasured fork lengths (n = 14) were extrapolated based on the following fork to total length relationship (L_T= 1.0793L_F+3.2131; r^2 = 0.99; n = 1,227). Lengths are grouped together in 5 mm bins. Counts of less than 3 individuals per bin are labeled for clarity.**

Hakes

A total of 384 silver hake were captured from April to July. Catches ranged from 1-28 individuals a tide with the largest catches during May and June which was similar to other weir studies (Leim 1924; Dadswell *et al.* 1984b). Captured silver hake ranged in length from 62-304 mm L_T.

A total of 7,214 red and white hake were captured during 2017. These two species are difficult to differentiate between and weir identification was probably inaccurate. Correct identification of red and white hake requires examining the gill racker count (Scott and Scott 1988). Most of the small hake would have required the use of a microscope for correct determination which would have resulted in their death. Fish identified as red hake occurred mostly during the spring, cold water period. Catches ranged from 1-25 a tide and size from 107- 248 mm L_T. An abundance of smaller hakes largely identified as white hake occurred during July. Catches ranged from 1-1,409 individuals a tide ranging in length from 50-105 mm L_T.

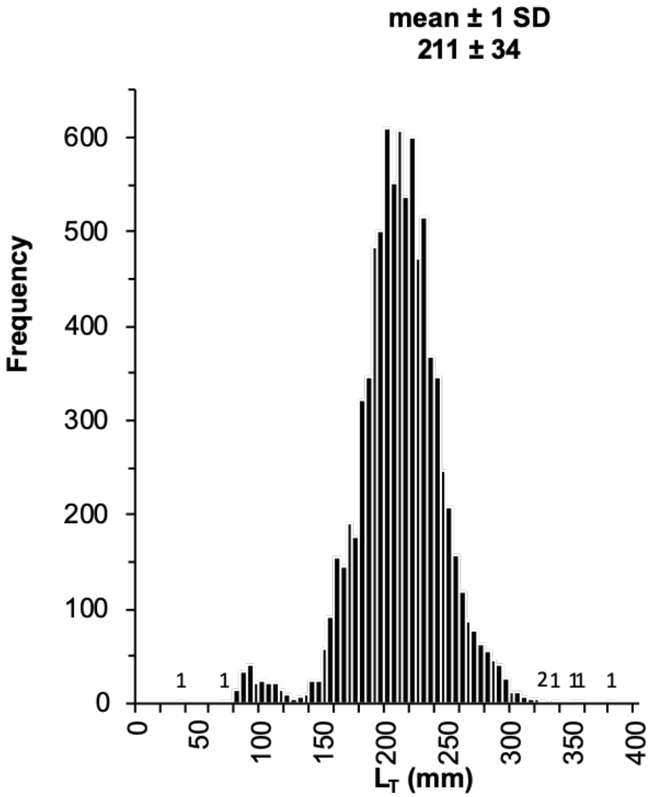

Fig 11 Total length (mm) frequency distribution of Atlantic tomcod sampled at the Bramber weir, from April to July, 2017. Lengths are grouped together in 5 mm bins. Counts of less than three individuals per bin are labeled for clarity.

Atlantic tomcod The estimated catch of Atlantic tomcod during 2017 was 68,212 or 10.1% of the total weir catch (Table 1). Weekly estimated catches ranged from several hundred to over 13,000 fish (Fig 9). Tomcod were captured throughout the fishing season but the largest catches were during April to early June.

The length distribution of tomcod was similar throughout the fishing period. Tomcod L_T ranged from 35 – 380 mm and the mean length ± 1 SD was 211 ± 34 mm L_T (Fig 11). These were mostly adult fish of age-2 to age-4 (Dadswell *et al.* 1984b). Juvenile tomcod (age-0) are pelagic and remain in the water column away from the intertidal zone until autumn (Scott and Scott 1988).

Tomcod are abundant in the inner Bay of Fundy especially in regions where the water is turbid (Dadswell *et al.* 1984b). They are an anadromous fish that spawns in freshwater streams during December and January and are often called ‘frostfish’ because of this behavior (Scott and Scott 1988). Since they are available when other fish are not they are fished during winter by the Mi’kamaq to whom they are known as ‘punamuiku’. There is an extremely large run of tomcod in the Shubenacadie River each winter that attracts large numbers of bald eagles (Reid 1982).

Monkfish

An uncommon species taken at the Bramber weir was the monkfish, a member of the angler or goosefish family (Lophiidae). Only four individuals were captured during 2017 (Table 1). Monkfish mostly prey on flounders and follow them onto the intertidal zone at high tide. They are often stranded in the intertidal tide zone since they are a lay-in-wait predator and the fast moving tide in Minas Basin catches them unawares (Bleakney and MacAllister 1973).

Other Rarely Captured Fishes

Other fishes that were rare or uncommonly captured in the Bramber weir were mummichog (two individuals), northern pipefish (seven), and cunner (51). All these fishes are much more common in Minas Basin than the weir catches suggest but were poorly represented because of their biology or physical characteristics (Scott and Scott 1988). Mummichog are extremely common in intertidal tide pools in salt marshes and remain close to that habitat (Bleakney and Bailey-Meyer 1979). Pipefish have a small diameter body and would pass easily through the weir mesh. Cunner are a species that remains close to rocky shores and wharfs and would rarely move over muddy, intertidal zones (Scott and Scott 1988).

Striped bass

A total of 1,388 striped bass were captured during 2017 (Table 1). Weekly catches varied from 20-35 fish during April to 70-190 fish during May-July (Fig 12). Largest catches were during May.

Striped bass captured ranged from 7.9 to 93.3 cm L_T and mean L_T ± 1 SD was 38.5 ± 10.8 cm (Fig 12). The majority of the catch was from 30-40 cm L_T which represented age-3 and age- 4 fish (Broome 2014). The largest bass were probably more than age-20. The length range

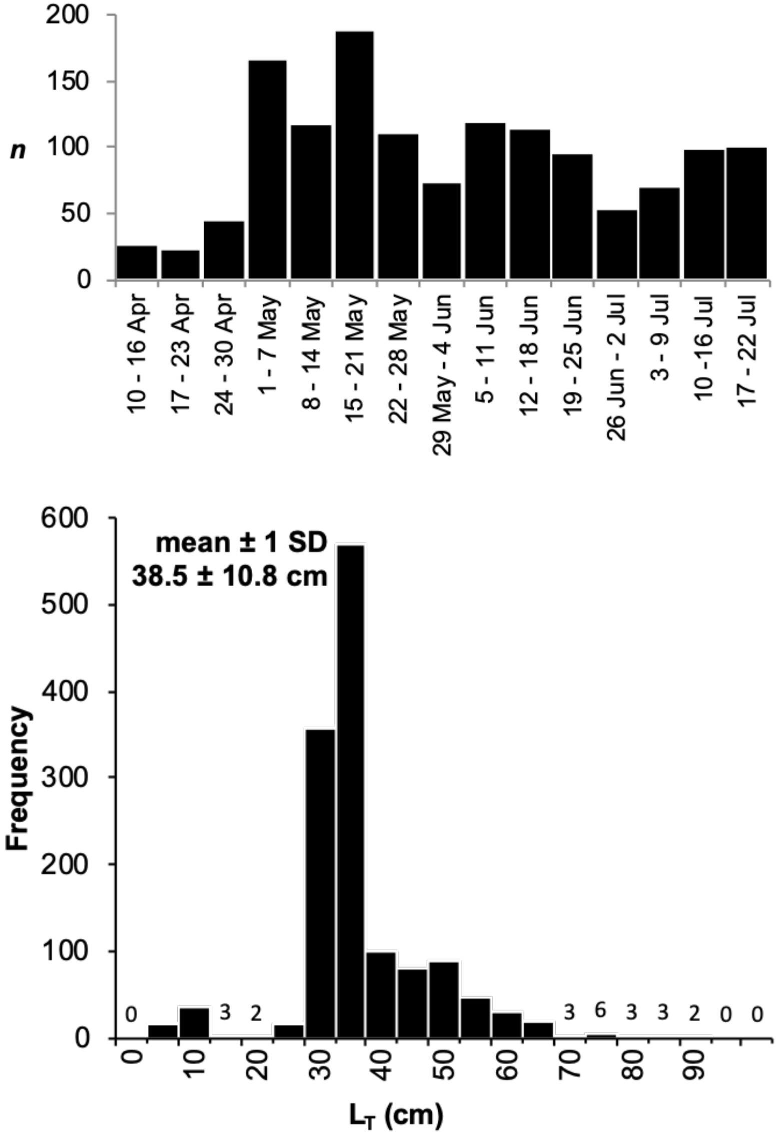

Fig 12 **(Top) Weekly catch (*n*) of striped bass from the Bramber weir during April to July, 2017. Total catch was 1,388 fish. (Bottom) Total length (cm) frequency distribution of striped bass captured at the Bramber weir from April to July, 2017. Unmeasured total lengths (*n* = 4) were extrapolated based on the following fork to total length relationship ($L_T = 1.0697L_F + 4.3996$; $r_2 = 0.99$; *n* = 1,381). Numbers along of x-axis are length groups with less than 10 fish.**

of striped bass captured during 2017 was similar to those captured in the weirs during 2013 (Baker *et al.* 2014).

Striped bass are an anadromous species that has riverine populations along the east coast of North America (Rulifson and Dadswell 1995). The major spawning population in Minas Basin occurs in the Schubenacadie River (Rulifson and Tull 1998). Most of the striped bass found in Minas Basin are from the local stock which largely remains in inner Bay of Fundy (Broome 2014; Keyser *et al.* 2016) but migratory bass also pass through each summer. Striped bass tagged in Minas Basin have been recaptured as far south as Virginia (Rulifson *et al.* 2008).

Striped bass are managed as a sports fishery in Canada and both sport and commercial catches are restricted to one fish a day in excess of 68.5 cm L_T (Broome 2014). A total of 105 of the released bass were tagged with external tags for researchers from Acadia University. Thirty- three of the bass caught had external tags applied in Minas Basin during previous years.

White Perch

White perch was rarely captured in the weir during 2017. Only 12 were taken (Table 1). White perch were not reported during the 2013 weir study (Baker *et al.* 2014).

White perch are an estuarine-freshwater fish and rarely move into high salinity habitats (Scott and Scott 1988). The Avon River head pond behind the causeway at Windsor has a large population of white perch which largely remain in the low salinity estuary (D. Porter, pers. obs.).

Silversides

Silversides are a small, schooling fish species that is important forage for striped bass. They generally remain over sandy and gravely beaches and are abundant in that habitat in Minas Basin (Gilmurry and Daborn 1981). They seldom live past 2 years of age or exceed 200 mm L_F. A total of 2,063 silversides were captured in the Bramber weir during April-July, 2017. Catches ranged from 1-164 a tide and were almost a daily catch over the entire weir season. Catches were, however, probably not representative of silversides abundance in the region of the weir and larger catches probably occurred when a school was intercepted by the weir. Silversides captured were from 72-127 mm L_F. Their small size would allow most to escape through the weir mesh.

Sculpins

Three species of sculpin were captured in the Bramber weir, longhorn sculpin, shorthorn sculpin and sea raven. During 2017 a total of 705 longhorn sculpin and 643 sea raven were captured but only four shorthorn sculpin (Table 1). Weekly catches of longhorn sculpin and sea raven occurred throughout the fishing season but were greatest during May and June when 60-80 sculpins were captured each week (Fig 13).

Longhorn sculpin captured during 2017 ranged from 30-398 mm L_T (Fig 14) and mean length ± 1 SD of was 261 ± 60 mm L_T. Sea raven captured during 2017 ranged from 102-502 mm L_T (Fig 14) and mean length ± 1 SD was 336 ± 55 mm L_T. Most of the sculpin captured were adults of 200-500 mm L_T (Scott and Scott 1988).

Summer-warm Fishes

Each year Minas Basin weirs capture a small number of rare, summer-warm species (Dadswell *et al.* 1984b). Only striped sea robin (one) and summer flounder (two) were observed during 2017 (Table 1). Striped searobin is an occasional catch in Minas Basin (Dadswell and Rulifson, in press). Summer flounder is a southern species rarely captured even in the Bay of Fundy (Scott and Scott 1988). In past years, scup, various drum species and black sea bass have been taken in the weirs (Dadswell and Rulifson, in press). Bluefish (*Pomatomus saltatrix*) were captured at the Bramber weir during 2013 (Baker *et al.* 2014) but not during 2017.

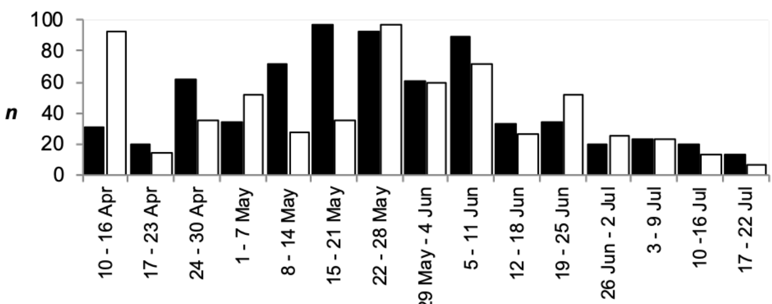

Fig 13 Weekly catches (*n*) of longhorn sculpin (solid bars, *n* = 701) and sea raven (open bars, *n* = 634) captured in the Bramber weir during April to July, 2017.

Butterfish

On the other hand, a number of other summer visitors are a yearly event and are often abundant. During 2017 a total of 536 butterfish were captured in the Bramber weir (Table 1). Catches were greatest during June (Fig 15). Butterfish are common in the pelagic zone of Minas Basin (Dadswell *et al.* 1984b) and catches in the Bramber weir

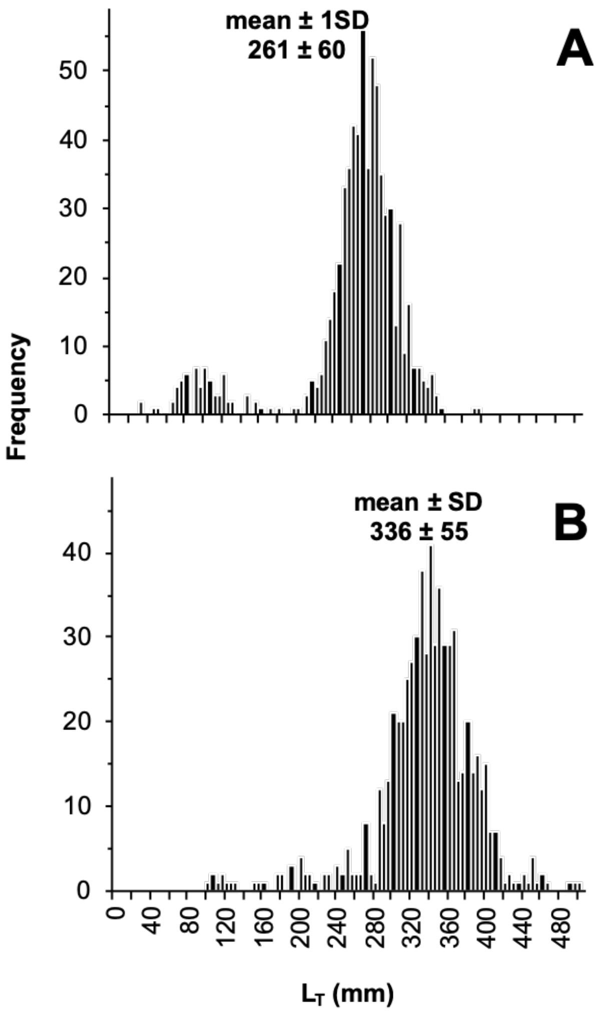

Fig 14 Total length (mm) frequency distribution of A) longhorn sculpin and B) sea raven captured in the Bramber weir during April to July, 2017. Lengths are grouped in 5 mm bins.

probably underestimated their abundance during 2017, since butterfish are a small fish and many could have escaped through the weir mesh. The catch during 2017 included individuals from 52-150 mm L_F.

Atlantic mackerel

The Atlantic mackerel run in Minas Basin occurs during early to mid-summer. Mackerel avoid the turbid water portion of Minas Basin (Cobequid Bay and the Southern Bight; Fig 1) and are only captured at the Bramber weir during periods of neap tides and light winds when the water is clear (D. Porter, pers. obs.). During 2017, a total of 1,820 mackerel were captured during June 17-22 (Fig 15). These fish measured 233-289 mm L_F, which is the average size for age-2 'tinker' mackerel (Scott and Scott 1988).

Flounders

Flounder were a daily and abundant catch during 2017. Total estimated catches for smooth, winter and windowpane flounder were 5,841, 24,214 and 18,860 respectively (Table 1). Weekly catches (Fig 15) of smooth flounder were greatest during April-May (100-1800), winter flounder from May to June (1000-4000) and windowpane from May-July (500-3500). Halibut is a cold water species and only two individuals were captured during early spring.

Captured smooth flounder ranged from 35-395 mm L_T (mean ± 1 SD, 199 ± 54 mm L_T), winter flounder from 47-420 mm L_T (mean ± 1 SD, 226 ± 78 mm L_T) and windowpane from 50- 393 mm L_T (mean ± 1 SD, 217 ± 82 mm L_T; Fig 16).

Flounder is harvested in Minas Basin by both the weir and trawler fisheries (Wehrell 2005; Baker *et al.* 2014). Smooth and windowpane flounder are year around residents of Minas Basin (Bleakney and McAllister 1973) but winter flounder migrate through Minas Basin each year, arriving in April-May to spawn and departing during August-September for offshore waters (McCracken 1963).

CHARACTERISTICS OF CAPTURED INVERTEBRATES

Data collected from captured invertebrates included species and number caught. A total of 13 larger and/or abundant species were identified (Table 2). Lady crab was the most abundant invertebrate captured and represented 75.6% of the catch. They began appearing

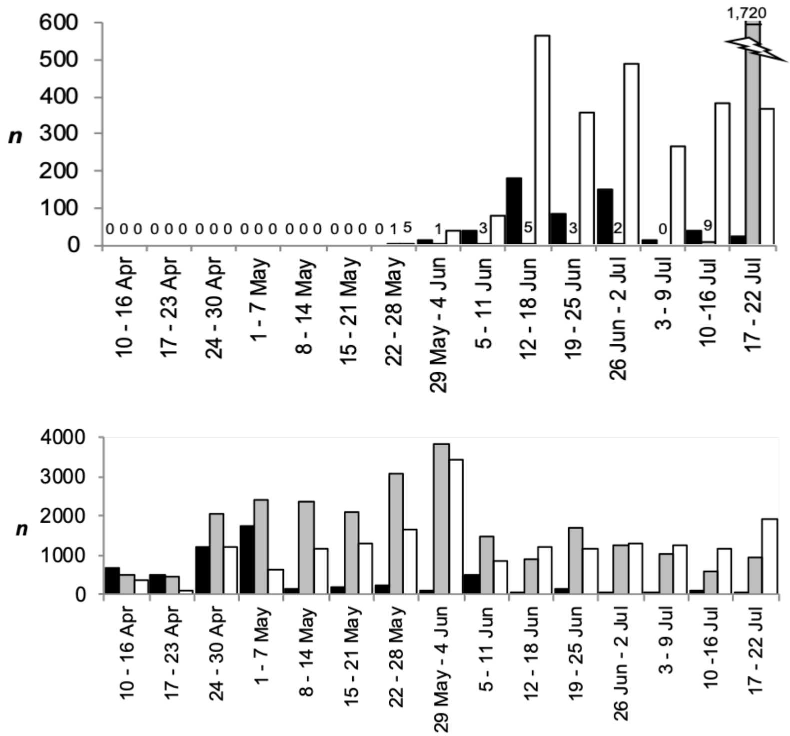

Fig 15 **(Top) Weekly catch (*n*) of summer visitors to Minas Basin: butterfish (solid bars, *n* = 536), Atlantic mackerel (shaded bars, *n* = 1,820) and longfin squid (open bars, *n* = 2,560), captured at the Bramber weir from April to July, 2017. Weekly catches of less than ten individuals are shown with numbers. The weekly catch of mackerel during 17-22 July is denoted with a number and broken bar to indicate the catch is above vertical axis numbering. (Bottom) Weekly estimated catches (*n*) of flounders captured in the Bramber weir during April to July, 2017. Total estimated catches were winter flounder (shaded bars, *n* = 24,214), smooth flounder (solid bars, *n* = 5,841) and windowpane flounder (open bars, *n* = 18,860).**

in the catch during mid-May (5-10 each tide) but were most abundant during mid-June to late July (100- 1,000 each tide).

Longfin squid

Long-fin squid was the only invertebrate species taken in the commercial catch at the Bramber weir. Squid are used by anglers for striped bass fishing and are eagerly sought out from the weir fishers. Long-fin squid are a pelagic species which winters off Long Island, USA and migrates north to Canada (Black *et al.* 1987). There

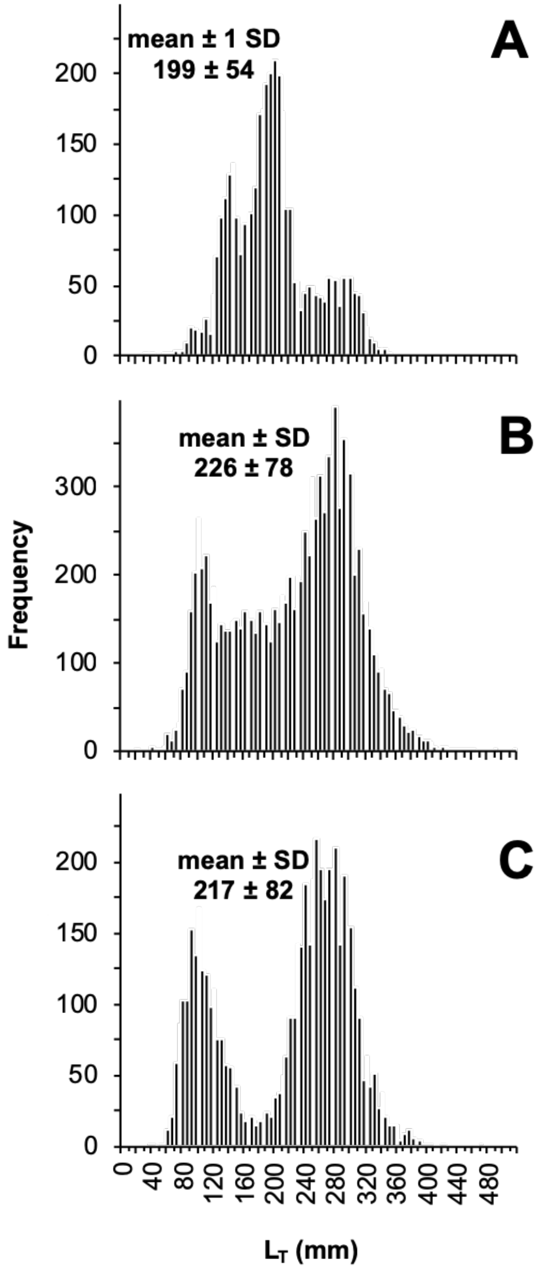

Fig 16 Total length (mm) frequency distributions of A) smooth flounder, B) winter flounder and C) windowpane flounder captured in the Bramber weir during April to July, 2017 (lengths in 5 mm bins).

is a stock that spawns in Minas Basin each summer from July to September (Dadswell, per.observ.). A total of 2,560 squid were captured in the Bramber weir during 2017 (Table 1). Catches began in late May and were highest during June to July when weekly catches were from 300-500 individuals (Fig 15).

Squid grow very rapidly but only live for one year (Black *et al.* 1987). After spawning the adults die. Young are born from July to September in Minas Basin and return as adults the following summer. A total of 1459 squid were sampled which ranged in total length from 95 – 640 mm. The catch was a mixture of age-0 and age-1 individuals.

CONCLUSIONS

The Bramber weir is one of six active weirs still operating annually in Minas Basin. There is one at Parrsboro, two at Five Islands, two at Economy and the Bramber weir on the Avon estuary (Fig 1). More weir licenses exist in Minas Basin but are not active every year.

The diversity of the fish catch (45 species) at Bramber during 2017 was similar to that observed by Leim (1924) and Dadswell *et al.* (1984b) at weirs along the north shore of Minas Basin during the 1920's and 1980's (44 species) and nearly twice as many as were recognized in 2013 during the FORCE study (28 species; Baker *et al.* 2014). Total known diversity of fishes occurring in Minas Basin during the last four decades is in the range of 75-80 species (Dadswell and Rulifson, in press). Fishes found in Minas Basin that were not captured at Bramber during 2017 included large sharks (great white, sand tiger, porbeagle) and some rare summer-warm migrants including scup, drums, bluefish, tautog, four-spot flounder and ocean sunfish. All of these species have been rare catches in the past. We know that a great white shark was near the Bramber weir during 2017 based on acoustic tag receptions (D. Porter, pers. comm.) but thankfully it was not captured since capture means the difficult process of removing it safely from the weir following the protocol established by DFO.

Abundance and size structure of fishes in the Bramber weir catch during 2017 was comparable to weir studies in the past (Liem 1924; Dadswell *et al.* 1984b; Baker *et al.* 2014) except the number of fish measured far exceeded past efforts. The 2017 study measured 57,950 fishes compared to approximately 8300 measured by the FORCE 2013 study (Baker *et al.* 2014) In all previously studies, the dominant catch species were gaspereau, Atlantic herring, American shad, skates, striped bass, mackerel and the flounders. Spiny dogfish shark were more abundant in the 1980 weirs catches because of the large increase in their stock size during 1970-1990 (Campana *et al.* 2008). The abundance and size structure of skates was similar to previous surveys conducted at the Bramber weir from 2012-2014 (Baker *et al.* 2014; Whidden 2015). Atlantic sturgeon were less abundant in past weir studies (Liem 1924; Dadswell *et al.* 1984b) largely because their stocks were formerly depleted by overexploitation and pollution (Dadswell 2006), but they are now recovering and annual catches in weirs have increased (Baker *et al.* 2014; Dadswell *et al.* 2016).

The abundance and size structure of gaspereau and striped bass in weir catches during the 1980's and during 2013 was comparable to the 2017 Bramber catch (Rulifson *et al.* 1987, 2008; Baker *et al.* 2014). Tomcod abundance and size structure was similar to a population sampled on the intertidal zone in Cumberland Basin, inner Bay of Fundy during 1979 (Dadswell *et al.*1984b) and those caught at the Bramber weir during 2013 (Baker *et al.* 2014). The abundance and size structure of winter flounder collected in a Minas Basin trawl catch survey during 2004 (Wehrell 2005) and weir surveys during 2013 (Baker *et al.* 2014) were similar to the 2017 Bramber weir catch. Individual catches/tide and size structure of Atlantic herring, rainbow smelt, longhorn sculpin, sea raven, smooth and windowpane flounders during 2017 were similar to catches of these species during 2013 at the Bramber weir (Baker *et al.* 2014).

In conclusion we propose that the Bramber weir catch during 2017 met the requirements set out by DFO for weirs to be a useful tool in gathering comprehensive baseline information to monitor diversity, seasonal abundance and size structure of fishes in Minas Basin. The information on diversity and abundance will be useful for future comparisons if there are changes in these characteristics of Minas Basin fishes caused either by tidal power development impact or exploitation. Also, the detailed length structure provided for each species will provide sufficient data for significant statistical comparisons in the future if the size structure of individual fish species is altered by propeller turbine mortality removing larger individuals (Dadswell *et al.* 2018) or overexploitation. All these comparisons will be important for assessing any future impact of tidal energy development in the inner Bay of Fundy.

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EARLY ENTANGLEMENT OF NOVA SCOTIAN MARINE ANIMALS IN PRE-PLASTIC FISHING GEAR OR MARITIME DEBRIS: INDIRECT EVIDENCE FROM HISTORIC 'SEA SERPENT' SIGHTINGS

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ABSTRACT

Marine environmental historians and ethnobiologists have resorted to imaginative means with which to back-cast the temporal frame of reference in order to assess recent anthropogenic changes. The present study, in support of previous work from around the world, indicates that anecdotal accounts from eyewitnesses of purported sightings of sea serpents provides indirect evidence that marine animals in Nova Scotia have been subjected to anthropocentric pressure for a much longer period than commonly presumed. This involves not only direct fishery exploitation, but also perhaps from being bycatch due to entanglement in deployed gear.

Key words: Unidentified marine object, entanglement, fishing gear

INTRODUCTION

One challenge faced by environmental scientists and historians occupied with documenting changes in the Anthropocene is the need to back-cast the temporal frame of reference in order to detect recent alterations. Occasionally this task can be accomplished without too much difficulty due to comprehensive notes kept by a few early scientists. One such case involved the meticulous phenological records tabulated from schoolchildren across Nova Scotia by Alexander Mackay (France 2010), thereby enabling assessment of climatic changes in the province (Vasseur *et al*. 2001, Culbertson-Paoli *et al.* 2019). Often, however, data sets collected by early 'citizen scientists' require much more work before they can be made of use. This is due to having to sort through unorganized, so-called 'shoebox' files of disparate observations, or the need to extract information carefully

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from that embedded in the often voluminous journals of natural historians (France 2010), as for example completed by Miller and Primack (2008).

That the world's marine ecosystems have undergone extensive alteration in consequence of human activity is widely accepted (e.g. Starkey *et al.* 2007; Bolster 2012). By analyzing catch records through time, marine scientists and historians have played a key role in documenting the deleterious alterations to global fisheries (e.g. Lotze *et al.* 2006, Lotze & Worm 2009). Such work relies upon a temporal consistency in the type of data being compared for assessing biological changes. However, obtaining such data is not always possible. In these cases, surrogates are needed from which to indirectly infer anthropogenic changes in variables of premier interest, as for example, shifting baselines (Pauly 1995; McClenachan *et al.* 2012). Some marine scholars have resorted to imaginative means by which to estimate past conditions and to indirectly measure recent anthropogenic changes (Camuffo 2001, McClenachan 2009, Drew *et al.* 2013, Rice *et al.* 2017). Other work is based on the qualitative examination of historical accounts from eyewitnesses (e.g. Mowat 1999). Studying dynamic relationships between people, the biota, and their shared environment through time, falls within the purview of environmental history, historical ecology, and ethnobiology.Together these play an integral role in conservation biology and natural resource management (e.g. Crumley 1994, Pauly 1995, Meine 1999). Ethnobiology can contribute to historical ecology through the use of anecdotal information, often compiled from a wide variety of non-scientific textural sources (e.g. Al-Abdulrazzek *et al.* 2012, da Silva *et al.* 2014, McClenachan *et al.* 2012, Saenz-Arroyo *et al.* 2005, 2006). This sort of work falls within the bailiwick of natural history, so it is neither appropriate to prejudicially dismiss the value of information contained within historical textual accounts (Pauly 1995), nor to insist upon rigorous hypotheses testing as per scientific procedure. The two approaches are very different (Peters 1980, 1991). Exclusively focusing on biophysical records while ignoring social ones can severely limit the usefulness of research undertaken to understand and manage complex social-ecological systems, such as the marine littoral (France 2016a), in the Anthropocene (Dearing *et al.* 2015).

In his comprehensive history of the North American fishery, Bolster (2012) made the bold assertion that "no marine environmental historian worth his or her salt can afford to ignore…nineteenth-century sea serpents.” Mining the literature of folkloric tales and eyewitness accounts concerning sea monsters can indeed offer ecological and ethnobiological insights (e.g. Parsons 2004, Narchi *et al*. 2013, Szabo 2018, Paxton & Naish 2019). In this respect, the present historical investigation in support of previous work (France 2016b,c, 2017, 2018, 2019a,b,c), suggests that textural records by laypeople provide surrogate information about the history of deleterious interactions between humans and marine animals. In particular, my thesis is that a careful parsing of the words contained in the anecdotal accounts of purported sea serpent sightings generate data (*sensu* Paxton 2009) to serve as a valuable resource. Such an approach can extend inferences made about what is today acknowledged as being one of the most serious threats to marine biodiversity, namely, the entanglement of bycatch in fishing gear or other maritime debris.

THE CASE OF THE GLOUCESTER ‘SEA SERPENT’

There have been hundreds of sea serpent sightings made from every conceivable corner of the globe over the last four centuries (Oudemans 1892). The centre for the greatest number of sightings has been the Northwest Atlantic seaboard (Heuvelmans 1968). More than two hundred and fifty sightings have occurred in New England (O’Neill 1999), and eighty in Atlantic Canada (France, in prep.), with at least half of the latter being in Nova Scotia waters (Hebda 2015).

Most sightings of sea serpents are either of an extremely brief duration or made by a single observer. This is not the case, however, with respect to the so-called ‘Gloucester Sea Serpent’ which frequented the Massachusetts and New York coasts during the early nineteenth century. Being observed by hundreds, if not thousands, of people, from all walks of life, often for durations of many minutes, and in some cases, even hours (Soini 2010), this particular unidentified marine object (UMO) remains the most sighted sea serpent in history (France 2019a). Another unique feature about the Gloucester Sea Serpent is that it is the most thoroughly investigated such creature of all time. The social ‘phenomenon’ (*sensu* Burns 2014) created by reports of the Gloucester Sea Serpent led to detailed interviews of eyewitnesses. These were conducted by legal authorities under the auspices of the region’s learned natural history society, the Linnaean Society of New England. These took place soon after the bulk of the sightings and played an important role in international discussions concerning the theory of evolution and in the birth of American science (Brown 1990, Lyons 2009, France 2019a). This is the reason why the Gloucester Sea Serpent forms such an important lynchpin in the theories touted by cryptozoologists in terms of being "by far the best-documented evidence that sea-serpents exist" (Bauer 2013).

The most notable behavioral feature (France 2019a) of the Gloucester UMO was its rapid speed of movement (which often produced a massive trailing wake). Eyewitnesses noted the remarkable flexibility of the UMO, which twisted and turned upon itself, coiling and uncoiling quickly with different portions of its body capable of moving side-by-side in diametrically opposing directions. Elements comprising the elongated body of the UMO were observed to independently undulate in an up and down motion as if floating on the surface. Sometimes, the entire bulk of the UMO was seen to be pulled downward, quickly disappearing into the depths with little or no warming, sinking as if a stone. At other times, the UMO was seen floating motionless upon the water, occasionally for extended periods. Intriguingly, the portion of the UMO observed above the sea surface appeared to be totally oblivious to its surroundings, including, most remarkably, to even being hit by musket shot, harpoons, and in one case, even a cannon!

The most notable anatomical feature (France 2019a) of the Gloucester UMO was its considerable or "monstrous" length, ascribed by eyewitnesses to being up to a hundred feet. The UMO was observed to have neither a discernable tail, nor any appendages. The UMO's component body parts, including the premier one which was taken to be the head, were frequently likened to being of a size similar to that of a keg, cask, barrel, or firkin (a small container used for holding liquids or butter). The bulk of the UMO's length was composed of a series of irregular or uneven, loosely articulated joints, humps, or bunches, sometimes identified as being of variable number (ranging from less than ten to more than fifty). Significantly, a number of accounts specifically describe the UMO's body as resembling a string or a chain of buoys, corks, or kegs tied or roped together and floating upon the surface (Table 1). This is the closest we have to a 'smoking gun' in terms of identifying that the UMO was actually an entangled animal; i.e. the so-called 'duck test' (i.e. "if it looks like a duck, swims like a duck, and quacks like a duck, then it probably *is* a duck") for abductive reasoning.

The Gloucester unidentified marine object (UMO), folklore's most famous sea monster, occurred coincidentally with history's most significant volcanic eruption that also led to the birth of literature's most famous monster, Frankenstein (France 2019c). The 1815 eruption of Tambora in Indonesia produced a social-environmental crisis around the world (Wood 2014). In New England, propagated changes completely transfigured the relationship of humans to their coastal ecosystem (Alexander *et al.* 2017). Slaughter of livestock occurred from want of fodder, and collapse of the anadromous fisheries due to spawning failures. This necessitated turning to the sea for food protein *in extremis*. Beginning in 1816, and motivated by desperation and the threat of starvation, the entire northeastern coast of America, as never before, became covered by a network of lines and deployed fishing nets. Netting was used to catch mackerel as well as herring and menhaden; the latter was used as baitfish for jigging. The result was a seascape primed to create a sea serpent through bycatch entanglement in fishing gear.

Once the switch to offshore fishing was made, it stuck. There was simply no going back to small, shore-hauled nets and weir-traps straddling streams and rivers, when larger nets could be deployed in coastal bays and offshore waters to collect more biomass. The result was a parallel and progressive rise throughout the rest of the century in New England of both entrapped small fish (Alexander *et al.* 2017) and bycatch-entangled animals misconstrued as sea serpents (France 2019c).

The same social-ecological emergency caused by the extreme climatic changes arising from the Tambora eruption also affected Atlantic Canada in an identical fashion (Harrington 1992). The purpose of the present environmental history investigation was to determine if anecdotal evidence exists that is similar to that of New England for inferred entanglement in the accounts of sea serpent sightings around Nova Scotia.

HISTORICAL DESCRIPTIONS OF NOVA SCOTIAN 'SEA SERPENTS' SUGGESTIVE OF ENTANGLEMENT

In mari multa latent, goes the old adage: "in the ocean many things are hidden." Similarly, Fama (2012) believed that truth behind sea serpents is often "hidden in the plain language of their own

Table 1 Descriptions of the UMO, imagined as a sea serpent, observed between 1815 and 1824 in Gloucester Harbor and elsewhere, and clearly indicative of a marine animal entangled in fishing gear or other maritime debris (France 2019a,c).

"…his appearance in this situation was like a string of buoys. I saw perhaps thirty or forty of those protuberances and bunches, which were about the size of a barrel."
"…looked like the buoys of a seine"
"…with a good glass [I saw what] seemed like gallon kegs tied together"
"His body when out of the water looks like the buoys of a net, or a row of kegs, or a row of large casks"
"…of the size of a barrel about the body, which…are so prominent, that they resembled buoys attached to each other"
"[The body] appears in joints like wooden buoys on a net rope almost as large as a barrel, that the musket balls appear to have no effect on it, that it appears like a string of gallon kegs."
"…as he moved he looked like a row of casks following in a right line"
"He appears to be full of joints and resembles a string of buoys on a net rope, as is set in the water to catch herring. Others describe him as like a string of water casks…Two [musket] balls were thought to hit his head, but without effect."
"…resembled the link of a chain."
"The first view I had of him appeared like a string of empty barrels tied together, rising over what little swell of the sea there was."
"The back was composed of bunches about the size of a flour barrel, which were apparently about three feet apart…and looked like a string of casks or barrels tied together."
"The body, which is formed into parallel rings, which—when he is on the top of the water—are so prominent, that they resembled buoys attached to each other."
"…and to seem jointed, or like a number of buoys or casks following each other in a line."
"…the curvature and bunches on his back. To some he appeared jointed, or like a string of kegs or buoys connected on a rope."
"…giving the appearance of a long moving string of corks."

descriptions." In this spirit, the corpus of accounts of Nova Scotian UMO sightings complied by Hebda (2015) and France (in prep.) were carefully examined. The anecdotes most suggestive of an entangled animal are described in abbreviated form below. The full texts can be found in Hebda (2015) and France (in prep.), with the former including some of his interpretive drawings of the described creatures.

At the height of the Gloucester sea serpent phenomenon which gained world-wide attention in 1817, William Less, a former consul of the United States at Bordeaux and an accountant in the treasury department, wrote a letter to the learned naturalist Dr. Mitchell.

In this, he described a trip he had made as a boy from Quebec, in 1787, aboard a schooner. While heading through the Gut of Canso, Cape Breton Island, a crew member warned that the schooner was heading directly for a shoal, which to their "great astonishment" moved past them, and in so doing, pulled its elongated body across the bow of the vessel, whereupon they "discovered it to be an enormous Sea Serpent, four times at least as long as the schooner. Its back was of a dark green color, forming above the water a number of little hillocks, resembling a chain of hogsheads [i.e. barrels]." The UMO's head was described as being the size of large as the small dory, and its passage made "a tremendous ripple and noise," comparable to that of the launching of a ship [Anecdote 1: *Niles Register*, September 20, 1817 *in* O'Neill 1999].

In 1825, a gentleman,"whose character, whose education and scientific attainments render it impossible that he could either be deceived or willfully misrepresent the facts was traveling with several ladies along the shore of the Bedford Basin, Halifax Harbour, when "their attention was arrested by the appearance of a black object upon the surface of the water" about sixty feet distant. As the UMO moved forward by wiggling its body without showing any fins, the gentleman concluded the "it could be no other animal but a sea serpent." Subsequent observation made over a five-minute period, we are told, confirmed his first impression. It included the head being raised about three feet above the water before dipping back down, and a note that the "after part of the body raised a coil which warped itself along to the tail, and this made it to be supposed that its extreme its length was at least 60 ft. Its colour appeared to be black, and it appeared to be in circumference about the size of a large log." Another observer who "had a distinct view of this monster" and whom "felt satisfied that it was a sea serpent" remarked that it "moved round the boat in a sweeping and circular direction" and possessed "eight coils of the body above the water, each about a yard in length and with the same space intervening between them," for a length of sixty feet. The UMO was observed to move with great rapidity so as to leave a trailing wake but was oddly devoid of any discernable fins to account for the propulsion [Anecdote 2: 'Sea Serpent at Halifax,' *The Nova Scotian*, July 27, 1825].

In 1838, multiple eyewitnesses in the fishing village of Meteghan, near Yarmouth on the southern tip of Nova Scotia, saw what they first thought to be a large shark or whale producing a notable wake in the water. Upon closer inspection, however, the UMO was of an incredible length of up to one hundred and fifty feet, and held its head, likened to being the size of a large barrel, above the water. The creature swam within an oar's length of the boat, yet ignored them completely, as if the head was oblivious to their presence [Anecdote 3: Dearborn 1998].

The UMO that was observed swimming past the pier at Arisaig, Cape George, in 1844, had a sixty-foot long body of a thickness of three-feet. The description reads like Heuvelmans' (1968) typical many-humped "chain of floats" sea serpent, such as that seen in Gloucester Harbour:

> It had humps on the back, which seemed too small and close together to be bends of the body. The body appeared to move in long undulations, including many of the smaller humps. In consequence of this motion, the head and tail were sometimes both out of sight, and sometimes both above water, as represented in the annexed outline, given from memory [Fig 1]. The head…was rounded and obtuse in front, and was never elevated more than a foot above the surface. The tail was pointed, appearing like half of a mackerel's tail. The colour of the part seen was black [Anecdote 4: Lyell 1850].

The following year, a similar (or the same) UMO was observed further along the Northumberland Strait at Merigomish. Enough of a stir was caused by the report of the event to attract the attention of famed Scottish geologist Sir Charles Lyell. who was traveling in the Maritimes at the time. The UMO's head, which was occasionally raised above the water during the observation period of half an hour, was said by several eyewitnesses to resemble that of a seal. Once again, the remaining description matches that of the famous Gloucester Sea Serpent:

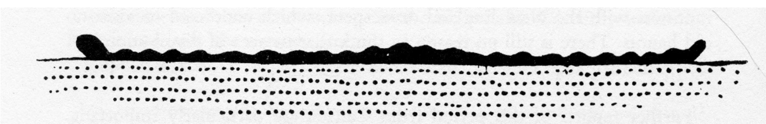


Fig 1 Huevelmans' (1968) interpretation of the UMO seen in 1844 off Arisaig, Nova Scotia, as described by Lyell (1850).

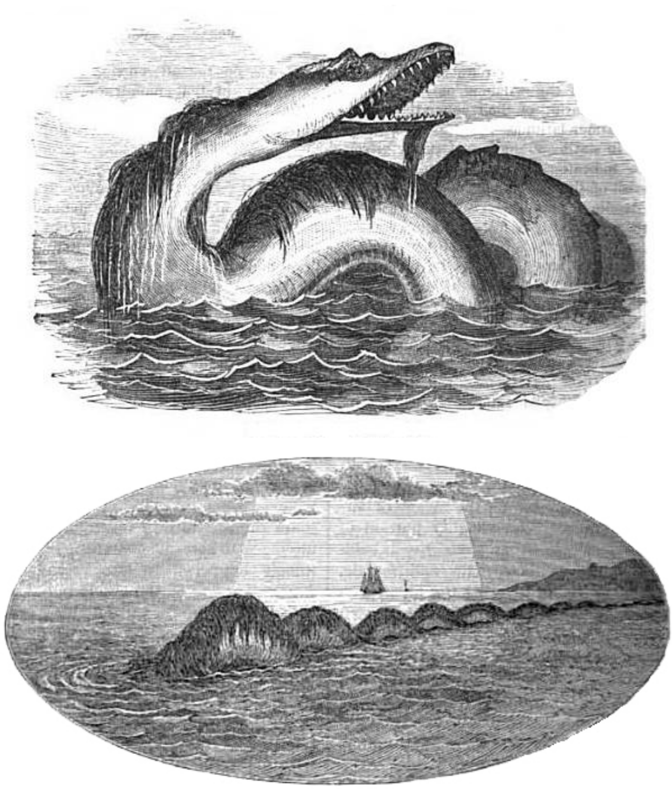
> Along its back were a number of humps or protuberances, which, in the opinion of the observer on the beach, were true humps, while the other thought they were produced by vertical flexures of the body. Between the head and the first protuberance there was a straight part of the back of considerable length, and this part was generally above water. The colour appeared black, and the skin had a rough appearance.
>
> The animal was seen to bend its body almost into a circle, and again to unbend it with rapidity. It was slender in proportion to its length. After it had disappeared in deep water, its wake was visible for some time. There were no indications of paddles [i.e. flippers or fins] being seen. Some other persons who saw it compared the creature to a long string of fishing-net buoys moving rapidly about [Anecdote 5: Lyell 1850].

In 1846, another (or possibly yet again the very same) UMO, noted to be about seventy to one hundred feet in length and of a steel-gray colour, was observed by three boaters, this time along the western shore of St. Margaret's Bay: "They saw that what they at first thought were floats of a long net, which began to move, leaving a wake as large as that of a schooner. They now perceived the object to be a large Serpent, with a head about the size of a barrel, and a body in proportion, and with something like a mane flowing down its neck. It carried its head erect, with a slight inclination forward." And as described in the later article: "[They] saw in the water at a distance, something which they thought to be a large fleet of nets…They were surprised, on again looking at the supposed fleet of net, to see it straightening itself out, and moving off so swiftly as to leave a wake." Reverend Ambrose concludes by stating that "I have not been able to ascertain the motion of these animals in swimming, whether vertical or horizontal in its sinuosities. Wilson's [one of the eyewitnesses] first idea of *corks* [author's own emphasis] would seem to indicate a succession of vertical motions" [Anecdote 6: Ambrose 1867, earlier read version from 1864 *in* Heuvelmans 1968].

In 1849, in the same location of St. Margaret's Bay, three fishermen spotted an UMO that resembled "an immense snake" of about sixty feet in length and with a circumference of the size of a puncheon, or cask. The men rowed out to examine the animal, which was strangely oblivious to their presence. Nearer inspection revealed the elongated creature to taper at both ends with no caudal fin present. Its back was composed of a "row of spines, each of about an inch in diameter at the base, erected along its back" in addition to a single very high dorsal fin. The latter resembled "in size and appearance the sail of a skiff" and which could be folded back into its body like the folding fin of a giant Bluefin tuna. Ambrose (1867) likens this structure to being a bristly mane. Furthermore, "the animal's back was covered with scales, about six inches long and three inches wide, extending in rows *across* [author's emphasis] the body, *i.e.* the longer diameter of the scale being in the direction of the circumference of the body." The UMO then raised its head, and opening its jaws, "showed the inside of its mouth red in colour and well armed with teeth about three inches long, shaped like those of a cat-fish [by which he probably means, barbels]" [Anecdote 7: Ambrose 1867].

The most detailed description of an encounter with a Nova Scotian sea serpent occurred in 1855 in Green Harbour, near the town of Shelburne, and was published eleven years later [Anecdote 8: Lord 1866]. It is also one of the more contentious narratives to come from the region. Some, such as Greg Ross (www.futilitycloste.com/2012/07/27), have questioned its veracity, as they deem it is unlikely that the author, a respected journalist who had worked for *Scientific American*, would have sat on such a sensational story for more than a decade. Hebda (2015) acknowledges that the literary stylistic elements verge on being purple prose, but concludes "when one examines the descriptive details provided in the text, one can see anatomical and behavioural elements that can only be derived from personal observation." Sadly, the author was not around long enough to be questioned, for several weeks following the article's publication, he took his own life while visiting the grave of his recently deceased wife. The anecdote begins on a hill overlooking the harbour, with Lord and other eyewitnesses observing fleet of fishing boats racing for the shore, where a group of women were shouting "The snake! The snake!" The UMO moved "slowly and majestically" but "fast enough to keep pace with the boats," and is thusly described:

> Near what might be the head, rose a hump or crest, crowned with a wavering mass of long, pendulous hair like a mane, while behind, for forty or fifty feet, slowly moved, or rolled, the spirals of his immense snake-like body [Fig 2]. The movement was in vertical curves, the contortions of the back alternately rising and



GOING OUT TO SEA.

Fig 2 Two illustrations of the UMO, imagined by the artist as a classic sea serpent, seen at Green Harbour, Nova Scotia in 1855 (Lord 1866). The upper image is quite similar to Pierre Belon's drawings in *De aquatilibus libri duo* (1553) which were used by Mercator in his famous world map of 1569 (see Van Duzer 2013).

> falling from the head to the tail, leaving behind a wake, like that of a screw-steamer, upon the glassy surface of the ocean.

Unperturbed by the commotion, the UMO approached the shore and then raised its smooth and horny textured, "dark dingy-blue" head and opened its "horrid jaws," which were filled with "rows of glistening teeth," uttering a loud hissing noise. Significantly, "a long tuft of hair like a goat's beard" hung from its head, about which a mane "floated about the neck." The body is also described as being composed of a series of "scales which defended the hide, glistening in the sun." The next morning, while out in a boat fishing, the "monstrous denizen" from “the Unknown depths of Neptune’s dark empire” approached to within an oar’s length. This time the head is described as being “shell-like,” a portion of the body being six or seven feet in diameter, with the rest of the shape displaying “an undulatory movement.” Again an “immense mane” is noted that “flowed wavingly, either by the motion of the current or the convolutions of the body.”

A schooner passing near Pictou Island in 1879 spotted “an enormous sea serpent” one hundred feet in length with a diameter the size of a barrel, which was moving at a rapid rate. At first the “great bulk” of the “terrible monster” appeared to suggest a whale. Closer inspection made the eyewitnesses change their mind when they saw “a bushy protuberance back of the neck” that some thought to be “a sort of mane” [Anecdote 9: ‘A terrible Monster,’ *The Reading Daily Eagle*, July 30, 1879 *in* Hebda 2015].

In 1905, a group of fishermen and wharf-side observers in Bras d’Or Lake (an inland sea on Cape Breton Island) saw a “leviathan” sporting a sixty-foot long snake-like body that moved at such a “terrible pace [so as to be] sending the spray from his head”, similar to that of a small cutter going through the water. This ‘head’ would occasionally surface and swing “slowly from side to side,” and most remarkably was impervious to being shot at, with the “rifle balls apparently doing little damage, other than producing a savage shaking of the body of the monster” [Anecdote 10: ‘Curlew’s Crew Saw Large Snake: Story of Thrilling Adventure in Nyanza’ – *Sydney Daily Post,* July 18, 1905 *in* ‘The Innocents Aboard, Local Sea Serpents: 3 Reports,’ *Cape Breton Magazine* 32, 1982 and *in* Hebda 2015].

Five years later, and around the side of Cape Breton Island at Ingonish, passengers aboard a steamer observed a black object disturbing the water. The body of the UMO was composed of a series of “spots” that “protrude from the water, and look like a snake fence viewed across a grain-field [snake fences are of course inanimate objects made of roughly split planks joined in a zigzag pattern with their ends crossing].” The interviewed eyewitness is careful in his description of the UMO, referring to it as “this whole mass, procession or whatever it might have been.” Whatever it indeed was, observers noted, it moved “rapidly away” [Anecdote 11: ‘Mr. McDuff, First Sea Serpent of the Year Puts in an Appearance off the North Shore,’ *Sydney Daily Post,* July 14, 1910 *in* ‘Local Sea Serpents: 3 Reports,’ *Cape Breton Magazine* 32, 1982 and *in* Hebda 2015].

Sydney Harbour was visited by an eighty-foot "sea-serpent" in 1939 that was capable of swimming at a rate of five to seven miles an hour. Described as being eel-shaped and as large as a ten gallon keg, little of the UMO was observed to be under, as compared to being *over* top of, the water. When swimming, "there would be one or two undulations coming up out of the water for 6 or 8 feet and the upper part of the undulations would come 4 or 5 feet out of the water." Overall, the eyewitness summed up the sighting simply as "No fins, just a big eel" [Anecdote 12: Huvelmans 1968].

DISCUSSION

Entanglement: Materials and Non-Lethality

Entanglement in marine debris and fishing gear is a serious environmental problem affecting the abundance and biodiversity of more than two hundred species of marine animals (Laist 1997). Significantly, for purposes of my thesis about the parsimonious (i.e. *al à* Occam's razor) explanation behind a portion of sea serpent sightings, is the fact that by no means every animal unfortunate to become entangled is fatally entrapped. Some can break free and remain non-lethally entangled in fishing gear or maritime debris for extended periods of months and even years (Johnson 2005). Fama (2012), for example, mentions a North Atlantic right whale named 'Necklace,' who was observed in the Gulf of Maine for a decade with a fishing net wrapped around her tail stock. Other entangled whales have been known to have traveled thousands of kilometres (Lyman *in* NOAA 2014, Anon. 2019a,b). Furthermore, the opportunity for an entangled animal to escape was much greater in days before the use of synthetic lines, which are much stronger and more elastic than hemp. In the past, a strong swimming cetacean, pinniped, or large fish could often muscle its way through gill nets made of cotton twine or hemp, "leaving behind a big hole and a frustrated fisherman" (Johnson 2005), and sometimes in the process, making off with portions of the net and its accompanying floats in tow.

Entanglement is widely believed to be a modern phenomenon related to the advent and widespread mid-century use of plastic (Wabnitz & Nichols 2010, Vegter *et al.* 2014), with little or no occurrence before that time (NOAA 2014). This is due to the assumption that materials made from hemp and other natural fibres will "lose their

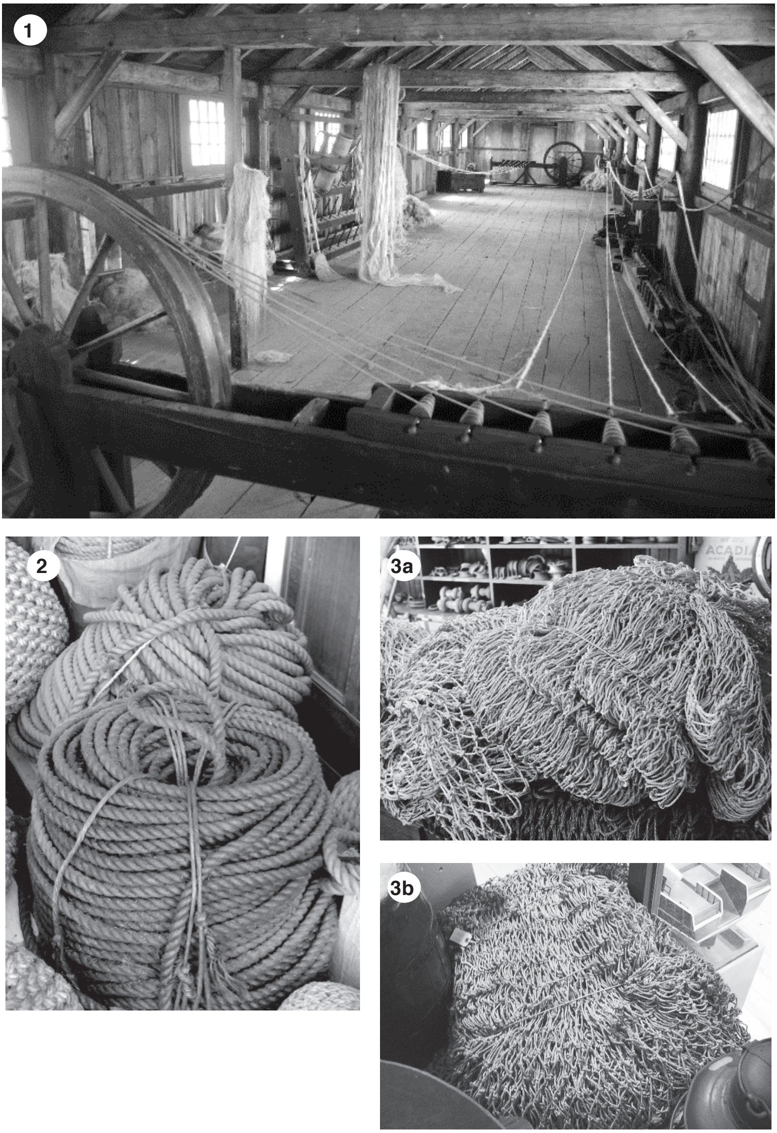


Fig 3 **1. Nineteenth-century rope-walk where hemp ropes would be braided together (photo taken at the Mystic Seaport Museum, CT). 2. Natural fibre ropes were often treated with tar (note darkening colour of front coil) to increase longevity (photo taken at the Maritime Museum of the Atlantic, NS). 3a & b. Fishing nets constructed of hemp (photos taken at the Maritime Museum of the Atlantic, NS and the Mystic Seaport Museum, CT). All photos from France (2019a).**

resilience in usage and if lost or discarded at sea [will] tend to disintegrate quickly" (Gregory 2009).

Compared to modern nylon or polyethylene ropes and nets, it is true that earlier ones made from natural hemp fibre (Fig 3) deteriorated more rapidly. But it would be erroneous to suppose that such material was not of sufficient durability for continued widespread use (Aiken & Purser 1936, McCaskil 2009) and would have lasted long enough to pose a threat for entangling susceptible wildlife. Hemp ropes were often impregnated with dye or pine tar to extend their longevity (Kristjonsson 1971, Bekker-Nielsen & Casola 2001). The rise in popularity of manila hemp during the nineteenth century was due to its natural oils that provided resistance to deterioration, thereby eliminating need for tar or other treatment to prevent deterioration.

Entanglement in the nineteenth and early twentieth centuries may have lasted, if not for half a decade or longer as today, due to nondegradable plastic, but at least for a few months, and possibly several years. This would certainly have been sufficient time for an unfortunately entangled animal to have been witnessed and misidentified as a sea serpent. An animal pulling a string of buoys, which during the nineteenth century shifted from being blown-glass balls to larger cork floats and even casks (Fig 4), through the water, could easily be misconstrued as the undulating motions of a supposed sea serpent. A NOAA spokesperson interviewed for his opinion about my thesis, is quoted as saying that "experts agree that anything left in the ocean could present an entanglement hazard for marine life," and the director of the entanglement response team with the Center for Coastal Studies on Cape Cod, confirms that "no doubt there has been an entanglement problem for as long as humans have been setting rope-based gear—plastic or not."

Animals in the Northwest Atlantic were susceptible to entrapment in fishing equipment long before Mount Tambora erupted. Fishing by Europeans in this region began by following Native techniques. This involved the use of weirs across rivers to trap anadromous fishes and it then progressed to inshore ground fishes, and finally to offshore pelagic species (Bolster 2012). Most fishing at the time of the Gloucester Sea Serpent sightings was undertaken through use of modest seines, gill nets, and hooks deployed from small boats. Baited hooks would be towed from outrigger poles and a "rat's nest of lines" (Bolster 2012). Filter-feeding menhaden could not be captured by mackerel jigs and

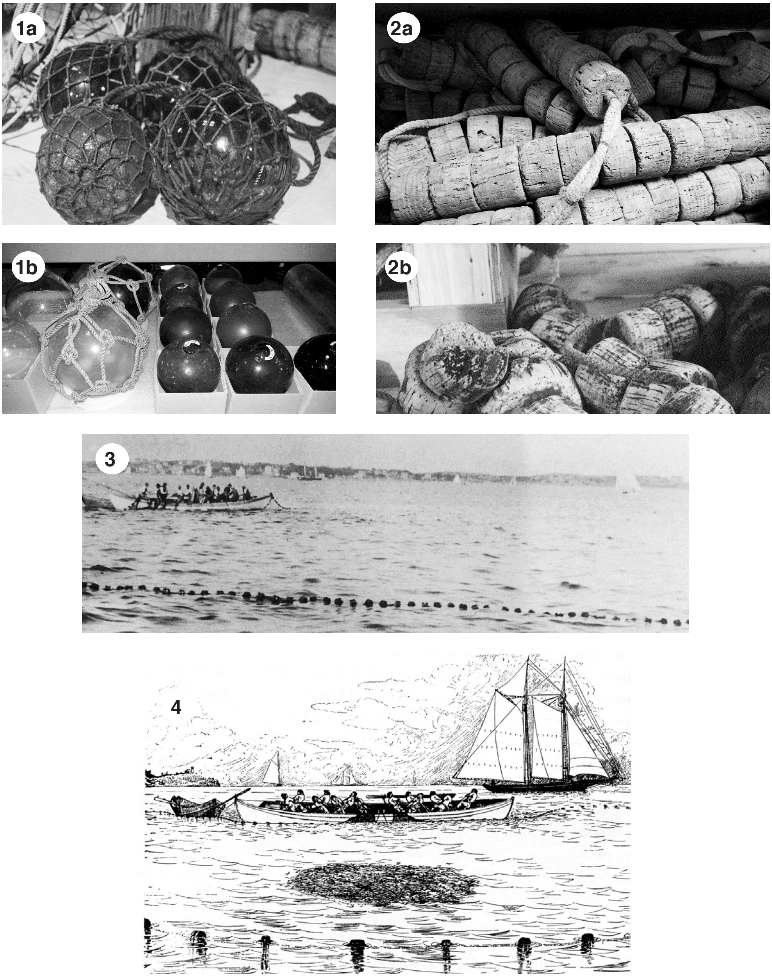


Fig 4 1a & b. Blown-glass balls used as floats from the nineteenth century (photos taken at the Fisheries Museum of the Atlantic, NS and provided curtesy of the Mystic Seaport Museum Archive and Collections, CT). 2a & b. Nineteenth-century cork floats (photos provided curtesy of the Mystic Seaport Museum Archives and Collections, CT and also taken at the Fisheries Museum of the Atlantic, NS). 3. Strings of fishing net floats which, possibly festooned with accumulations of seaweed, and viewed from a distance while pulled behind an entangled animal, could easily give the impression of being the long tail of a sea serpent (photo taken at the Cape Ann Museum, MA). 4. Casks used to mark deployed fishing nets in the nineteenth century (Goode *et al.* 1884), which also viewed from a distance while pulled by an entangled animal, might look like a long tail of a presumed sea serpent, especially if also trailing a 'mane' of fishing net and attached seaweed. All images from France (2019a).

had to be caught in beach seines. The nets for these were suspended from a head-rope buoyed by floats (Goode *et al.* 1884).

Additionally, during the eighteenth and nineteenth centuries, hemp nets were specifically set to entrap marine mammals (Mowat 1997). Seals and porpoises in the Gulf of Maine were then, as now, considered to be in competition with fishermen with respect to cod and mackerel. Indeed, one person collected a generous bounty for producing a staggering five hundred tails of porpoises over a two-year period (Bolster 2012). A large-scale commercial net fishery also existed in the Gulf of St. Lawrence and southern Labrador for seal oil. Operating on the same principle as gill nets for fish, but made with stronger hemp twine, seal nets up to 83 metres long would be moored to the bottom two metres below with primitive anchors. They were kept perpendicular by a string of corks along a surface head-rope. As described by one fishermen, "as the seals dive along near the bottom to fish they strike into the net and are entangled" (Bolster 2012). Another technique, employed across narrow choke-points in shallow bays where seals were known to congregate, was to construct a semi-permanent frame of large nets to herd the pinnipeds into a pound which would then be hauled ashore via a capstan. In short, by the early nineteenth century, an obstacle course of deployed fishing nets existed along the Northwest Atlantic seaboard. These nets could entrap any large marine animal unfortunate to become entangled.

At this time, there were also fisheries that involved hunting animals such as whales, sharks, tuna, and other large fishes, using thrown harpoons (Fig 5). It is likely that some of these struck creatures would have survived for extended periods (Gardner 2007). Indeed, in pre-ballistic times, as many as a quarter of all struck whales actually managed to evade capture. An account can be found from the noted polar explorer Fridtjof Nansen (see Mowat 1997 and France 2016b) who lost equipment to an escaping whale. One wonders if the next person who spotted Nansen's struck whale, pulling along its three intertwined ropes and series of large casks behind, imagined that it was a glimpse of the elusive sea serpent.

There must have been plenty of opportunities to invent a sea serpent in this way. For it is worth noting that the customary technique used over the centuries in harpooning, be it for whales or for tuna, is 'kegging,' wherein the harpoon line is tied to a single (Fig 5) or a series of wooden kegs which the struck animal tows about until it becomes exhausted and slows down enough to enable being caught and subsequently slain (Johnson 2005). "Usually," but by no means always, as for example when the harpoon head is not buried too deeply and works its way out, the entanglement persisted with the rope line wrapped around the head, caudal flukes or fins of the escapee, and sometimes with the head of the harpoon waving about in the air which could be misconstrued as being the serpent's tongue (as, for example, described for the Gloucester UMO, France 2019a).

Entanglement: 'Sea Serpent' Evidence

There is an absence of entanglement records prior to the middle of the twentieth century, which NOAA (2014) posit as being due to either the low use of synthetic materials in fishing gear and/or the general lack of awareness of the problem. For example, Balazs' (*in* NOAA 2014) 1985 survey of the published literature found no cases of entanglement of marine turtles before 1950. In their expanded survey on all species susceptible to entanglement in maritime debris, Vegter *et al.* (2014) identify only a few papers published on the subject prior to the 1970s. NOAA's (2014) own comprehensive survey records three

Fig 5 1. Fishing harpoons from the nineteenth century. 2. Fishing harpoons from the mid-twentieth centuries (photos taken at the Trinity Museum, NL and the Wedgeport Tuna Museum and Interpretive Centre, NS). 3. Kegging fishing gear (photo taken at the Wedgeport Tuna Museum and Interpretive Centre, NS). All photos from France (2019a).

published articles on early pre-plastic entanglement, dating from 1923 for a seal, 1928 for a mackerel, and 1931 for a shark.

Given the lack of attention, until recently, paid by scientists to entanglement, one has to follow the lead of conservation biologists such as, e.g. Pauly 1995, Sanez-Arroyo *et al.* 2005, 2006. They have used non-standard descriptive sources to find such information. Some of these sources are historical accounts of fisheries. For example in the case of basking sharks, mention is made of the animals ruining nets following entanglement, accounts coming from the nineteenth and mid-twentieth centuries (Wilcocks 1884, Fairfax 1998, Wallace & Gisborne 2006, Speedie 2017; see France 2019b for specific anecdotes extracted from these books). Basking sharks, because of their enormous size and their nose-to-tail surface swimming behavior, have a propensity for becoming entangled in fishing nets. Indeed, their Latin taxonomic name, *Cetorhinus maximus*, means 'pointy-nosed monster.' As a result they are likely candidates for being misidentified as sea monsters (Speedie 2017, France 2019b). It is therefore no coincidence that sea serpent sightings peak when basking sharks are abundant (Magin 1996), and this is also contemporaneous to when ruined fishing nets abound (Wallace & Gisborne 2006).

The literature on purported sea serpents is another source for documenting the early entanglement of marine life in pre-plastic fishing gear. For example, Bishop Pontopiddian, in his seminal The Natural History of Norway, the 1755 book which started the modern sea serpent phenomenon, provides one of the earliest descriptions of fisheries bycatch when describing sea monsters. In France (2016a), I provide three accounts of what were almost certainly whales misconstrued as sea monsters encountering fishing nets. One of the anecdotes, from 1912, goes as far as using the word "entanglement." De Camp and de Camp (1985) posited that one of the most famous sightings of all time, that made from the HMS Daedalus in 1848, could be explained by an animal pulling maritime debris. Additionally, there is Heuvelmans' (1968) interpretation behind the 1857 sighting of a sea serpent in South Africa (see France 2018). He stated that the "so-called body is so unlike any part of an animal that one cannot help thinking that it may have been a net or rope towed by a shark or porpoise which had got caught in it." This interesting interpretation was made at a time when the threat posed by entanglement was being ignored by marine biologists. Consequently, Heuvelmans, in his 1968 book that gave birth to the modern contemporary field of cryptozoology, described the typology of “many-humped” sea serpents as looking like “a string of buoys,” although, with the exception of the 1857 UMO discussed above, he regarded these trash-cyborgs as being real sea serpents. Loxton and Prothero (2013) touch upon this but do not elaborate further on the alternative and parsimonious explanation behind certain sightings of sea serpents.

It is important to recognize that eyewitnesses do not usually report having seen animals shaped like serpents. Instead, they describe a series of discrete coils, humps, or dark rounded objects (‘like a string of buoys’ is typical) and infer that they are connected beneath the water’s surface. The problem, of course, is that such sightings are by their nature ambiguous; a humungous serpentine animal might resemble a string of buoys, but a group of smaller objects (say, an actual string of buoys) also might resemble a string of buoys.

However, by no means can all the encounters of the UMOs observed by thousands of eyewitnesses over the centuries be explained by entanglement. For example, anecdotal analysis suggested that only 20 of more than a hundred and fifty descriptions about purported sea serpents made in New England during the post-Tambora years between 1831 and 1925 (see O’Neill 1999) can be reinterpreted as being misidentified entangled animals (France 2019c). For Nova Scotian sea serpent sightings over a period of more than a century (Hebda 2015, France in prep.), less than a quarter seem to indicate that the observed animals were indeed entangled in fishing gear or other maritime debris.

In toto, then, for Nova Scotia, we have a limited group of animated UMOs which can be described as having highly flexible bodies of lengths equaling those of the largest whales but of only a narrow circumference. Against all laws of hydrodynamics, they are capable of rapid propulsion solely through vertical undulations in the absence of a tail or lateral fins. Furthermore, the bodies are described as being composed of a series of many segmented ridges or protuberances that are displayed as actually being above the surface of the water. The UMOs often seem oblivious to their surroundings and one is even unaffected by gunshot. Several exhibit what is thought to be a mane (perhaps netting) as well as scales (possibly glass floats). Most significantly, in three instances, UMOs were said to resemble “a

Table 2 Observed physical and behavioral attributes of UMOs posited to have been entangled animals. Attributes are those used to describe the UMO observed in and around Gloucester in 1817, and clearly indicative of an animal entangled in marine debris (France 2019a). Numbers shown indicate the incidence of occurrence for 12 different Nova Scotian sightings between 1787 and 1939, 20 different sightings in New England between 1831 and 1925 (France 2019c), 28 different sightings of putatively entangled whales (France 2016b, 2018), and 16 different sightings of putatively entangled sea turtles (France 2016a, 2017).

Attribute	Nova Scotia	New England	Cetaceans	Chelonians
Notable length	11	9	12	7
Body composed of a series of irregular, jointed component parts (multiple humps, coils, or a ridge)	7	9	6	8
Rapid speed of movement	5	3	6	-
Notable flexibility of body	3	1	4	4
Vertical undulating movement of body segments	5	3	3	4
Body components likened to kegs or barrels, and sometimes scales or saucers	8	2	3	4
Oblivious of surroundings or impervious to disturbance	4	2	2	3
Overall body likened to a string of floats, kegs or buoys	3	3	2	0
Obvious trailing wake or water disturbance	6	2	2	3
Floating motionless, gently swaying in waves, or moving very slowly	1	2	2	5
Narrow, tapering, sinuous, snake/eel-like shape, often with absence of a caudal fin or lateral appendages	8	3	14	10
Extended body pulled down into water, thrown up into the air, or thrashed about on the surface	0	1	11	1
Presence of a horn, spike, spine, mane, or other protuberance (sometimes identified as a head)	3	2	5	6

chain of hogsheads," a "long string of fishing-net buoys," or the "floats of a long net." Again, consider the aforementioned 'duck test' here.

Paxton (2009) demonstrated that when anecdotes of anomalous phenomena, such as those pertaining to UMOs, are considered in aggregate, they can constitute data meritorious of legitimate scientific study. In this regard, Table 2 shows the concordance between the observed physical and behavioral characteristics of the Nova Scotian UMOs and those from the post-Tambora sightings in New England, as well as sightings from around the world which I believe to have been entangled whales and sea turtles. This is based on how closely their characteristics match those for the obviously entangled animal(s) observed in and around Gloucester (France 2019a).

One other sighting of notable mention explicitly links Nova Scotia ‘sea serpents’ to entanglement. In 1872, an UMO said to resemble a barrel floating upon the water of St. Margaret’s Bay, was reported to have been “destroying the poor people’s nets going through them, and rending them at its pleasure” (Hebda 2015, France, in prep.). Another sighting of a sixteen foot-long, two foot-circumference UMO was seen in 1865 “swimming and splashing” in the landwash (break zone of waves) while “apparently endeavouring to get ashore” near Peggy’s Cove (Ambrose 1867). Given that there are no sea snakes anywhere in the Atlantic Ocean, the candidates for such a serpentine form are limited, with none displaying amphibious inclinations. In contrast, there are examples of the many-humped bodies of sea serpents, said to resemble strings of floats, that are sometimes seen to be temporarily draped upon the shore while the entangled animal at the other end is submerged (France 2017, 2019a,c). Elsewhere in Atlantic Canada, a two hundred foot-long “sea monster” was observed in 1888 off the west coast of Newfoundland that sported “a mane larger than that of any horse” (France, in prep.), which quite likely was entangled netting. And along the New Brunswick/Maine border in 1938, a fifty foot “snake-like creature” composed of a number of “plainly visible humps” separated by empty spaces “distanced between them” was seen in active pursuit of a school of porpoises (O’Neill 1999, France, in prep.). A sea serpent “in pursuit of” a school of porpoises is one explanation but another is that it is merely one of the porpoises pulling along a trailing string of floats of a herring net from which it had incompletely freed itself after becoming entangled.

Entanglement: Conjectures and Implications

Inferring non-lethal entanglement from accounts of sea serpent encounters is generally an easier task than is postulating the identity of the animal responsible for pulling the debris. That said, sometimes the accounts do make specific mention of animals. Often this takes the form of first assuming that the UMO is a known animal based on an initial resemblance. But then, upon further or closer observation, the extended body, or the tail of component parts that are noted are obviously incongruous with the supposed animal. This results in a second appraisal based on a popular belief in the existance of sea monsters which concludes that a sea serpent or sea monster is being seen (France 2019a). Entangled whales, sometimes thought to be engaged in battling elongated sea serpents (France 2016b), are often the most likely candidates (France 2018). Descriptions of strange creatures that look like *Island of Doctor Moreau* hybrids are frequently entangled sea turtles (France 2016c, 2017). In other cases, and for reasons mentioned earlier, basking sharks are also candidates (France 2019b).

For the Nova Scotian encounters focused on in the present paper, the "great bulk," shoal-like shape, and size "as large as a small dory" of Anecdotes 1 and 9 suggest a whale as the viewed animal. Indeed, the eyewitnesses of the latter account first supposed this along with those in Anecdote 3. In Anecdote 7 the three inch-long teeth or catfish like barbels seen inside the red mouth of the UMO sighted are exactly what a leatherback turtle looks like when it displays the horny papillae on its palate (Brongersma 1968, France 2017). The "horny textured…shell-like" head of the UMO in Anecdote 8 also reads like the body of a leatherback turtle, as does the notable presence of "rows of glistening teeth" to that animal's papillae. However, the buccal description also fits for the rows gill-rakers inside the long, pointy-snout of a basking shark (Heuvelmans 1968), animals that were often misidentified as sea serpents (Speedie 2017, France 2019b).

It is likely that there has been a bycatch of non-targeted species ever since fishing began (Alverson *et al.* 1994; Saila 1983), and that this may have played a role in the decline of certain species in medieval Europe (Bolster 2012). This, in turn, led to the attraction, exploitation, and eventual colonization of the North American seaboard (Pope 2004), given that herring were the staff of life in Christian Europe.

Life for non-lethally entangled animals, then as now, would not have been ideal with impaired swimming ability from pulling around a net and floats (Feldkamp *et al.* 1989). Such animals, especially today when they have struggled free from synthetic lines, experience health problems. Many entangled animals display wounds from the abrasion and cutting action of the debris (Derraik 2002). This increases their long-term risk of infection. Fully eighty percent of all humpback whales surveyed in New England today carry scars from entanglement with fishing gear (Johnson 2005), which makes this an issue of deep concern.

The significance of the present environmental history is its suggestion, based on examination of anecdotal evidence compiled from eyewitness encounters with purported sea serpents, that marine animals in Nova Scotia have been subjected to pressure not only from direct fishery exploitation (Mowat 1997) but also from being bycatch due to entanglement in deployed gear, for a much longer period than commonly presumed. Entanglement is recognized to be a serious problem in the region today (e.g. Goodman *et al.* 2019, Myers *et al.* 2019, France 2019a) and has probably been a factor for several hundred years (France 2019c).

Finally, to some it may seem remarkable that so many eyewitnesses failed to recognize and identify in writing a train of fishing equipment, hunting gear, or other maritime debris in the process of being dragged behind an entangled animal. However, go online today and it is possible to find photographs of unfortunate animals pulling long lines of entangled debris, that from a distance, do assume a serpentine form. This is especially the case when the debris of floats, netting, and entwined ropes are festooned with seaweed, the whole taking on an appearance of solidity. Back in the nineteenth century, even experienced mariners and fishermen were fooled. Often, it was not until they were within a few metres of the UMO that the deception became recognized, as for example: "a closer and more critical inspection had taken place, and the supposed sea-monster turned himself into a long dark root, gnarled and twisted, of a tree, secured to the moorings of a fishing net, with the strong tie passing it rapidly, and thus giving it an apparent life-like movement and serpentine aspect" (France 2018). And that was for an UMO that was fastened at one end to a pier. If there is also movement, due to the netting and floats bobbing up and down as a result of being attached to a live animal swimming about in the open ocean, it becomes easy to imagine that the observed creature was a famous sea serpent that was creature fleetingly glimpsed. Furthermore, there was the often considerable observation distance and short duration of sightings that added to uncertainty. In one remarkable case, it was not until the supposed sea serpent was actually hoisted onto the deck of the ship for close examination, following it being shot at, captured, and dragged behind a dory, that its true inanimate nature was revealed (Oudemans 1892). An examination of the background of observers of the Gloucester UMO, the most sighted and studied ‘sea serpent’ in history, revealed that similar conclusions were reached irrespective of whether eyewitnesses were wet-behind-the-ears landlubbers or old experienced salty-dogs (France 2019a). With the widespread belief in the existence of antediluvian creatures, sea serpents abound. If one wants to observe a sea serpent, this is always easy, for both nature and human action provide many opportunities to provide believable doppelgangers. Surveys of nineteenth- and twentieth-century sightings of UMOs revealed that conclusions made that sea monsters were being seen occurred irrespective of viewing distance and prior experience of eyewitnesses (Paxton 2009, Paxton & Shine 2016). Confirmation bias (i.e. believing is seeing) has always exerted a strong influence on receptive minds with respect to sea serpents. In the past, this was due to the widely accepted theories of natural history (Brown 1990, Westrum 1979, Lyons 2009, France 2019a). In more recent times, this has occurred as a consequence of the popularity of cryptozoology speculations (Dendle 2006, Loxton & Prothero 2015, Rossi 2016, France 2019a). Given the strength of these belief systems, it should be of no surprise that it is literally possible to conjure up an aquatic cryptid right out of the air (Lehn 1981, Lehn and Schroeder 1981).

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INTO THE WILDERNESS: REDISCOVERING TITUS SMITH JR'S PHILOSOPHY OF NATURE

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ABSTRACT

Except in some academic circles, Titus Smith Jr. is mostly a forgotten man. The year 2018 marked the 250th anniversary of Titus Smith Jr's. birth in Granby, Massachusetts (1768-1850). While general articles about Smith's life exist (Punch 1978), surprisingly there have only been three serious studies celebrating his knowledge and scientific thinking (Piers 1938, Clark 1954, Gorham 1955). Smith lived prior to the era when science hardened into specialized fields and when a single mind could move between disciplines allowing each to inform the other. Smith's interdisciplinary methods and his belief that nature is a global force are once again coming to the forefront as climate change emerges as the single most important threat to the survival of the planet. This essay attempts to bring this 19th century philosopher of nature into a modern environmental context.

INTRODUCTION

On March 9, 1802, the provincial treasurer Mr. Michael Wallace stood in the Nova Scotia House of Assembly and presented the account of the expenses owed to Titus Smith Jr. for his surveys of the interior parts of Nova Scotia. Lieutenant Governor Wentworth's instructions to Smith were to communicate his discoveries in the form of a journal, which Mr. Wallace also tabled. Wentworth clearly communicated to Smith that he was not to explore the interior parts of Nova Scotia as a naturalist seeking to document any rare and previously unknown flora, but as an agent of the government hired to carry out an agenda to provide information useful to the Navy Board and Admiralty. However, in the tradition of similar government enterprises, Smith

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was to convey in the journal his conclusions with "reference to notes at the end, which will contain the detail" (Wentworth 1802).

Wentworth's orders to Smith and his travelling companion Mr. Carter, whose identity remains a mystery, were explicit. "Your principal object in this survey will be, to visit the most unfrequented parts, particularly the banks and borders of the different rivers, lakes, and swamps, and the richest uplands, for the purpose of discovering such spots as are best calculated for producing hemp and furnishing other naval stores" (Wentworth 1802). In addition, Wentworth instructed Smith to evaluate the soil, portray the landscape, determine the species, the size, and the quality of timber, and estimate the number of acres suitable for cultivation. Smith also was to record topographic details and correct local place-names on the poorly drawn existing provincial map (Cuthbertson 1983). Smith's stipulated second objective was to provide information on the major river systems including the Stewiacke, Musquodoboit, and Saint Mary's, and examine those rivers that empty into the Annapolis River. Wentworth also wanted Smith to examine Lake Rossignol, and investigate any other phenomena and objects in natural history he might encounter, as long as these observations did not delay or impede the principal purpose of the survey.

Smith's inventory of forest reserves represented a new way of thinking about the role of government in resource management and linked what historian Suzanne Zeller has called the colonial inventory tradition highlighted by "the mapping and cataloguing of resources and other natural phenomena" (Zeller 2009) to the beginning of Canada's "transcontinental national existence" (Zeller 2009). Throughout Smith's journeys, local people played fundamental roles in helping him to determine the character of the land and to document local place-names. Often these colloquial designations reflected the hopes and dreams of settlers (Garden of Eden), their ethnic heritage (Dundee), their loyalty to the homeland (New Germany), or the acceptance of indigenous place names (Musquodoboit). Smith also recorded idiomatic words for mountains, rivers and forests, and carefully drew the dirt tracks and roads connecting remote communities that would become the highways of the future. In the end, Smith's journals and map (Morrison 1986) took the fragmented descriptions of the interior parts of the province and consolidated them into a unified geographical vision. Smith's 1801 and 1802 journeys were also pivotal in setting the course of his own life. Following his return, Smith immersed himself in discovering and understanding the processes of nature, finding not conflict but harmony, and in doing so came close to the nature of things, the essence of which he distilled in his writings and lectures. The scientific observations Smith made during these travels would fuel both his ecological theories and his unpopular environmental discourse about the destructive forces of resource exploitation on nature and society.

Throughout his life, Smith's scientific method was relentlessly inductive, employing observation, measurement, and experimentation to study natural occurrences. Smith practiced natural philosophy in a disciplined way recording the processes of change and renewal that he observed in the natural world. His writings were both a celebration of the forces of nature and a warning about the social ills that resulted from the destruction of forests and other natural habitats. His ideas about the interconnectedness of all living things rooted his thinking in Anglo-American nature writing and incorporated ecological concepts not previously considered. Above all things, Smith was a keen observer. He compared everything he saw in nature to what he had previously seen and learned. Unlike other naturalists, he was not seemingly interested in discovering new species or filling taxonomic gaps, but in collecting knowledge to understand the workings of the natural world. In doing so, Smith generated an environmental discourse based on his belief that human beings and nature could not be understood in isolation but were inextricably linked.

Another of Smith's achievements was to make science and nature accessible and popular through his agricultural experiments, his lectures before the Halifax Mechanics' Institute, and his articles in various regional newspapers, particularly the *Acadian Recorder*. For Smith, specialized knowledge, visible and comprehensible by only small numbers of elite individuals, was not the inevitable consequence of social hierarchies. Such knowledge, he believed, should be shared, exchanged, and made available to everybody to motivate people to work collectively for the good of society. In doing so, Smith embraced the notion of an "ecology of community" to overcome the social distances between individuals created by rigid class distinctions. This would coordinate social, environmental, political, educational, and scientific initiatives and activities, thereby sustaining the community as a whole. (Field 2019).

Harry Piers considered Smith to be one of the first botanists to study the flora of Nova Scotia using Linnaeus's system of classification. Smith became familiar with this taxonomic method as a young man following Lieutenant Governor Wentworth's gift to his father of Linnaeus's *Systema Naturae* (1758-1759) that introduced the system of binomial nomenclature. This gift to Smith marked "the commencement of scientific taxonomical botany in Nova Scotia" (Piers 1938). Smith used this system throughout his Nova Scotia journeys when identifying plants, using both the common and Linnaean names for 33 species of trees, 50 species of shrubs, and 20 species of grasses, sedges, and rushes. Smith also documented over 100 medicinal plants (Clark 1954). Consequently, Smith's botanical research not only represented the first systematic description of the natural history of Nova Scotia, but also contributed to the origins of a provincial scientific community that eventually reported their findings before newly created learned societies including the Halifax Mechanics' Institute (1831) and the Halifax Literary and Scientific Society (1839).

SMITH'S NOVA SCOTIA JOURNEYS, 1801-1802

Although Piers and others have presented Smith's 1802 northern journey as if it was part of his original surveys for the government, according to Wentworth's instructions to Smith it was not. Wentworth's letter to Smith clearly stated that he was to survey the eastern and western sides of the province. The northern part of the province from Halifax to Pictou was better known and settled, and thus it remains unclear as to who authorized and/or funded his northern survey. It is possible that Smith undertook this journey on his own, unaccompanied by Mr. Carter, in order to complete a survey of the entire province. The fact remains that Smith did not depart on the Northern Tour until September 1, 1802, six months after Mr. Wallace, the provincial treasurer, had tabled Smith's expenses and the final report that Wentworth had requested. Smith's 1801 travels for the government included "The Eastern Tour," from May 12 to June 19, and "The Western Tour" from July 8 to October 16. "The Northern Tour" took place in 1802, from September 01 to October 16. In all, Smith spent 123 days over a period of two years surveying some of the most difficult terrain in Atlantic Canada (Field 2013).

For most of his travels in the eastern and western regions of the province, Smith was reliant on the good will of settlers to provide him with provisions, information on the wilderness, routes to travel, and introductions to planters and fisher folk. Particularly consulted were land surveyors and members of the local militia for their knowledge about the topographical character and geological composition of the terrain. Smith was quick to praise the help and friendly treatment he received from people, at times expressing specific regard for individuals who impressed him. Two distinct trends emerged from Smith's journals during his 1801-1802 field seasons. The first were the day-to-day scientific descriptions of the geography, natural habitat, and geology of the province. These were occasionally laced with comments about the communities and peoples he encountered. The second trend, recorded in his "General Observations" for the Eastern, Western, and Northern Tours, expressed Smith's personal and philosophical judgments about the agricultural, mineral, and settlement potential of the province that he later recounted during his appearance before Lord Durham's Commission at Quebec City in 1838.

Ten days after receiving Wentworth's letter (May 2, 1801), Smith departed from Halifax journeying east, beginning the colonial government's first official expeditions. He set out to inventory the natural resources of the interior parts of Nova Scotia. Rumours and unconfirmed reports offered conflicting descriptions of daunting barriers of water and rock, and a topography devoid of arable soil and commercial timber —hardships imposed by nature that seemingly made settlement and farming impossible. Smith experienced first-hand some of those adversities, negotiating impenetrable thickets of black spruce, facing voracious incessant insects, and confronting the relentless spring rains that forced him to alter his itinerary and often seek food and shelter through the kindness of strangers.

Smith's *Journals* and *General Observations* represented the first systematic description of the natural history of the interior, which were also documents full of personal annotations and reflections about provincial society. Smith gave accounts of the farms and communities he visited, commented on the daily lives of some of the French inhabitants he encountered, and was openly sympathetic to the plight of the Mi'kmaq. He observed that many of the settlers, who were originally tradesmen turned farmers, were somewhat awkward at their new occupation. For instance, in his *General Observations on* *the Western Tour*, Smith expressed his views on fishing and agriculture. "In every part of the province where we have been we generally found those who followed fishing complaining of poverty and hard country; whilst those who depend entirely on farming generally hold an opposite language and appear well satisfied with their situations, and sensible that they are in a thriving condition" (Smith 1802). Smith's travels took him through the rugged interior where ordinary farmer and fisher folk struggled to survive against the hardships imposed by climate and nature, and where inhumanity toward the indigenous population remained an unpleasant fact. Smith detailed the struggles of the Mi'kmaq to protect their way of life, and commented on the prejudices of white settlers and Mi'kmaq alike. Smith first voiced some of his concerns about the treatment and condition of the Mi'kmaq in his *General Observations of the Western Tour.*

"We have found it impossible to converse with the few Indians we have met with, owing to their suspicious temper which renders them afraid of strangers. We have met with a very few instances of Indians who have undertaken to cultivate the ground, and to work with some industry, but where they do it gives great uneasiness to their relations and countrymen, who use every means to disengage them from their new occupation, and seem to have as strong a prejudice against our way of living as we can have against theirs" (Smith 1802).

Smith also revealed his sentiments toward indigenous peoples in a story he related about an "Indian" farmer at Nictaw.

> "There is an Indian at Nictaw who has been at work this season, and raised a small crop of corn, wheat and potatoes, and who is very desirous of continuing his new occupation: but his countrymen have taken as much pains to divert him from the miserable Kind of life which they fancy he must lead as white men could have done to prevent one of their Friends from living with the Indians…He still persists in his resolution to be a farmer, but most probably his countrymen will finally persuade him to quit his new occupation, as he will be accounted an Indian by white men and if he follows farming, [and] will be looked upon as a white man by Indians" (Smith 1802).

Smith also recorded comments concerning the Mi'kmaw population in his *General Observations of the Northern Tour*:

> "The beavers are almost all destroyed, although there is perhaps no country where they have been more numerous heretofore than in the barren part of this province… I have not seen more than half a dozen inhabited Beaver houses in the whole course of my tour. The consequence of this scarcity of game is that the internal parts of the Province are but little frequented by the Indians in the Winter… I think a considerable number of them have left the Province… Several of them are employed in the Fisheries… and a small number as labourers by the farmers but the greater part choose to follow their ancient mode of living, and make up for the deficiency of their hunting by making baskets and other small articles (which they barter for provisions) and by begging. They are so much addicted to drinking and suffer so much from their own indolence that I think their number must be decreasing… Notwithstanding the low condition to which the Indians are reduced they still retain a considerable portion of national pride and are many of them, much influenced by their religion… I have never heard an instance of theft committed by any Indian who had not been very much accustomed to the company of white people" (Smith 1802).

Smith also gauged the well-being of the European farmers he encountered. "In several places I have seen persons bringing up a large family of sober industrious Children, whose habits of intemperance would probably have made them useless members of Society if they had lived in a seaport, but the charm of acquiring property, constant employment, and above all the difficulty of procuring the means of gratifying their appetites in a new settled place, have got the better of habits, which in a different situation would have proved their ruin" (Smith 1802). He also noted, "I have in the course of my tour, met with many whose Kindness has laid me under an obligation, but not a single person who I have had any reason to complain of" (Smith 1802).

Smith's surveys through the eastern and western parts of the province were a strenuous feat of exploration. Travelling on foot because the rough and sometimes impassable terrain made employing horses impractical, Smith navigated and mapped the landscape using rod and compass. One month into his Eastern Tour, he stated: "We have travelled many miles in black spruce thickets, where we were obliged to squeeze our way through the bushes, which were so thick that we could seldom see two rods (10 m) ahead…and were often obliged to go constantly on a zig zag line to avoid such places as were absolutely impassable" (Hawboldt 1955). Smith's engagement with this process was also profoundly scientific and political. His reports and observations did more than unlock the natural mysteries of the colony. Smith framed a new understanding of Nova Scotia by providing a measured scientific and cartographic vision that countered the speculations of lumberjacks, farmers, and hunters about the supposedly uninhabitable interior. In the end, what emerged from Smith's pen was a consolidated landscape with towns and roads fixed on a map that for the first time integrated Nova Scotia into a recognizable and governable geographical entity. Secondly, Smith commented on land use and waste, estimating for example that over a million acres of timber had been lost to fire, an observation that eventually led to the managed use of Crown Lands (Leeming 2012). In 1851, one year after Smith's death, it became illegal to burn any forest and the Crown Land Department no longer granted land but leased it to foresters.

Smith's surveys were important on two levels. First, they occurred as major changes were beginning in agriculture, manufacturing, transportation, communication, science, and technology. These profoundly affected the socio-economic and political conditions in America, Britain, and Europe. The critical questioning of traditional authority generated greater rights for common people and precipitated the American and French revolutions. This period preceded the industrialized revolution that accelerated the rapid manufacture and accumulation of mass-marketed material goods. Equally important, the early 1800's were a time when there was an expansion of scientific knowledge. John Dalton's atomic theory (1803), Michael Faraday's demonstration of electric current (1831), and the discovery of the planet Neptune by Urbain Jean Joseph Le Verrier in 1846, signalled the beginnings of a new age of science and industry. Furthermore, Britain's Slave Trade Act of 1807, the French invasion of Russia in 1812, the defeat of Napoleon at Waterloo in 1815, and the Slavery Abolition Act of 1833, shifted the balance of political and moral power in Europe. However, no expedition so dramatically and quietly punctuated this new age more than the five-year voyage (1831-1836) of HMS *Beagle* that led Charles Darwin to his origins of humankind.

Smith's journeys also coincided with new approaches to the study of nature that emerged in the American nation. The Eurocentric assertions of the French naturalist, mathematician, biologist, cosmologist, and author Comte de Buffon's (Georges-Louis Leclerc), about the superiority of Old World plants and animals over their New World cousins galvanized the patriotic fervour of men such as Thomas Jefferson and other supporters of independence. In his massive *Historie Naturelle*, Buffon laid out his theory of degeneracy arguing that all species in America were weak and feeble and proposed that species that had moved away from the centre of creation deteriorated from their original forms. It seemed impossible for European naturalists to entertain the prospect that humans, as well as flora and fauna, had multiple centres of origin, the Americas being one of them. Buffon declared that the indigenous fauna of North America was inferior to that of Eurasia noting that no American mammal was equal in size or strength to the elephant or hippopotamus. Thomas Jefferson stoutly debunked Buffon's degeneracy theory in his 1785 *Notes on the State of Virginia* (Dugatkin 2009, Watson 2006), noting that the excavated skeletal remains of mammoths proved that they were indigenous to North America and at least five or six times larger than an elephant. He also famously dispatched soldiers to the New Hampshire woods to capture a bull moose for Buffon to demonstrate the majesty of living American quadrupeds (Dugatkin 2009). By outspokenly defending the uniqueness of American flora and fauna, Jefferson and others helped to reinforce the self-governing spirit of the emerging nation by stating that discoveries in nature and advances in technology would reveal ways by which Americans could imagine themselves becoming independent from Britain and Europe (Magee 2007).

After the 1783 Peace of Paris confirmed the independence of the Thirteen Colonies, a more independent "scientific" approach to the study of the natural world rose from the ashes of the American Revolution (Magee 2007). While the British continued to view natural history and botanical knowledge as fundamental to their empire building enterprises, America looked to the cultures of natural history as activities essential to the development of an independent nation. As Judith Magee pointed out, "The pursuit of the study of the natural history of America was itself a patriotic activity because it described productions of the New World. The desires to explore, discover, describe, name, and classify the natural world helped serve the utilitarian principle of the age and define the character and future of the young nation" (Magee 2007). It was important for Americans to become the philosophers, naturalists, and historians of their own national destiny, and not look to Britain or Europe for guidance. The architects of the constitution believed that natural order mirrored democratic order in the new republic. As a new century dawned, naturalists including William Bartram (1739-1823), Alexander Wilson (1766-1813), and John James Audubon (1785-1851) recounted dramatic river journeys and hunting trips collecting, sketching, and describing the young nation's wildlife, and following the Louisiana Purchase, Jefferson commissioned Meriwether Lewis and William Clark to make their way westward through the Continental divide to the Pacific Coast (1804-1806) that would redefine the country's burgeoning national identity.

Breaking Nova Scotia's intellectual and philosophical dependence on Europe, however, was entirely another matter. Half a century after the founding of Halifax, the Province still lacked a methodical system of scientific inquiry. Ironically, it was Britain's need for a reliable source of naval stores, following the American Revolution, that led Wentworth to send Smith into the wilds of Nova Scotia. This was the beginning of a process to liberate the province from the influence of European natural theories. As historian Julian Gwyn (2001) points out, until the outbreak of hostilities with the American colonies, so adequate was the New England supply of mast, spar, and topmast timbers that it never occurred to the Navy Board to look for suitable timber in Nova Scotia. However, all that changed following the forfeiture of the American Colonies. Indeed, in 1777, when the threat of invasion from New England and fears of Mi'kmaw reprisals faded, naval contractors began roaming the woods of Nova Scotia looking for timber (Gwyn 2001). In 1784, the Navy Board concluded that British shipbuilding yards would not need any supplies of masts or deck timber from Nova Scotia. This decision was reversed three years later under pressure from the Admiralty (Gwyn 2001). By 1801, the need for naval supplies became critical. This justified the principle objective of Smith's surveys outlined in Wentworth's letter to locate and record the "thickness and length of mast timber" and "the facility with which it can be removed to market," as well as identify locations for cultivating hemp used for making rope (Gwyn 2001).

Although Smith's journeys contributed significantly to the physical and ecological understanding of Nova Scotia, it was not until the founding of the Halifax Mechanics Institute in 1831 that the beginnings of an independent scientific community began to emerge.

Two years later, the government commissioned Smith to collect zoological, geological, botanical, and mineral specimens for an Institute Museum. In the fall of 1838, by which time Smith had testified before Lord Durham's Commission in Quebec City, the systematic study of the flora and fauna of Nova Scotia independent from European science had begun. Thus, Titus Smith Jr. represents a transitional link between two eras of Nova Scotian history. The first looked to England for every aspect of its social, cultural, material, political, and scientific traditions. The second saw the establishment of an increasingly independent scientific community in which Smith was an active participant during a lifetime that bridged the intersections of the Enlightenment, Romantic, and Victorian eras. At first, Smith's ideas reflected early to mid-18th century views on religion and nature inherited as an adolescent from his fundamentalist Christian father. Following his Nova Scotia journeys, however, Titus began to discover a far deeper set of rules beneath the surface of all living things. First, by using his own experiences and observations, he detected interactive networks operating within biological systems that led to his Theory of Ecological Succession (Gorham 1955). Second, and more importantly, Smith generated an alternative narrative that represented the first wave of 19th century conservational thinking by suggesting that capitalist driven industrial development was socially and environmentally destructive.

SMITH'S JOURNALS

The historian I. S. MacLaren in his study of 17th and 18th century exploration and travel writing identifies four stages of narrative development beginning with the logbook or field notebook, followed by the journal, the draft manuscript, and finally publication (MacLaren 1992). Smith's original two leather-bound notebooks, one for each of his Eastern and Western journeys, which measure 4 x 6 inches and 3 x 7 inches respectively, would have fitted neatly into his breast or back pocket. Smith seldom writes in complete sentences, uses inconsistent spelling and grammar, and a stream of consciousness style narrative that employs dashes, colons, semi-colons, and commas to break his thoughts and observations in keeping with the *en route* immediacy of his note taking. Smith also used these notebooks to record information about his other travels. As a result, many pages do not pertain to his journeys. For example, his first notebook of his Eastern Tour covers a period of 35 years from 1801 to 1836.

When Smith returned from his Western Tour of the province on October 19, 1801, he immediately began to prepare a final report of his surveys for the Nova Scotia House of Assembly. There were two reasons for Smith's haste in doing so. The first was because of the considerable sum of money he was owed, and the second was because at age 34, he returned with the intention of marrying the 17- year- old Sarah Wisdom. Interestingly, his family members living in America noted this great difference in age. In a letter written by Titus's brother William from Litchfield, Connecticut on August 29, 1802, to their father (Smith Sr.) in Halifax, he states, "As to domestic affairs…I never supposed Titus' disposition calculated to suit, or be suited by a young girl (who are not generally much attracted with philosophy or the history of the world.) …but …supposed him to be a person who would be best suited to one who was a trifle given to thoughtfulness and a little sentimental" (Creighton n.d.). Despite the differences in age, the couple produced fourteen children. On March 9, 1802, when the Treasurer Mr. Wallace tabled Smith's journal, Titus the traveller was transformed into Titus the author, who provided an organized narrative for his intended audience, the members of the Nova Scotia House of Assembly.

MacLaren's third stage is represented by two manuscripts, in which a writer other than the traveller becomes involved and alters the ideas and descriptions of the traveller for the intended audience. The first was a transcription by Robert James Wilson's (Wilson 1857) now in the Public Archives of Nova Scotia, and the second was a reprint of Wilson's manuscript edited by Lloyd S. Hawboldt for the Nova Scotia Department of Lands and Forests, published in 1955 and titled *A Natural Resources Survey of Nova Scotia 1801-1802: by Titus Smith Jr.* (Hawboldt 1955). When compared to Smith's notebooks, both selectively delete personal anecdotes, descriptions of rivers and landscapes, settlers encountered, and the difficulties of navigating the terrain in favour of concentrating on Smith's observations about the soil, mineral, and forestry resources. MacLaren's fourth stage of travel writing–a formal publication–does not exist for the Smith journals.

LORD DURHAM'S COMMISSION

In 1838, Lord Durham arrived in Lower Canada to investigate the circumstances surrounding the rebellions of Louis-Joseph Papineau and William Lyon Mackenzie. At the time fewer than two hundred thousand people lived in Nova Scotia with Halifax counting less than 18,000 residents. Nova Scotia did have a representative government in the House of Assembly, but responsible government and municipal institutions were completely lacking. Farming, fishing, mining, shipbuilding and forestry were the chief industries. Durham's main task was to find a way to reconcile the cultural and political differences between the English and French of Upper and Lower Canada. This he finally did by recommending a modified form of responsible government and a legislative union of Upper and Lower Canada and the Maritime Provinces. The proposal was rejected by the British government, and it took 10 more years before parliamentary democracy became established.

In a series of commissions held at Quebec City beginning in 1838, Durham compiled information about the people, geography, resources, agriculture, and immigration in Lower Canada, Upper Canada, the Eastern Provinces, and Newfoundland. Durham stated in his final report that the present condition of the Eastern Provinces presented none of the alarming political features of the two Canadas, their loyalty and attachment to the Mother Country was warm and general. However, he noted that their varied and ample resources were turned to little account. His remarks on the scanty population of the Provinces were indeed bleak, many exhibiting an aspect of poverty, backwardness, and stagnation. He goes on to say that, wherever improvements are evident they result from enhancements made by American settlers and capitalists (Lambton 1839). Durham garnered his opinions from Major Head, one of his assistant commissioners sent to Nova Scotia who described the province as melancholy with lands abandoned and falling into decay. Head also commented on the fact that, like Nova Scotia, the people on Prince Edward Island permitted the Americans to take ownership of the fisheries for the sheer want of capital, and added that a merchant in Halifax told him those wealthy capitalists in the city preferred investing their money in the United States (Lambton 1839).

Durham realized that the suffering of the population and lack of industrial growth and capital venture was due to the "existing disorder and the doubt which hangs over the future form and policy of the Government" (Lambton 1839). He realized that without government, "the development of the vast resources of these extensive territories is arrested; and the population, which should be attracted to fill and fertilize them, is directed into Foreign States" (Lambton 1839). Durham clearly understood that to create a productive economy you needed not only a stable government but a fraternity of capitalism, industry, and an educated and willing population to participate in the enterprise. "While the present state of things is allowed to last, the actual inhabitants of these Provinces have no security for person or property—no enjoyment of what they possess—no stimulus to industry … I allude to the striking contrast which is presented between the American and British sides of the frontier line, in respect to every sign of productive industry, increasing wealth, and progressive civilization" (Lambton 1839). Durham goes on to say,

> "On the American side, all is activity and bustle. The Forest has been widely cleared, every year numerous settlements are formed, and thousands of farms are created out of the waste; the country is intersected by common roads; canals and railroads are finished, or in the course of formation, the ways of communication and transport are crowded with people, and enlivened by numerous carriages and large steamboats….Good houses, warehouses, mills, inns, villages, town, and even great cities, are almost seen to spring up, out of the desert….On the British side of the line with the exception of a few favoured spots, where some approach to American prosperity is apparent, all seems waste and desolate" (Lambton 1839).

In fairness, the Americans emerged from the revolution an independent nation with a stable government and patriotic consciousness that drove them to promote useful knowledge, popularize science, and mechanize forms of manufacturing that led to the urbanization and industrialization so envied by Durham. All this while expanding west, systematically studying their flora and fauna, and developing a science independent from that of Europe that helped define their new political identity.

In September, 1838, Smith was selected by Nova Scotia's Lieutenant Governor as one of the delegates to represent the province and testify in Quebec City before Lord Durham's Commission of

General Enquiry on Crown Lands and Emigration in British North America about the natural history, geography, geology, agriculture, fishing, mineral resources, and people of Nova Scotia (Lambton and Buller 1839). This was the only time Smith left Nova Scotia since his arrival as a teenager in 1783. After informing the commission that he had travelled extensively throughout the province for the government, a reference to his surveys for Wentworth, and explaining that the Province consisted of 14 counties, the commissioners began to question Smith about each county, beginning with Digby and Annapolis. Most of the questions concerned the nature of the soil, the capabilities for agriculture, and the availability of mineral resources, particularly iron and coal. Smith stated that the lands in Digby and Annapolis were good for cultivation but not settled for want of roads, and that the lands bordering the sea were considerably cultivated. When asked about the slowness of improvement to Annapolis County, Smith replied that the general depression that had existed for a long time was slowly improving.

At the end of the interview, Smith estimated that one-half of the land in the Province of Nova Scotia was available for agricultural production and if these lands were improved, could support twice the number of inhabitants. He also commented that there was great room for improvement in the fisheries that should succeed better than the Americans who had to travel further to the rich fishing grounds. While commenting that the timber industry was in decline, Smith was positive about mineral production in the Province, commenting that more coal mines needed opening, that the grindstone business was increasing rapidly, that there was an inexhaustible supply of plaster of Paris, and that granite was being exported to the United States. Delegate after delegate from Nova Scotia gave similar opinions about the need for an increase in population and investment capital to take advantage of the natural advantages of the province—fisheries, agriculture, mining—and to develop mills and other manufacturers.

While the economic setting of Nova Scotia in 1838 did indeed seem bleak, the intellectual awakening that started on that winter evening of 1831 when Joseph Howe spoke so eloquently before the first meeting of the Halifax Mechanics' Institute about the Province's future eventually fostered a turning point in the fortunes of the Province. With industrialization driving the need for public education in Britain and America, the Institute's agenda to educate workers led to the first public lectures by men such as Titus Smith, Jr. Dr. Thomas McCulloch, and Dr. William Grigor among others.

THE WILDFLOWERS OF NOVA SCOTIA, 1839-1840

Along with advancements in the study of astronomy, mathematics, and physics during the scientific revolution of the 17th century, there also occurred extraordinary developments in the field of natural history. As the astounding variety of unknown species flooded in from the Americas, a new commitment to describe, organize, and accurately illustrate nature marked the beginnings of modern natural history (Freedberg 2002). As botany became a science, 17th century florilegia containing magnificent hand-coloured copperplate engravings of exotic flora began to emerge marking the separation of the arts and sciences. The audience for these lavish publications were not scholars, but flower-lovers, who were not interested in plant nomenclature or detailed studies of their habitats, but who simply wanted practical information on how to cultivate them successfully. While these pleasure gardens bolstered the image of their owners, the public display of indigenous plants dispatched from foreign outpost's to be planted in the soil of the mother country also demonstrated imperial power and territorial dominion of the state. In time, plants and seeds from the margins of the known world and from the very heart of the British Empire itself "bloomed at the feet of the king" (Olwell 2005).

An early florilegium that shows the role played by botany in dominating foreign territory is Jacques-Philippe Cornut's (1606-1651) *Canadensium plantarum aliarúmque nondum editarum Historia Cui adiectum est ad calcem Enchiridion Bontanicum Parisiense Continens Indicem Plantarum, quîœ in Pagis, Silius, Pratis, & Montosis iuxta Parisios locis nascuntu* published in Paris in 1635 (Cornut 1635). Cornut was a physician in the Faculty of Medicine in Paris, where Jean Robin and his son Vaspesien curated the important faculty gardens for Henry IV. Cornut successfully exploited colonial networks of botanical correspondence and exchange by studying plant rarities that arrived from North America, including some shipped from Port Royal, Nova Scotia, via Marc Lescarbot and Louis Hébert (Dickenson 1998, Field 2019). Incorporating medical usage and horticultural information, his work reflected the growing importance of applying new scientific techniques to the study of botany. Yet he still felt obliged to cite Pliny and Dioscorides even though neither knew of the existence of the New World. Cornut catalogued eighty-six plants chiefly from the Faculty of Medicine, including thirty from North America described for the first time. Most of them were illustrated using full-page copper plate engravings based on drawings made from living and herbarium specimens showing root, stems, leaves, flowers, and sometimes fruit (Dickenson 1998).

Published in 1840, *Wildflowers of Nova Scotia* (Morris and Smith 1840) was the first provincial florilegium and is important on several levels. First, it successfully combines an ecological perspective of each plant written by Smith rather than a simple description. This was accompanied by an accurate scientific illustration of each species rendered by Morris from living specimens. Secondly, its publication represents the culmination of Smith's lifelong efforts to educate the public about the natural history of the province, and thirdly, it is also one of the first systematic studies of the flora of Nova Scotia independent from European and British influences. The collaboration between Titus Smith Jr. and Maria Morris (1810-1875), who later married and took the name Miller, to produce this work was part of a widespread trend during the first half of the 19th century that saw the naturalists' task of description and classification becoming inseparable from accurate visual representations (Bolzoni 2008). The 1840 edition of *Wildflowers of Nova Scotia* is a superb example of this development. Morris followed a long line of female botanical illustrators, stretching back to the 17th century, who worked directly from nature in conjunction with naturalists who supplied textual descriptions (Tosi 2008). As the title page indicates, Maria Morris "executed from nature the full size of the blooms" that were "accompanied by information on the history, properties, &c., of the subjects by Titus Smith" (Morris and Smith 1840).

Maria Morris was born circa 1810 in Country Harbour, Nova Scotia, and moved to Halifax after the death of her father in 1813. According to her entry by Charles Bruce Fergusson in the *Dictionary of Canadian Biography*, Morris studied painting under Professor L'Estrange, a visiting British artist, and drawing under W. H. Jones, a Bostonian who taught at Dalhousie College. In 1830, she opened a school to instruct young women in drawing and painting. Six years later, the North British Society of Halifax honoured her as "Painter of the Year." Shortly thereafter, she was encouraged by Titus Smith, Jr. to produce watercolour paintings of the native flora of the province. In 1840, under the patronage of the governor, Sir William Campbell, C. H. Belcher and John Snow of London, and A. W. MacKinley of Halifax, Morris published six lithographs of her botanical illustrations with scientific descriptions and habitat notes of each plant by Titus Smith Jr. Following Smith's death in 1850, her London publisher issued a second series of lithographs in 1853, this time with scientific notations by Alexander Forrester, followed by a third series in 1866 with notes by George Lawson, the Edinburgh-trained botanist who founded the Botanical Society of Canada.

The six wildflowers illustrated in the 1840 series include the Mayflower (Plate 1: *Epigoea repens*), Pigeon-berry (Plate 2: *Cornus canadensis*), White Pond lily (Plate 3: *Nymphoea odoraton*), Indian Cup (Plate 4: *Sarracenia purpurea*), Tree Cranberry (Plate V: *Viburnum opulus*), and Indian Hemp-Milkweed (Plate 6: *Asclepias syriaca*). Smith's ecological notes for each flower provide a description, habitat, occasional anecdotes, and personal comments. In his entry for the Mayflower (Plate 1) for example, he states, "This neat little flower grows in healthy grounds, in woods, and in turfy soil. Its delicate tints, and delicious perfume, make it a general favorite. Its name is connected with a custom of repairing to the Wodds [woods] on a "May Morning," for the purpose of gathering specimens of this earliest of Nova Scotia wild flowers" (Morris and Smith 1840).

SMITH'S PHILOSOPHY OF NATURE

Today, we face a disappearing world. We are witnessing the complete collapse of ecosystems that go back thousands of years, as the seemingly irrevocable consequences of fossil fuel pollution overwhelms the climatic and environmental integrity of the planet, dramatically transforming the traditional economic, social, and ritual significance of everyday life. With the increasing impact of these changes, a host of scientific, government, community-based, and individual efforts have been implemented to save the planet. However, as much as this crisis is perceived as a modern development, it ignores the passionate environmental views expressed by past individuals and groups about the destructive influences of industrialization on nature and society. Like Smith, many openly expressed reservations about the unchecked exploitation of nature for profit, and the destruction of old growth forests to fuel the fires of industry.

Smith was correct in his belief about the deep ties linking humans and nature stating that "whenever man neglects the dictates of nature, he is sure to suffer" (Smith 1835). What Smith did not understand, however, was that, if God inscribed the search for knowledge on the human heart, why were there so many crimes directed against the natural world? Importantly, Smith's philosophy of nature was 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 North American naturalists during the 19th century including Susan Fenimore Cooper (1813-1894), the daughter of James Fenimore Cooper. Her book, *Rural Hours* that appeared in 1850, the same year Smith died, is the first major work of American literary environmentalism that anticipated and influenced Thoreau's *Walden* (Walls 2009). Cooper also framed her beliefs on the notion that nature represented the manifestation of God's design, which provided humankind with the ability to shape and cultivate the wilderness. More importantly, she believed the human social community was situated within the larger context of the shared ecological community, thereby linking changes in one to alterations in the other. And like Smith, Cooper expressed the same pointed critiques about the destructive influences of industrial capitalism on society and nature that Smith did two decades earlier (Walls 2009).

Cooper's solutions to counter the excessive exploitation of nature for profit were also the same as Smiths—knowledge and a community-based ecology where people experienced nature through connection and direct engagement with their local environment. Thus, if people knew more about their natural world, they might approach it with more respect and less greed. According to Laura Walls, "Cooper's writings are an extended argument 'for a sustainable balance' between culture and nature, approached through an ecological awareness that actions have unanticipated consequences" (Walls 2009). Essentially, this is the same message Smith presented in his lecture on natural history to his Mechanics' Institute audience in January 1835. Smith concluded, "The accounts we so frequently receive of the distress of the manufactories appear to prove that more hands are employed in them than there ought to be. …many among us, who might have supported themselves by agriculture, are now suffering from the failure of projects for acquiring wealth, in which they would not, perhaps, have been engaged, but for the same disposition to follow the beaten track, and to trust the supposed wisdom of others…" (Smith 1835).

Finally, it seems we have come full circle. Just as Smith forewarned, the specter of humankind's accumulated transgressions against nature haunt the 21st century. Along with his travels, his experimental gardens, his exchange of plant specimens with European correspondents, his testimony before Lord Durham's Commission, and his popular articles on agriculture and nature, Smith was inextricably linked to the forces behind the emergence of a new provincially-based natural science and the very beginnings of a unified Canada. More importantly, Smith's environmental advocacy and natural philosophy not only represented the first wave of 19^{th} century environmentalism but also facilitated the historical beginnings of the environmental movement in Nova Scotia to create a sustainable society in balance with the global forces of nature. Ironically, Smith's proposed utilitarian approaches to land use and agriculture that challenged the wisdom of a society organized around extensive manufacturing, and his rejection of the rampant exploitation of natural resources for profit, seem almost as radical today as they did during his lifetime.

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OPTIMISING 3-PHENYL-1,4,2-DIOXAZOL-5-ONE AS AN ELECTROLYTE ADDITIVE FOR LITHIUM-ION CELLS

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ABSTRACT

An effective method to reduce carbon dioxide emissions is to switch to renewables for energy generation and transportation. Since current sources of renewable energy, such as wind and solar, are intermittent, it is essential to find ways to store energy to match supply and demand. If vehicles are to be powered by renewable energy, they need portable energy storage. Currently, lithium-ion batteries are one of the most viable solutions for energy storage. Extending the lifespan of lithium-ion batteries is the goal of this research, carried out with Dr. David Hall of Dr. Jeff Dahn's research group at Dalhousie University in late 2017. We developed and tested a chemical compound, 3-phenyl-1,4,2-dioxazol-5-one (PDO), which greatly improves the lifespan of lithium-ion batteries. One percent of this by weight in a cell's electrolyte, along with two percent ethylene sulfate, will extend a battery's lifespan more than three-fold over those containing conventional vinylene carbonate-containing electrolyte.

INTRODUCTION

In the scientific community, it is generally agreed that in order to slow the current increase in global temperatures and the resulting weather-related disasters, fossil fuels must be phased out as soon as possible (World Meteorological Organization, 2018).[1] To reduce emissions, several jurisdictions will be phasing out internal combustion vehicles. Several cities, including Paris, Madrid, Athens, and Mexico City, are expected to phase out the sale of new diesel cars by 2025 (Dahn, 2018). Norway will ban the sale of new internal combustion cars by 2025 (Dahn, 2018), followed by Denmark in 2030 (Nielson 2018), France and British Columbia in 2040 (Gordon & Grebler 2018),[2,4] and the United Kingdom by 2050 (Dahn 2018).

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To maximise the emission reductions afforded by switching to electric vehicles, their energy must come from renewable resources, such as wind or solar. Although renewables are quickly becoming the most economically viable means of energy production, they are intermittent. Their energy must be stored when their supply is not sufficient to meet demand (Dahn 2018). While energy can be stored using pumped hydroelectricity, there are only limited numbers of suitable sites for such projects worldwide, so, for now, rechargeable batteries will be the most important means of storing energy, whether for stationary or portable applications (Dahn 2018).

Currently, the most practical secondary battery is the lithium-ion battery, widely used in portable electronic devices and electric vehicles, such as the Tesla Model 3, Nissan Leaf, and Chevrolet Bolt (Tesla 2019). The advantages of lithium-ion batteries include high energy density, long cycle lifetime, low self-discharge, fast recharging, ability to be made into a wide variety of shapes and sizes, and relatively low cost (Dahn 2018). A schematic diagram of a typical lithium-ion cell is shown in Fig 1.

Standard lithium-ion cells, as used in cell phones or power tools, may last only approximately 400 full charge/discharge cycles (100% to 0% capacity) before losing 20% of their original capacity, the usual

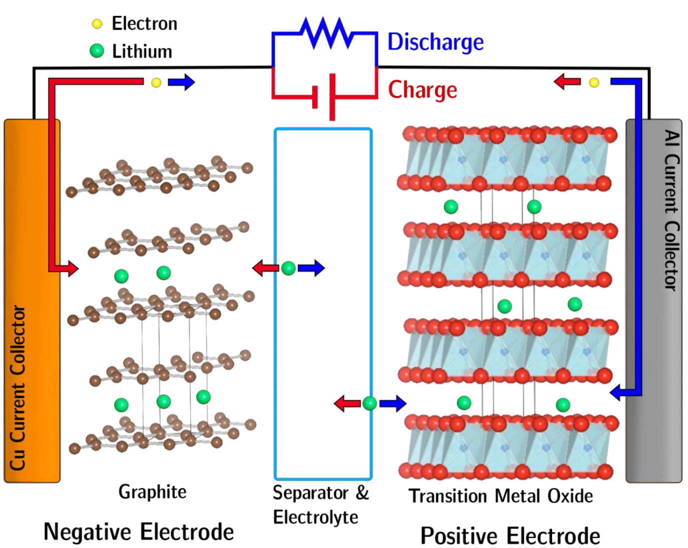


Fig 1 Diagram of a typical lithium-ion cell (Louli 2017).

criterion for end of life (Ecker *et al.* 2014). Such cells, however, are not suitable for grid powerstorage applications, where they must last for several decades at least (Dahn 2018). Therefore, it is desirable to increase cycle and calendar life of lithium ion batteries as much as possible.

A vital component of every lithium-ion cell, that is not shown in Fig 1, is the solid-electrolyte interphase (SEI), a thin film between the electrolyte (liquid that conducts electrons) and the graphite particles in the negative electrode. This film is ionically conductive (i.e. Li^+ ions can move through it to get into the graphite), but electrically insulating Verma *et al.* 2010.

If a cell is made using 1.2M $LiPF_6$ in 3:7 EC:DMC, it will rapidly degrade during cycling, as the SEI formed is not very stable (Seo *et al.* 2014, Wang *et al.* 2014a, b). In order to prevent this, another chemical, known as an additive, is typically added to the electrolyte in a few weight percent. Because only small amounts are used, the cost of the cell is not significantly increased (Xu 2004, 2014). Common chemicals used (Fig 2) include vinylene carbonate (VC) (Aurbach *et al.* 2002, Burns *et al.* 2013a, Lee *et al.* 2005, Xia *et al.* 2014a), fluoroethylene carbonate (FEC) (Etacheri *et al.* 2012, Ma *et al.* 2014, Ryou *et al.*2010), ethylene sulfate (1,3,2-dioxathiolane-2,2-dioxide, DTD) (Li *et al.* 2014, Madec *et al.* 2014, Xia *et al.* 2014b), lithium difluorophosphate (LFO) (Liu *et al.* 2018, Zhai *et al.* 2018, Hong *et al.* 2018), methylene methanedisulfonate (MMDS) (Xia *et al.* 2015, Xia *et al.* 2014c), and tris(trimethylsilyl) phosphite (TTSPi) (Han *et al.* 2015, Koo *et al.* 2015, Mai *et al.* 2014,Yim & Han 2017). Some additives, such as VC and FEC, help build a more resilient SEI,(Jin *et al.* 2018) while others, such as DTD and MMDS, are thought to be involved in forming a film over the positive electrode, although their precise mechanism of action remains unknown.

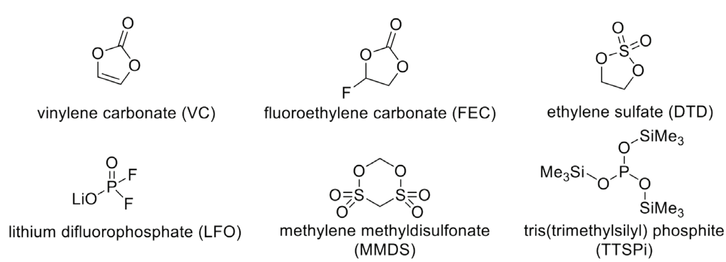


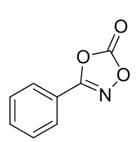
Fig 2 Structures of some commonly used lithium-ion battery electrolyte additives, where Me is a methyl group.

In the late summer of 2017, Wagner *et al.* published a paper in which 3-methyl-1,4,2-dioxazol5-one (MDO), an amidating agent (compound for adding an amide function group by creating a C-N bond), a class of compounds never used before as an electrolyte additive, was shown to make an excellent SEI on graphite in a $LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$ (NMC532)/graphite cell using 1M $LiPF_6$ in propylene carbonate (PC) (Roser *et al.* 2017)[33] a cyclic carbonate solvent that usually rapidly exfoliates graphite on the negative electrode, thereby destroying the cell (Xu 2004).

Wagner *et al.* (2017) found that cells containing 2% (by weight) MDO in the electrolyte reached 450 charge/discharge cycles at 25°C before losing 20% of their original capacity, while cells containing 2% VC or 2% FEC suffered 20% capacity fade by 36 and 87 cycles, respectively. Additionally, the MDO cells had a much higher discharge capacity than either the VC or FEC cells.(Roser *et al.* 2017)

Since MDO showed impressive performance in PC electrolyte, which usually cannot be used at all in cells with a graphite negative electrode, it was logical to wonder if MDO would similarly benefit cells prepared with EC:DMC electrolyte. However, tests performed by Hall *et al.* (2018) were not encouraging; MDO-containing cells produced lots of gas in formation (the first charge and discharge cycle when a lithium ion battery is first made). Top-of-charge (4.3V) storage testing at 60°C for 500 hours showed significant voltage drop and large volumes of gas production (Hall *et al.* 2018).

At the same time that MDO was being developed, a related compound, 3-phenyl-1,4,2-dioxazol5-one (PDO, Fig 3) was discovered in work by Park et. Al (2015). Since the precursor to PDO, benzohydroxamic acid, could be obtained commercially, and phenyl containing compounds such as diphenyl carbonate have been shown by Petibon *et al.* (2015) to be effective additives, Dr. David Hall suggested that I test PDO as an electrolyte additive (Hall *et al.* 2018).



3-phenyl-1,4,2-dioxazol-5-one
PDO

Fig 3 Structure of PDO.

MATERIALS METHODS

Synthesis of additives

PDO was synthesised based on a method reported by Park *et al.* (Fig 4) (Park et al, 2015).

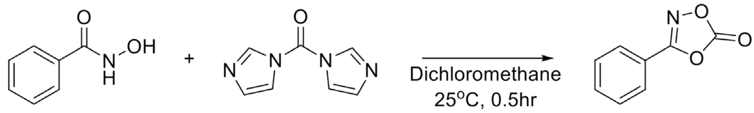


Fig 4 Synthesis of PDO as reported by Park *et al.*2015)[35]

All solvents and reagents were used as received, without further purification. 1,1carbonyldiimizole (CDI, ≥98%) was purchased from Oakwood Chemical Inc, and benzohydroxamic acid (98%) was purchased from Alfa Aesar. Benzohydroxamic acid (5.00g, 36.5 mmol, 1eq) was dissolved in dichloromethane (120 mL) and stirred. 1,1′-carbonyldiimidazole (5.92g, 36.5 mmol, 1 eq) was added in one portion. The mixture was stirred for half an hour at room temperature, quenched with 50 mL of 1N H_2SO_4, extracted with dichloromethane (3× 40 mL), and dried over Na_2SO_4. Volatiles were removed using a rotary evaporator to give crude product, which was recrystallized from a 10:1 mixture of cyclohexane:acetone to give 3-phenyl-1,4,2-dioxazol-5-one (PDO).

Lithium-ion cells

Our study was conducted using pouch cells (Fig 5) (Trask *et al.* 2014), in which the positive and negative electrodes, along with the separator, were rolled together and inserted into a plastic and aluminum pouch, with current collection tabs sticking out of the pouch. The advantage of using pouch cells, widely used in cell phones and consumer electronics, is that the cells were machine made, greatly improving experimental consistency, and that any gas produced during operation can be measured by recording the change in the cell's volume.

In this study, the negative electrode was copper foil covered with a layer of artificial graphite. The positive electrode was made of aluminum foil covered with a thin layer of a lithium transition metal oxide. Additionally, the pouch was slightly larger than the electrodes,

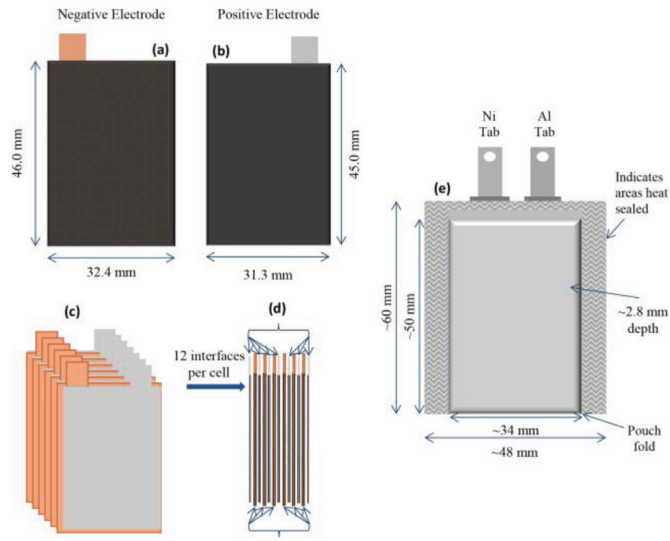


Fig 5 **Schematic diagram showing (a) negative electrode, usually made of graphite-coated copper, (b) positive electrode, made of transition-metal oxide coated aluminum foil, (c) and (d) front and side view of electrode stack, (e) complete pouch cell. A polypropylene or polyethylene film (not shown) separates the positive and negative electrodes (Trask *et al.*2014).**

leaving a small empty space, to allow the cells to be cut open for degassing purposes, and resealed.

Dry (no electrolyte) vacuum sealed $LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$ (NMC622)/graphite pouch cells, with a capacity of ~230 mAh, were purchased from Li-Fun Technology (Tianyuan District, Zhuzhou, Hunan, China). The NMC622 was a conventional polycrystalline material. Before filling, the cells were cut below the heat seal in an argon-atmosphere glovebox, inserted directly from there into a vacuum oven, dried at 80°C under vacuum for 14 hours, and returned to the glovebox for filling. Except for PDO, which was purified by recrystallisation from a mixture of cyclohexane and acetone, all solvents, salts, and additives were used as received, without any further purification. All solutions used this work contained 1.2 mol L^{-1} $LiPF_6$ (BASF, ≥99.9%) in a 3:7 solvent blend, by mass, of ethylene carbonate (EC) and dimethyl carbonate (DMC) (BASF, ≥99.9%, <20ppm H_2O). The additives, PDO (synthesized and purified at Dalhousie, see above),

VC (BASF, ≥99.8%), DTD (Guangzhou Tinci Materials Tech. Co. Ltd., ≥98%), $LiPO_2F_2$ (LFO, Shenzhen CapChem Tech. Co. Ltd.), TTSPi (TCI America, Inc, ≥95%), and MMDS (Guangzhou

Tinci Materials Technology, 98%), were added singly or as binary or ternary blends in the indicated mass percentages. Cells were filled with 1.0±0.1g of solution, sealed at -90kPa (gauge pressure) using a compact vacuum sealer (MSK-115A, MTI Corp.) and immediately held at 1.5V to prevent corrosion of the copper current collector during the ~24 hr wetting period that followed at 21-25^{o}C. Cells then underwent formation of the SEI. Because some gas was expected to be produced during formation, the cells were clamped at ~25 kPa gauge pressure using soft rubber, to push gas bubbles into the empty part of the pouch and prevent them from becoming trapped between the electrodes, resulting in imprecise measurements.

Electrolyte

The electrolyte in these lithium-ion cells was made of a combination of a cyclic carbonate (Fig 6), ethylene carbonate (EC), which solvates lithium salts well but is a solid at room temperature, and a linear carbonate (Fig 3), in this case dimethyl carbonate (DMC), which is not very polar but lowers viscosity. In this work, the ratio of EC to DMC was 3:7 by weight.

The salt used in this work was lithium hexafluorophosphate, $LiPF_6$ (Fig 6), selected for its solubility in the linear carbonate electrolytes, and low cost (Xu 2004, Kawamura *et al.* 2005).[11,38] Much of the electrolyte was soaked in a separator, made of microporous polypropylene or polyethylene, to prevent the positive and negative electrodes from making contact and shorting.

Electrochemical testing

Formation of the SEI was performed inside temperature-controlled boxes at 40.0±0.1^{o}C.

Charging and discharging was performed using a Maccor 4000 Series automated test system (Maccor Inc.) by charging cells to 4.3V at C/20, holding at 4.3V for 1hr, discharging to 3.8V at C/20, and holding at 3.8V for 1hr, where C/20 defines a current needed to full charge (or discharge) a cell in 20 hours.

Cells were weighed under water before and after formation, allowing the change in displacement volume, and hence quantity of gas produced, to be calculated using Archimedes principle. Before storage and cycling, cells were degassed by cutting open the pouch in the argon atmosphere glovebox, and resealing using the compact vacuum sealer. The cells were then reweighed.

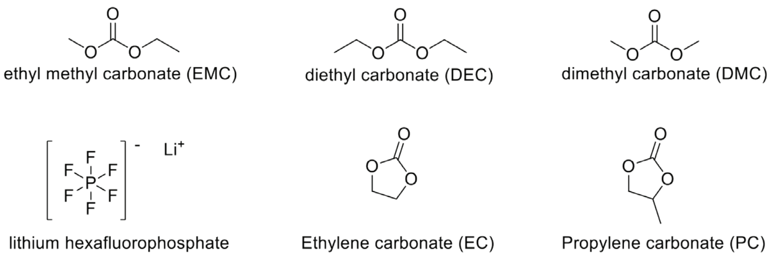


Fig 6 Structures of common lithium ion battery electrolytes and lithium hexafluorophosphate, the lithium salt used.

Long-term cycling was performed on a Neware cycler at 40.0±0.1°C, charged at C/3 to 4.3V, and held there until the charging current dropped below C/20. Cells were then discharged at C/3 to 2.8V, following which they were charged again. Every 50 cycles, a slow charge/discharge cycle was performed at C/20.

RESULTS

As seen in Fig 7, all of the cells produced some gas during formation, although both ternary blends, namely the 1% PDO + 1% MMDS + 1% VC (PDO111V) and 2% PDO + 1% MMDS + 1% TTSPi (PDO211T), produced very little gas, 0.172±0.004 mL and 0.23±0.05 mL, respectively. In fact, the PDO111V produced less gas even than the 2% VC, which produced 0.190±0.003 mL. All the cells containing only PDO, except for the 4% PDO, produced less gas than cells made without any electrolyte additive, which produced 1.3±0.2 mL. Binary blends not containing DTD also produced little gas, with the 2% PDO + 2% VC and the 2% PDO + 1% LFO cells producing 0.44±0.01 mL and 0.522±0.009 mL respectively.

The PDO and DTD blends varied widely in their gas production. The lowest gas production came from 1% PDO + 2% DTD, with 0.30±0.02 mL of gas, while the most gas came from 4% PDO + 1% DTD, producing 1.19±0.05 mL of gas.

The total number of cycles required for each cell type to lose 10% of its original capacity is summarised in Fig 8. Cells with no additive performed very poorly, losing 10% of their original capacity within only 192 cycles, while those containing 2% VC, common in many commercial cells, lasted 388 cycles. All the cells containing PDO alone outperformed the 2% VC cells, lasting 675 cycles when only

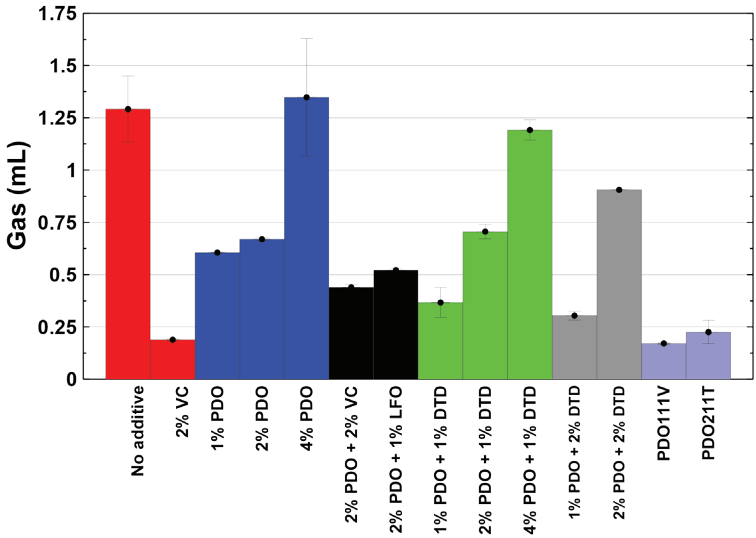


Figure 7. Quantity of gas, measured using Archimedes' principle, produced during formation of the PDO containing cells. Electrolyte composition is indicated on the figure, except for PDO111V, which is 1% PDO + 1% MMDS + 1% VC, and PDO211T, which is 2% PDO + 1% MMDS + 1% TTSPi.

1% was used, and 714 cycles when 2% was used; the 4% PDO cell experienced relatively rapid capacity loss by 369 cycles, so it was stopped, with 96.3% capacity remaining. 2% PDO added to 2% VC increased lifespan to 551 cycles, while 2% PDO + 1% LFO lasted for 897 cycles. Ternary blends containing PDO were also very successful, with the PDO111V and PDO211T cells lasting 763 and 672 cycles, respectively.

The best longevity, however, came when PDO was combined with DTD. 1% PDO + 1% DTD was worse than 1% PDO, lasting 521 cycles. Increasing the DTD from 1% to 2%, however, more than doubled the cell's lifespan; the cell with this electrolyte blend lasted 1265 cycles before losing 10% of its original capacity and is still cycling as of the time of this writing. 2% PDO + 1% DTD has also showed excellent capacity retention, reaching 1139 cycles before losing 10% of its original capacity. The 2% PDO + 2% DTD cell did not perform quite as well, reaching only 891 cycles, while the 4% PDO + 1% DTD cell experienced 10% capacity loss after 791 cycles.

Fig 10 displays the normalised capacity and voltage hysteresis of cells containing PDO alone, along with a cell containing no electrolyte additive, and a cell containing only VC.

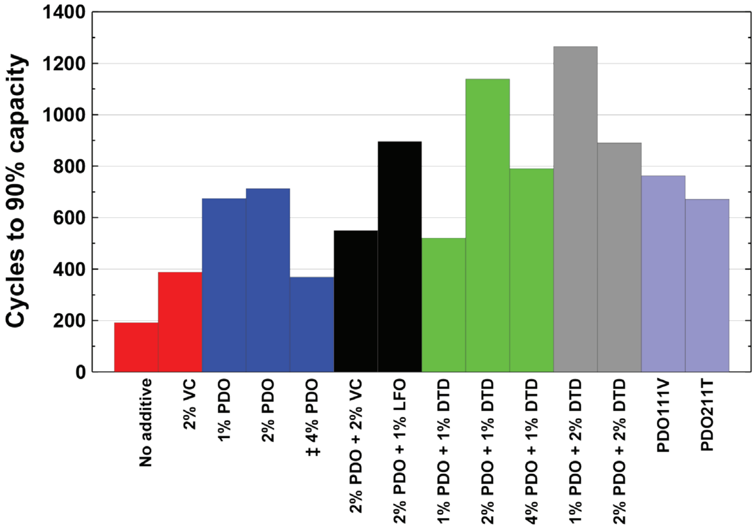


Fig 8 The total number of cycles required for a 4.3V NMC622/artificial graphite pouch cell to lose 10% of its original capacity at 40oC, C/3 charge-discharge rate. Electrolyte additive compositions are indicated on the Fig, except for PDO111V, which is 1% PDO + 1% MMDS + 1% VC, and PDO211T, which is 2% PDO + 1% MMDS + 1% TTSPi. ‡: Cycling was stopped at 96.3% capacity.

Normalised capacity is calculated as seen in the equation below.

$$Normalised\ capacity = \frac{Capacity\ in\ mAh\ at\ cycle\ n}{Capacity\ in\ mAh\ at\ cycle\ 3}$$

The average charge and discharge voltage used to determine voltage hysteresis, a measure of the cell's impedance, is calculated from a capacity vs voltage plot. High impedance reduces the rate at which a cell can be charged and discharged, much like the way a partially clogged water pipe reduces flow rate.

Voltage hysteresis is calculated as shown in the equation below,

$$\Delta V = V_{av,c} - V_{av,d}$$

where ΔV = voltage hysteresis, $V_{av,c}$ = average charge voltage, and $V_{av,d}$ = average discharge voltage.

An example of a capacity vs voltage plot for cycle 400 of 2% PDO + 2% VC, a cell with high hysteresis, along with 1% PDO + 2% DTD, a cell with much lower hysteresis, is shown in Fig 9.

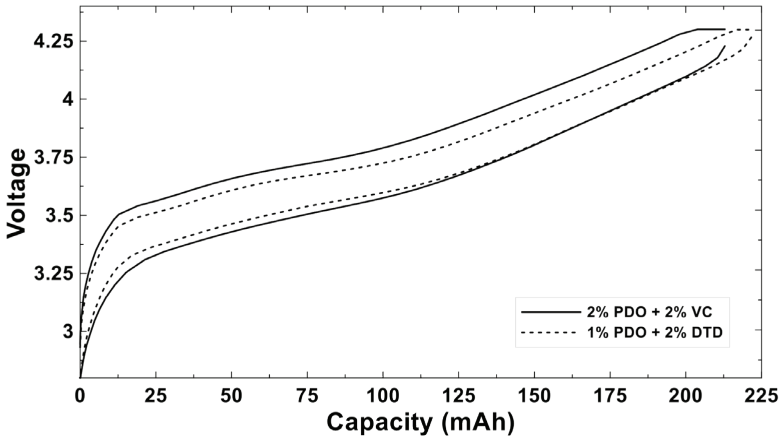


Fig 9 Voltage vs capacity plot for cycle 400 of two NMC 622/artificial graphite pouch cells, cycled to 4.3V at C/3 charge-discharge rate and 40oC. Electrolyte additives are 2% PDO + 2% VC (a cell with high hysteresis) and 1% PDO + 2% DTD (a cell with low hysteresis).

The voltage hysteresis for that cycle is the area between the charge and discharge curves, divided by the capacity. The voltage hysteresis for this cycle is 0.2193V for the 2% PDO + 2% VC cell, and 0.1343V for the 1% PDO + 2% DTD cell.

As seen in Fig 10, all these cells, except for the 4% PDO cells showed better cycling behaviour and slower hysteresis growth than the 2% VC and the cells made with no additive. Notably, both the cells containing VC and those with PDO showed a sudden increase in hysteresis at the same time as their capacity loss started to accelerate. Some cells, such as the 2% PDO cell, show outlying data points; these are due to noise on the Neware charging system.

Fig 11 shows the effect of adding further additives to PDO. Once again, all the cells containing PDO outperformed the 2% VC and additive-free cells. This time, none of the PDO containing cells showed a sudden drop in capacity together with a rapid increase in hysteresis. Instead, their capacity loss was much more gradual.

The best performers of all were those containing PDO and DTD. Fig 12 shows their normalised capacity and voltage hysteresis plots. Once again, the decline in capacity and increase in hysteresis for all the PDO-containing cells was gradual, except for the 1% PDO + 1% DTD, which showed a sudden drop in capacity around 500 cycles, accompanied by a quick increase in hysteresis.

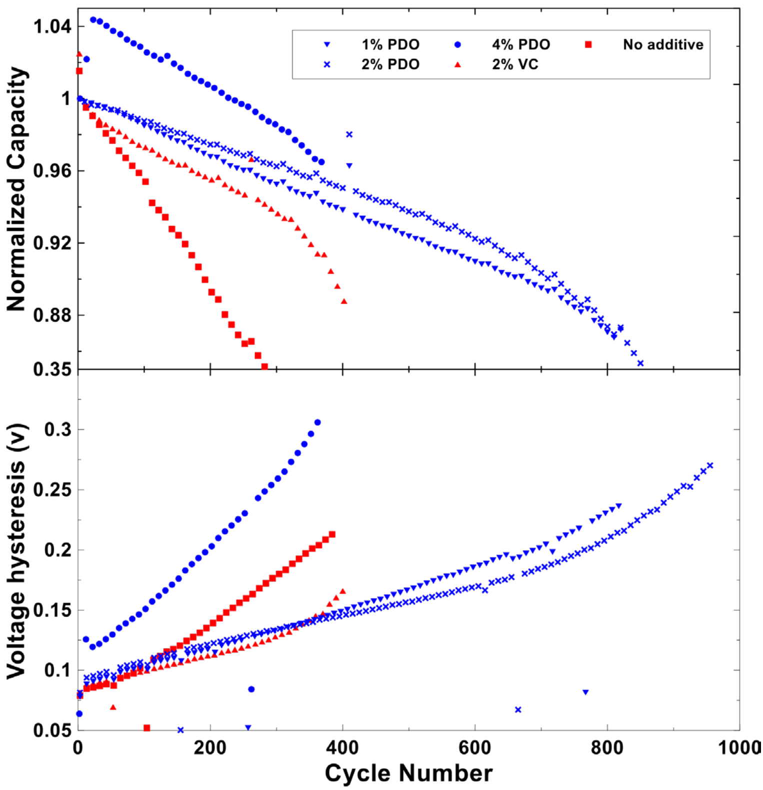


Fig 10 **Normalised capacity (top) and voltage hysteresis (bottom) of NMC622/graphite cells cycled at 40oC and C/3 charge-discharge rate to 4.3V. Electrolyte additive concentrations are indicated on the figure.**

DISCUSSION

While almost all lithium-ion batteries produce gas, consisting mostly of hydrogen and ethylene, with smaller quantities of CO_2, CO, and CH_4 during the initial formation of the SEI (Ellis *et al.* 2017), it is desirable to develop cell chemistries that do not produce excessive quantities of gas. As seen in Fig 7, while all the PDO-containing cells produced more gas than commercial cells containing 2% VC, only the ones containing 4% PDO and 4% PDO + 1% DTD produced more than 1 mL of gas, and these did not show the best cycling behaviour (Fig 10). Therefore, gas production in formation is not likely to be a major issue for PDO.

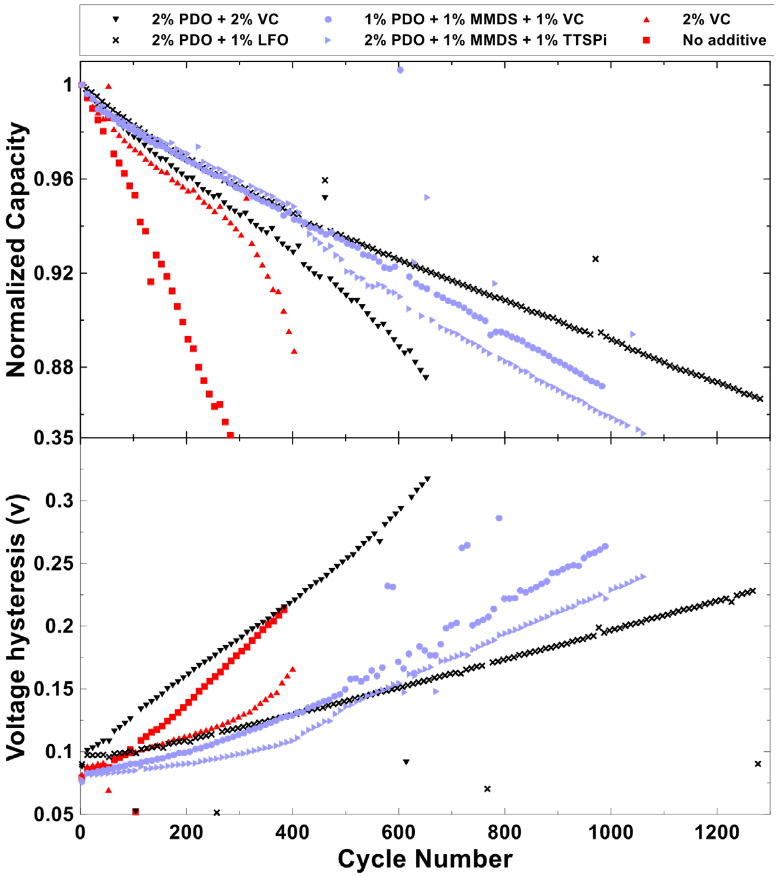


Fig 11 **Normalised capacity (top) and voltage hysteresis (bottom) of NMC622/graphite cells cycled at 40oC and C/3 charge-discharge rate to 4.3V. Electrolyte additive concentrations are indicated on the Fig.**

A cell containing no additive (Fig 8) does not perform very well, showing fast growth in hysteresis and rapid capacity loss (Fig 10). The correlation between these two is not surprising, since a rapid growth in voltage hysteresis means that the cell's impedance is growing rapidly, and this is a common cause of cell failure (Burns *et al.* 2013b).

Adding 2% VC nearly doubles a cell's cycle life (Fig 8), and greatly slows the rate of hysteresis increase (Fig 10). The use of just 1% PDO, however, produces even greater benefits, extending cycle life by about 65% when compared to 2% VC, and more than triple compared to a cell with no additive. Adding 2% PDO, however, provided only

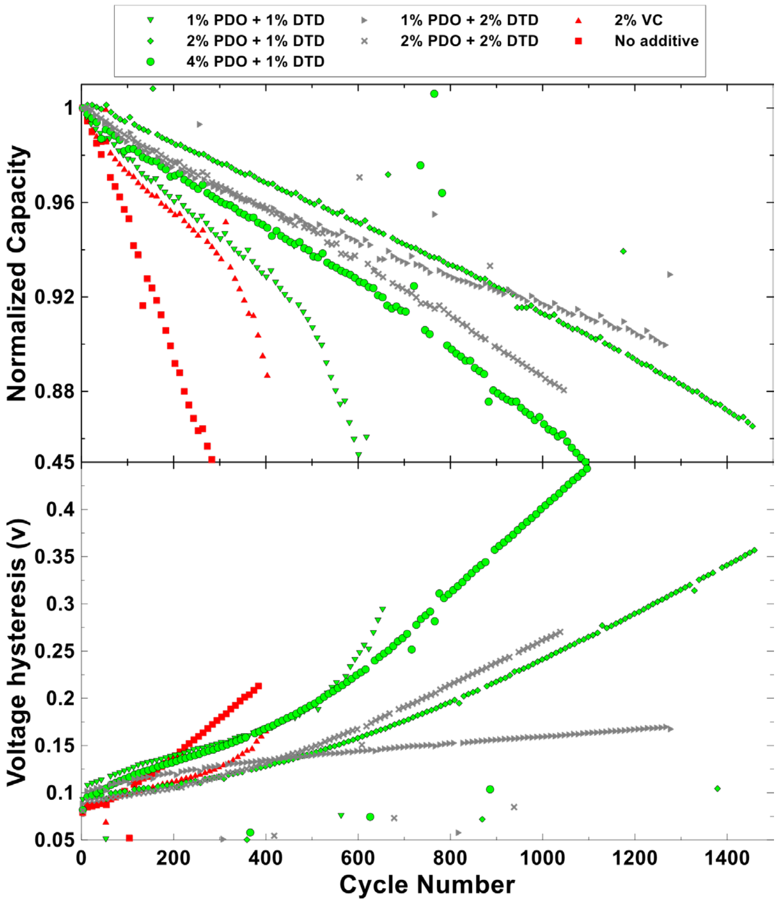


Fig 12 Normalised capacity (top) and voltage hysteresis (bottom) of NMC622/graphite cells cycled at 40oC and C/3 charge-discharge rate to 4.3V. Electrolyte additive concentrations are indicated on the Fig.

modest increases in cycle life (Fig 10), and did not significantly slow impedance growth compared to 1% PDO. This suggests that 1% PDO is enough to make a good SEI, and that adding extra PDO provides little to no benefit.

When the PDO concentration was increased to 4%, the gas produced during formation was greatly increased, and the cell showed unusual capacity behaviour, with the capacity increasing rapidly for the first 35 cycles, before dropping sharply. Throughout this entire process, the impedance increased rapidly, a behaviour similar to that reported for

MDO.(Hall *et al.* 2018)[34] Adding 1% DTD prevented the rapid initial growth in capacity, and also slowed the rate of impedance growth and capacity loss, but it was plain that 4% PDO was too much. Maybe the excess PDO was being oxidized at the positive electrode, but the reasons for this spike and subsequent crash are unknown and are an area warranting future study.

Two of the binary blends tested included 2% PDO + 2% VC and 2% PDO + 1% LFO (Figs 8, 11). The latter was one of the best cells, with slow impedance growth and long cycle life. The former cell, however, showed faster impedance growth than a cell with no additive (which would limit fast charging and discharging) and moderately fast capacity loss, likely due to the VC making an excessively thick SEI. This suggests that VC and PDO are not a good additive pair.

The best binary blends tested were those containing PDO and DTD (Figs 8, 12). While combining 1% PDO with 1% DTD was worse than using 1% PDO alone, adding 2% DTD to 1% PDO produced the best cell of all, with slow impedance growth and exceptional cycle life, demonstrating the complex interactions occurring between the components of a cell's electrolyte. Furthermore, the slope of the normalised capacity appears to slowly curve upwards, suggesting that this cell may last over 2500 cycles before experiencing 20% capacity loss – the usual criterion for a cell's end of life. The second-strongest performer was 2% PDO + 1% DTD. Unfortunately, the slope of the normalised capacity appears to be curving slightly downwards, and the voltage hysteresis plot has a slight upward curve, suggesting that this cell may experience sudden failure when its impedance becomes too great for it to continue cycling. 2% PDO + 2% DTD came in third place, with similar capacity retention and hysteresis behaviour to 2% PDO + 1% DTD. Using 4% PDO with 1% DTD, however, was too much; the cell's impedance grew quickly, and its capacity declined quickly.

The cell containing the ternary blend of PDO111V showed slower impedance growth and capacity loss than the 2% PDO + 2% VC (Figs 8, 11), but it still was only a moderately good performer when compared to the PDO/DTD blends. Another ternary blend, PDO211T, also showed very low gas production in formation, and slower impedance growth than PDO211V, but it lost capacity faster. However, the rate of capacity loss of PDO211T appears to slowly be decreasing, and it may, in time, show slower capacity loss than PDO111V. Most interestingly, the ternary blend of PDO211T showed a dramatic increase in impedance around 400 cycles, but this rapid rise in impedance slowed somewhat around 600 cycles, possibly due to the consumption of one of the three additives.

The exact reason why 1% PDO + 2% DTD is such a good electrolyte additive blend is not known, but it may be because PDO forms an excellent SEI on the negative electrode but is susceptible to oxidation on the positive electrode, and that adding DTD forms a protective film on the positive electrode, protecting PDO from oxidation at high cell potential. This may also be the reason why adding 2% PDO produces little benefit when PDO is used by itself, as the excess PDO that does not go into forming an SEI gets oxidized at the positive electrode. This could make products that degrade the cell (Xiong *et al.* 2017, Xiong *et al.* 2016), and that this problem is made worse when even more PDO is used.

A disturbing trend observed for some cells, namely the 2% VC, 1% PDO, 2% PDO, and 1% PDO + 1% DTD cells was their mechanism of failure. Instead of showing a gradual decline in capacity throughout their cycle life, these cells showed a slow and gradual loss of capacity initially (Figs 10, 12), followed by a sudden increase in hysteresis and drop in capacity, a mechanism known as rollover failure (Burns *et al.* 2013b). This is problematic for the consumer, because it means that a cell can go from having good capacity retention to failure within relatively few cycles, with little to no advance warning. Luckily, the best performing blend, 1% PDO + 2% DTD, showed no sign of this behaviour.

CONCLUSION

A new electrolyte additive, PDO, was chemically synthesized and tested in lithium-ion cells. In moderate quantities, PDO is an excellent electrolyte additive, especially when used in combination with DTD, with the combination of 1% PDO + 2% DTD by weight showing excellent long-term cycling behaviour along with low gas production in formation and slow impedance growth in cycling. Combining PDO and VC, as well as using 4% PDO, should be avoided, as these blends do not show as good a cycle life as the PDO/DTD blends. Additionally, the precise ratio of PDO to DTD is very important, since 2% PDO + 1% DTD and 1% PDO + 2% DTD are very good blends, but other ratios of PDO to DTD, such as 1% PDO + 1% DTD, are not as good.

Finally, all the PDO-containing cells outperformed cells containing 2% VC, a common additive used commercially. Due to the promising results obtained for PDO, a patent has been filed on the use of PDO and related molecules as additives in Li-ion batteries (Hall *et al.* 2019).

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Proceedings of the Nova Scotian Institute of Science (2020)
Volume 50 Part 2, pp. 393-395

BOOK REVIEW

Hot Carbon: Carbon-14 and a Revolution in Science. Columbia University Press, New York, NY. 264 pp.

This most readable book presents an exhaustive review of the radioisotope carbon-14 and its many applications in science that have had an impact on our daily lives. The book reveals some of the secrets involved in developing our understanding of this important, naturally occurring isotope that were discovered during the second half of the twentieth century. Chapters 1 and 2 begin by describing the discovery of carbon-14 at the Berkeley Radiation Laboratory in California in 1940. The discovery of radiation and how it is measured are reviewed in Chapter 3. Chapter 4 describes how the natural occurrence of carbon-14, created by cosmic radiation bombarding atmospheric nitrogen, allows the dating of any substance that accumulates carbon during its lifetime. The role of carbon-14 in unraveling the details of photosynthesis, the process that converts carbon dioxide into organic matter, is discussed in Chapters 5 and 6. The next, Chapter 7, describes how the advent of accelerator mass spectrometry to measure carbon-14 allowed the development of techniques for radiometric dating. Various applications of carbon-14 in dating archeological relics are reviewed in Chapter 8. Chapters 9 and 10 consider the role of carbon-14 in understanding the circulation of the deep ocean, the Earth's carbon cycle, and how the carbon cycle affects the Earth's climate. The role of carbon-14 in studying the productivity of the ocean is reviewed in Chapters 11 and 12 while Chapter 13 concludes by addressing the application of carbon-14 to climate studies. This fascinating technical story is made very readable by including personal information on the principal players who conducted the research and by describing in considerable detail the events that actually happened behind the scenes.

The author, John Marra, was a graduate student in the Department of Oceanography at Dalhousie University in the 1970s. The department was chaired at the time by Gordon Riley, an eminent oceanographer, who moved to Dalhousie from Yale University in 1965. John was the last of Riley's PhD students and went on to spend most of his career studying marine productivity at the Lamont Doherty Earth Observatory of Columbia University, and later at Brooklyn College.

He includes in the book some his own personal experiences working with carbon-14 that are most interesting.

John describes in considerable detail the controversy that erupted over the accuracy of carbon-14 in measuring global ocean productivity, a controversy in which Gordon Riley played a central role. During the 1930s and 1940s, developing an understanding of ocean productivity was based primarily on measuring and comparing the biomass of the food-web components, namely phytoplankton, zooplankton and fish. Riley was a leader in this field. He also attempted to measure phytoplankton photosynthesis directly by following changes in oxygen concentration when water samples were incubated in glass bottles. In the early 1950s, a Danish botanist named Einer Steeman Nielson began using carbon-14 to measure phytoplankton photosynthesis by adding isotopically labeled sodium bicarbonate to seawater samples and measuring the radioactivity in particulate matter after incubation. This method was relatively simple to use and won the day with new oceanographers eager to measure ocean fertility, and its variability in both space and time. However, a controversy erupted when the rates of photosynthesis determined by the two methods were compared in the Sargasso Sea off Bermuda. The rates determined by Riley using the oxygen method were at times on the order of ten times higher than those measured by Steeman Nielsen using the carbon-14 method. Steeman Nielson attacked Riley and claimed his numbers were wrong. Riley in turn defended his results. This controversy simmered for many years without resolution. However, the sensitivity and ease of the carbon-14 method proved strong and Steeman Nielsen prevailed. During the 1960s and 1970s, his carbon-14 method was widely used to measure the productivity of lakes, estuaries and the ocean. Nevertheless, concerns about using carbon-14 to measure productivity persisted, especially when it was discovered that bacteria, also consumers of production, were much more abundant in seawater than previously thought.

Much of this 30-plus year controversy was resolved after Riley moved to Dalhousie, and John Marra played a leading role in this. Part of the difference in results could be explained by the fact that two different ocean regimes had been sampled in the earlier studies. Then in early 1985, John participated in a cruise to the Sargasso Sea and measured phytoplankton production using the carbon-14 method. His results were closer to Riley's earlier results using the oxygen method than Steeman Nielsen's results using carbon-14. John communicated these results to Riley who was relieved to learn that his work was verified. This occurred just before Riley's death. Later that year, John participated in a 30-day experiment called PRPOOS (Plankton Rate Processes in Oligotrophic OceanS), headed by Richard Eppley of Scripps, which was carried out in the Pacific Ocean off Hawaii. The purpose of this major experiment was to compare rigorously, and for the first time, the different methods for measuring ocean production at a single ocean location, including both the oxygen and carbon-14 methods. The results indicated that the productivity of the ocean in this region was approximately double than previously thought. Steeman Nielson based his conclusions about ocean productivity on what happens in a bottle, while Riley favoured evidence based on a broader set of trophic variables. Steeman Nielsen's earlier low numbers for production have not withstood the test of time. Current opinion is that Riley's estimates for global ocean production were about a factor of two too high, while those of Steeman Nielson were a factor of two or three too low.

I highly recommend this book to anyone with an interest in radiochemistry, Earth processes, oceanography, marine production, climate change and human history. It is easy to read, enjoyable and informative. It contains numerous illustrations, including photographs of the principal players, as well as notes, key scientific references and an index. The book is available in both hard copy and on line.

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Volume 50 Part 2, pp. 397-404

BOOK REVIEW

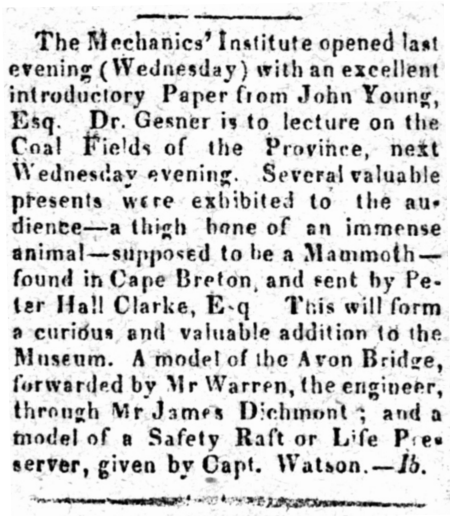
Abraham Gesner: the Lure of the Rocks and a Burning Ambition. E.V. Haigh. 2019. Tellwell Talent, Victoria, BC. 388 pp.

If you are concerned about climate change, you should be interested in the history of geoscience. The early history of geology includes the people and places that have shaped the modern view of our world. In Nova Scotia, the history of geology during the colonial period (1820-1860) features the adoption of new worldviews, fueled by advances in how science was communicated and shared around the world. With our ongoing social adaptation to the new worldview of climate change, and the rapid changes in communication through digital media, these are exciting times to look back at the history of geoscience for some insights.

If you are someone interested in the geology of the Maritimes, you likely know the name Abraham Gesner and some of his history. Gesner was a physician-geologist, as well as the inventor of kerosene. However, if you wish for a more complete picture of this important person in the history of Nova Scotia geology, take time to read this new biography by Elizabeth Haigh.

I was initially attracted to it because of Gesner's connection to Parrsboro, as physician from 1826-1836, but also because Gesner was appearing along the fringes of other historical projects that I have been working on. For example, while preparing a summary of Mastodon discoveries in Nova Scotia, I noticed that Gesner gave a talk to the Halifax Mechanics' Institute on Wednesday, November 9, 1836, speaking on "*The Coal Fields of Nova Scotia*" (Fig 1). This was the week after the "thigh bone of an immense animal – supposed to be a Mammoth" (we now know it is a Mastodon) was first put on public display. Gesner surely saw the important new fossil discovery when he gave his public lecture in Halifax. Gesner seems to be everywhere you turn while researching the history of Nova Scotia geology during this period.

The book is filled with insightful histories and intersections between geology, exploration, and collaborations with the indigenous Mi'kmaq and Maliseet. I was particularly interested in information about Gesner's publications and his ambitious entrepreneurial spirit.



The Mechanics' Institute opened last evening (Wednesday) with an excellent introductory Paper from John Young, Esq. Dr. Gesner is to lecture on the Coal Fields of the Province, next Wednesday evening. Several valuable presents were exhibited to the audience—a thigh bone of an immense animal—supposed to be a Mammoth—found in Cape Breton, and sent by Peter Hall Clarke, Esq. This will form a curious and valuable addition to the Museum. A model of the Avon Bridge, forwarded by Mr Warren, the engineer, through Mr James Dichmont; and a model of a Safety Raft or Life Preserver, given by Capt. Watson.—*Ib.*

Fig 1 The Acadian Recorder, Saturday November 5, 1836. Nova Scotia Archives.

The biography provides a richly researched and lively narrative that conveys the diverse and exciting life lived by Abraham Gesner, with many new historical insights.

As Elizabeth mentions in her introduction, she has been interested in Abraham Gesner for many years. Indeed, we can trace her interest back at least thirty years when she gave a presentation about Gesner at the *Science and Society in the Maritimes* conference in 1988. Her book presents the findings of her long-time interest in Abraham Gesner, including his work in New Brunswick, completing a geological survey and working closely with Maliseet guides, as well as detailed history with the Mi'kmaq in Parrsboro and later during his time as Commissioner of Indian Affairs in Nova Scotia from 1848-1849. The biography is also filled with many small gems that can spark a richer appreciation of the time and the person, the physician, entrepreneurial geologist, and inventor.

One might ask - why is the history of geology important? As mentioned above, it seems especially helpful for us today as we see the growing social acceptance of climate change science. As we examine this earlier period in the history of geology, we find debates about the age of the earth, and evolution would begin to gain social acceptance. Gesner and other geologists who visited Nova Scotia, such as Dawson, Honeyman, Harding, and Webster, were following Charles Lyell, famed for his book Principles of Geology (1830-1833), and were moving away from scripture to discover the story of natural history in the rocks along the shores of the Maritimes. It seems today that the history of these changes in worldview is similar in magnitude to the changes and adaptations that will be required today by society as we address climate change.

Gesner was a physician in Parrsboro from 1826-1836 and he used this time travelling the local landscape to explore the region's geology. Parrsboro was closely tied to Windsor at the time, because of the importance of the shipping route through the Minas Basin from Windsor, Nova Scotia, to Saint John, New Brunswick. While in Parrsboro, Gesner met and befriended two Americans, Jackson and Alger, while they were surveying the area for minerals. This relationship would establish a challenge for Gesner's future reputation as an author.

Haigh's biography provides a detailed summary of the legal and political challenges that affected Gesner after he published his *Mineralogy of Nova Scotia* in 1836 – a volume that was very similar to the works published just before by Jackson and Alger. Legalities aside, both of these documents provide the earliest geology maps of Nova Scotia, as well as early scenic vistas of this important geological area (Fig 2) that has recently been nominated for recognition by UNESCO as the *Cliffs of Fundy Aspiring Geopark* (http://fundygeopark.ca).

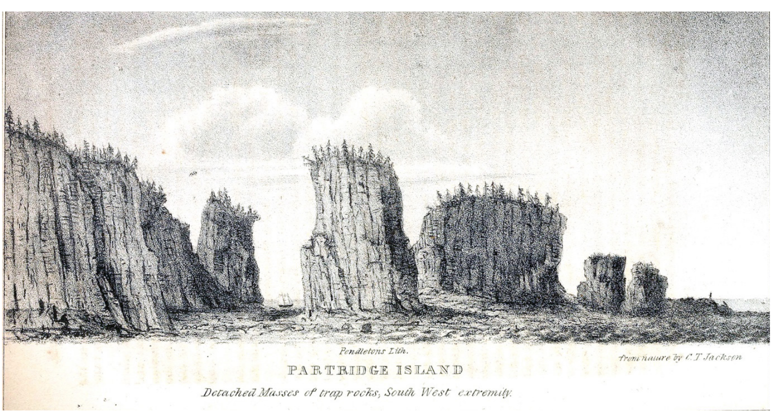


Fig 2 Large fold out lithograph image of Partridge Island, drawn "from nature by C. T. Jackson", in report by Jackson and Alger (1832).

Spending time with the Nova Scotian history of geology provides insights into the cultural and social changes happening with concepts of geological time, evolution, and the changes to worldview that come with these new perspectives. Of course, there were economic interests largely centered on the mineral resources of coal, iron, and later gold. However, the early history of geological science in Nova Scotia involved an important period of natural science, as Charles Lyell published his highly influential tome and later visited Nova Scotia in 1842, when he would meet Gesner among others.

The book ends with the "Golden Years", a shockingly traumatic time for Gesner, who was living in New York from 1853 until around 1862, while the American Civil War raged around him. I have been conducting other research into this important time related to the discovery of gold, and Rev. David Honeyman who represented Nova Scotia at the London International Exhibition. In this work, I had not previously come across the paper "The Gold Fields of Nova Scotia" that Gesner published in 1862, which Elizabeth describes in her final chapter. Gesner stated that the paper was "Communicated to the Geological Society". However, I have not been able to find any record of this document in their archives or published proceedings. Rather, it seems likely that Gesner self-published this work by using the New York printer J. P. Prall, whose promotional material is listed in the American Advertiser in 1850 (Fig 3).

The document, The Gold Fields of Nova Scotia, that Elizabeth describes in her final chapter is very rare. Only two copies of this

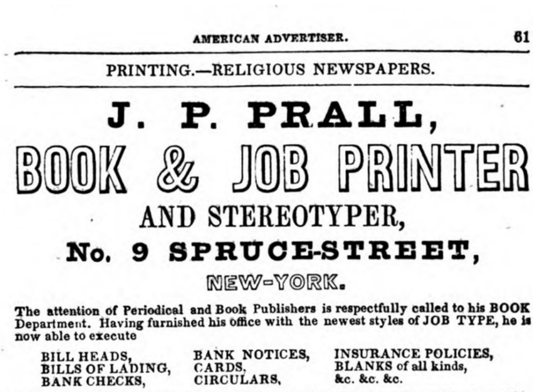
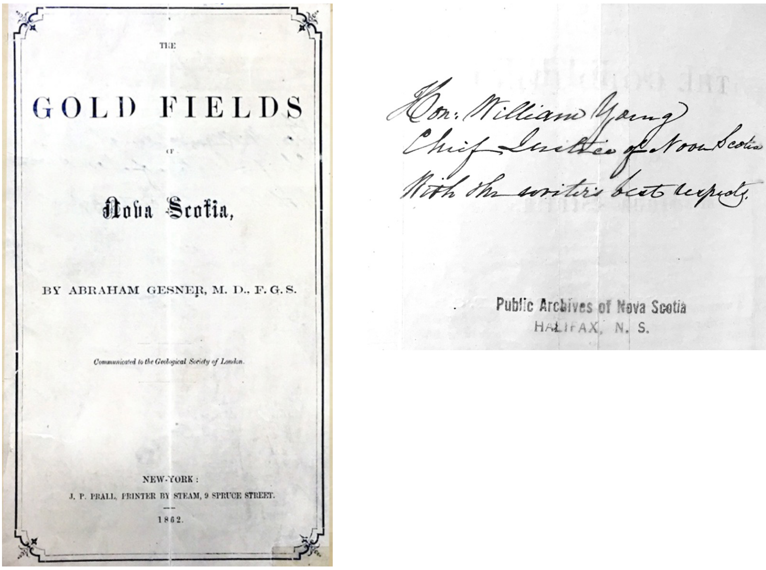


Fig 3 J. P. Prall Printer, listed in American Advertiser, 1850.



THE

GOLD FIELDS

OF

Nova Scotia,

BY ABRAHAM GESNER, M. D., F. G. S.

Communicated to the Geological Society of London.

NEW-YORK:
J. P. PRALL, PRINTER BY STEAM, 9 SPRUCE STREET.
1862.

Fig 4 **Cover page of Genser's 1862 printed report, titled "The Gold Fields of Nova Scotia", addressed to Hon. William Young as a note, hand-written by Gesner on the inside cover.**

document are known, and both are in the Nova Scotia Archives. A note hand-written by Gesner in one of these copies (Fig 4) was addressed to "*Hon. William Young, Chief Justice of Nova Scotia, With the writer's best respects*."

The short paper by Gesner provides an overview of the gold fields of Nova Scotia. However, there is something about the tone and details that are similar to "The Gold Fields of Nova Scotia" published by O.C. Marsh in November 1861, and also mentioned in the January 1862 issue of *Scientific American*. Marsh had visited Nova Scotia in August 1861, finished and submitted his report in October, which was then published the following month. A copy of the Gesner paper was printed by J. P. Prall in January 1862, and apparently also sent to *Scientific American*, to be later mentioned in the February 15 issue.

Could it be that Gesner again took liberties with his publication by reworking Marsh's 1861 report in order to re-establish opportunities in his home province of Nova Scotia? The copy in the Nova Scotia Archives was addressed to William Young, who would have had knowledge about Gesner's previous challenges associated with Jackson and Alger. So, perhaps Gesner's paper printed by Prall was

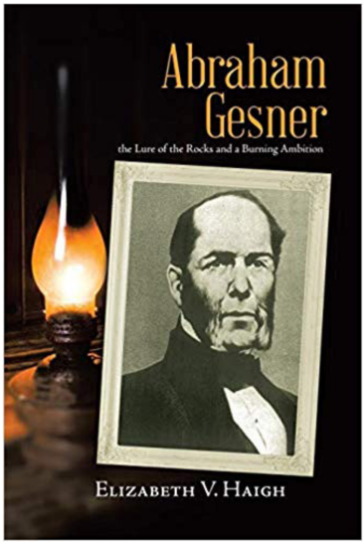


Fig 5 **Elizabeth V. Haigh. 2019.** ***Abraham Gesner: the Lure of the Rocks and a Burning Ambition.***

received by Young with some scepticism. Regardless, other Nova Scotians were already busy promoting Nova Scotia gold fields at this time, with David Honeyman organizing exhibits for the London International Exhibition. Gesner's note became lost until Elizabeth uncovered this and other historical gems during her research.

History comes to life if you imagine what it might have been like for Abraham Gesner, a Nova Scotian doctor and entrepreneurial geologist, to find himself and his family in New York city in 1860 during the convulsions of the American Civil War. One can only wonder - was Gesner one of the 1,500 that heard Lincoln's *Cooper Union Speech* on February 27, 1860?

Gesner did return to Nova Scotia during this time and was an important voice for the establishment of the *Nova Scotian Institute of Science (NSIS)*. Gesner read "*Gold and its Separation from Other Minerals*" to the new group in May of 1863, and his paper was published in the first printed issue of the Institute's Proceedings in 1867, several years after his death.

This biography (Fig 5) is a triumph of scholarly research conveyed with an engaging narrative that explores this fascinating person, his communities, challenges and unending determination. It shines a bright light on Gesner and an important period of Nova Scotia geology. It will undoubtedly be a source of inspiration for more insights about this time and Gesner's contributions.

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NSIS COUNCIL REPORTS
Reports From The Annual General Meeting, May 2019

AGENDA
158TH ANNUAL GENERAL MEETING

5 pm - May 6, 2019

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

1. Approval of the Minutes of the 157th Annual General Meeting of May 7, 2018
2. President's Annual Report (Tana Worcester)
3. Logo Renewal (Tim Fedak)
4. Editor's Annual Report (David Richardson on behalf of Peter Wells (regrets))
5. Librarian's Annual Report (Michelle Paon)
6. Treasurers Annual Report (Angelica Silva)
7. Lecture Program for 2019-2020 (Darlene Smith)
8. Excursions Annual Report (Hank Bird)
9. Student Science Writing Competition Annual Report (Hank Bird)
10. Membership Report (Dylan Miller)
11. Webmaster's Report (Patrick Upson)
12. Report of the Nominating Committee for the 2019-2020 Council (Sherry Niven)
13. Any Other Business
14. Adjournment

Followed by an Informal Reception at 6 pm and a Public Lecture at 7:30 pm

Ecosystem Research in the Bras D'Or Lakes - Bruce Hatcher, Cape Breton University

The application of ecosystem understandings to the aquatic realm is challenged by the opacity and fluidity of marine environments. Ecological tools en-abled improvements in marine ecosystems, while research has improved the capacity to characterize the degree of ecological integrity and dynamics of physical-chemical-biological interactions. Dr. Hatcher summarizes these advances and draws on first-hand experiences in the Bras d'Or biosphere to consider marine ecosystem outcomes for better management of human behaviour in the oceans during the anthropogenic climate change.

MINUTES OF THE 157TH NSIS ANNUAL GENERAL MEETING

7 May, 2018
Dalhousie University Club

Council Members present: Sherry Niven (President), Patrick Ryall (Past President), Tana Worcester (Vice-President), Michelle Paon (Librarian), Angelica Silva (Treasurer), Linda Marks (Secretary), Dylan Miller (Membership Officer), Peter Wells (Editor), Richard Singer, Hank Bird (Excursions and Student Science Writing Competition Coordinator)

Members present: Robert Cook, John Young, Alan Ruffman, Judy Bird, Sheila Crain, Sally Marchand, Michael Sinclair, Jeff Turner, David Richardson

Regrets (Council Members): Tamara Franz-Odendaal, Nicole LeBlanc (Publicity Officer), Suzette Soomai (Webmaster), Alexa Kirste (Student Representative)

The President welcomed members and called the 157th Annual General Meeting (AGM) to order. The President noted that presentations would be kept short and informal and that the reports, excluding the minutes from last year's AGM, would be passed as a unit at the end of the presentations.

1. **Approval of the Minutes of the 156th Annual General Meeting of 1 May, 2017:**
   Motion to accept the minutes of the 156th AGM
   Moved: Tana Worcester
   Seconded: Alan Ruffman
   All in favour: Carried

2. **President's Annual Report (Sherry Niven):**
   The President thanked the 2017-2018 Council for their work and support and noted that it was an honour to serve for a second term as President of one of the oldest learned societies in Canada.

   The President described a successful series of public lectures in 20172018 and thanked the speakers, with special thanks to Graham Daborn for stepping in at the last minute to provide the February lecture; the Lecture Committee; and lecture hosting venues (Museum of Natural History, Acadia University, the Halifax Central Library and Dalhousie's University Club).

The President reported that the Institute co-hosted a public lecture with the Ocean Frontier Institute in November by the 2017 recipient of the A.G. Huntsman Medal for Excellence in Marine Sciences, Dr. Jeffrey Hutchings (Dalhousie University).

The President noted that Council is planning a strategic planning session in June.

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 2017 – 31 March 2018 and reported that the NSIS has 60 regular, 13 life, 5 student and 14 institutional members

As of 31 March 2017, the net worth of the NSIS was $49,654.81 with $12,529.08 in cash and $37,125.73 in savings and investments. The Treasurer noted that again expenditures ($15,832.02) exceeded revenue ($5,367.66). The final $5K from Dr. Alan Taylor's bequest has been distributed to Nova Scotia 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,* postage, and lecture posters and brochures.

The Treasurer reported that Robert Cook has agreed to audit the finances of the Institute. There has not been an audit for several years.

Motion to approve Robert (Bob) Cook as auditor of the NSIS finances
Moved: Angelica Silva
Seconded: Michelle Paon
All in favour: Carried

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

The Editor reported that Vol. 49 (2) 2018 of the *Proceedings* has been published in hard copy and will be digitally available (6 months following publication). Vol. 50, a special issue on marine polychaetes, is undergoing final editing.

The Editor reported that Vol. 49 contains new Instructions to Authors which are intended to reduce the time involved in the final editing of manuscripts.

The Editor thanked the Editorial Board and especially Production and Layout Editor, Gail LeBlanc for their work.

Linda Marks asked if the free access to the digital issues could be delayed to longer than 6 months (following publication of the hard copy) to possibly increase sales of the *Proceedings*.

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

Michelle Paon described her role as Librarian.

The Librarian reported that in 20172018, sales of the *Proceedings,* from the Reference and Research Services office of the Killam Library, yielded $500.00. The *Flora* continues to sell well and with 50 copies reprinted in July 2017.

The Librarian reported that this past year 779 complimentary copies of unsold past issues of the *Proceedings* have been distributed. This give-away of over-stocked copies of the *Proceedings* (5000+) will help alleviate the space shortage at the Killiam Library and will continue.

The Librarian reported that forms were submitted to Access Copyright for the 2017 repertoire payment to publishers and that a payment of $337.03 was received.

The Librarian reported on two copyright-related issues. In November 2017 Council granted permission to Biodiversity Heritage Library (BHL) to redigitize the *Proceedings of the NSIS.* Also in November the NSIS received a request to reprint a NSIS publication on Titus Smith. Since this publication was published in 1938 and its author, Harry Piers, died 78 years ago it was determined that no formal permission from the Institute was necessary.

The Librarian reported that the NSIS has 16 institutional members and 86 exchange partners. Last year 110 publications from around the world were received from the exchange partners.

The Librarian thanked the Killam Library staff and Carol Richardson for ensuring that NSIS materials are available on the Killam Library shelves and noted that Carol Richardson, Killam Administrative Assistant, does many jobs for the Institute and expressed her appreciation for her valuable work.

Sherry Niven thanked Michelle Paon and Carol Richardson for their work, particularly for selecting appropriate past *Proceedings* for display and distribution at the lectures.

6. Lecture Program for 2018-2019 – Report of the organizing committee (Tana Worcester):

The Vice-President thanked members of the Lecture Committee: Patrick Ryall, Sherry Niven, Don Stoltz and Carol Morrison for their work and presented the report of the committee.

Oct 1, 2018 – Jeff Hutchings (Dalhousie University)
Distinction between Advice and Advocacy in Science

Nov 5, 2018 – Shelley Adamo (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)
Organic and Natural Wines and the Role of Science

Jan 7, 2019 – Noni MacDonald (Dalhousie University)
MicroResearch in the Nova Scotian Context: how approaches used successfully in East Africa may help to address health issues in Nova Scotia

March 18, 2019 – Fiona Brooks (Nova Scotia Nature Trust)
100 Wild Islands on the Eastern Shore, NS

May 6, 2019 – Bruce Hatcher (Cape Breton University)
Ecosystem Research in the Bras d'Or Lakes

Sherry Niven thanked Tana Worcester for chairing the committee and noted how challenging it is to ask lecturers to commit to participate a year in advance.

7. Proposed Excursions for 20182019 (Hank Bird):

Hank Bird reported that successful excursions took place in 2017:

– Joggins Fossil Cliffs in August 2017
– Dalhousie Planetarium in November 2017
– The Bedford Institute of Oceanography (BIO Expo 2017) in September 2017

Following a survey of the membership excursions were selected for 2018-2019:

– Labrador Castle, hike to be organized by Pat Ryall
– Otter Ponds Demonstration Forest, visit to be organized by Hank Bird
– Petroglyphs in Kejimkujik National Park, guided nature hike to be organized by Peter Wells
– Habitats & Habits of NS Birds, to be organized by Hank Bird in June 2018

A repeat of the successful The Art and Science of Making Beer, or an excursion to a vineyard may also be arranged.

Hank Bird thanked Nicole LeBlanc and Linda Marks for their assistance.

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

Hank Bird reported one winning paper (post graduate) and two honourable mentions (under and post graduate) were selected from 7 manuscripts. Awards were presented at the April 2018 NSIS public lecture. Hank Bird thanked the judges, Tamara Franz-Odendaal, Tom Rand, John Rutherford, Pat Ryall, Rick Singer and Don Stoltz for their work.

Sherry Niven thanked Hank Bird and the other judges for their considerable investment in this contest, reading manuscripts and providing constructive feedback to the students.

9. Publicity Report (Nicole LeBlanc):

No report

Sherry Niven thanked Nicole LeBlanc for her ideas and considerable work in designing posters and brochures and for promoting the Institute via social media.

10. Webmaster's Report (Suzuette Soomai):

The Webmaster was not present but provided a written report.

Suzuette Soomai reported that this has been her final term as Webmaster. In 2017-2018 she continued to provide general maintenance and updates to the website, including posting of the monthly lectures, but the website still requires a redesign which will require regular technical support to maintain and enhance its functions and update its security.

11. Membership Officer's Report (Dylan Miller):

The Membership Officer reported that there are currently 51 paid members. Membership includes 2 Honorary members, 11 Life members and 14 free 1 year memberships which are offered to speakers and students who enter the Writing Contest.

Angelica Silva thanked Dylan Miller for his work.

Sherry Niven noted that the Institute should focus on retaining and regaining members as well as recruiting new members.

David Richardson reminded the audience that a $30 membership ensures that you will receive a copy of the *Proceedings*.

Motion to accept the Annual Reports:
Moved: Pat Ryall
Seconded: Alan Ruffman
All in favour: Carried

12. Report of the Nominating Committee for the 2018-2019 Council (Sherry Niven):

The President, as Chair of the Nominating Committee, asked the AGM to elect the following to NSIS Council for 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	vacant

Councillor	Tamara Franz-Odendaal
Councillor	Hank Bird
Councillor	Donald Stoltz
Councillor	Richard Singer
Councillor	Carol Morrison

There was a call for additional nominations from the floor, including the vacant position for Webmaster. There were no other nominations.

Motion to accept the Nominations
Moved: Michelle Paon
Seconded: Jeff Turner
All in favour: Carried

Sherry Niven thanked Pat Ryall and Tana Worcester for their work on the Nominations Committee.

Retiring from Council are Past President Pat Ryall, Webmaster Suzuette Soomai and Secretary Linda Marks. New to Council are Darlene Smith (Vice-President), Lorraine Hamilton (Secretary) and Carol Morrison (Councillor).

Pat Ryall reported that there are also several Observers on Council, returning are Kara MacPhee (Discovery Centre) and Laura Bennet (NS Museum) and new are two Science Teacher representatives, Sally Marchand (Women in Science and Engineering - WISEatlantic) and Sarah Kuehm (Bedford Academy).

13. Any Other Business:

Alan Ruffman reported that two prominent scientists passed away in 2018: geoscientist Dr. Clinton Milligan and vertebrate paleontologist Dr. H. B. S. (Basil) Cooke. Dr Cooke was a Life member of the NSIS.

Bob Cook regretfully reported that Dr. James E. (Jim) Stewart recently passed away. Jim Stewart was a Past President of the NSIS and long-time Editor of the *Proceedings*. Peter Wells noted that an article on Jim Stewart will be published in the next issue of the *Proceedings*.

Sherry Niven invited all present to enjoy the public lecture at 7:30 PM, following the dinner.

14. Adjournment:

Motion by Pat Ryall to adjourn the 157th Annual General Meeting of the NSIS at 6:04 PM.

Respectfully submitted
Linda Marks
Secretary

PRESIDENT'S REPORT
2018-2019

Welcome to the Annual General Meeting for the 158th year of the Nova Scotian Institute of Science. I would like to start by thanking the 2018-2019 Council:

Officers: Sherry Niven (Past President); Darlene Smith (Vice-President); Lorraine Hamilton (Secretary); Angelica Silva (Treasurer); Nicole LeBlanc (Publicity Officer); Dylan Miller (Membership Officer); Michelle Paon (Librarian); Peter Wells (Editor); and Patrick Upson (Webmaster).

Councillors: Hank Bird (Excursions and the Student Writing Competition); Tamara Franz-Odendaal; Carol Morisson; and Richard Singer.

Observers: Jilian Philips (Discovery Centre); Tim Fedak (Nova Scotia Museum); Sarah Kuehm (Schools); Sally Marchand (Schools); Alexa Kirste (Student Representative).

And thank-you also to David Richardsoon, Associate Editor of the NSIS Proceedings, and all other members of the editorial board.

Public Lectures

I'd also like to thank all the lectures in this year's lecture series for sharing their knowledge and experiences on a range of interesting topics. We had some really good talks, with excellent discussion afterwards. Unfortunately, we also some issues with weather and unforeseen events that led to a few cancellations at the last minute. We're sorry for any inconvenience this might have caused members, and we are working on a cancellation protocol to ensure greater clarity on a notification procedure.

Oct 1, 2018: Jeff Hutchings (Dalhousie University) *Distinction between Advice and Advocacy in Science.*

Nov 5, 2018: Shelley Adamo (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) *Organic and Natural Wines and the Role of Science.*

Jan 7, 2019: Noni MacDonald (Dalhousie University) *MicroResearch in the Nova Scotian Context: how approaches used successfully in East Africa may help to address health issues in Nova Scotia.*

March 18, 2019: Fiona Brooks (Nova Scotia Nature Trust) *100 Wild Islands on the Eastern Shore, NS.*
May 6, 2019: Bruce Hatcher (Cape Breton University) *Ecosystem Research in the Bras d'Or Lakes.*

NSIS extends thanks to the Museum of Natural History for hosting most of the lectures this year, and thanks to the Halifax Convention Centre for hosting our November lecture, which was held there to coincide with STEMFest activities.

The Institute provided support for a number of other public lectures, including 2 panel discussions in the Science in Public Life series, a lecture by the A.G. Huntsman Award recipient for 2018, Dr. Terry Hugues, and a lecture by Dr. Scott of the hit children's TV series "The Dinosaur Train" on May 8th.

Other Activities

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

Looking to the Future

This year, the NSIS Council held a Strategic Planning meeting on February 16, 2019. This session provided an opportunity for discussion of the future of the NSIS, and what might be done to increase participation in our various activities and continue to ensure that our activities are fulfilling the NSIS mandate. The minutes and action plan arising from this meeting are included here.

Introduction: Excerpts from an address to the NSIS on the occasion of its 100th birthday in 1962, by C.B Ferguson.

"It is natural on a birthday to look to the future. Some planning for the future is essential in all endeavours but it is a great mistake to make plans that are too elaborate and detailed. It is not right to plan for everything that it may seem necessary to do; it is wiser to plan to do everything that is necessary as it arises. This leaves a person or an organization in a state of perpetual readiness to take advantage of whatever means are available to meet his or its immediate needs. To this end it is helpful to be flexible in attitude, every ready to respond to the necessity for change. This is one aspect of the true scientific spirit and we should bring this spirit to our Council meetings… "

"First we have to seek clearly what our goal is before we can pursue it with selfish devotion. We must discover our essential self, lay it bare, and then foster it delicately and with loving care. The fact that our Institute has an essential self, and that this self has in some measure been well served, is indicated by observing that we have survived for one hundred years. No institution that fails to meet a need will last this long. It is not too easy to cut away cant and pomposity and see the true basis on which our permanence lies. Sometimes we claim that we are fostering this, promoting that, pursuing the other thing, and such meaningless phrases; however I suspect that what really keeps us going is that we enjoy each other's company, we respect each other's ability, we are proud of each other's success, and that we value the chance to talk to each other about our work, to have it criticized and discussed in a friendly spirit. This is a perfectly sound basis for a successful society provided the topics discussed are important and relevant to a certain number of those present at each meeting."

Objectives of NSIS

According to the NSIS Bylaws, "The objectives of the Society are to represent and promote science. This is done by holding regular public meetings, by publication of work in its *Proceedings*, by maintaining a library of journals and databases, and a website which includes a Hall of Fame."

We currently represent and promote science to Nova Scotians by:

- Archiving, Communicating and Celebrating the History of NS Science. For example:
    - Publication of the Proceedings.
    - Maintaining a library of journals.
    - Posting of historical material on the NSIS website, including the Wall of Fame.

- Building a Stronger NS Science Community. For example:
    - Holding monthly meetings of the NSIS Society.
    - Organizing events for our membership, including excursions and lectures.

- Promoting Science Literacy in Nova Scotia. For example:
    - Advertising science lectures, panels, and other events through the NSIS distribution list.
    - Writing of editorials and articles within the Proceedings.

Our Strengths

– Our long history. We have been in operation since 1962.
– Committed council members and broad membership base. We build from our strengths and interests, with regular monthly meetings where we come together in person to guide and support the NSIS.
– Multi-disciplinarity. We bring together people and activities from a range of disciplines.
– Proceedings. A high quality publication that includes peer review, is Open Access after 6 months, is accessible and inexpensive to publish in, and provides articles of interest to Nova Scotians.

Our Challenges

– Attracting new membership
– Ensuring sustainability of incoming funds
– Establishing a sustainable way forward for the Proceedings
– Maintaining consistent attendance at lectures
– Adapting to changes in how people communicate
– Adapting to changes in use of technology
– Reflecting the full diversity of the science community in Nova Scotia

Action Plan

The 2018-2019 NSIS Council agreed to strengthen our Strategic Vision and develop a corresponding Action Plan to present at the 2019 AGM. This follows:

Proposed activities to "Archive, Communicate and Celebrate the History of NS Science"

Proceedings	Develop ways to make content more accessible to a public audience
	Re-post material on other social media outlets (e.g. Twitter)
	When new Proceedings are published, organize informal events for members to encourage discussion/feedback
	Initiate succession planning
	Establish new approach for monitoring of the Proceedings mailbox.
	Survey past authors, board members, and members to provide suggestions for the future.
	Collect use statistics.
Website	Update out-of-date material on website (e.g. list of council members).
	Work with graphic designers to redesign NSIS website (e.g. as part of a class project).
	Add council profiles to the website.
	Periodically spotlight NS scientists on the NSIS website, including profiles and links to publications, and encourage them to become members of the NSIS.
Educational materials	Develop new educational materials on the history of NS Science, and share materials with schools.

Proposed activities to "Promote Science Literacy in Nova Scotia"

Lecture Series	Remain open to the public, with topics of broad public interest.
	Include emerging as well as established scientists.
	Explore other lecture locations, to expand geographic accessibility.
	Post lectures on the NSIS website, to make them accessible to a wider audience.
Public Engagement	Do more family events, e.g. "Science for the Whole Family" event held previously at Dalhousie University.
	Host conferences or panel discussions issues of interest to a broad public audience, e.g. on adaptation to a digital world or climate change adaptation. What does science tell us about this?

Communication	Periodical electronic NSIS newsletter (e.g. twice per year) of topical short science communication pieces about NS based research.
	Web-based links to what's happening in science (e.g. current news).
	Include more visual elements in our communications materials.
	Photo/artwork contests.
	Make better use of social media to communicate NSIS activities (e.g. sharing of pictures of NSIS activities).

Proposed activities to "Build a Stronger NS Science Community"

Attracting New Members	Create a better membership package, including promotional material.
	Council members to actively reach out to their work and social networks.
	Send reminders to regular members who haven't renewed their membership.
	Make joining NSIS easier, e.g. ongoing work on web-based membership form and payment.
	Enhance advertising of events and lectures to membership.
	Engage membership more fully in organization of events and excursions.
Community-Building Events	Organize panel discussions on topics of interest to existing members and potential new members.
	Organize workshops on topics such as, communicating science.
	Organize more social events for members, e.g. informal wine and cheese events.
	Remind members that they are welcome to participate in council meetings.
	Give incoming members more of an active role in the planning and development of NSIS.
Training or Capacity-building Activities	Hold workshops, e.g. how to organize a panel discussion.
	Conduct training activities, e.g. media training, scientific writing, how to navigate social media.

Networking	Complete inventory of other existing science-based groups and societies in NS.
	Develop and distribute a questionnaire to other science-based groups to determine possible linkages and opportunities for mutual benefit.
	Describe key council activities at the beginning of public lectures.
	Make better use of partnerships with other science-based groups to co-host activities, and continue to provide advertising and promotion of other science-based events and activities of interest to members.
Enhancing Diversity	Better engage with communities currently under-represented in NSIS, e.g. through lectures, workshops and outreach.
	Survey incoming young members about what they hope to gain from membership in the NSIS and what they hope to offer. Use that feedback to shape the activities of the NSIS.
	Consider mentorship opportunities for junior scientists to help match them with an educational pathway that suits their interests and future career aspirations or to help them discover interests/fields in science that they may not be aware of. Example: drop in Q&A sessions with top NS scientists about their career pathways.

Respectfully submitted

Tana Worcester
President

TREASURER'S REPORT 2018-2019

NOVA SCOTIAN INSTITUTE OF SCIENCE
April 1, 2018 - March 31, 2019

ASSETS as March 31, 2019	
Bank Account BMO (as of March 31, 2018)	8,910.26
Investments (as of March 31, 2018)	32,901.83
TOTAL ASSETS:	**$41,812.09**

INVESTMENTS (as of March 31, 2019)	
Renaissance High Interest Savings Account (March 29, 2019) @1.0%	4,158.29
Equitable Bank GTD Investment Cert CA @ 1.81% due June 17, 2019	7,162.00
Equitable Bank GTD Investment Cert CA @ 2.46% due March 09, 2020	10,262.39
Equitable Bank GTD investment Cert CA @ 2.72% due May 08, 2021	11,319.15
TOTAL INVESTMENTS as of March 31, 2019	**$32,901.83**

REVENUES AND EXPENDITURES 2018-2019

REVENUE 2018-2019 as of March 31, 2019	
Membership dues Regular	$ 1,950.00
Membership Life	383.83
Membership Students	40.00
Membership Institutions	390.00
AGM Dinner (May 2017)	910.00
Sales NSIS Proceedings, Birds of Brier Island, Flora NS	345.00
Donations	20.00
Income/Royalties ACCESS Copyright Royalty	344.78
TOTAL REVENUE	**$ 4,383.61**

EXPENSES as of March 31, 2019	
Proceedings printing/ layout PNSIS	$ 1,785.95
NSIS Annual Brochure, Monthly Lectures	810.18
Mail PNSIS to members, NSIS postage	252.50
AGM Dinner (2017) venue, dinner	1,062.77
NSIS Lecturer dinner	44.85
NSIS Dr. Taylor’s bequest contribution to NS Regional libraries	4,999.99
Lecture Sponsorships	550.00
Nova Scotia Regional Science Fairs contributions	2,600.00
NSIS 2018 Writing Competition (Undergraduate/Graduate)	750.00
Supplies office	29.93
Bank charges	42.25
TOTAL EXPENSES	**$ 12,997.43**

Finances

The net worth of NSIS is **$41,812.09 as of March 31, 2019** from a total of $ 8,910.26 at BMO account plus current Investments of $32,901.83.

For this past 2018-2019 period, NSIS had a total income of $ 4,383.61 that resulted from all paid Memberships: regular, students, and institutions ($2,763.83); revenue from AGM dinner ($910), Sales of Proceedings PNSIS, Flora of Nova Scotia, Birds of Brier Island ($345), donations ($20), Copyright Royalties ACCESS ($344.78).

Total expenditures of $12,997.43 did result from costs associated to Printing of Proceedings of Nova Scotian Institute of Science (PNSIS) ($1,785.95), plus expenses related to communications and publicity that included Annual NSIS Brochures, Monthly posters ($810.18), website with Chebucto Community Net ($70), mailing costs of PNSIS to members ($252.50), AGM venue and dinner ($1,062.77), 3rd year of NSIS Dr. Taylor's bequest to NS Regional Libraries ($4,999), Lecture Sponsorships ($ 550), Regional Science Fairs ($2,600), NSIS Student Writing Competition (Loay Jabre $750), Office supplies ($ 29.93), Bank charges ($42.25), extra cost ($44.85) supplies for guest lecturer).

Membership

2018/2019: NSIS had a total of 68 paid memberships (n= 63 regular 2018 +2 for 2019) + n= 4 student memberships + n= 1 life membership. A total membership of n= 94 members includes Life Members n=13 from last earlier years plus an additional n=13 NSIS memberships awarded to students and lecturers. NSIS also has n=14 Institutional Members.

The Nova Scotian Institute of Science continues to dedicate all its resources towards communication and support of scientific issues relevant to all Nova Scotians as it has supported lectures, conferences, student competitions, printing of the Proceedings of the Nova Scotian Institute of Science, Regional Science Fairs and also some Field excursions to NSIS members (not in 2018). This past year 2018/2019 was the 3rd and last year of support to Nova Scotia Regional Libraries as per Dr. Alan Taylor's bequest to NSIS.

As recommended at the 2017-2018 AGM NSIS did request directly to Dr. Robert Cook to carry out and audit of the NSIS Financial Report for 2017-2018 and he did so on December 2018. Dr. Cook did indicate the following "I have found the financial information provided in the NSIS's Treasurer Report to be accurate". We thank Dr. Cook for his contribution and Dr. Cook's letter will be available at the AGM 2018-2019. As a Treasurer I once again recommend that NSIS request Dr. Cook's help with conducting an audit for 2018-2019 Financial Report.

It is recommended to renew investments at time of maturity to maintain a minimum of $25,000 or greater level of savings to avoid extra fees.

Respectfully submitted to NSIS AGM 2018-2019
on May 6th, 2019

Angelica Silva PhD
NSIS Treasurer
Angelica.Silva@dal.ca

EDITOR'S REPORT
2019

Prepared for AGM May 6, 2019

The latest issue of the PNSIS, Volume 50, Part 1, was completed in February 2019.

It is now distributed in hard copy to members and present on the NSIS and Dalhousie University websites.

PNSIS Volume 50, Part 2, is in progress, with a number of articles submitted and in review, including one student award paper.

Once again, I sincerely thank the journal's Editorial Board for their continued excellent service to the NSIS, especially Dr. David Richardson, Assoc. Editor, and Gail LeBlanc, Copy Editor.

NSIS members are requested to submit articles related to science topics of interest to Nova Scotia and the Maritime Region.

These can include commentaries, book reviews, and suitable photographs for the covers.

It is hoped that all the annual speakers will be active members of the Institute and also support the Proceedings in this regard.

Respectfully submitted by:

Peter G. Wells,
Editor, PNSIS.
April 21, 2019

LIBRARIAN'S REPORT
2018-2019

Prepared for AGM May 6, 2019

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 Dalhousie Libraries' staff members in the Killam Memorial Library who prepare these journals for the shelves and facilitate access to the online *Proceedings of the Nova Scotian Institute of Science*.

Proceedings of the Nova Scotian Institute of Science

During 2018/2019, sales of the *Proceedings* from the Killam Library's Reference & Research Services office generated $195 in revenue (see Appendix A). Many thanks to NSIS member Eric Mills and Killam Library Administrative Assistant Carol Richardson for bringing copies of *Birds of Brier Island* (v. 46.1) to Wally DeVries (R.E. Robicheau Ltd.) of Brier Island, who has been selling the publication to island visitors for several years. NSIS now has contact information for Mr. DeVries and will be able to send him replacement inventory as needed. NSIS sent complimentary copies of the most recent issue of the Proceedings (49.2) to Library & Archives Canada, the Library of Congress, and several indexing services.

In the fall of 2018 Geoff Brown at the Dalhousie Libraries confirmed that digital object identifiers (DOIs) have now been assigned to all of the online issues of the *Proceedings of the NSIS* that have been published on the Open Journal System (OJS) platform. For each new issue, the DOIs will be automatically generated.

Distribution of Overstock Issues of the Proceedings

During the year, NSIS distributed 294 complimentary copies of the *Proceedings* (see Appendix B) from the overstock inventory stored in the Killam Library. NSIS will continue to give away overstock copies of the journal during the upcoming lecture season. This initiative has continued to prove successful. Distribution details are provided in the table below:

Access Copyright

During the summer of 2018, the NSIS Librarian submitted the required forms to Access Copyright for the repertoire payment to publishers. NSIS subsequently received a payment of $344.78.

Institutional Members and Exchange Partners

The NSIS renewal invoices were sent to institutional partners, eleven of which have renewed their subscriptions. There are currently 15 institutional members and 85 NSIS exchange partners. In February 2019, one institutional member cancelled its membership: the Fisheries and Oceans Canada Biological Station Library at St. Andrews, NB. In addition, several exchange partners communicated changes to their programs. In May 2018, the Zentralbibliothek Zurich notified NSIS that they would be terminating their publication exchange program "for reasons of operations and human resources". This exchange included the publications *Vierteljahrsschrift der Naturforschenden Gesellschaft*, and the *Neujahrsblatt der Naturforschenden Gesellschaft*. In April 2018, the Museum of Comparative Zoology (MCZ) at Harvard University alerted NSIS that its publications *Breviora* and *Bulletin of the Museum of Comparative Zoology* are freely available on the internet. In light of this news, NSIS Council agreed to discontinue the print exchange of journals with this partner.

NSIS Exchange Journal Collection

NSIS receives journal issues from exchange partners around the world. As an example, from

April 2018 to March 2019, 104 journal issues and society publications were delivered to Dalhousie's Killam Library from the Institute's exchange partners. These items have been processed and added to the NSIS collection in the library.

On behalf of NSIS, I would like to thank the Killam Library's Administrative Assistant Carol Richardson and the Dalhousie Libraries' Resources staff, who process the exchange journals and make them shelf-ready.

Report respectfully submitted by:

Michelle Paon, NSIS Librarian
May 1, 2019

APPENDIX A

Proceedings sold by Killam Library Reference & Research Services Office (April 2018 – March 2019)

Date (2018-19)	Volume/Issue of *Proceedings of the Nova Scotian Science Journal*	# Sold	Price	Amount Received ($)
August	Birds of Brier Island (v.46.1)	8	$15.00	$120.00
October	Birds of Brier Island (v.46.1)	5	$15.00	$ 75.00
Total		13	—	$195.00

APPENDIX B

Distribution of Complimentary Copies of the Proceedings (Apr. 2018 – Mar. 2019)

Date	Event	# Copies distributed
April 2018	NSIS Lecture – Central Library	24
May 7	NSIS AGM /dinner / lecture	15
Sept. 17-23	Science Literacy Week (Dalhousie Libraries - Killam Library)	69
October	Giveaways – Dalhousie Libraries – Killam Library	38
October	Giveaways – Dalhousie Libraries - Sexton Library	18
March 2019	Giveaways – Dalhousie Libraries – Killam Library	130
	Total distributed during April 2018 to March 2019:	294

WEBMASTER'S REPORT
AGM MAY 2019

Period of: 2019 September 1st - May 4th

Work completed:

1. General maintenance of the NSIS website.
    a. Refactored Menus to add 2018-2019 heading
    b. Pushed 2017-2018 headings into the Public Lectures > Previous Lectures menu
    c. Add all 2018-2019 lectures to the website
    d. Updated monthly lecture series for October to April
    e. General web content updates
        i. Link updates
        ii. Updated the wordpress theme for the site to Graphene 2.0, this gives the site a slightly more modern look
        iii. The site is now using the built-in social media links and is displayed in the bottom right footer of the page instead of as a custom menu added to the right side menu

2. Looking into new web hosting
    a. We looked into moving to a new webhost for better service, but opted to stay with Chebucto net.

3. Online membership and payments
    a. Partly complete
        i. Resolved technical issues connecting Paypal to NSIS website
        ii. We have a paypal account and it is connected to a button on a membership form on the NSIS website.

Work in progress:

1. Online membership and payments
    a. Require NSIS member to check Paypal account setup
    b. Require NSIS Treasurer to link Paypal to the NSIS bank account to move money from Paypal to the NSIS bank account.
    c. Membership form needs to be made public once paypal information is sorted out.

Work on hold:

1. Seeking web designer
    a. This is on hold while I focus on the membership form and registration pages.
    b. I noted that in the previous report and in some e-mails it was noted that NSIS was seeking web-designer. I personally feel this is still a good idea. I am a technical person and tend to focus on functionality. Graphic design and making things look pretty is not my specialty. I would like to explore some options for offering a student a chance to undertake the task and focus on the sites aesthetics, while I work with them focusing on the functionality.

Submitted by

Patrick Upson
Webmaster

STUDENT SCIENCE WRITING COMPETITION 2019

May 2019 Report for the AGM

This year 15 students expressed interest in participating in the competition, the same as last year (see below). By the February deadline, eight students submitted manuscripts (3 undergrads and 5 postgrads), one more than last year.

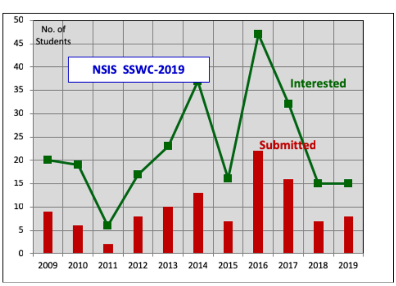
The general level of the papers was quite high this year The judges (Sally Marchand, Tom Rand, Pat Ryall, Rick Singer, and I) read and assessed the papers and we met in mid-March to arrive at our final decisions.

The Winner in the Undergraduate category (prize of $500) was Toren Hynes of Dalhousie University. The paper described how additions of specific small amounts of an organic material known as PDO, in combination with other materials, can significantly improve the performance – especially lifetime – of lithium-ion batteries.[1]

The Winner in the Postgraduate category (prize of $750) was Joseph Tassone of Dalhousie University. The paper described an experimental study of the effectiveness of catalysts which use base metals instead of semi-precious and/or scarce metals to promote chemical reactions.

There were no Honourable Mentions this year.

Thanks to the judges for their diligence, insights, and assessments. Because the NSIS Public Lecture on April 1st was cancelled due to bad weather, the awards were mailed to the winners.



Univ.	Interest	Submitted
Acadia	0	0
CBU	0	0
Dalhousie	13	7
MSVU	0	0
SFX	1	0
SMU	1	1
NSCC	0	0
Total =	15	8

Hank Bird
SSWC Coordinator

[1] This paper is published in this volume, 50(2): 373-392.

NSIS EXCURSIONS 2019

REPORT FOR AGM, MAY 2019

An excursion on the Habits and Habitats of NS Birds in June 2018 was in association with the NS Birding Society and some local birding groups. It was rained out on the scheduled date but took place a week later, in early June. It thus had smaller NSIS participation but nonetheless it was a pleasant and educational outing near Brooklyn with a group of bird enthusiasts.

An excursion to the Otter Ponds Demonstration Forest was in early October 2018 and had about a dozen attendees. The enthusiastic staff gave us a thorough and interesting account of the purpose and methods of the OPDF, which is to demonstrate how a forest can be sustainably managed to provide greater long-term economic value while enhancing the ecology and biodiversity of the flora and fauna.

An excursion about the Science and Art of Making Beer was held in late April 2019 at the 2 crows Brewing Company. About 25 members and guests attended. Dr. Gordon McOuat of University of King's College gave his excellent presentation of how beer-making and science have influenced each other, and society, over the millennia. The lecture was followed by an interesting description and tour of the brewery.

We are currently working on the following possible excursions for the rest of 2019:

- Petroglyphs and Guided Nature Hike (Kejimkujik N.P.)
- Discovery Centre (incl. behind the scenes) (Halifax)
- Geological Museum + Tidal Power Exhibit (Parrsboro)

We are holding the following in reserve, likely to take place in 2020:

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

For the record, we did eight excursions in late 2016 and 2017:

- Natural History of McNab's Island
- Annapolis Royal Historic Gardens
- The Science and Art of Making Beer
- Burke-Gaffney Observatory
- Joggins Fossil Cliffs
- Shubenacadie Canal
- Bedford Institute of Oceanography
- Dalhousie Planetarium

Hank Bird
Excursions Coordinator

NSIS 2019-2020 PUBLIC LECTURES

The lecture series committee proposes the following line-up for the 2019-20 series. Titles and abstracts will be available by the end of May.

October 7, 2019
Dr. John M. Kennedy. Drawings of the Blind and the Sighted

November 4, 2019
Jonathan Ferrier. Indigenous Food, Medicine, and Material Security

December 2, 2019
Sean Haughian. Lichens in Nova Scotia: an overview of lichen diversity, conservation, and current research

January 6, 2020
Kevin Hewitt. Science outreach including Imhotep's Legacy Academy

February 3, 2020
Maryanne Fisher. Human Sexuality

March 2, 2020
Craig Brown. Sea-floor imaging and its applications

April 6, 2020
Dr. John Calder. Big Footprint: Humanity’s Role in Global Environmental & Climate Change

May 4, 2020
Sarah Wells. Strength and Potential of Women’s Hearts

MEMBERSHIP OFFICER REPORT

REPORT FOR AGM, MAY 2019

By the end of the 2018-2019 year, we had:

89 total members (up 11 from last year)
8 from the student writing competition (up 3 from last year)
5 from speakers (down 3 from last year-several were already members) 2 Honorary members (no change from last year)
11 lifetime members (no change from last year)
63 paid members (up 12 from last year)

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

As part of our organization's move into the future, we are working on adding the ability to become a member to our website in a fully-online process.

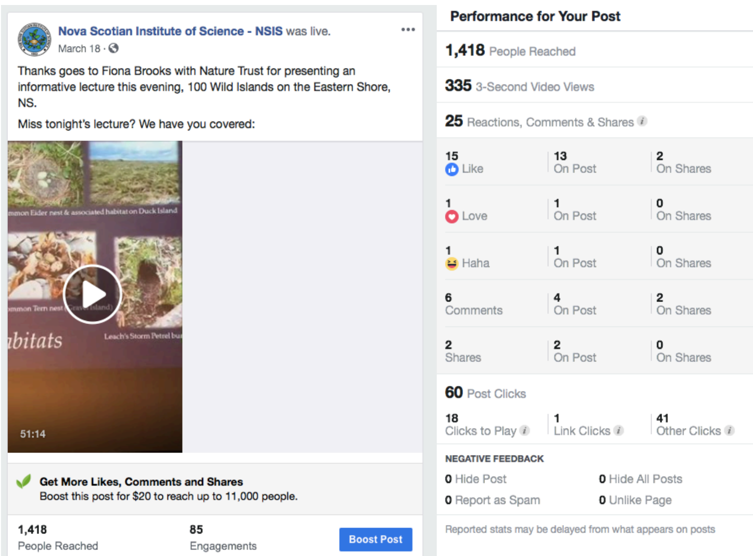
Dylan Miller

PUBLICITY OFFICER REPORT

REPORT FOR AGM, MAY 2019

Facebook

Total Page Likes: 389, increase of 124 new followers this year (2018 = 265) Top Post: Fiona Brooks live lecture (see below):



Student Writing Competition

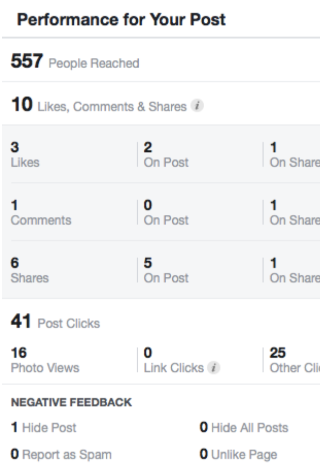
- Poster Re-designed
- Printed and distributed
- Boosted post advertised the poster with target to students aged 18-25 in HRM
- Visual promoted via Facebook (see post statistics next page)

Notes:

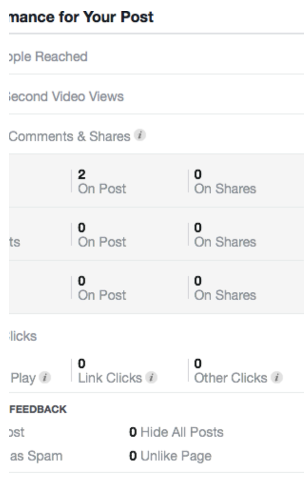
1. 6 Post Shares
2. 1,252 people reached (up from 340 in 2018), 12 post likes (up from 3 in 2018)

(see next page)

VISUAL / POSTER

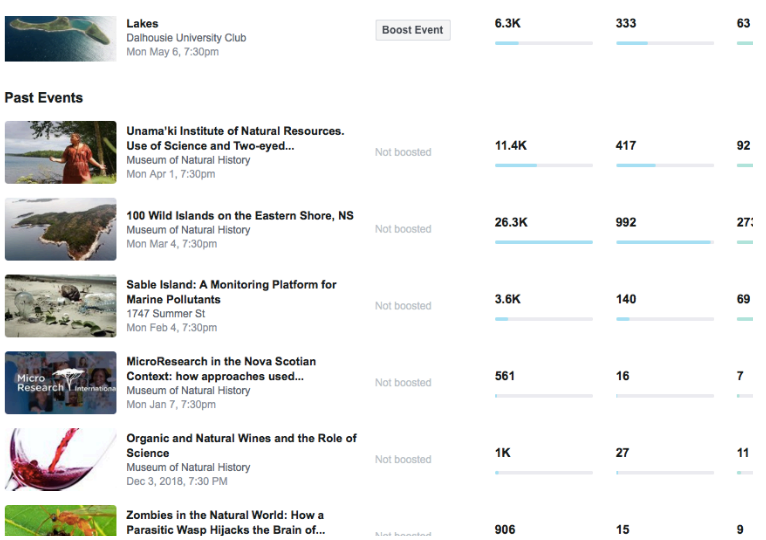


BOOSTED POST



Lecture Events on Social

Interest garnished from the 100 Wild Islands on the Eastern Shore talk really pit NSIS on the map. You'll see a drastic increase in likes, post engagements, and event interest since the March talk, affecting all other events held after.



Event Brite

A website that promotes local events. This has been a great platform to recruit event attendees and advertise our NSIS Facebook page and website.

Website: www.eventbrite.ca

Print Promo

- Monthly Event Posters (distributed around HRM)
- Student Writing Competition posters & visuals (via Social Media)

Email Requests to Promote Event Lectures

- Sent monthly to *Metro News, The Coast,* and *The Herald*

Submitted by
Nicole LeBlanc

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Past-President	Sherry Niven
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NOVA SCOTIAN INSTITUTE OF SCIENCE

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

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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 GO OVER YOUR PAPER TO AVOID ERRORS OR DELETIONS. SPELL CHECK THE ENTIRE PAPER BEFORE SUBMITTING.**

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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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