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EDITORIAL

Climate change in the Maritimes – concerns and challenges

Global climate change is accepted now as a fact by the scientific community, as well as by other informed groups in society. The evidence is overwhelming. Five assessments from the IPCC (the Intergovernmental Panel on Climate Change) indicate a rapidly warming planet, outside of historic limits, that is driven by the increased concentration of CO_2 in the atmosphere now over 400ppm. This issue of the PNSIS has two articles on the topic, one by Charles Schafer, formerly at the Bedford Institute of Oceanography, and a second by David Garbary of St. Francis Xavier University. The first paper discusses historical warmer climatic periods that the earth has endured; the second describes a practical way of teaching about climate change. The reader is implored to read these articles carefully as they present different perspectives and draw attention to this pivotal environmental and social challenge of our time and one with great consequences for the Maritimes.

Society faces many climate-change related events which are becoming well documented. They include: sea-level rise and the increased height of storm surges; more fierce storms (such as one just experienced in January 2018, with wind gusts of over 200 km/hr); increased coastal erosion, aggravated by the storms and higher sea levels; increased water temperatures in the North Atlantic, both at surface and in places, such as the Gulf of Maine, at depth; acidification of the ocean, with pH dropping by 0.1 units (30%); changing distribution of various species (invertebrates, fish, birds, marine mammals), linked to changing water temperatures and food availability; and the prospect of hotter and drier summers on land, with implications (positive and negative) for agriculture and forestry.

The causes and the impact of climate change are highly complex. Indeed, understanding it is the number one problem of ecology, environmental science, atmospheric science, and oceanography. It also involves a consideration of both complexity theory and Gaia theory. The latter considers the earth to be a self-regulating system in a state of homeostasis, a global example of symbiosis (see book review of *One Plus One Equals One* in this issue, and articles and books by Lynn Margulis, James Lovelock, and Stephen Lewis).

For Atlantic science, the challenges posed by global climate change are many and surviving them requires science, adaptation, mitigation, and public education. Continued research is needed on the possible impacts of changing temperature regimes and ocean acidification on species of economic importance, e.g., fisheries species such a cod, haddock and lobsters. Research is also required to understand the physical and chemical processes that drive climate change and affect the seas of the NW Atlantic, and the adjacent land. This should involve obtaining long-term data sets by monitoring and measuring key variables associated with the weather, climate, and the water column. Research should also continue on approaches for mitigation and adaptation. What can be done or should be done? Can we reduce CO_2 emissions and eliminate the use of coal? And what should not be done? It can be argued that armouring shorelines or constructing houses and roads close to cliff tops and on top of barrier beaches should no longer be allowed. There is an urgent need for more public and political education on this issue, but it should be solution-based, not apocalyptic. Education should focus on what we, as individuals and collectively as a society, can do to reduce our carbon footprint (for example, for related marine conservation initiatives, see www.bridge.ocean.org).

The NSIS has an important role to play in this challenge. We can continue to be a conduit for information through talks and this publication; to fund student research projects; and to encourage the membership to be involved in the various local and regional initiatives. These include improving public transportation, reducing our use and dependence on fossil fuels, and encouraging greater appropriate protection for our coastlines and coastal habitats.

Rapid climate change is upon us; the time for effective action is now to ensure a liveable planet for future generations. Further suggestions from all NSIS members and our other readers are encouraged.

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PERSPECTIVE ON WARM CLIMATE INTERVALS AND THEIR HISTORY: HOW MIGHT COASTAL CANADA ADAPT TO AN OCEAN-RELATED AND POTENTIALLY NEGATIVE IMPACT OF PREDICTED WARMER CONDITIONS?

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ABSTRACT

Past warm intervals lasting from decades to centuries can be observed throughout the late Holocene geologic record using various proxy physical, chemical and fossil indices, in conjunction with seasonal information such as the timing of the first flowers of the spring season, or by the dates of first freezing and thaws of fresh water bodies, that have been recorded in various journals. Three important warm intervals that have been identified over the past 3500 years include the Late Bronze Age Optimum (BAO) (~1350 to ~1200 BC), the Iron/Roman Age Optimum (I/RAO)(~250 BC to ~400 AD) and the Medieval Warm Period (MWP)(~950 to ~1250 AD). The early phase of the BAO featured maximum development of the Hittite Empire and the evolution of the *palace* economy. The timing and duration of the later I/RAO show considerable variation from place to place in the Northern Hemisphere. MWP proxy records from several regions indicate that, like the I/RAO pattern, peak warmth occurred at different times in different places included in the Period's overall footprint. Paleo-temperatures, both slightly cooler and warmer than present, have been reported. The WMP occurred during the Middle Ages at a time of the expansion of major commercial routes along the Mediterranean Sea coast and during an interval when Vikings explored and settled in some areas of the North Atlantic region.

Sea level rise is among the suite of important ocean-related negative impacts that are often associated with contemporary global warming scenarios. Both early and modern societies have developed effective adaptation strategies and mitigation techniques to resist rising sea levels and flooding. Many of these have utility for Canada in both inland and especially in coastal areas of the Maritime Provinces. Early sea level rise and tidal flow mitigation measures include the construction of dykes around low-lying areas, sand dune stabilization and shoreline armoring using large

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boulders in concert with breakwaters and groynes. Today, there is also opportunity for the application of beach nourishment and artificial dune construction to resist erosion by storm waves and alongshore currents but these typically require annual maintenance to remain effective. Last resort mechanisms range from stilt home construction to abandonment (managed retreat) of previously impacted coastal areas. It is very likely that, when needed, Canadians will be able to apply a broad range of modern and ancient effective technologies and to engage engineering expertise to develop new (e.g., hybrid) approaches for combating specific negative coastal impacts than were available to BAO, I/RAO and MWP societies.

INTRODUCTION

Natural climate variation is an ever present condition that must be addressed by all societies, some more effectively than others. A book published in 1981 by Cambridge University Press entitled *Climate and History* focused the attention of the scientific community of that time on the evidence for linkages between past climates and their impact on man (e.g., Rosa and Dietz, 1998). It comprises 21 papers that were delivered at a Conference on Climate and History held in England at the University of East Anglia in 1979. In their introductory chapter, the book's editors (T.M. Wigley, M.J. Ingram and G. Farmer) emphasized the need for a precautionary approach in researching climate/history relationships that considers deficiencies in proxy and documentary records, and in scientific data aimed specifically at extending the climate record back in time, which they concluded is often inadequate for demonstrating past climate-history interactions. They go on to point out that a review of then available (1979) well-dated proxy data showed "considerable" differences in the timing of both warmer and cooler intervals from place-to-place and that the effects of climate change documented by earth scientists and archaeologists typically demonstrated pronounced regional variation (Rahman *et al*., 2015). It is in the context of those constraints that the following sections of this article attempt to portray a general picture of key historical events during three well-defined relatively warm climate intervals that have occurred over about the past 3500 years and then proceed to describe how some European and North American societies have been adapting to warmer conditions and to important negative impacts such as rising sea level over the past several hundred years.

ANCIENT CLIMATES RESEARCH METHOD

Earth scientists working with various kinds of proxy indicators that are preserved in geologic, isotopic and paleobiologic archives have been able to describe the temperature and timing characteristics of ancient warm and cool climate intervals (e.g., Kobashi *et al*., 2011). Some of the more commonly used archives include tree rings, ice cores, sediment cores from lakes and oceans, cave deposits (speleothems), and fossil remains. Collectively, proxy indices extracted from these source materials, such as the oxygen 18 graphs shown in Fig 1, complement and/or extend climate information derived from historical documentary data (e.g., Ogilvie, 1992). Past climate conditions and their regional variation have been inferred from studies of proxy indicators such as the isotopes of carbon and oxygen, pollen grains and from fossil remains of tiny phytoplanktic species such as diatoms and dinoflagellates preserved in unbioturbated lake sediments (e.g., Briffa *et al*., 1992). Marine sediment archives offer additional proxy indicators of fundamental ocean water parameters such as sea surface and bottom water temperatures that control the distribution, species diversity and abundance of small fossil-forming organisms (e.g., planktic and benthic Foraminifera). Some of the earliest documentary records of changing climate conditions in Canada have often been expressed through seasonally-controlled biological phenomena such as trends of the dates of the first appearance of cherry blossoms in the spring, or by physical events such as long-term variations in the dates of river and lake freeze-ups and thaws. A substantial amount of these kinds of phenological data covering the 19th and early 20th centuries have been documented in Hudson Bay Company journals (e.g., Ball, 1992).

SOME RECOGNIZED OLDER WARM CLIMATE INTERVALS

The Late Bronze Age Optimum (BAO), Iron/Roman Age Optimum (I/RAO) and the Medieval Warm Period (MWP) comprise three prominent century-scale warm intervals that have been described in the scientific literature using both proxy indices and historical written accounts. Dates, durations and geographical expression of these events vary somewhat from place to place but the footprint of all three indicates that they were very likely at least of inter-regional

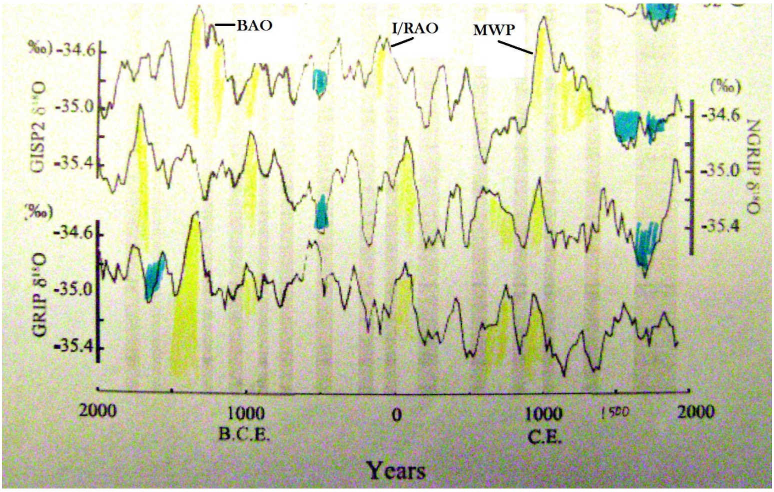

Fig 1 Oxygen 18 isotope graphs of data collected from several Greenland ice core samples (Modified from T. Kobashi *et al.*, 2011). The graphs show the timing, duration and relative magnitude of the three warm intervals (upper graph) discussed in this article. During relatively warm intervals, Oxygen 18 is found in greater concentrations compared to the lighter Oxygen 16 molecule because the latter evaporates more easily than its heavier counterpart.

geographical extent i.e., similar to what is currently being witnessed for the post 1960's Northern Hemisphere warming trend, although long-term predictions of the duration and maximum intensity of present-day warm conditions remain essentially speculative.

The Late Bronze Age Optimum

The Late Bronze Age Optimum (BAO) warm interval lasted for about 200 years and was relatively well developed between 1350 BC and 1200 BC (e.g., Dickinson, 1994). It was followed by the Hekla event at about 1159 BC, a relatively cool interval that is said to have severely impacted agriculture production in parts of Europe for about 20 years. During the main phase of the BAO, the extent of the foot of the Great Aletsch Glacier (located in the European Alps) was reported to be approximately 1000 m shorter than it is today. However, despite current relatively warm conditions, there has still not been enough melting to move the leading edge of the foot of the Aletsch Glacier back to the position that it occupied during the BAO (Prats-Iraola *et al.*, 2009). In general, European glaciers show nearly synchronous advances that coincide with carbon 14 (C^{14}) peaks measured in various physical (e.g., ice), geologic and paleobiologic archives. C^{14} peaks are indicative of weaker solar activity that is typically associated with cooler temperatures and a reduced rate of melting of glaciers (Bray, 1967; Hufbauer, K., 1991). When sun activity is weak, it causes a weakening of the heliosphere (i.e., the region of space through which the solar wind extends) that reduces its shielding effect with respect to cosmic rays. Penetration of the Earth's upper atmosphere by larger numbers of cosmic rays produces greater amounts of C^{14} that is eventually sequestered in various natural archives. Consequently, relatively high C^{14} values are typically interpreted as reflecting relatively cooler climate conditions while relatively low values of C^{14} point to relatively warmer times.

The very early part of the BAO is marked by the maximum development of the Hittite Empire around 1350 BC (Dickinson, 1994; Genz and Mielke, 2011). It is also the time during which Tutankhamun reigned over Egypt (1332-1323 BC). He is said to have been affected by the most severe strain of malaria on several occasions during his life, a condition typically associated with warm environments. The main part of the BAO witnessed the development of the *palace* economy (or redistribution economy) in which a substantial share of the wealth falls under the control of a central administration (the palace) and from there outward to the general population (Halstead, 1994). During the second millennium BC, Mycenae was one of the major centers of Greek civilization. It reached its peak during the BAO and, at that time, the Acropolis was surrounded by massive cyclopean walls (massive limestone boulders fitted together with minimum clearance) that were built in stages around 1350, 1250 and 1225 BC. Bronze Age civilizations flourished before the Urnfielders arrived around 1250 BC (Pearce, 1998). They are believed to have moved south as the result of a pronounced climate deterioration that heralded the end of the BAO. This time is often referred to as the Late Bronze Age Collapse or Crisis. It coincides generally with the onset of a 300 years long drought that began in about 1200 BC. This was also a time of transition in the Aegean Region, SW Asia and in the eastern Mediterranean. The drought caused widespread famines and, eventually, the political and economic collapse of eastern Mediterranean civilizations that many historians believe was sudden, violent and culturally disruptive (www.scienceheathen.com).

The Iron/Roman Age Optimum

The Iron/Roman Age Optimum (I/RAO) (*aka* the Roman Warm Period) occurred generally between 250 BC and 400 AD although its timing and duration show considerable variation from place to place (McDermott *et al*., 2001). For example, oxygen isotope data observed in mollusk shells retrieved from a sediment core raised from an Icelandic inlet indicate relatively warm conditions between 230 BC and 40 AD (Patterson *et al*., 2010). Although the peak of the I/RAO is generally considered to fall between 90 BC and 50 AD, some deep ocean sediment core data suggest an I/RAO peak at about 150 AD (Bianchi and McCave, 1999; Esper *et al*., 2012). During the I/RAO, the foot of the Great Aletsch Glacier is said to have retreated to its present extent or was perhaps even somewhat shorter. Tree ring data from Italy covering the late 3rd century BC interval describe a period of mild conditions at the time that Hannibal crossed the Alps with elephants (Oliver, 2005; Kullman, 2013). Sea surface temperature (SST) proxy reconstructions for the Gulf of Taranto at a location near the distal end of the Po River discharge plume reflect warm and stable temperatures between 60 BC and 90 AD followed by a gradual decrease between 90 and 200 AD indicating that the Roman Classical Period spanned both warmer and somewhat cooler climates. For areas near the ocean, warmer climates are often associated with greater ocean water evaporation that produces higher amounts of precipitation over land areas (e.g., Greece during the I/RAO; Scheidel *et al*., 2012). The relatively warm and stable conditions that existed between the first and second centuries AD correspond to the time of the Pax Romana i.e., to a long period of *relative* peace and minimal expansion by military force in the Roman Empire. Evidence continues to accumulate suggesting that, for the most part, relatively warm historical times have been more peaceful times (www.britannica.com).

During the I/RAO, there is proxy evidence of a strong 11-year cycle (Tinner *et al*., 2003). A pronounced visual correlation of proxy SST data and river discharge records in relation to the variation in $\Delta\ ^{18}O$ anomalies leads to the contention that solar activity variation might have been an important climate-forcing factor during this time (Patterson *et al*., 2010; Lamb, 1977). Some key historical events during the I/RAO are listed in Table 1.

Table 1 Some Key Events During the Iron/Roman Age Optimum.

- 200-100 BC: Construction of the Roman Aqueduct system.
- 91-88 BC and 49-45 BC: The Civil wars.
- 63 BC: Romans take control of Judea.
- 54 BC: Julius Caesar stabbed to death by the Republicans.
- 45 BC: Rome bans all vehicles from within the city because of traffic jams.
- 45 BC: The Julian calendar is introduced.
- 44 BC-14 AD: Establishment of the Roman Empire; Rome is largest city in the world with between 450,000 and 2 million residents.
- 42 BC: Construction of second (stone) temple of Saturn.
- 41 BC: Emperor Caligula assassinated.
- 31 BC-14 AD: Construction of many triumphal arches to commemorate victorious
- Campaigns.
- 27 BC: First treatise on architecture ("De Architectura") is completed.
- 20 BC: King Herod begins construction of the great temple in Jerusalem.
- 19 BC: Roman poet Virgil completes the Aeneid.
- 6 AD: Judea becomes a Roman province.
- 30 AD: Crucifixion of Jesus.
- 34-60 AD: Missionary Journeys of Paul the Apostle.
- 43 AD: First London Bridge (a temporary pontoon bridge) is built by the Romans.
- 53 AD: Parthians annihilate an army of 40,000 Romans.

The Medieval Warm Period

The warm interval that preceded the present day (late 19th century to 21st century) warming is known as the Medieval Warm Period (MWP). It is evident in proxy data between 800 and 1300 AD and was apparently fully developed between 950 and 1250 AD (Wigley *et al.*, 1981). Proxy records from several regions show peak warmth of the MWP occurring at different times. Global temperature records extracted from ice core, tree ring and lake sediment archives indicate that the Earth may have been about 0.03^0 C cooler during the MWP than has been reported for the later decades of the 20th century (Hiller *et al.*, 2001). In contrast, proxy SST data for the Sargasso Sea area show values from almost 1000 years ago that are about 1^0 C warmer than today (Keigwin, 1996).

The MWP occurred during the European Middle Ages at a time that witnessed the establishment of major commercial routes along the coast of the Mediterranean Sea and the flourishing of Feudalism between the 9th and 15th centuries. Norse colonization of the Americas started as early as the 10th century when Vikings explored and settled North Atlantic areas including SE Greenland and the fringes of North America (Pallson, 1965). Some other noteworthy historical events during the MWP are listed in Table 2.

Table 2 Noteworthy Historical Events During the MWP.

- 10th century: Magyars ceased their expansion.
- 1000 AD: Kingdom of Hungary recognized in central Europe.
- 11th century: Populations north of the Alps began to settle new lands – some of which had reverted to wilderness following the end of the Roman Empire. There was a rapid increase in the populations of Europe reaching levels not seen again in the same areas until the 19th century.
- 1096 AD: "Progroms" featured the destruction of Jewish communities in Speyer, Worms and Mainz – said to have been triggered by an epidemic of the plague.
- 1096-1099 AD: First Crusade begins and, coincidentally, it was also the first major step towards the reopening of international trade in western Europe since the fall of the Western Roman Empire.
- 1099 AD: Recapture of Jerusalem.
- 13 century: Major nomadic incursions into Europe ceased – except for the Mongol invasions.
- 1215 AD: Magna Carta proclaimed.
- 1001-1300 AD: Papacy reaches the height of its power.

Warming Impact Mitigation Measures

In a paper published in the proceedings of a 1990 international symposium on *Climate Change – Implications for Water and Ecological Resources*, Geoffrey Wall (Dept. of Geography, University of Waterloo) attempted to summarize potential climate impacts for some key economic sectors of Canada (Wall, 1990). His findings recognize important sea level negative impacts with respect to developed coastal areas (Table 3).

Not surprisingly, there are already a respectable number of tried and proven adaptation techniques that address the impacts of warmer climate that Wall identified. Many of them are "win-win" or "no regrets" programs initiated by various levels of government over the past three decades (e.g., the federal government's R2000 insulation retrofit program for older homes and commercial buildings). Others reflect the direct action of individuals. In some large urban settings of the United States that feature summer climates that are generally comparable to cities such as Toronto and Montreal, residents are using existing technologies such as insulation and reflective window panes along with air conditioning to mitigate the impact of anomalously high summer temperatures. In a paper published by Petkova *et al*. (2014), the authors show that there was a greater risk of heat-related mortality for New York City residents 65 years and older in the first five decades of the 20th century compared to the 1973 – 2006 period that they argue as being primarily due to "the rapid spread and widespread availability of air conditioning."

Table 3 Canadian Economic Sectors: Potential negative effects from higher temperatures (Modified from Wall, 1990).

Economic Sector	Possible Climate Warming Effects	Potential Negative Impacts
Great Lakes Basin	Lower lake levels	Increased dredging (ports and shipping channels).
Marine coasts	Rising sea level	Increased height and penetration of storm surges. Coastal flooding (roads, residential and commercial waterfront developments and industrial facilities).
The Prairies	Higher temperatures and drier conditions.	Less favorable conditions for barley and oats production. Increased energy requirements for air conditioning. Northward displacement of fauna and flora including some disease-bearing species.

In the remainder of this paper, I offer some specific comments about negative impacts of predicted global warming in Canada's coastal environments with respect to sea level and storm surges and how some Maritime Provinces, individuals and foreign nations have adapted to them. However, before launching into that part of the story, it is helpful to understand the history of some of the research that has set the framework for managing and protecting coastal environments in the Maritime Provinces that may be particularly sensitive to rising sea level and storm surge impacts. That part of my Maritimes marine geology education begins with an October, 1971 *Conference on Environmental Change in the Maritimes* hosted by Dalhousie University and sponsored by the National Research Council. The proceedings of the meeting were published in 1975 by the Nova Scotian Institute of Science. That conference produced one report by D. Grant (1975) that is particularly relevant to this article. He begins by reminding us that it has been known for more than a century that coastal areas of the Maritimes have been submerging as a consequence of post-glacial crustal adjustments which vary regionally and that this submergence process is still continuing today (1971) at an average rate of about 30 centimetres per century. For Halifax, he estimated total subsidence at about 20 centimetres between about 1910 and 1960 while the average trend of the world-wide rise in sea level between 1925 and 1965 (based on tidal records) added about 4.3 centimetres per century. He goes on to mention that measurements of the elevation of mooring rings mounted on a seawall built in the early 18th century at Fortress Lewisburg in Cape Breton indicate an average rise in relative sea level (i.e., crustal subsidence plus world-wide sea level rise) of about 32 centimetres per century along that part of the Nova Scotia coast. Jumping ahead two decades to November 19, 1991 finds me at a one day symposium held at the Bedford Institute of Oceanography (BIO). *The Climate of Nova Scotia* meeting was sponsored by the Nova Scotia Climate Advisory Committee and featured a paper by a team of BIO coastal geologists entitled *Impact of Accelerated Sea-level rise on the East Coast of Nova Scotia* (Shaw *et al.,* 1992). The opening line of the paper's abstract states that *The current high rates of relative sea-level rise in Nova Scotia may increase further if ocean volume increases as a result of global warming* and then goes on to present a comprehensive summary of Nova Scotia coastal settings that are particularly at risk from the intensified wave action of storms and the estimated long-term rise of relative sea level of about 20 centimetres per century. Their review of comparatively recent tide data (1896 – 1988) for Halifax indicated that sea level had risen by about 32 centimetres per century for the 1920-1988 interval but that the rate of relative sea level rise had slackened during the 1980's. August 19, 2001 witnessed my return to Dalhousie University for the *1st International Conference on Global Warming and the Next Ice Age*. From a global perspective, this was an especially unique meeting because the organizers seem to have made a deliberate effort to bring together members of both the pro and anti-global warming scientific communities to debate the issue of man-made versus natural warming. Curiously, of the 89 presentations (talks and posters) recorded in the proceedings, none of them have the words *sea level* in their title. A new science research band wagon, with both political and economic underpinnings, was under way to stoke up the enthusiasm and energy of both global warming proponents and skeptics (e.g., Medioli and Schafer, 2011) that, indirectly, raised new questions about sea level trends in a cooling world.

Despite all of the dire predictions, there is ample evidence of successful adaptations to rising sea levels and coastal flooding from storms in Canada and throughout the world that have often been derived from techniques used by riverside communities (e.g., US Army Corps of Engineers, 2010). These techniques have been used for centuries to minimize and mitigate river flooding damage based on strategies that aim to protect, accommodate, retreat from or avoid negative impacts (Fig 2).

Fig 2 **Photograph of some 15th and 16th century homes built along the headwaters of the Weser River in the German city of Hann Munden. Note the use of high foundation walls to raise the first floor level above the maximum expected height of flooding that might occur as a result of intensive rainstorms or river ice jams (photograph by the author).**

For seashore communities in Canada, they include the construction of tens of kilometers of dikes (i.e., hard measures) around low-lying areas (e.g., Richmond B.C. and the marshlands of the Isthmus of Chignecto near the Nova Scotia \New Brunswick border), sand dune stabilization (i.e., soft measures) to resist storm wave and wind erosion using salt resistant grasses (e.g., Cavendish, PEI) or beach nourishment techniques (e.g., Parlee Beach, NB) (CBC News, 2013; CBC News, 2015; Oorschot and Raalte, 1991).

Hybrid measures consist of a combination of hard and soft measures such as sand dune rebuilding using an armour rock core (e.g., Crowbush Cove, PEI) and shoreline armouring with large rocks to resist the undercutting of sea walls and soft sediment slopes to protect, for example, seaside boardwalks in Charlottetown and Summerside, PEI and coastal roads at various locations in the Maritime provinces (www.gov.pei.ca; CSRPA, 2011). Shoreline erosion issues have also been addressed in other parts of the world using seawalls or structures installed a short distance offshore parallel to the coast or perpendicular to the shore such as breakwaters and groynes to trap sediment and dampen wave erosion effects. However, these types of hard structures, although very effective locally, can cause erosion in adjacent areas (Fig 3).

Fig 3 Section of an armoured seawall at the foot of a steep hillside that faces the Mediterranean Sea in the lower city area of Monaco. The rock armour apron is intended to prevent the seawall's foundation from being undermined by wave erosion during intense storms (Photograph by author).

At some low-lying seashore areas of the U.S., there are examples of other adaptation techniques that could perhaps be applied more widely in coastal parts of the Maritime Provinces if necessary. They include beach nourishment projects using outer continental shelf sands to increase the resiliency of the coast to wave erosion (e.g., the work of the U.S. Bureau of Ocean Energy Management in partnership with local organizations such as the Central Atlantic Sand Management Working Group; Coburn, 2012); building artificial dunes on the landward side of eroded shorelines (e.g., Cape Canaveral Florida; Williams, 2007); managed retreat (i.e., abandonment) programs aimed at demolishing damaged residential housing in flood prone areas and converting the cleared areas to parkland (e.g., Oakwood Beach, New York, Rush, 2015); construction of stilt (raised foundation) homes and commercial buildings (Fig 4 and 5) in high risk flood zones (e.g., low lying coastal cities in the Maritimes and southeastern U.S. states); and complex flood control systems of dikes, locks and spillways (e.g., New Orleans, Louisiana; Marshall, 2014).

Fig 4 Stilt homes featuring ground level storage and 2nd floor living areas are becoming more common in coastal and flood prone areas of many southern states (e.g., Florida) (Photograph by author).

DISCUSSION

In an attempt to place the current warming interval in perspective, some scientists argue that, although the rate of warming from the 19th to the 20th century is clearly the greatest between any two consecutive centuries during the last 1200 years, this should come as no surprise since conditions during the preceding 500 years-long Little Ice Age are recognized as having been the coldest multi-century interval since the retreat of the Wisconsinan glaciers about 14,000 years ago (Wantanabe *et al*. 2014). Studies of climate oscillations have identified cycles having periods of 9.1, 10-10.5, 20-21, and

Fig 5 **Architectural concept drawing of the south building of the Queens Marque development that is presently under construction on the Halifax Harbour waterfront. Note the stilt design of the ground floor (source: https://my-waterfront.ca/development/queens-marque).**

60-62 years that may explain a large part of the climate variation observed between 1850 and the present day. Other investigations of 80 and 160-year oscillations indicate that they appear to account for a significant portion of the warming trend observed in instrumental records between the 1850s and 1970s (Scafetta, 2012). When proxy and documentary records of past warm intervals are considered together, ever-increasing numbers of scientists have come to believe that there is nothing unusual, unnatural or unprecedented about the Earth's current level of warmth (C02 Science, 2017). This view seems to be generally consistent with the apparent *business as usual* social, demographic and political dynamics of the three older warm intervals described earlier. Conclusions from some of the latest scientific studies continue to auger increasingly for a solar-induced millennial-scale cycling of the Earth's global climate that is totally independent of anthropogenic CO_2 emissions (Lenton, 2000).

Diverse scientific results regarding the forces that drive climate change (both internal and extra-terrestrial) appear to explain why the issue of the major causes of global warming at decadal and century time-scales remains so controversial. Nevertheless, the controversy does not in any way lessen the need to explore new adaptive technologies and government policies that will facilitate economic stability and the safety of all the planet's inhabitants regardless of whether future climate trends produce long periods of unusual warming or cooling with characteristics comparable or more intense than those observed in proxy and historical documentary records. In their introductory chapter, the editors of the 1981 *Climate and History* book offer a realistic perspective on climate adaptation (Wigley *et al*., 1981). On page 36 they note that:

> "Man is a highly adaptive animal, capable of deploying a wide range of technologies and social strategies to cope with a variety of environmental conditions. In view of this fact, and given the comparatively small range of climatic variations in historic times, it maybe assumed that past human societies have to a considerable extent had the potential to adapt successfully to changes in climate. In the future, the scope of such potential may be increased by the development of sophisticated climate modification technologies."

In general, adaptation has operated along two pathways; proactive actions that are undertaken at a time scale of decades to centuries and crisis-management initiatives developed at a time scale of weeks to years. The two approaches reflect economic and safety considerations by both individuals and various levels of government. An example of the former is the extensive construction of dikes for land reclamation to expand farmland capacity over the past several hundred years in the Netherlands, some of the Maritime Provinces and along some coastal areas of China (Warren and Lemmen, 2014a, Krystek, 2011, Zhang, 2006). The Dutch Deltaworks Project, built more than 20 years ago between 1950 and 1997, is a prime example of the former. It includes a number of storm surge barriers of which perhaps the most impressive is the Oosterschelde or Eastern Scheidt storm surge barrier that that was built at the seaward end of a canal called the New Waterway that connects the Rhine River to the North Sea (Fig 6). Its gates are each 210 metres long. Examples of the crisis management approach include work initiated after Hurricane Sandy flooded the Rockaway, Queens's area of New York City in 2012. Following that event, the U.S. Government replenished more than 3.0 million cubic metres of beach sand and New York City planted 9.6 kilometres of sand dunes and built a new concrete and steel reinforced 8.8 kilometre long boardwalk to replace the one destroyed by the storm. New York City also plans to spend $120 million dollars to finance

Fig 6 The Oosterschelde storm surge barrier is closed when a storm surge 3 metres above normal is expected. Once closed, the doors are flooded causing them to sink and turning them into a massive barrier. By way of comparison, during hurricane Juan, which made landfall in Halifax on September 29, 2003, the associated storm surge in Halifax Harbour was, at one point, recorded as 1.5 metres above normal high tide levels (source: www.deltawerken.com/Maeslant-barrier/330.html).

the construction of seven parks designed to be more resilient to storm surges than those destroyed during Hurricane Sandy.

Fast-forward to 2014 to a federal government report entitled *Canada in a Changing Climate: Perspectives on Impacts and Adaptation*. It presents a bar graph showing the number of climate change adaptation articles published by Canadian researchers in 13 economic sectors between 2000 and 2012 (Warren and Lemmen, 2014b). The graph shows that agriculture, the forest sector, water management, and health have received the most attention while coastal management; energy, transport and mining seem to have been of much lesser concern. However, the apparent lower levels of scientific interest in the latter four categories are not necessarily a true reflection of the level of adaptation attention that is being paid to them in coastal parts of Canada.

A primary concern of coastal managers revolves around the effects of sea level rise and flooding from storms. On Canada's east coast, for example, James *et al*. (2004) note that crustal subsidence combined with dynamic oceanographic changes generates relative sea level projections that are similar to, or larger than, the global mean projections for large parts of Atlantic Canada and New England. A January, 2015 report published in the journal Nature notes that global mean sea level (GMSL) has risen at an average rate of 3.0 +/- 0.7 millimeters per year or about 30 cm per century between 1901 and 1990 (Hay *et al*., 2015). If their results are verified, then the ranked importance of rising sea level in relation to other identified negative impacts of predicted global warming noted in the Warren and Lemmen (2014b) government report may need to be revisited. For example, an article in the September 2014 issue of the Canadian Climate Forum notes that, for Nova Scotia, sea level is predicted to rise between 70 and 140 cm by 2100 (~ 82-~164 cm per century) and that, in general, roughly 7 million people live in coastal areas of Canada that may be impacted in one way or another (Canadian Climate Forum, 2014). Historical data for the Nova Scotia Atlantic coast tells us that this predicted rate of rise, if realized, will likely not be a linear one and could, at times, be extreme. For example, the Goddard *et al*. (2015) long-term analysis of tide gauge records show that within a two-year period (2009-2010), coastal sea level north of New York City "jumped" by 128 mm. This rise equates to 640 cm per century, which is about 27 times greater than the average rise of 23 cm per century that has been estimated in many research papers for the Halifax Nova Scotia coastal area. Goddard *et al*. linked their findings to a combined effect of a 30% downturn of Atlantic meridional overturning circulation during the two-year rapid rise period and to the concurrent presence of a significant negative North Atlantic Oscillation index (NAO) at that time. The NAO is an atmospheric pressure phenomenon that modulates the direction and strength of storm tracks and westerly winds across North America. During its negative phase, the U.S. east coast typically experiences more cold air outbreaks (southeasterly flows) and hence more snowy weather conditions. However, not all relevant natural forces result in a positive effect on sea level dynamics. For example, Greenberg *et al*. (2012) have indicated that certain tidal effects can promote a reduction in the rate of sea level rise in the Bay of Fundy and adjacent coastal areas.

Some of the other 12 Canadian economic sectors noted in the federal government's 2014 report have likely received similar or perhaps greater levels of proactive attention with respect to adaptation to both the direct and indirect impacts of warmer temperatures. However, in general, Canadians can expect that most future initiatives will likely remain crisis-management-driven as opposed to the long-term planning-focused flavour. Nevertheless, there appears to be an ever increasing understanding of the long-run cost benefit of proactive adaptation policies for low lying and economically valuable coastal areas that are reflected by the activities of both Canadian government departments at all levels (e.g., Environment Canada's Ecological Gifts Program) and by federal/provincial partnerships such as the Atlantic Canada's Regional Adaptation Collaborative which is administered by the Atlantic Climate Solutions Association. Their establishment was provoked by natural disasters, by a general recognition of the need for long-horizon adaptation and mitigation planning strategies, and perhaps by the reluctance of Canadian insurance underwriters to offer coverage to private homeowners that have elected to occupy flood-prone areas for various personal reasons (e.g., ocean views and proximity to the seaside). Flood insurance coverage varies from one country to another. For example, the U.S. government-subsidized National Flood Insurance Program, created through the National Flood Insurance Act of 1968, issued 5.5 million policies in 2010 (www.floodsmart.gov). In contrast, Germany has only offered insurance for natural disasters since 1991 but its policies do not cover flooding from storm surges. The widespread availability of flood insurance for private homeowners in Canada will likely depend on a broadening of the risk pool by bundling flood insurance with other forms of coverage such as fire and theft. That approach may meet with considerable resistance from homeowners that have elected to occupy higher ground i.e., low risk areas. In the U.K., there are about 2.2 million homes at risk because of their exposure to potential coastal or inland flooding. British insurance underwriters have elected to use the bundling approach to allow them to offer coverage to high-risk homeowners (www.abi.org.uk). This decision has been complemented by various government policies to insure that flooding risks are taken into account at all stages of the planning process to force development away from high-risk areas.

SUMMARY AND CONCLUSIONS

Canadian provincial efforts to date seem to indicate that, for the foreseeable future, adaptation to predicted sea level rise and to coastal storm hazard conditions will likely continue to be mostly dependent on vulnerabilities dictated by local geological, oceanographic and extreme weather conditions. However, for some areas, there seems to be a keen awareness by local governments of the economic benefits of proactive adaptation infrastructure development, and for the ongoing upgrading of existing projects such as that witnessed for the 49 kilometers of dikes surrounding Richmond BC. Nevertheless, these proactive initiatives will not come cheap. For example, An ambitious long-term project to harden the Rockaway area of New Yok City that includes flood walls and levees, estimated to be worth about four billion U.S. dollars, is scheduled to begin in 2020. It involves building 13 new jetties (groynes) on the beach side of the peninsula to trap sand and to extend five existing groynes to slow coastal erosion. It is anticipated that these proactive initiatives will be complemented by a suite of increasingly restrictive zoning regulations (i.e., setbacks, building codes etc.) for future coastal zone development. However, the change from crisis-management to more proactive planning initiatives will depend, to a large degree, on the availability of more accurate and verifiable predictions of climate change and local relative sea level rise rates, and on impacts that can justify the high cost of larger multi-year or multi-decadal undertakings such as the Dutch Deltaworks Project. Some of the relatively recent flood zone development regulations evident in Canada and throughout the world involve the restriction of new buildings to designs that are able to withstand seawater inundation (e.g., stilt homes and stilt-designed commercial buildings), or the conversion of flood prone areas for use only as vegetated buffer zones or community parks (e.g., the Ocean Breeze neighborhood of Staten Island, New York). Although there is a consensus among one group of scientists and politicians that current climate conditions have been modulated by a human element, tabulated historical highlights for the three warm intervals depicted earlier in Fig 1 seem to imply that coastal-living Canadians can probably expect a *business as usual* dynamic to prevail during the current warm interval unless future climate predictions can demonstrate unequivocally the potential for dangerous, widespread and economically-unacceptable levels of impact. There is a second group of scientists that argue that, to date, those predictions are based on the speculations of climate modelers and that they have not been established by physical evidence i.e., hard data (www.sepp.org).

For non-catastrophic flooding by ocean water storm surges and rainstorms (e.g., relatively weak hurricanes), many individual homeowners have installed basement sump pumps, sewage backup valves and portable generators in concert with shoreline armoring to mitigate or eliminate costly impacts such as those witnessed in low lying areas on both the Dartmouth and Halifax shores of Halifax Harbour during hurricane Juan in September, 2003. These private citizen adaptive actions, along with "no-regrets" larger complex regionally-focused projects managed by governments (e.g., the Nova Scotia Regional Adaptation Collaborative Program) suggest that 21st century Canadians will be able to successfully apply a broad range of modern technologies and engineering expertise to address negative climate impact issues such as rising sea levels and storm surges compared to those that were available for BAO, IRAO and MWP societies. In addition, there is also mounting evidence of several potentially positive climate impacts for Canada associated with the change from historical (*Little Ice Age*) cooler conditions to current and predicted relatively warmer temperatures (e.g., reduced winter heating costs). Advances are being made in more efficient transportation technologies, such as the driverless busses that are currently being road-tested in Finland, along with practical energy conservation options (e.g., LED lighting, electric cars, heat pumps for residential heating and cooling, more effective and energy-efficient public transportation systems, and energy-saving recycling programs). These are just some of the devices and programs that will lead the charge back to a more environmentally-sustainable world, but one in which its resident population will still have to cope with the negative impacts of naturally-driven climate variation.

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Remembering Distinguished NSIS **Members**

DAVE JAMIESON – A LEGACY OF HIGH STANDARDS

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William David Jamieson, 1929-2017

W. David (Dave) Jamieson, distinguished analytical chemist and long-time member of the Nova Scotian Institute of Science, passed away peacefully on 19 September, 2017, aged 88. Dave was born in Toronto but spent most of his life in Halifax, where he was educated at Queen Elizabeth High School and Dalhousie University (B.Sc. 1950, Dipl. Chem. Eng. 1951, M.Sc. 1951). In 1951 he was awarded a Royal Commission for 1851 Overseas Scholarship to pursue research in Physical Chemistry at Cambridge University, where he received his Ph.D. in 1954. The title of his thesis, supervised by Prof. R.G.W. Norrish, was "Photochemical studies in solution at high pressures". Just before leaving for the UK, he married Muriel Anne (Ritch) Ritchie, a partnership that lasted 66 years. Their daughter Rebecca Anne (Becky) was born during their time in Cambridge.

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Following his return to Halifax, Dave joined the National Research Council of Canada, Atlantic Regional Laboratory (ARL; later Institute for Marine Biosciences, IMB), where he had a long and successful career, including terms as Assistant to the Director, Head of the Analytical Chemistry section, and Manager of the Marine Analytical Chemistry Standards program, until his retirement as Principal Research Officer in 1990.

Although Dave's early research was in physical chemistry, in the 1960's he began working with Charles Masson and Stirling Whiteway in the internationally known High Temperature Chemistry Section at ARL. This soon led him into analytical chemistry, where he established his independent scientific reputation. A noteworthy analytical project undertaken in this period involved characterization of lunar specimens acquired by the Apollo 11 mission. This required developing methods for determination of silicate anions in small samples by gas chromatographic separation with mass spectrometric identification (GC/MS) of their trimethylsilyl derivatives. It also provided an opportunity for his characteristically wry sense of humour, as he always referred to this as his "lunacy project".

In 1966 he established the analytical mass spectrometry group at ARL with both GC/MS and a high-resolution magnetic instrument that could be operated in scan mode or with parallel detection using a photoplate. Over 20 years this facility provided invaluable service to the natural products chemists at ARL and elsewhere. The notable characteristic of those analyses was the wide range of compounds identified, from indoles, to sporidesmin mycotoxins, to red algae polysaccharides. Dave was not only a skilled user of commercial analytical equipment, but also undertook to improve it, and became an inventive designer of new peripheral devices. His best-known work in this regard involved the then gold-standard INCOS data system from Finnegan Corporation, which controlled data acquisition and processing for GC/MS. He so impressed the Finnegan engineers that they gave him access to the source code so that he could properly implement his novel ideas. In 1985 his reputation had grown to the point that NRC funded a modern high-resolution instrument capable of the new tandem mass spectrometry techniques. This resulted in a new generation of analytical chemists attracted to ARL. A paper that drew attention to the new facility exploited the abundant doubly-charged ions formed from polycyclic aromatic hydrocarbons (PAHs).

These appear at half-integral *m/z* values, providing a means of increasing the selectivity and sensitivity in analyses of PAHs in complex samples. He suggested that this technique be termed "half-massed mass spectrometry", which greatly amused the journal editor but unfortunately had to be changed for publication.

In 1970 Dave was part of "Operation Oil", the scientific task force that dealt with an unprecedented cold-water spill of Bunker C oil following the February grounding and break-up of the *MV Arrow* on Cerberus Rock in Chedabucto Bay. He led the "Clean-Up Technology" team, much to the amusement of his family (Dave was a notorious pack-rat). A major accomplishment was the design, installation, and successful use of a dry-cleaning system for fouled fishing gear and other equipment. The time from design proposal to installation was 3 weeks, at a cost of $26,000, considerably less than the cost of replacing the fouled gear. Not bad for a government clean-up project by today's standards!

This special assignment led to a promising new research direction that was to become a highlight of Dave's already successful career. The major effort required to monitor the clean-up pointed to the urgent need for accurate analytical standards and reference materials for monitoring various environmental contaminants. In 1976, Dave initiated the NRC Marine Analytical Chemistry Standards Program (MACSP), which he managed from 1976 until his retirement in 1990. This involved the combined efforts of the Analytical Chemistry sections at ARL and NRC's Division of Chemistry in Ottawa. Key elements in the program were the assembly of a world-leading research team and the acquisition of advanced analytical instrumentation. From 1977-1987 the ARL component of MASCP focused on developing analytical methodology, environmental standards, and reference materials (RMs). Products included harbour-sediment RMs certified for a suite of PAHs and polychlorinated biphenyls (PCBs). Instrument calibration standard solutions were also produced for 51 individual PCB congeners.

Another turning point came in late 1987, when three deaths and numerous illnesses were traced to the consumption of cultivated mussels from Cardigan Bay, PEI. An unprecedented emergency investigation by Dave and many colleagues at NRC, DFO, UPEI, and other agencies led to the identification of domoic acid as the contaminating agent in the shellfish. There was an urgent need for analytical methods and standards for this toxin to prevent future incidents. In 1989, the first calibration standard, a mussel tissue RM certified for domoic acid, and corresponding analytical protocols, were released by MACSP. These efforts allowed comprehensive monitoring of shellfish for the toxin – notably, there have been no other human intoxications due to domoic acid despite its widespread distribution in marine environments. Many analytical methods and RMs for other classes of toxins were developed by his group in the following years, and the IMB rapidly became the worldwide supplier of marine toxin standards and RMs. Finally, after more than 35 years of scientific service to the Canadian public, Dave retired from NRC in 1990.

Retirement was an entirely hypothetical concept to Dave – and one that failed repeated testing. Following his official departure, he remained with IMB for another four years as a guest worker. He also became associated with Fenwick Laboratories as an advisor on the development of organic methods of chemical analysis and incorporation of robotics in water analysis procedures. In 1992 he co-founded and became principal associate of a small consulting firm, Scotia Chemical Technology Associates (SCTA), and continued his work there for 10 years. While at SCTA, Dave used his vast experience in quality assurance in chemical analysis to prepare quality control workshops for government laboratories, including Health Canada labs, and private organizations such as the Nova Scotia Power Corporation. Established laboratories were not always ready to hear that operational improvements could be made by implementing the procedures outlined in the ISO standards and guides, but Dave could be very persuasive. During this time he also acted as an Assessor of Laboratory Quality Systems for the Canadian Association for Environmental Analytical Laboratories, performing laboratory audits for the CAEAL and chairing its Committee on Standards and Reference Materials from 1989-1994. In 1993-94 Dave served as the scientist member of the Environmental Assessment Panel advising the Nova Scotia government on a proposal to build a solid waste incinerator in Dartmouth. The proposal was rejected on the advice of the panel, opening the door to the development of solid waste composing programs in the Halifax Regional Municipality.

Dave was an active member of several local and national professional societies, including the Nova Scotia Chemists' Society, Chemical Institute of Canada, and the American Society for Mass Spectrometry. He joined NSIS in 1949, while still an undergraduate, and served as its Secretary in 1965-67 and its President in 1975-77. He was also an active member of several community organisations and the NDP Halifax Citadel-Sable Island Constituency Association.

At ARL, Dave Jamieson laid the foundation of a world-class analytical chemistry effort, with state-of-the-art instrumentation and skilled personnel. As the developer of the first NRC chemical metrology program, his legacy lives on in the Halifax group, an essential element of NRC's current Measurement Science and Standards Program. His keen mind, ready wit, and unflagging optimism, which were with him until the very end, will be sorely missed by his many colleagues and friends in Halifax and beyond.

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CHEMICAL LIGHT STICKS AS BAIT TO TRAP PREDACEOUS AQUATIC INSECTS: EFFECT OF LIGHT COLOUR

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ABSTRACT

We measured the efficiency of floating minnow-traps (Gee traps), unbaited or baited with red, green, blue, or white chemical light sticks (glowsticks) to trap large, predaceous, aquatic beetles (Coleoptera) and bugs (Hemiptera) in 50 fresh water, lentic systems in northern Nova Scotia, Canada. Standard minnow-traps buoyed with Styrofoam® floats were set overnight in a variety of freshwater habitats, including ponds, marshes, bog pools and vegetated lake margins throughout the ice-free seasons over three years, for a total of 695 trap-nights. Giant Water Bugs (*Lethocerus americanus*) were captured with equal frequency in traps baited with any colour glowstick and in unbaited controls. Brown Waterscorpions (*Ranatra fusca*) were significantly more abundant in light-baited traps than in dark controls, and showed a strong preference for green lures over other colours. The large, Vertical Diving Beetle *Dytiscus verticalis* was caught significantly more than expected with white or red lures and significantly less with green or blue lures; males were caught even less often with green or blue lures than in unbaited controls. Our results reveal a heretofore unknown component of the biology of these insects, and suggest a novel method for simple and effective sampling of aquatic insects in still waters.

Keywords: light; trapping; phototaxis; aquatic insects; colour

INTRODUCTION

Many methods are in use, or have been tried, to catch free-swimming (nektonic) aquatic insects such as Predaceous Diving Beetles (Dytiscidae) and Giant Water Bugs (Belostomatidae), yet the standard piece of equipment remains the D-net (Larson *et al*. 2000).

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Collecting insects by sweeping with nets provides only crudely quantitative density estimates and is restricted to shallow water. Bottle traps, which trap insects in wide-mouthed jars with a funnel opening, are less destructive to the substratum and vegetation than D-nets, and effectively capture fast-swimming beetles that evade nets (Aiken and Roughley 1985). Bottle traps can be bulky and fragile (Henrikson and Oscarson 1978; Aiken and Roughley 1985; Downie *et al*. 1998), and submerged traps may drown air-breathing insects. Bottle traps are sometimes baited with fish or meat to attract predaceous insects, but there is no clear evidence that such baiting improves capture success.

Although motile aquatic insects are attracted to light when in flight, and light is routinely used to attract nocturnal flying insects, light-baited traps have rarely been used to collect specimens from water. The few light traps described in the literature have each been designed for a single study, and no standard method has emerged (e.g., Husbands 1967; Espinosa and Clark 1972; Aiken 1979). Moreover, most conventional light sources are impractical for field work, especially in water or at isolated sites. Electric generators and a variety of batteries have been used as power sources for light traps, but these can be unwieldy because of their weight and size, or are dangerous near water (McCafferty 1983). Early attempts to use light as an attraction include sealing a flashlight inside a Mason® Jar, which was then inserted into a large bottle-trap (Hungerford *et al*. 1955). Aiken (1979) used a 12-V car battery to power a single light trap which measured over 60 cm long. This device may not be practical for routine field use.

Technological advances have made chemical light sources cheap and readily available. Glowsticks, or snaplight chemical light sticks, are an alternative light source which do not require an external power source; once activated, they produce light for 8-12 hours (Williams *et al*. 1996). Glowsticks are compact, submersible (and float), inexpensive, non-toxic, practical to take into the field, and simple to use. Despite the evident advantages of light sticks in safety and convenience, there are few published studies on the effectiveness of non-electric light sources such as chemical light. Traps composed of a submerged can with a funnel entrance, baited with glowsticks, have been used to catch nektonic aquatic insects by Lancaster and Scudder (1987) and Williams *et al*. (1996), but neither of these studies evaluated the efficacy of the light bait.

Similarly, there have been no studies comparing the effectiveness of different light colours (wavelengths) for capturing aquatic insects. In the past, traps have usually been baited with white light (wide-spectrum) sources, although black light (long-wave ultraviolet, UV-A) was tried by Carlson (1971, 1972), who found it useful for catching Diptera, but not Coleoptera. Neither Lancaster and Scudder (1987) nor Williams *et al*. (1996) mention the colour of glowstick they used in their submerged traps; chemical light sticks in various colours may not have been available at the time of these studies.

There is reason to expect that light of different colours may be differentially effective for attracting aquatic insects, because of the range of wavelength sensitivities of insect visual perception and the differential absorption of long-wave radiation (red and infra-red) by water. Most insects appear to have a trichromatic colour perception system, with absorption peaks in the ultraviolet, blue and green wavelengths (Briscoe and Chittka 1991). Therefore, these insects cannot perceive red light. Red-blindness is not universal, however (Peitsch *et al*. 1991, Johnson and Bond 1994, Crook *et al*. 2009) and the enormous diversity of insect species and life histories suggests that visual capabilities may be similarly varied (Briscoe and Chittka 1991).

The issue is complicated by insect perceptions of light polarization. Aquatic insects in flight, including bugs and beetles, detect water by sensing horizontally polarized light reflected from the surface (Horváth and Kriska 2008, and references therein). This mechanism depends on detection of both the degree and angle of polarization, and may respond to light in the visible and ultraviolet range (Schwind 1991, 1995). The same perceptual system may help aquatic insects distinguish preferred habitat under water. Thus, in addition to wavelength and intensity, insects may use light polarization to provide information about the aquatic environment (Schwind 1995). Flying aquatic insects respond to polarization of light in long wavelengths that they cannot otherwise perceive (Horváth and Kriska 2008).

The purpose of this study was to test the efficacy of light-baited traps for capturing large, predaceous aquatic insects in lentic fresh waters. Our tests were designed to catch three kinds of insect that are seasonally abundant in regional standing waters: large Predaceous Diving Beetles (Dytiscidae), Giant Water Bugs (*Lethocerus americanus* (Leidy), Hemiptera: Belostomatidae) and Brown Water-scorpions (*Ranatra fusca* Palisot de Beauvois, Hemiptera: Nepidae).

We tested the efficiency of glowsticks as light bait in minnow traps (Gee traps), and compared four easily available colours: red, green, blue and white, to see if the insects showed a colour preference or an aversion.

METHODS

Insects were collected from freshwater ponds, small lakes, marshes, and bogs in northern mainland and northern Cape Breton, Nova Scotia, Canada, during the ice-free seasons (May to October) from 2011 to 2013. The main study site, accounting for more than half of all trap-nights, was Dagger Woods Marsh (centred at 45°35.98' N, 61°50.38' W, 14 km east of Antigonish, NS), a 60-ha wetland complex created in 1988 by damming the outlet stream. Vegetation in the marsh is largely emergent macrophytes, mostly sedges (*Carex* spp. L.), as well as floating-leaved and submerged aquatic macrophytes, especially white water-lily (*Nymphaea odorata* Aiton), cow-lily (*Nuphar variegata* Engelm. ex Durand), watermilfoil (*Myriophyllum* spp. L.) and pondweed (*Potamogeton epihydrus* Raf.). The wetland has a broad, slow-flowing central channel and innumerable smaller channels reticulating among islets of emergent vegetation. Dagger Woods Marsh was chosen for intense study because its large size permitted ten minnow traps to be laid at one time, and because preliminary sampling there in 2011 revealed a robust community of predaceous diving beetles. In contrast to the remaining sites, Dagger Woods Marsh also supports a dense population of Northern Redbelly Dace (*Chrosomus eos* Cope), as well as other small fishes.

Sampling sites outside Dagger Woods Marsh were mostly small to medium sized, (0.01 to 0.2 ha) fishless ponds in Antigonish County, though sites in adjacent Guysborough County and in or near Cape Breton Highlands National Park were sampled as well. We preferred fishless ponds to reduce by-catch, mostly dace, and because preliminary sampling showed capture success was much greater in those sites compared with ponds with fish. Sites sampled included farm ponds, natural woodland ponds, open-water pools in marshes or other wetlands, river floodplain ponds, marshy bays along lake margins, and rain-fed ponds in bogs. We preferred ponds < 2 m deep with emergent and submergent vegetation to act as habitat for

Fig 1 **A light-baited trap set in a wetland pool. Note the end of the glowstick to the right of the Styrofoam® float.**

predaceous, nektonic insects. In all, we set 695 minnow traps in 50 waterbodies across northern Nova Scotia.

The traps used were conventional minnow traps, also known as Gee traps (Cabela's Canada, Fig 1). The traps are barrel-shaped, with a maximum diameter of 22.2 cm, tapering to 17.8 cm ends, and mesh openings of 1.1 x 0.64 cm. Each end of the traps invaginates into a tapering, funnel-shaped cone leading to a 2.5 cm opening which guides insects to enter but hinders their escape. A white Styrofoam® block, 4 x 6 x 25 cm, was placed inside each trap to provide buoyancy, so the traps floated horizontally, with the openings completely submerged (7 cm deep) but with the top of the trap above the water surface; this arrangement allowed trapped insects access to air and ensured that trapping occurred at the same depth (i.e., the surface) in each trial. A 15 cm glowstick (MagicLight, Montréal, Québec) radiating light in one of the four tested colours (red, green, blue, white; Table 1), was placed in each trap, except in controls, which were left unbaited. The unanchored glowsticks floated vertically, mostly submerged, so light being blocked by the foam float was negligible.

Wherever possible, minnow traps were set in groups of five, one control (no glowstick) and four traps each with a different colour of glowstick, but fewer or more were sometimes set depending on the size of the pond and availability of materials. Replicate sampling among ponds and across years was balanced so the total number of

Table 1 Peak emission wavelengths of the four glowstick colours. Light spectra were measured with a Sekonic SpectroMaster C-700. Light intensity was measured with a Hannah Instruments HI 97500 portable lux meter.

	Colour Wavelength (nm)	Peak Intensity (lux)
red	643, 655	9
green	517	23
blue	453	10
white	439, 553, 584	12

trap-nights baited with each colour is very similar in the final data set (133-140). Traps were set at least 10 m apart at the deep-water margin of the littoral zone or the edge of a channel, near aquatic vegetation, but in water deep enough for the trap to float above the bottom. Traps were set near dusk, tethered by a line to a stake or shrub on shore, and collected early the following morning, when the glowsticks were still glowing; therefore, a trap-night was always 10-12 h. The colour of the lure used to bait each trap was determined by blindly pulling a glowstick out of a pocket; a dead glowstick indicated that the next trap would be an unbaited control.

Two complete sets of minnow traps (four colours plus control, 10 traps) were set in Dagger Woods Marsh on four occasions in May and June 2011, on 10 occasions in May 2012, and twice-weekly (22 May - 10 June) or weekly until 28 October 2013 (25 occasions, missing two weeks in early October). More intense sampling in spring aligned with the maximum abundance of adult dytiscids (Larson *et al*. 2000) . Coordinates for ten permanent trap locations, evenly distributed along 350 m of the main channel, were taken in spring each year using a handheld GPS (Garmin GPSmap 60Cx). Traps were placed at the margin of the central channel, among water-lilies and submergent vegetation, then secured with a line to a stake driven into a sedge island. On each sampling occasion, the first five minnow traps were randomly assigned one of the coloured glowsticks or to be a control; the second five traps were laid out in the same pattern as the first five.

Trapping outside Dagger Woods Marsh proceeded from May to August, 2011, March to May 2012, and May to early July in 2013. Boyd's Pond (45°30.24' N, 61°56.53' W, 20 km south of Antigonish), a fishless, 250-m^2 modified bog pond, <1 m deep, was sampled on

12 occasions over three years; all other sites were sampled once or twice.

Insects caught in the minnow traps were either transported in labelled jars to the laboratory to be curated for the permanent collection, or identified, sexed (some Dytiscidae) and released. Most insects captured in Dagger Woods Marsh were released. By-catch such as fish and amphibians was released after being identified. Non-target insects (e.g., nymphs of Odonata, Trichoptera) or other invertebrates (e.g., snails) were released. Mortality in the traps was extremely rare.

Colour preferences were revealed through Chi-square analysis of numbers caught in traps baited with each glowstick colour, using equal probability of capture by each colour as the null hypothesis. Each analysis was run once to determine whether numbers were proportionately greater in baited traps than in controls, then again to discern differences among colours. Further Chi-square analyses were run on some subsets of the data to examine specific colour preferences more closely. Data from all sites and times were combined for analysis. A separate analysis was performed for Dagger Woods Marsh alone. For the dominant predaceous diving beetle (*Dytiscus verticalis* Say, Coleoptera: Dytiscidae), analyses were done for males and females separately, and for all animals combined, which included individuals for which sex was not determined. Giant Water Bugs and Brown Waterscorpions were not separated by sex.

Light-baited minnow traps intended to capture insects sometimes also captured tadpoles, adult amphibians and small fish (see Results). Because tadpoles and fish are prey for predaceous aquatic insects, our target organisms could be attracted to traps containing by-catch, potentially biasing attempts to distinguish light colour preferences. We examined possible sampling bias caused by Green Frog tadpoles (*Rana clamitans melanota* Rafinesque) and Northern Redbelly Dace by far the most common and abundant elements of by-catch, by testing whether these species showed an attraction or aversion toward any of the four light colours (Kruskal-Wallace Test), and looking for correlations with numbers of predaceous insects captured in the same traps (Spearman Rank Correlation). All species and sexes of Dytiscidae were combined for this analysis.

Tests with tadpoles used data from all sites and years, except Dagger Woods Marsh in 2011, when no tadpoles were captured. Tests with dace used data from Dagger Woods Marsh only, 2011-2013.

Because we preferred fishless ponds, very few fish were captured outside Dagger Woods Marsh. Traps that captured no organisms were omitted from the analysis.

RESULTS

Among the large predaceous diving beetles, our traps caught *Dytiscus verticalis, D. harrisii* Kirby, *D. dauricus* Gebler, and *D. fasciventris* Say, but only the first of these was caught in numbers sufficient for analysis. The traps caught a total of 280 *D. verticalis* (164 male, 48 female, 68 unassigned), 90 adult *Lethocerus americanus* and 196 adult *Ranatra fusca*. In Dagger Woods Marsh, captures of *D. verticalis* were most successful in early spring and declined swiftly after mid-June (Fig 2A). *L. americanus*, while less frequent, showed a more or less normal distribution across the sampling season, with a peak in early August (Fig 2B). *R. fusca* showed a barely discernable decline from a peak in late May (Fig 2C). Hence, our sampling included both times of abundance and scarcity for all three species

Dytiscus verticalis (total) showed a statistically significant difference in capture rate among trap bait colours, including unbaited controls ($X^2 = 24.3$, df = 4, $p<0.01$), as did males ($X^2 = 22.6$, $p<0.01$) and females ($X^2 = 10.4$, $p<0.05$) separately (Fig 3).

Removing the unbaited control traps, i.e., comparing only among different coloured lures, produced essentially identical results (males, $X^2 = 22.6$, $p<0.01$; females, $X^2 = 8.8$, $p<0.05$; total, $X^2 = 21.9$, $p<0.01$). In total counts (which are dominated by males) and counts for males separately, there is a clearly higher capture rate in traps baited with white or especially red light compared with green or blue light (Fig 3). Among female beetles, only the difference for red light is apparent; other colours produced capture rates not very different from unbaited traps. This result must be tempered by the low numbers of female beetles captured. Unexpectedly, capture rates for male beetles in traps baited with green or blue lures were significantly less than those in dark, unbaited traps ($X^2 = 4.7$, df = 1, $p<0.05$). These colours apparently repel male beetles instead of attracting them.

L. americanus was the only species which showed no significant difference in capture rate among traps baited with different coloured lights ($X^2 = 5.8$, df = 4, $p>0.10$), and no difference among lights

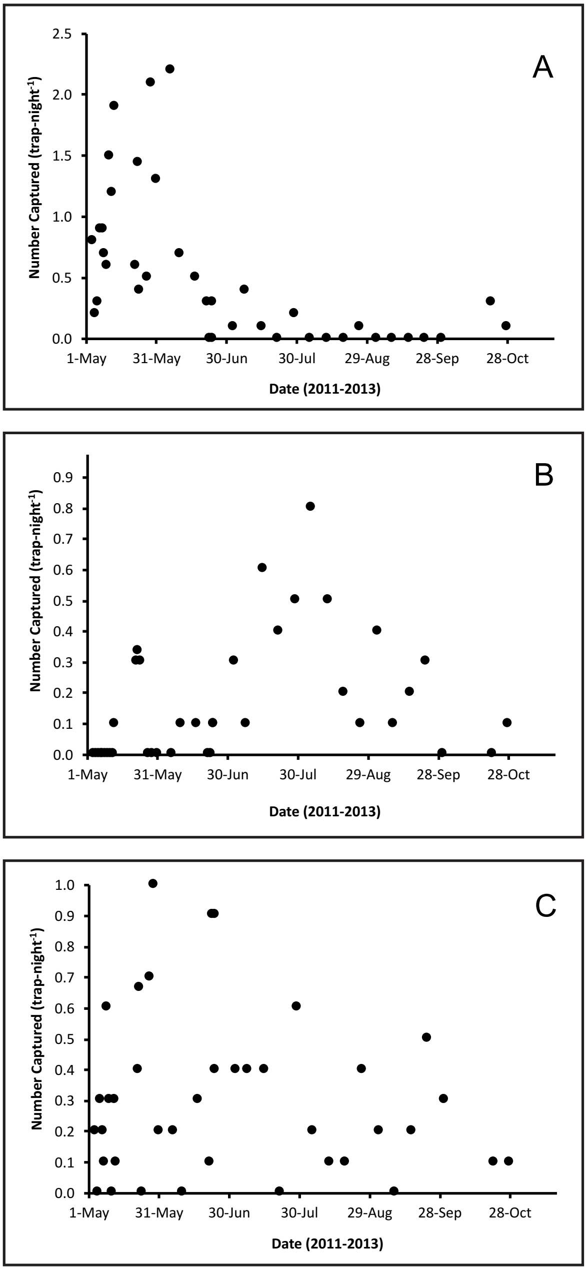

Fig 2 **Temporal distribution of adult (A) *Dytiscus verticalis* (B) *Lethocerus americanus* and (C) *Ranatra fusca* captures in light-baited traps set in Dagger Woods Marsh, Nova Scotia, based on combined data from 2011-2013.**

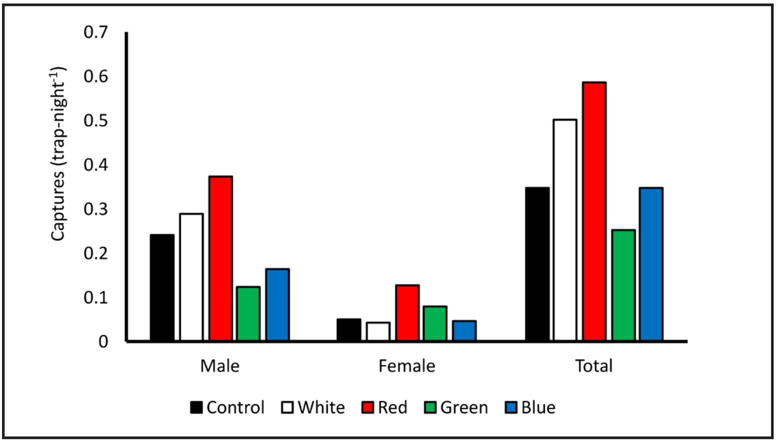

Fig 3 **Rate of *D. verticalis* captures per trap-night in floating Gee traps baited with glowsticks of different colours, based on data from all sampled sites, 2011-2013.**

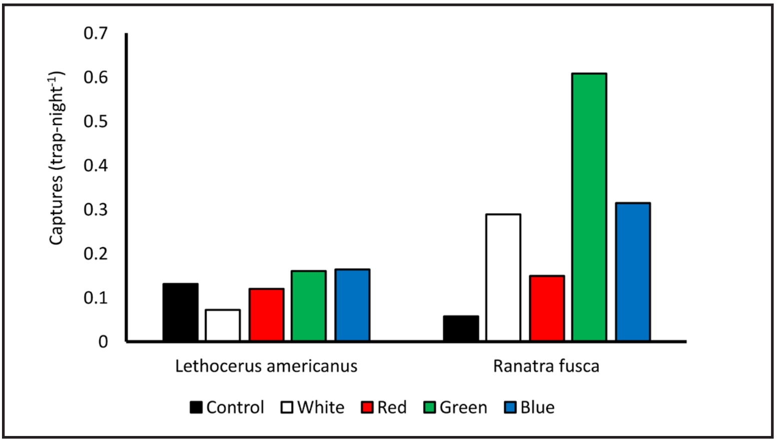

Fig 4 **Rates of capture per trap-night of *Lethocerus americanus* and Ranatra fusca in floating Gee traps baited with glowsticks of different colours, based on data from all sampled sites, 2011-2013.**

and unbaited controls ($X^2 = 5.8$, $p>0.10$). Giant Water Bugs appear indifferent to whether a trap is baited with light or not (Fig 4).

In contrast, *Ranatra fusca* shows a highly significant difference in frequency trapped according to colour of the lure when controls are included ($X^2 = 85.4$, df = 4, $p<0.001$), which remains strong when only light colours are compared ($X^2 = 45.3$, df = 3, $p<0.001$). Light-baited traps were far more effective than unbaited traps at capturing Brown Waterscorpions (Fig 4). *R. fusca* was trapped conspicuously more often in traps baited with green light than other colours, and was least attracted to red light.

Results of Chi-square tests on data from Dagger Woods Marsh (not shown) were identical to those from the whole data set, except that there were no significant differences among bait colours for female *D. verticalis*. Only 37 identified females were captured in Dagger Woods Marsh, compared with 155 males (207 total). Sixty *L. americanus* and 117 *R. fusca* were captured in Dagger Woods Marsh.

A total of 503 Green Frog tadpoles were captured in 644 traps. Among the 389 traps that captured at least one organism, the median, first quartile, and third quartile number of tadpoles in a trap are all zero. Most tadpoles were captured in a few traps. The Kruskal-Wallace Test, based on 60-105 replicates of each light colour, revealed no significant difference in tadpoles captured among glowstick colours, or between baited traps and controls ($P = 0.26$). Spearman correlation showed weak but significant negative correlations between tadpoles and total dytiscids ($r_s = -0.26$, $P<0.001$), Brown Waterscorpions ($r_s = -0.10$, $P = 0.043$), Giant Water Bugs ($r_s = -0.15$, $P = 0.004$), or the sum of all three taxa ($r_s = -0.37$, $P<0.001$). Tadpoles were less frequent in traps that contained predaceous insects (Fig 5A).

Results for Northern Redbelly Dace were similar to those for tadpoles. A total of 590 dace were captured in 380 traps in Dagger Woods Marsh. Among the 269 traps containing at least one fish or predaceous insect, the median number of dace is zero (3^{rd} quartile: 1). The Kruskal-Wallace Test, based on 45-59 replicates of each light colour, revealed no significant difference among glowstick colours, or between baited traps and controls ($P = 0.19$). Spearman correlation showed a weak but significant negative correlation between tadpoles and total dytiscids ($r_s = -0.25$, $P<0.001$) but not with Brown Waterscorpions or Giant Waterbugs. Dace were less frequent in traps that contained dytiscid beetles (Fig 5B).

DISCUSSION

It is clear from our results that glowsticks are an effective bait to attract nektonic pond insects. The low cost, portability, ease of disposal, and safety (especially compared against electrical devices) of these widely available lures makes them an attractive alternative

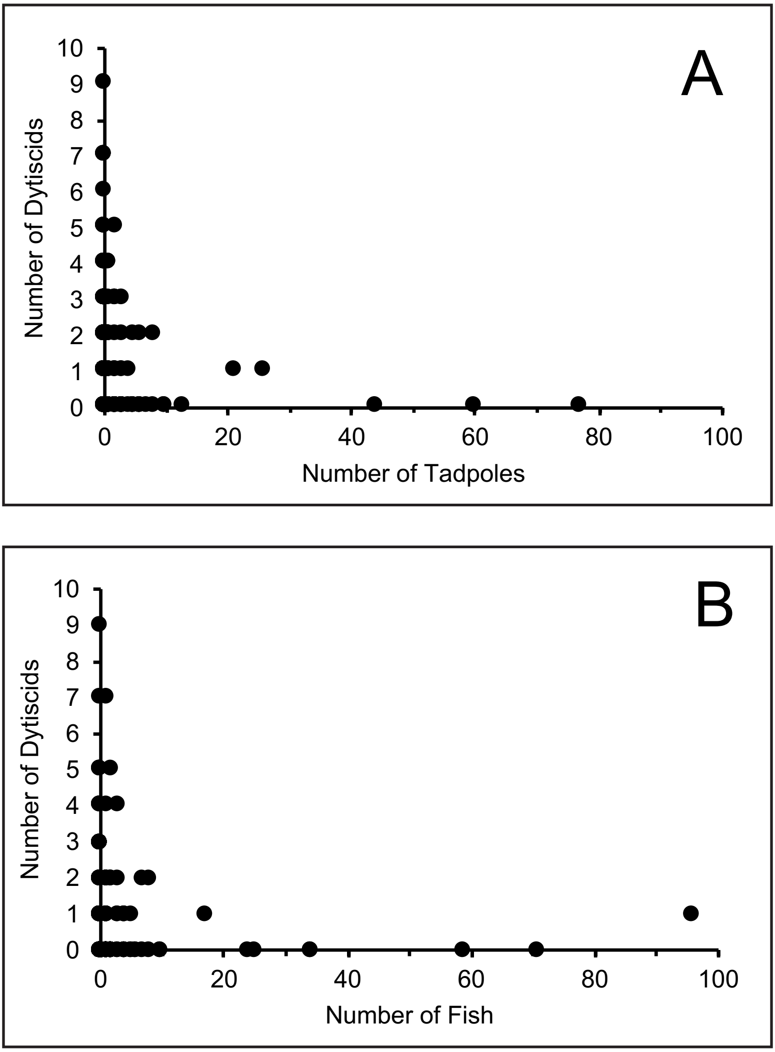

Fig 5 Number of dytiscid beetles captured in each trap compared with the (A) number of green frog tadpoles or (B) northern red-bellied dace caught in the same trap. Data for tadpoles are from 389 traps from all sampled sites and years where tadpoles were encountered. Data for fish are from 269 traps from Dagger Woods Marsh.

for aquatic entomologists. The relatively large mesh size of the minnow traps used in our study limited potential captures to the largest swimming insects. We have tested similar traps with finer mesh which appear to be effective for catching the many smaller species of Dytiscidae, as well as Corixidae (water boatmen) and Notonectidae (backswimmers). The limitation on mesh size is that very fine mesh may not let enough light escape to attract insects.

While by-catch, mostly of small fish and tadpoles, was sometimes an issue in our study, the traps do the organisms no harm, and for organisms such as tadpoles, may provide a temporary safe haven from vertebrate predation. Air-breathing organisms have access to the atmosphere in the horizontal, floating traps. Predaceous aquatic insects could be attracted to traps containing prey organisms, irrespective of light colour, but in our data the associations between dytiscids (or other predaceous insects) and fish or tadpoles were negative. It would be maladaptive for predators to avoid confined prey; the negative correlations probably arise from prey organisms avoiding traps containing predators. Moreover, non-insect aquatic life showed no preference for traps baited with glowsticks over unbaited control traps, nor any preference for a particular colour of glowstick.

The negative association between fish and predaceous insects would not arise from predation within the traps. The size of these large insects precludes predation by dace, or indeed any fish small enough to enter the traps. Green Frog tadpoles, being largely herbivorous, would not consume the insects either. Conversely, predaceous insects feeding on trapped fish would leave prey corpses, which were never observed. Hence, the presence of by-catch in some traps does not bias our assessment of glowstick colour preferences by predaceous aquatic insects, and apparently has little influence on effectiveness of baiting with light.

It is also clear that there are important differences among insect species, and even among sexes within the same species, in the attractiveness of glowsticks of different colours. Both systematic, multi-year sampling of one site, Dagger Woods Marsh, and opportunistic sampling across a wide variety of sites and times produced the same results, suggesting our findings are robust. Hence, the optimal colour to use in a particular study will vary according to the objectives of that work. Summarily, red and perhaps white lures are best for *D. verticalis*, and probably other large dytiscids, while green is best to capture *R. fusca*. Baiting with glowsticks does not improve trapping frequency of *L. americanus*. So strong are these preferences that setting traps with the wrong colour of bait could actually reduce trapping success rather than augment it.

A fair assessment of glowstick colour as it affects insect trapping must take into account differences in light intensity among glowsticks of different colours along with the perceptual ability of the insects. Light output from white, blue and red glowsticks is similar (9-12 lux), but green glowsticks are much brighter (23 lux). Hence, some of the differences in capture success with different coloured glowsticks as bait may have arisen from the intensity rather than the wavelength of the emitted light. The European nepid *Ranatra linearis* L., for example, moves toward the water surface at night and downward during the day, following a light gradient (Joly and Cloarec 1980). The conspicuously greater trapping success of *R. fusca* in traps baited with green light could be attributable at least in part to a more intense light proving more attractive than weaker ones, or to the light being perceived at a greater distance.

However, neither of the other two insect species examined showed a preference for green light. *L. americanus* showed no distinguishable attraction to light of any kind, and green light attracted *D. verticalis* less than white or red sources of lower intensity, or for males, less than no light at all. It cannot simply be the intensity of the light source that accounts for the varying effectiveness of glowsticks of different colours.

A second obfuscating factor is the differential transmission of light of different wavelengths through water. The rapidity with which red light is absorbed, relative to shorter wavelengths (Wetzel 2001) could limit the distance over which the light is perceptible to aquatic organisms and therefore the area from which potential specimens may be drawn. Again, however, this difference does not correspond with the observed effectiveness of glowsticks of different colours. While *R. fusca* was least often trapped in traps baited with red light, relative to other colours, and *L. americanus* capture was unaffected by lure colour, red glowsticks were more likely to capture *D. verticalis* than were baits of any other colour, or dark traps. The high absorption coefficient for red light in water therefore does not appear to be a significant factor limiting the value of red glowsticks as bait.

Strong responses to red glowsticks are perhaps surprising because many insects are believed incapable of perceiving red light (Briscoe and Chittka 1991). Nevertheless, Kriska *et al.*, (2006) showed that flying aquatic insects, including Dytiscidae and predaceous bugs, were attracted to red or black surfaces because the reflected light was horizontally polarized in the blue and green parts of the spectrum, eliciting a positive polarotactic response even if the insects were red-blind. The same response could be elicited by a red glowstick, with reflection in the water providing the polarization. White glowsticks emit a mixture of wavelengths, so the same response, perhaps weaker, would be expected. Crook *et al*. (2009) showed that compound eyes of female emerald ash borers (*Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae)) were sensitive to red light, while male's eyes were not. Hence, both the evident response to red light by *D. verticalis* in this study, and the less definite difference between males and females, are consistent with known elements of insect vision.

The remaining question concerns how these differences in trapping frequency with baits of different colours arise. Evidently the glowsticks elicit a positive phototaxis (or in one case, a negative phototaxis) which is stronger for some colours than others and differs among species. Menzel (1979) points out that the difference in spectral composition between sunlight (rich in blue light) and light reflected from plants and soil (rich in yellow-green) could be a cue allowing aquatic organisms to differentiate open space from vegetation or other cover. More generally, the reflection and polarization characteristics of underwater light allow organisms to finely differentiate among habitats (Schwind 1995).

Dytiscids are active predators and scavengers. The differential absorption of light of different wavelengths by water, magnified by dissolved organic matter (Kalff 2002) could provide a useful cue to depth; attraction to red or white light, abundant only near the surface, and avoidance of green and blue light, increasingly dominant at depth, would be consistent with air-breathing organisms seeking to remain near the surface of the pond. These organisms may perceive a blue glowstick as indicative of deep water where they do not belong.

Brown Waterscorpions, *Ranatra fusca*, by contrast, are sit-and-wait predators (Joly and Cloarec 1980). They may perceive green light as an indicator of green aquatic vegetation, their preferred habitat and the habitat of the small fish and tadpoles on which they prey. It would be reasonable then for these organisms to be strongly attracted to glowsticks radiating green light in preference to other colours. Such sensitivity to green light has been observed in other aquatic bugs (Horváth and Kriska 2008). Even within the context of this behaviour-based model, the indifference of Giant Water Bugs, *Lethocerus americanus*, to light bait, despite reports of positive phototaxis in the Belostomatidae (Severin and Severin 1911, Ward 1992, Ohba and Takagi 2005), remains an enigma.

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THE TROUT FISHERY OF THE UPPER MEDWAY WATERSHED, NOVA SCOTIA, 2016-17

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ABSTRACT

During the spring of 2016 and 2017, the Mersey Tobeatic Research Institute (MTRI), in collaboration with the Nova Scotia Department of Fisheries and Aquaculture, conducted an angler creel survey in the Medway Lakes Wilderness Area that is located within the upper Medway watershed. Since 2012, public access to this region was improved to numerous lakes and streams, increasing the risk of overexploitation and the illegal introduction of invasive fish species. The purpose of this study was to assess the current status of the fishery for Brook trout, *Salvelinus fontinalis*, investigate the possible presence of invasive Smallmouth bass, *Micropterus dolomieu,* and Chain pickerel, *Esox niger*, and inform anglers of the effects of invasive species on local biodiversity. Over the course of this two-year study, a total of 264 anglers spent 1017 hours to catch 1279 trout, of which 74% were released. Median length of retained Brook trout was of 25 cm and the maximum length was 43 cm. The majority of the catch was 2+ and 3+ years old. Angler catch rates were similar to nearby Kejimkujik National Park and greater than in the Tangier Grand Lakes Wilderness Area. The study area does not currently appear to be inhabited by invasive fish species. Most of the anglers interviewed lived nearby and had a long history of fishing in the upper Medway watershed. The study provides baseline data from the trout fishery which could be used to evaluate management strategies and future impacts of invasive fish species.

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INTRODUCTION

While there is a long history of angling in the upper Medway watershed that includes the Medway Lakes Wilderness Area in southern Nova Scotia, public vehicle access to this region has long been restricted. In 2012 the Province of Nova Scotia purchased lands from Resolute Forest Products' predecessor, Bowater Mersey Paper Company, who had first built gated logging roads in this region in the 1950s. Soon after the crown purchase of these woodlands, now totaling approximately 92,130 hectares, the gates were opened in 2016 to allow vehicle access to the public (Nova Scotia Department of Natural Resources, 2015). With this improved access, a primary concern in the upper Medway watershed is to sustain a healthy wild trout fishery. The potential increase in access and angling pressure could result in overexploitation and increase the risk of introductions of invasive Smallmouth bass and Chain pickerel.

Limited data are available on the status of the trout resource in the numerous streams and lakes in the upper Medway watershed. Brook trout prefer cold water temperatures and will avoid temperatures greater than 20°C (Biro 1998). Most species that are considered to be competitors of Brook trout have a thermal preference for warmer water conditions (MacMillan *et al*. 2008). Previous surveys demonstrated that lakes in the upper Medway watershed are acidic and are occupied with native fish species including Brown bullhead, *Ameiurus nebulosus*, White perch, *Morone americana*, White sucker, *Catostomus commersoni*, and Yellow perch, *Perca flavescens*, that are considered important competitors of Brook trout (Alexander *et al*. 1986). Competition from perch and other species can greatly impact trout population densities (Munro & MacMillan, 2012; Ryan & MacMillan, 2016).

The Upper Medway watershed and neighboring Kejimkujik National Park and National Historic Site (hereafter referred to as Kejimkujik) are some of the last strongholds for Brook trout but are in close proximity to lakes inhabited by invasive Smallmouth bass and Chain pickerel. Smallmouth bass has been the third most preferred sport fish species by anglers in Nova Scotia (Nova Scotia Department of Fisheries and Aquaculture, 2014). Smallmouth bass and Chain pickerel can have adverse effects on native Brook trout populations (Ryan & MacMillan, 2016). In northeastern Ontario where road access to lakes and rivers had been improved, an increase in angling pressure and prevalence of Smallmouth bass was detected (Kaufman *et al*. 2009). Smallmouth bass is more prevalent in lakes that are easily accessible by vehicle with road accessibility being one of their major vectors for inland spread (Kaufman *et al*. 2009). The first introduction of Smallmouth bass to Nova Scotia was in 1942 and since then it has spread to more than 248 lakes and rivers due to accidental transfers, legal and illegal transfers, and dispersal within watersheds (Leblanc, 2014). Invasive species may also pose a direct predatory threat to species at risk including young Blanding's turtles, *Emydoidea blandingii* (Blanding's Turtle Recovery Team, 2002) which inhabit the upper Medway watershed.

The objective of this study was to assess the current status of the trout fishery, to provide baseline data for the management of the local trout fishery, to investigate for the presence of Smallmouth bass and Chain pickerel, and to provide information to anglers about the risks posed by invasive species to local biodiversity.

STUDY AREA

The study site is located within Nova Scotia's Western Ecoregion at the headwaters of the Medway River, northeast of Kejimkujik and the Tobeatic Wilderness Area (Fig 1). Much of the upper Medway watershed is composed of the Medway Lakes Wilderness Area and is situated within the South Mountain Ecodistrict. This land mass is made up of predominantly well-drained soils and coarse sandy loams that is underlain by Devonian granite (Webb & Marshall, 1999; Davis & Browne, 1996). The upper Medway watershed also includes the Lahave Drumlin Ecodistrict to the south and a small portion of the Valley Slope Ecodistrict to the north. Acid deposition has affected lakes in the southwestern Nova Scotia more severely than lakes elsewhere in the province because of the region's thin soils, granite bedrock formation, and low buffering capacity (Ginn *et al*. 2007). Prolonged warm-water conditions are common in the Southern Uplands that include the upper Medway watershed. Warm and dry summers can restrict Brook trout into crowded cool-water refugia for prolonged time periods resulting in increased predation, exploitation, and disease transmission (MacMillan *et al*. 2008). These factors could contribute to annual variability of trout populations and recruitment to the fishery.

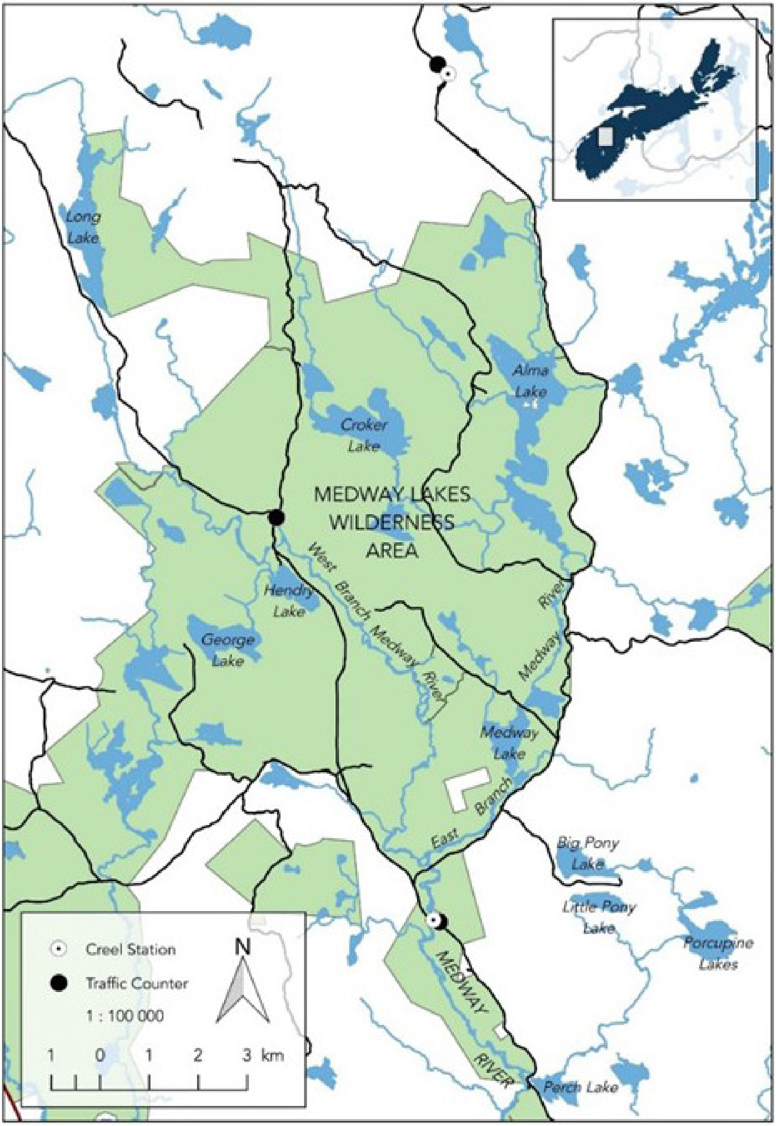

Fig 1 The location of the creel census check point and traffic counter sites within the Medway Lakes Wilderness Area (green), 2016-2017.

METHODS

A creel census was conducted in the upper Medway watershed from May 4 to June 4 2016 and April 12 to May 26 2017. Sampling occurred seven days per week in 2016 but was focused on peak angler activity from Wednesday to Sunday in 2017. Anglers were interviewed for approximately 10 minutes as they exited the study area at one of two creel stations where large placards were displayed to notify anglers that a survey was underway (Fig 1). Small incentives (hats and pins) were given out to anglers when available. Roadside surveys were typically conducted for 7 h periods each day. The primary creel station in the south was set up in an old clearing where Bowater had its logging basecamp in the past. A secondary creel station in the north was located near the community of West Dalhousie. Roving creel surveys took place occasionally along the East Branch of the upper Medway watershed to opportunistically obtain additional interviews.

Anglers were asked to voluntarily provide retained fish for measurements of fork length (FL) in millimeters and weight in grams. Occasionally anglers had cleaned their catch prior to arriving at the creel station. If a trout was cleaned, the presence or absence of the pectoral fin was recorded and it was not weighed. As in MacMillan *et al*. (2013), if the head was removed and pectoral fin was attached, FL was measured and 30% was added to estimate adjusted FL. If pectoral fins were removed, 35% was added to estimate adjusted FL. The additions to length to approximate FL were adopted from a previous creel survey by Sabean (1980) in the TGLWA.

Scales are commonly used to age trout (Stolarski & Hartman, 2008). Approximately 20 scales were collected between the dorsal fin and lateral line of 40 Brook trout. A compound microscope was used to identify scales with a small focus and regenerated scales were discarded. Annuli or winter marks were counted and identified from locations on the scale where there was tight spacing of circulli and the presence of broken circulli. Aging of scales from larger trout, usually older than 3 years, have a greater potential to be underestimated compared to scales from younger years (Stolarski & Hartman, 2008). For this reason, scales were aged by two readers.

There are few access points to the study area which helped to facilitate traffic counts during the fishing season. In 2017, three PicoCount 2500 traffic counters were installed along main access points to the upper Medway watershed. Traffic counters were used to determine activity patterns and traffic volume in the upper Medway watershed. Each traffic counter used two hoses spaced 2.3 m apart for count redundancy in the event of a hose malfunction. The purpose of the traffic counter was to direct limited creel survey resources toward peak time in traffic activity and provide baseline to evaluate future changes in angler effort.

Anglers were asked a series of questions pertaining to their angling efforts including gear type, catch, time spent angling, site(s) fished, history of fishing in the upper Medway watershed, the angler's residence, species caught (including species of interest such as Atlantic salmon, *Salmo salar*, Chain pickerel, and Smallmouth bass), and Blanding's turtle observations. The hours fished and catch were recorded to establish catch per unit effort (CPUE). Angler catch data from a similar creel survey conducted in the Tangier Grand Lake Wilderness Area (TGLWA) in 2007 by MacMillan *et al*. (2013) were compared with data from upper Medway. Similarly, creel data from an angler diary program in the Upper Mersey River watershed, were provided by Kejimkujik. An angler diary form is provided with all Kejimkujik fishing licenses and anglers are asked to voluntarily fill in the form and return it at the end of the season. Data collected included target species, hours fished, location, species caught, and if they used fly fishing tackle. Only fly fishing data were compared to the study area during concurrent dates from mid-April to early-June 2016 and 2017. The data were not normally distributed. Significant differences in CPUE between years and study areas, and the size of the catch between years were evaluated using non-parametric Mann-Whitney Rank Sum Tests ($P<0.05$) in Systat. CPUE, FL, length, and weight statistics were described as medians and interquartile ranges were provided in parenthesis.

RESULTS

During 2016 and 2017, MTRI staff and volunteers interviewed 264 anglers in the upper Medway watershed (Table 1). In 2016, 136 anglers spent 559 hours to catch 737 Brook trout; they retained 197 and released 540. In 2017, 128 anglers spent 458 hours to catch 539 trout; they retained 136 and released 403. The percentage of released trout in the total catch of anglers was 74% from 2016-2017.

Many anglers reported that they only retained a catch when there was severe hook damage to the trout.

Table 1 Catch statistics from 264 angler interviews conducted during the upper Medway watershed creel.

Date	Anglers	Hours	Retained trout	Released trout (number)	Release trout (proportion)	Trout caught per hour	Trout caught per angler
4-May-16	2	15	0	21	1.00	1.4	10.5
5-May-16	1	4.5	0	6	1.00	1.3	6.0
6-May-16	6	25	3	32	0.91	1.4	5.8
7-May-16	2	4	5	6	0.55	2.8	5.5
8-May-16	3	13	10	7	0.41	1.3	5.7
10-May-16	4	6	6	13	0.68	3.2	4.8
11-May-16	5	23	11	46	0.81	2.5	11.4
12-May-16	2	4	0	2	1.00	0.5	1.0
13-May-16	12	41.5	13	47	0.78	1.4	5.0
14-May-16	12	79	11	43	0.80	0.7	4.5
15-May-16	4	11.1	12	11	0.48	2.1	5.8
16-May-16	2	2	3	0	0.00	1.5	1.5
17-May-16	10	10	3	6	0.67	0.9	0.9
18-May-16	2	4	3	3	0.50	1.5	3.0
19-May-16	3	21	9	36	0.80	2.1	15.0
20-May-16	11	28	12	20	0.63	1.1	2.9
21-May-16	15	82.5	53	60	0.53	1.4	7.5
23-May-16	4	18	10	25	0.71	1.9	8.8
24-May-16	2	16	0	30	1.00	1.9	15.0
25-May-16	4	20	8	7	0.47	0.8	3.8
27-May-16	2	12	0	0	0.00	0.0	0.0
28-May-16	11	63.5	10	56	0.85	1.0	6.0
29-May-16	4	12	2	0	0.00	0.2	0.5
30-May-16	2	-	0	17	1.00	-	8.5
31-May-16	5	20	0	20	1.00	1.0	4.0
3-Jun-16	6	24	13	26	0.67	1.6	6.5
4-Jun-16	0	0	0	0	0.00	0.0	0.0
2017 sum/median (quartiles 25-75%)	**136**	**559**	**197**	**540**	**0.68 (0.5-0.9)**	**1.4 (0.9-1.9)**	**5.5 (2.9-7.5)**
13-Apr-17	1	0.5	0	0	0.00	0.0	0.0
14-Apr-17	2	10	1	0	0.00	0.1	0.5
15-Apr-17	4	3.5	0	0	0.00	0.0	0.0
28-Apr-17	6	28	13	64	0.83	2.8	12.8
29-Apr-17	24	78	15	32	0.68	0.6	2.0
30-Apr-17	4	21	5	23	0.82	1.3	7.0
3-May-17	4	16.3	6	21	0.78	1.7	6.8
4-May-17	12	25.3	3	26	0.90	1.1	2.4
5-May-17	9	26	12	43	0.78	2.1	6.1
7-May-17	3	1.5	0	0	0.00	0.0	0.0
10-May-17	6	19	7	4	0.36	0.6	1.8

Table 1 Cont'd

Table 1 ***Cont'd***

Date	Angler s	Hour s	Retained trout	Released trout (number)	Release trout (proportion)	Trout caught per hour	Trout caught per angler
12-May-17	9	50	12	14	0.54	0.5	2.9
13-May-17	9	39.5	22	22	0.50	1.1	4.9
14-May-17	1	2.5	2	6	0.75	3.2	8.0
17-May-17	4	10	5	5	0.50	1.0	2.5
18-May-17	7	17	4	33	0.89	2.2	5.3
19-May-17	5	37	14	37	0.73	1.4	10.2
20-May-17	6	26.5	1	32	0.97	1.2	5.5
21-May-17	2	4	0	8	1.00	2.0	4.0
24-May-17	2	10	3	22	0.88	2.5	12.5
25-May-17	2	16	0	0	0.00	0.0	0.0
26-May-17	6	16.5	11	11	0.50	1.3	3.7
2016 sum/median (quartiles 25-75%)							
	128	**458**	**136**	**403**	**0.70 (0.3-0.8)**	**1.2 (0.4-2.0)**	**3.8 (1.5-6.8)**
2016-17 sum/median (quartiles 25-75%)							
	264	**1017**	**333**	**943**	**0.68 (0.5-0.9)**	**1.3 (0.6-1.9)**	**4.9 (1.9-6.8)**

The total (retained and released) number of trout creeled from the Upper Medway watershed was 1279, (737 in 2016, 539 in 2017). The median trout caught per hour of angling was 1.3 (0.9 -1.9) in 2016 and 1.2 (23.0 – 27.8) in 2017 within the upper Medway watershed and the difference between years was not significant (P=0.267). The median number of trout caught per angler was 4.9 in the upper Medway watershed and ranged from 0 to 15 trout caught per angler. The preferred gear type of anglers interviewed was bait, followed by fly or a combination of bait and fly in the upper Medway watershed and TGLWA (Table 2). Angler CPUE was significantly greater in the upper Medway watershed compared to the 0.39 (0.09- 1.0) in the TGLWA (P<0.001). Fly fisher catch per hour was 1.6 (0.9 - 2.7) in the upper Medway watershed, 1.30 (0.5 – 3.0) in Kejimkujik and 0.8 (0.1 - 2) in the TGLWA (Table 3). Fly fishing CPUE between the upper Medway watershed and Kejimkujik was not significantly different (P=0.35). Fly fishing CPUE between the upper Medway watershed and TGLWA was significantly different (P=0.042). No significant difference was detected between fly fishing CPUE from Kejimkujik and TGLWA (P = 0.12).

Table 2 Angler catch rate and gear types used by anglers in the Medway Lake and Tangier Grand Lakes wilderness areas, Nova Scotia, 2016-17.

Site	Year (s)	Gear	Anglers N	Trout catch per hour Median	Quartiles (25-75%)
Medway Lakes Wilderness Area	2016-17	Bait	156	1.00	0.52 - 2.5
		Bait / Fly	19	1.05	0.13 - 1.5
		Bait / Lure	2	1.10	-
		Bait / Lure / Fly	2	1.33	-
		Fly	50	1.56	0.97 - 2.7
		Lure	12	0.90	0.4 - 1.0
		Summary	241	1.33	0.6 - 1.9
Tangier Grand Lake Wilderness Area	2007	Bait	61	0.12	0.0 - 0.63
		Bait / Fly	48	0.77	0.48 - 1.28
		Bait / Lure	40	0.25	0.13 - 0.63
		Bait / Lure / Fly	1	0.33	-
		Fly	34	0.83	0.13 - 2.0
		Lure	10	0.21	0.04 - 0.39
		Summary	194	0.39	0.09 - 0.98

Table 3 Brook trout catch per hour from fly fishing anglers in the Upper Medway.

System	Year	Dates	Anglers	Hours	Trout	CPUE Median	Quartiles (25-75%)
Upper Medway	2016	4 May - 4 Jun	21	114	207	1.75	1.2 - 3.1
	2017	12 Apr - 26 May	29	136	222	1.56	0.6 - 2.4
		Summary	50	250	429	1.56	1.0 - 2.7
Upper Mersey (Kejimkujik)	2016	17 Apr - 4 Jun	75	281	657	1.33	0.5 - 3.3
	2017	21 Apr - 4 Jun	51	208	384	1.2	0.6 - 2.7
		Summary	126	507	1098	1.30	0.5 - 3.0
Tangier Grand Lake Wilderness Area	2007	6 May - 26 May	34	155	137	0.83	0.1 - 2.0

Mean age of trout retained was 2.6 (±0.6) yrs and ranged from 2 to 4 yrs. In the Upper Medway watershed. Mean length at age of the trout caught was 23.4 cm (±2.1) for age 2+ yrs, 27.5cm (±1.3) for age 3+ yrs, and 31.5cm (±0.7) for age 4+ yrs. The majority of the trout caught by anglers were from the 2+ and 3+ yrs age classes. From 2016-2017, median FL of retained trout was 25 cm (23 - 27) and ranged from 18.0 to 42.9 cm (Fig 2). Median FL was 24.9 cm (22.9 - 27.0) in 2016 and 25.4 cm (23.0 - 27.8) in 2017 and was not significantly different between years in the Upper Medway watershed (P=0.267). Median length of 219 trout caught by anglers in the TGLWA was 25.2, (23.0 - 28.2). Median weight of retained trout was 170g (140 - 217.5) in the Upper Medway watershed. The weight length relationship for 168 retained trout was FL = $0.0191x^{2.85}$, $r^2 = 0.884$ (Fig 3). Few upper Medway watershed anglers reported retaining the possession limit of five trout and most anglers (80%) reported that they retained less than three trout (Fig 4). Yellow perch was reported as a by-catch and was always released by interviewed anglers.

In 2016 there was one verbal unconfirmed report of Smallmouth bass caught in the stillwater behind the southern creel station; however, additional angling effort directed at this site did not result in additional captures in 2017.

Seventy anglers provided information about their residence in 2017 and 64% lived in nearby Queens and Annapolis counties and 23% resided in Kings and Lunenburg counties. Anglers from Halifax and Hants County accounted for 10% of the interviews, 3% from Digby and Yarmouth, and one individual was from Inverness County. Anglers interviewed in 2017 were primarily returning visitors who had a long history of angling in the upper Medway watershed. Very few anglers interviewed in 2017 were accessing the area for

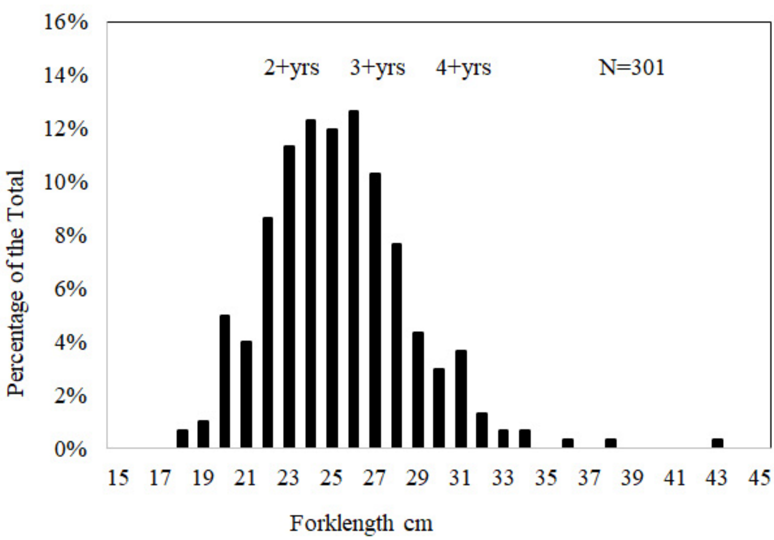

Fig 2 Forklength (FL) frequency distribution and approximate age in years.

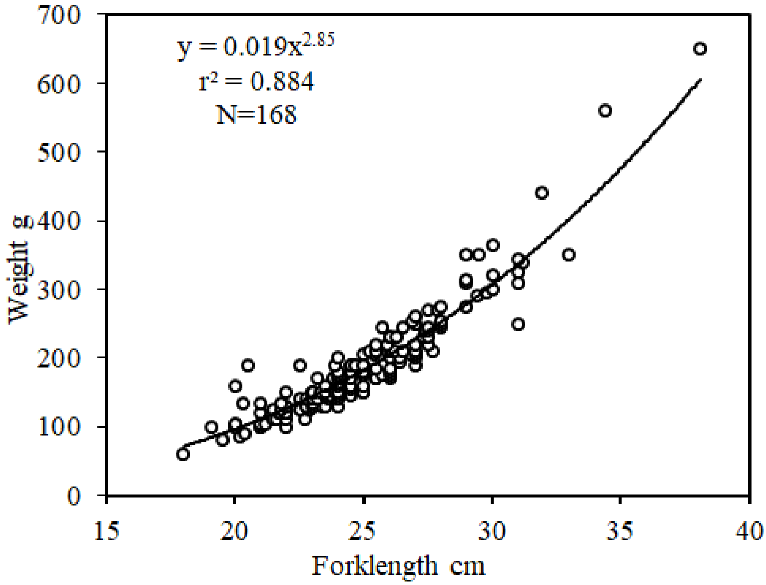

Fig 3 Weight-length relationship of Brook trout caught by anglers.

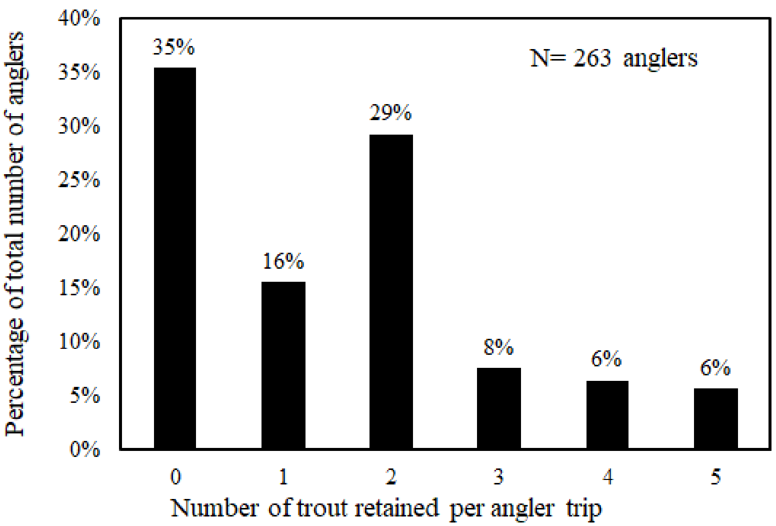

Fig 4 Catch of retained trout from 263 angler trips in the Upper Medway.

the first time. Among 44 angling parties, the average length of time spent fishing in the upper Medway watershed was 20 years.

Many anglers were supportive and provided information at the voluntary creel check points; however, several refused to participate or were not angling. During May 2017, mean daily vehicle counts at each site were 21 (±10 SD, N=638) at Albany New, 7 (±6 SD, N=218) at West Branch, and 11 (±11 SD, N=352) at East Branch. During June, after peak fishing season, mean vehicle counts declined to 16 (±15 SD, N=452) at Albany New 5 (±5 SD, N=143) at West Branch, and increased to 25 (±19 SD, N=739) at East Branch. The increase in vehicle traffic at East Branch was potentially due to road construction along that access road. Peak activity for vehicle counts per hour was between 12:00 and 18:00. Traffic typically entered and exited the same access point and was counted each time, occasionally traffic would enter one entrance and exit another. Traffic data do not include late April to avoid uncharacteristically high levels of traffic due to an off-road rally during the weekend of April 29th, 2017. The mean number of vehicles was lowest on Monday and Tuesday. For surveyed dates during May 2017, approximately 196 vehicles passed the Medway basecamp; of those 196 vehicles, 54 (28%) stopped to participate in the creel survey.

DISCUSSION

Angler CPUE and catch size were similar between 2016 and 2017 despite some variation in weather, water levels, survey times, and total number of anglers. Angler effort during spring 2017 was delayed compared to 2016 because of snow cover and unfavorable road conditions. High water levels and fast moving streams throughout the upper Medway watershed in spring 2017 may have also reduced angler effort.

Catch rates were greater in the upper Medway watershed compared to the TGLWA, however the size of the catch and preference of gear used during the upper Medway watershed creel census were similar to those reported in TGLWA. Anglers interviewed in the Medway during 2016-2017 released an average of 74 % of their catch compared to the TGLWA's 50% in 2007 and 19% in 1979 (MacMillan *et al*. 2013). This increase suggests a growing preference for catch and release amongst Nova Scotian anglers.

The difference in the catch rate between the upper Medway watershed and Kejimkujik compared to the TGLWA could be due to natural variability or differences in habitat and exploitation. The Medway and Mersey rivers are two of the larger stream systems in Nova Scotia compared to TGLWA (Davis & Browne, 1996). Migration of Brook trout populations inhabiting lakes in small stream systems may be limited compared to migratory opportunities in large systems. Past telemetry and trout tagging studies on Brook trout in the nearby upper Mersey River in Kejimkujik indicated that Brook trout migrate up to 12 km per day and up to 85 km annually to access feeding areas in spring, cool water refugia in summer, fall spawning grounds, and overwintering habitats (Corbett *et al*. 2007). Upstream spring migration may result in increased trout densities, angler effort, and catch rates in the headwaters of larger systems such as in the upper Medway. The upper Medway watershed and upper Mersey watershed are more remote from large urban centers such as Halifax, relative to the TGLWA. These factors along with past access restrictions could have reduced angler effort and exploitation within the upper Medway watershed.

Anglers visiting the upper Medway watershed primarily resided in the counties of Queens and Annapolis in Nova Scotia that are in close proximity to the study area. Although the area had been gated, our survey results show that many people have had access to the area for decades, mainly through the use of all-terrain vehicles or access to gate keys from Bowater Mersey Paper Company. Many of the interviewed anglers in the upper Medway watershed preferred catch and release which may reduce overexploitation of Brook trout in the area. As the upper Medway watershed becomes more accessible through improved roads and knowledge of access points, though, maintaining a healthy wild trout fishery may be difficult in the long term. For conservation and educational purposes, it may be crucial to reach the motorists who did not stop for a voluntary survey in 2016 or 2017. The traffic counter information indicated that a sizable number of anglers visiting this area were not surveyed. Future research could include an attempt to determine the proportion of anglers who do not voluntary participate in road side creel survey check points.

Through this census, interviewed anglers were in unanimity that keeping invasive fish species out to sustain the trout fishery in the upper Medway watershed should be a high priority for this region. Active monitoring and angler awareness campaigns should be continued to prevent the introduction of invasive species and provide early warnings should the introductions occur.

The presence of native competitor fish species that currently occupy the upper Medway watershed and upper Mersey watershed suggest that trout biomass could be limited in many lakes of this region and small trout populations may be sensitive to over exploitation. For example, in Nova Scotian lakes that were occupied by Yellow perch, trout biomass was 0.19 kg-ha^{-1} compared to 4.5 kg-ha^{-1} in lakes occupied by non-perch species (Ryan & MacMillan, 2016). Yellow perch prefer warmer temperatures and are more tolerant to acidic conditions compared to salmonids and these factors may provide perch with a competitive advantage over Brook trout (Munro & MacMillan, 2012). When large Brook trout are removed by anglers, this can cause shifts in species abundance in lakes that favour perch species (Browne & Rasmussen, 2009).

The upper Medway watershed catch information suggests that the fishery is comparable to nearby waters in Kejimkujik and superior to TGLWA. Additional restrictions to vehicle access to some of the secondary roads could reduce current access to angling locations within the Medway Lakes Wilderness Area. Special management area angling regulatory strategies in Nova Scotia include a reduction in bag limit to two trout or catch and release with a bait restriction. Additional regulations to reduce trout harvest could improve the sustainability of the trout fishery under increased effort particularly in the face of a combination of threats including climate change, acidity, and invasive fish species.

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USING LASER PHOTOGRAMMETRY TO MEASURE LONG-FINNED PILOT WHALES (*GLOBICEPHALA MELAS*)

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ABSTRACT

Knowledge of animal morphometry is important to understanding their ecology. By attaching two parallel lasers to a camera, known as laser photogrammetry (LP), a scale is projected onto photographed animals, allowing measurement of their body. Our primary aims were to test LP precision, and to estimate body length from dorsal-fin dimensions of *Globicephala melas*. Secondary aims involved demonstrating applications of LP, such as sex and leader determination. Using photographs taken over two-months, we measured dorsal base lengths (DBL) of 194 individuals individually-identified with natural markings. Results indicated 33 individuals were photographed in multiple encounters and eight matched previously-sexed whales. A mean difference of <2.1% between DBL's of 58% of repeatedly-sighted individuals was found, and whales closer to the boat (<22m) produced more precise measures. The length from the blowhole to anterior insertion of the dorsal fin (BAID) was a better predictor of total body length in stranded whales than DBL, and laser-estimated lengths fell almost all within known pilot whale size. Despite our small sample size, we showed two examples of how LP could be applied in research: (1) males and females had similar DBL (*n*=8), but large males could be distinguished using DBL; (2) leaders were not necessarily bigger than other individuals in the same cluster (*n*=4). The ease of use of LP makes it a valuable tool in collecting measurements of body features, especially when coupled with photo-identification.

Keywords: laser photogrammetry, morphometrics, measurement, length, *Globicephala melas*

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INTRODUCTION

In the study of animal biology, the ability to measure individuals is central to understanding an organism's life history and ecology. Linear measurements have long been used to quantify growth (Clark *et al*. 2000, Fearnbach *et al*. 2011, Busby *et al*. 2017), and to distinguish size classes (Meise *et al*. 2014), subspecies (Meijaard and Groves 2004), geographic forms (Jaquet 2006, Segura-García 2016), and sexes (Ramos *et al*. 2002, Martin and DaSilva 2006). Length estimates have been used to explain size-related social behaviours (Bergeron *et al*. 2010, Pack *et al*. 2012), as well as life history parameters such as pregnancy and age at maturity (Waters and Whitehead 1990). Morphometrics may easily be obtained from deceased animals or in certain circumstances, from live-captures. However, the capture of animals is often expensive, stressful to the animal, and dangerous (Pelletier *et al*. 2004, Meise *et al*. 2014), especially in the case of large aquatic animals, such as cetaceans (whales, dolphins, and porpoises). Historically, body lengths of whales and other large aquatic animals were estimated through visual observation. However, comparison of visual estimates to measured lengths from capture or stereo-video systems, indicates the discrepancy and bias of visual estimates (Gordon 1990, Rohner *et al*. 2015, Sequeira *et al*. 2016). For example, visual estimates of whale shark lengths were found to be underestimates of true lengths, with a 10% increase in the number of large individuals measured with stereo-video camera (Sequeira *et al*. 2016). As such, developing reliable methods to measure free-ranging animals has been an ongoing topic of research.

Photogrammetry involves obtaining morphometric measurements using photographs, such that disturbance to animals is minimized. Two methods of photogrammetry exist: stereo and single-camera. Stereo-photogrammetry involves photographing the individual from two angles, using two cameras, and overlapping the two images to create a three-dimensional optical model. Morphometrics may then be derived from the scale provided by the lens magnification and the distance between cameras (e.g. Dawson *et al*. 1995). Successful estimations of body size have been made for terrestrial and aquatic animals using this technique (e.g. bats, *Myotis daubentoni*, Jones and Rayner 1988; humpback whales, *Megaptera novaeangliae*, Spitz *et al*. 2000; sea lions, *Zalophus wollebaeki*, Meise *et al*. 2014; whale sharks, *Rhincodon typus*, Sequeira *et al*. 2016). However, despite its accuracy, the cumbersome nature of stereophotogrammetry setup may be impractical for use on research vessels that are limited in space and prone to movement (Bell *et al*. 1997, Spitz *et al*. 2000, Rowe and Dawson 2008). Such small research vessels are often the primary platform used to study marine mammals. Single-camera photogrammetry simplifies the equipment required by using an object of known size (Best and Rüther 1992, Flamm *et al*. 2000), or by using the distance from the individual to the camera for scale (Gordon 1991, Spitz *et al*. 2000, Jaquet 2006). Large terrestrial mammals have been measured this way (e.g. elephants, *Loxodonta africana*: Shrader *et al*. 2006, gorillas, *Gorilla gorilla*: Breuer *et al*. 2007). However, applications for use with cetaceans have been relatively limited (e.g. sperm whales, *Physeter macrocephalus*: Jaquet 2006, blue whales, *Balaenoptera musculus*: Durban *et al*. 2016) likely due to the challenges of taking measurements at sea, where only a small portion of the animal's body is briefly visible.

Laser photogrammetry is a recent advance to single-camera photogrammetry in which two parallel lasers are mounted to a digital camera, projecting dots of a known distance apart onto each photographed individual. Lasers may be used remotely from the study subject, as long as the target is perpendicular to the photographer, making data collection non-invasive for free-ranging animals. The setup itself is lightweight and operational by a single photographer, such that laser photogrammetry is gaining popularity. For example, laser photogrammetry has been used to measure the horn length of Alpine ibex *Capra ibex* (Bergeron 2007), total length of whale sharks *Rhincodon typus* (Rohner *et al*. 2015), and body size of manta ray *Manta alfredi* (Deakos 2010). In the study of cetaceans, laser photogrammetry has been used to measure dorsal fin dimensions of orca (*Orcinus orca*, Durban and Parsons 2006), bottlenose dolphins (*Tursiops truncatus*, Rowe and Dawson 2008, Rowe *et al*. 2010), and Hector's dolphins (*Cephalorhynchus hectori*, Webster *et al*. 2010). Knowledge of dorsal base lengths of Hector's dolphins was also used to estimate total body lengths (Webster *et al*. 2010). As such, the potential of laser photogrammetry to be applied to other marine mammal species is promising, and its continued use may be the best approach to non-invasively measure large animals in challenging field environments.

Long-finned pilot whales (*Globicephala melas*) are one of the largest members of the dolphin family (Delphinidae) and listed as *data* *deficient* under the International Union for Conservation of Nature (Taylor *et al*. 2008). Males are larger in size than females, ranging from 6-7 metres in length and 3 tons in weight, compared to the smaller 4-5 metre long and 1.5 ton females (NOAA Fisheries 2014). As other delphinids, pilot whales possess high cognitive capabilities (Herzing and Johnson 2015) and show social complexity in their established social units, with an average of 11-12 individuals travelling together (Ottensmeyer and Whitehead 2003). However, social bonds may also contribute to the high rate at which pilot whales mass strand, when healthy whales will beach themselves presumably to remain with other members of their group (Oremus *et al*. 2013, Whitehead and Rendell 2014).

Of the three recognized subspecies of long-finned pilot whales, one population, the North Atlantic (*Globicephala melas melas*), has long been known to summer off Cape Breton Island, Nova Scotia (Ottensmeyer and Whitehead 2003). For the communities of Pleasant Bay, Chéticamp, Bay St. Lawrence and Ingonish, Nova Scotia, whale-watching of this species represents an important part of the local economy (Fisheries and Oceans Canada 2006). As a result, providing new means to enhance our understanding of pilot whales in the region may be beneficial for species management.

The primary objective of this study was to assess the precision of a laser photogrammetry setup by measuring dorsal-fin dimensions, and estimating total body length of long-finned pilot whales residing off Pleasant Bay. Pilot whales are ideal candidates for testing this methodology as they travel in clusters and tend to surface more frequently relative to other species, thereby increasing the number of photographic opportunities. In addition, the appearance of natural marks on the dorsal fins and saddle patches of some pilot whales allows for photo-identification of up to 67% of individuals (Auger-Méthé and Whitehead 2007). Secondary objectives included testing applications of photogrammetry to demonstrate its use in a broad range of cetacean research areas. For our study, we tested two possibilities for application: whether dorsal fin base length differs between the sexes, or between leaders and followers. The distance between the blowhole and the dorsal fin was the focus, as this is the area most often seen and photographed when observing whales from a boat. Although laser photogrammetry has been used to measure cetaceans, for example, orca (*Orcinus orca*, Durban and Parsons 2006, Durban *et al*. 2017) and bottlenose dolphins (*Tursiops trunctus*, Rowe and Dawson 2008, Rowe *et al*. 2010), its use has been primarily restricted to measuring specific body regions, with few using linear regression to estimate total body length (Hector's dolphins, *Cephalorhynchus hectori*, Webster *et al*. 2010). Furthermore, despite the importance of measurement validation, few applications of laser photogrammetry have compared laser-estimated lengths to previously-recorded lengths of cetaceans (Durban and Parsons 2006, Webster *et al*. 2010). Thus, our study's estimation of total body length and validation of results using data on locally-stranded pilot whales is among the first to do so, and if shown to be precise, will strengthen the credibility of measurements obtained through these means.

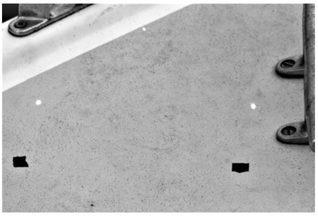
MATERIALS AND METHODS

Field methods

Data were collected during July and August 2015 on the long-finned pilot whale population that summers off Pleasant Bay, Nova Scotia, Canada (46.8208° N, 60.8158° W), a population that has been studied since 1998 (Ottensmeyer and Whitehead 2003, Augusto *et al*. 2017). Three 2.5- to 3-hour trips were conducted per day, weather permitting, aboard a 12.8 m commercial whale-watch vessel. Pilot whales were generally observed within 10 km from shore, and were approached slowly alongside the group, in accordance with the DFO whale-watch guidelines.

Two parallel laser pointers (Z-bolt Duet Emerald D5G) were secured 23.5 cm apart on an aluminum frame, which could be attached to any camera via the tripod mount (Fig 1a). A Canon 50D digital camera with a 300mm f/4L lens (Canon Inc., Tokyo, Japan) was used to photograph the whales. Laser pointers projected dots onto the blowhole to dorsal fin area of whales as they surfaced. Green lasers (power output: 4.0-5.0 mW) were preferentially used over red lasers, due to their greater visibility in daylight conditions and their long range (>100 m). In addition, the lasers used were designated as Class IIIa by the U.S. Food and Drug Administration, meaning brief exposure to whales and researchers is presumed not to cause any significant health consequences (Durban and Parsons 2006). As a precautionary measure, lasers were powered off when the whales displayed behaviours, such as "spy-hopping", which are among the

(a)


(b)


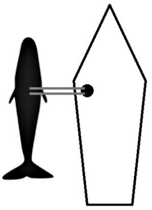
(c)


Fig 1 **Laser photogrammetry system used to obtain field measurements: (a) Laser photogrammetry setup, where two laser pointers are held in parallel by an aluminum frame; (b) Photograph of laser projections onto reference points taped 23.5 cm apart on vessel; (c) Perpendicular positioning of photographer relative to photographed whale.**

rare events when the whales have their eyes above water, and potentially exposed to the lasers.

Laser measurement precision is most commonly challenged by non-parallel alignment of lasers, horizontal axis error and parallax error (Durban and Parsons 2006, Bergeron 2007, Deakos 2010). Non-parallel alignment could result from physical interference with the mount during rough sea conditions. To ensure that lasers remained parallel throughout encounters, laser pointers were aligned at the start and end of each encounter at varying distances of 50 cm, 250 cm, 500 cm, 1000 cm, and 1250 cm. A photograph was taken of the laser projections onto fixed scale reference points (23.5 cm apart) (Fig 1b). To further minimize misalignment during trips, checks back to these fixed scales were conducted every ten minutes. Horizontal axis error occurs when the lasers are not perpendicular to the target, such that the target appears smaller than is actually indicated by the reference lasers, resulting in negatively-biased estimates (Durban and Parsons 2006). To minimize horizontal axis error, photographs were taken as perpendicular to whales as possible (Fig 1c). Finally, parallax error occurs when the plane of the lasers is not parallel to the water at which the whales are surfacing. As such, whales directly below our vessel that required the photographer to look down at the animal, were not photographed.

Photographic effort began when the boat entered within a ~80 m range from the whales, marking the start of an encounter. Dorsal fins were photographed to identify individuals (Auger-Méthé and Whitehead 2007), and whales with distinctly-notched fins were preferentially photographed for ease of recognition in analysis, and availability of previously-collected life history data, such as sex. When possible, a sequence of photographs during the surfacing period were taken in an attempt to capture the maximum length, or blowhole to dorsal fin region of an individual. "Logging" whales, or those that were seen resting at the surface, were preferentially photographed for ease of obtaining length measurements. An individual consistently surfacing at the front of the cluster (individuals within one body length of each other), was categorized as a group leader.

Photographic analysis

To ensure consistent and precise length estimates, we selected photographs that were in focus, contained both laser points on the whale, captured the entire dorsal fin, and for which the angle between the whale and camera axis was about 90°. From these images, a catalogue of recognizable individuals was compiled based on nicks and notches in the dorsal fin, saddle patch pattern, tooth rakings, and any other identifying natural scars (Auger-Méthé and Whitehead 2007). When multiple photographs of an individual were taken during the same encounter, the photograph that captured the whale's body in its most elongated form was chosen for analysis (Rowe and Dawson 2008; Webster *et al*. 2010). To determine whether lasers remained parallel during encounters, photographs taken of the fixed scales were measured using *ImageJ* software. To provide the most consistent estimates as possible, only cases where the distance between laser projections at the start and end of the encounter did not differ by more than 5% were used in our analysis.

To assess the precision of the laser measurement system, we compared the differences between measured dorsal base lengths (DBL) of the same individual across separate encounters (ΔDBL), and generated a coefficient of variation (CV). DBL was defined as the axis running from the anterior to the posterior insertions of the dorsal fin

(Fig 2a). The approximate distance of the whale from the photographer was compared with the ΔDBL in order to determine whether the photographer's proximity to the whale had a significant effect on the precision of the laser measurements. Approximate distance to photographed whales was calculated using the following formula:

$$\text{Distance} = \frac{(\text{focal lens length} \times \text{DBL} \times \text{width of camera frame in pixels})}{(\text{image width in pixels} \times \text{sensor width of camera})}$$

We wanted to verify whether we could estimate the total body length of pilot whales based on features of the dorsal fin or other morphometric measurements. Because Bloch *et al*. (1993) found that DBL was a better predictor of total body length than fin height in pilot whales, the DBL of each individual in our study was measured using *ImageJ*.

To determine whether partial body lengths would be appropriate for estimating the total length of pilot whales, photographs of a surfacing sequence were overlaid using GIMP software (GNU Image Manipulation Program; Fig 2b). The resulting image represented a larger section of the pilot whale body, generally including the blowhole to anterior insertion of the dorsal fin (BAID). To verify whether the DBL or BAID were correlated with total body length, we used morphometric data of locally-stranded pilot whales in Nova Scotia, collected by the Marine Animal Response Society (MARS). MARS has been operating a stranding record database for Nova Scotia since 1990, and as part of their protocol they measure, with a measuring tape, 15 body sections of deceased whales. These body sections include DBL, total length, tip of the upper jaw to the tip of the dorsal fin, and tip of the upper jaw to the blowhole. The records provided by MARS had measurements for 17 pilot whales, to which we applied simple regressions to understand the relationships of total length with DBL and BAID. If closely correlated, the estimated parameters from the regression could be used to predict the total length of the pilot whale based on laser measurements of DBL and BAID. MARS's stranding measurements of DBL and BAID were also used to verify whether our laser-estimated lengths from whales photographed at sea were representative of realistic measures.

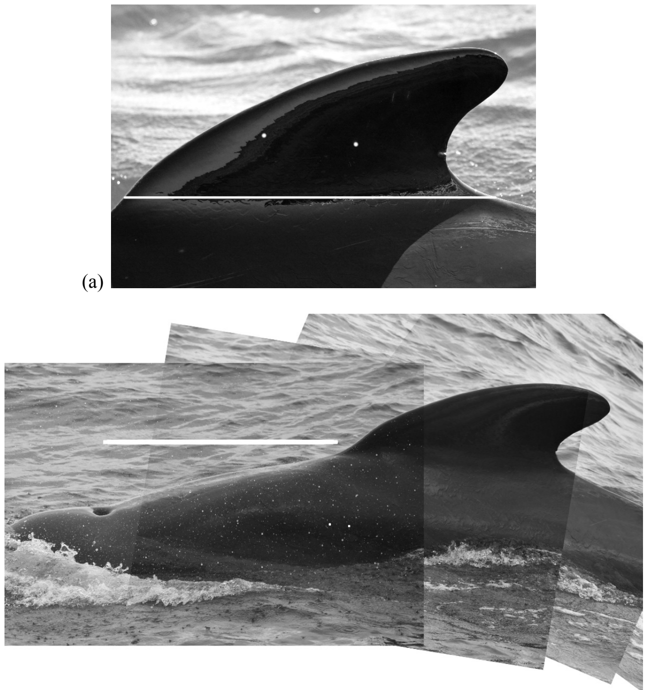


Fig 2 Morphometric measurements showing (a) DBL as measured on all 194 individuals, and (b) BAID as measured on the 12 sequenced individuals, in which a straight line angled at 90 degrees from the blowhole was used to measure BAID across merged photographs in *ImageJ* (measures indicated by white line).

All photographed individuals were compared to a catalogue of whales that had been sexed previously, using DNA extracted from skin biopsies (Augusto *et al*. 2013). The DBL of known sex individuals were compared to assess whether the DBL could be used to differentiate male pilot whales from females. Similarly, the DBL of the leading whale in an encounter, was compared to those from the remaining individuals in the cluster. All photographic analyses were performed by J. Wong to minimize variability between observers.

RESULTS

Precision of laser photogrammetry structure

A total of 1179 photographs of 194 identifiable individuals displayed projected laser dots, where whales were also in-focus and orientated perpendicular to the camera. All individuals were photographed multiple times within each encounter (2 to 15 photographs per individual). Thirty-three individuals were photographed during multiple encounters (2 to 3 encounters), producing a mean Coefficient of Variation (CV) of 5.09%, and a median CV of 3.59% for the variability of DBL between photographs.

Comparisons of the DBL difference between first and second encounters of the same individual (ΔDBL), and the distance between the whale and the photographer, indicated lasers produced more consistent measures when photographs were taken in close proximity to the whale (Fig 3). When the distance between the whale and the photographer was relatively small (11 – 22 m; defined by a DBL that comprised >45% of the frame), the ΔDBL was minimal (mean = 3.31 cm, median = 1.82 cm; <15 cm different, or a 4.9% mean size difference between encounters) (Fig 3). Conversely, in cases where the photographer was farther away (23 – 120 m; DBL comprised <45% of the frame) from the photographed whale, the ΔDBL was greater (up to 45 cm between encounters or an 8.9% mean size difference, mean = 10.83 cm, median = 6.96 cm) (Fig 3).

Although in some cases the measurements were imprecise, our laser system produced relatively consistent measures of DBL for the same individual across encounters. The ΔDBL was less than or equal to 5 cm different in 58% of all measured cases (Fig 3). In comparison, individuals that were photographed closer to the vessel (<22 m), had a ΔDBL less than or equal to 5 cm in 82% of cases (Fig 3). A <5cm ΔDBL was equivalent to a 2.1% mean size difference between DBL measures.

Estimating the total body length

A simple regression between the DBL and the total body length of 17 locally stranded pilot whales revealed a weak, yet significant, correlation between the two measures, as represented by a low r value of 0.610 (p = 0.009; Fig 4a). However, comparison between the BAID (Fig 2b) to the total length of the pilot whales, indicated a much stronger significant correlation ($r = 0.805$, $p < 0.001$; Fig 4b). Thus, BAID was used to estimate the total length of the free-swimming whales in this study.

Surfacing sequences for 12 individuals were digitally overlaid to construct a larger section of the pilot whale body. Only 12 individuals

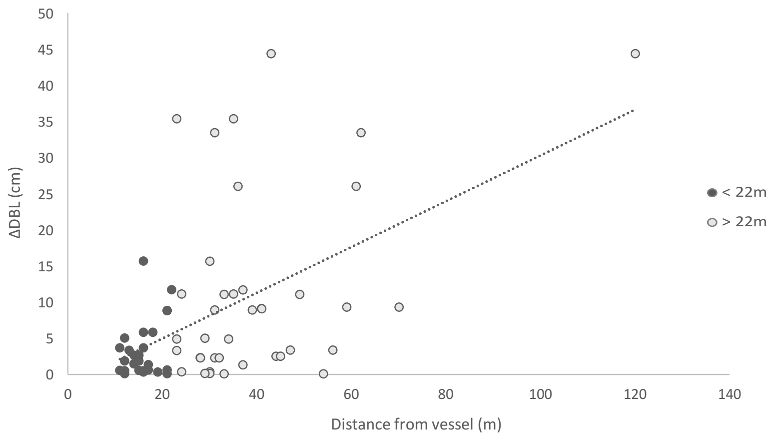


Fig 3 ΔDBL for 33 individuals, where photographs taken within close proximity of whales (< 22m) are shown in relation to photographs taken at all ranges.

were used as these represented the only sequences where all visible sections of the individual were photographed. Estimation of the total length from the BAID from these individuals produced a range of lengths from 335–837 cm, with a mean body length of 568 cm (Fig 5). An independent two-sample t-test was conducted to compare total length of whales that were stranded, and those that were estimated using our sequenced photographs. There was a significant difference in the mean lengths for stranded (368 cm, SD = 120 cm) and photographed (568 cm, SD = 165 cm) individuals ($t_{14} = 3.78$, $p < 0.001$), suggesting that lengths estimated using the lasers were greater than those recorded from strandings.

Using DBL to differentiate sex

Eight individuals were matched to a catalogue of 87 previously-biopsied individuals, identifying three males and five females. The mean male DBL was 133 cm (range: 79 to 198 cm), while the mean female DBL was 92 cm (range: 62 to 134 cm; Fig 6). The DBL of male whales was more varied, while those for females were closer to the mean length. Although the largest DBL was exhibited by a male, the DBL of males and females did not differ significantly from one another ($t_3 = 1.08$, $p = 0.36$).

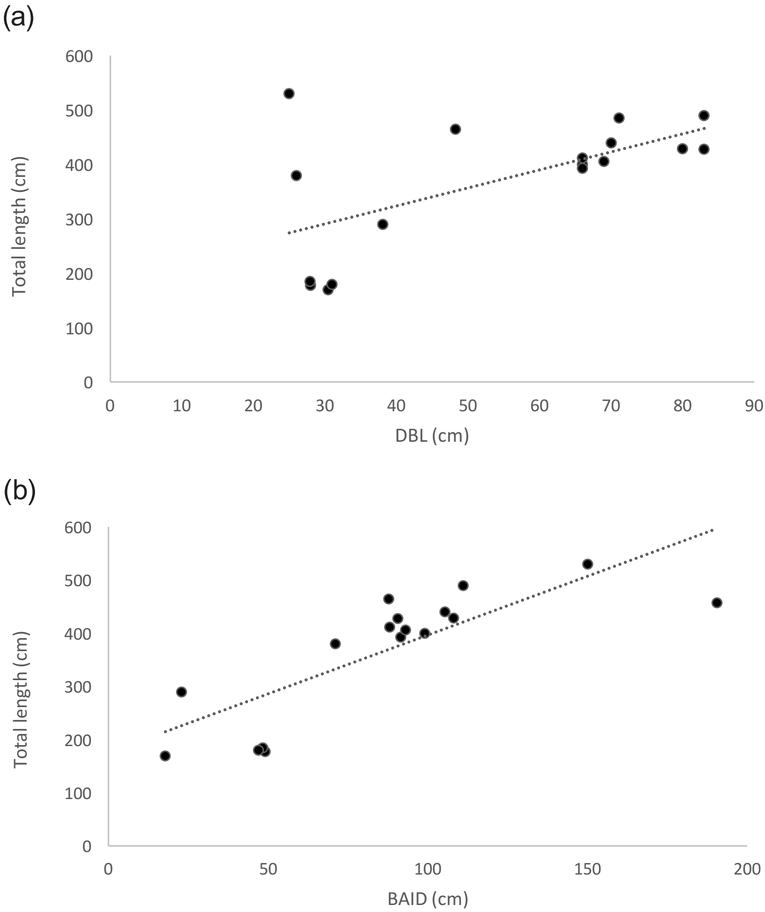


Fig 4 **Linear regression indicating the relationship between: (a) DBL and the total length, and (b) BAID and the total length, for 17 locally-stranded pilot whales.**

Using DBL to differentiate leaders

Four leaders were identified in four encounters and their DBL measurements were compared to those of the remaining individuals that surfaced within the same cluster. Leaders were either the largest (50% of cases; cluster size = 5-6 individuals), in which case their DBL was at least 30 cm larger than the largest non-leader, or the third-largest whales (remaining 50% of cases; cluster size = 5-8 individuals) within their cluster (Fig 7).

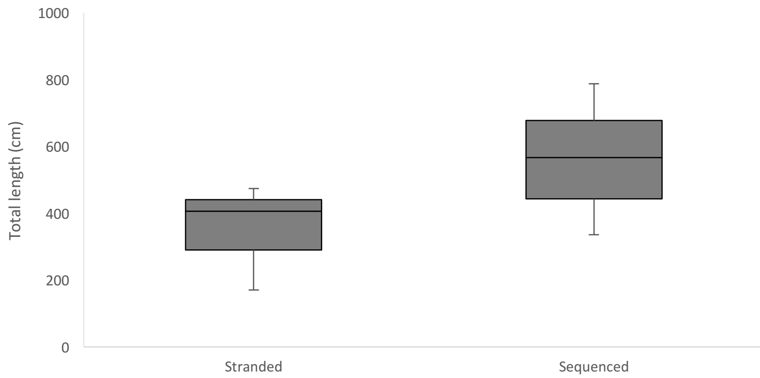


Fig 5 **Estimated total length of 12 photographed individuals based on measuring BAID, in relation to the measured total length of 17 locally-stranded individuals.**

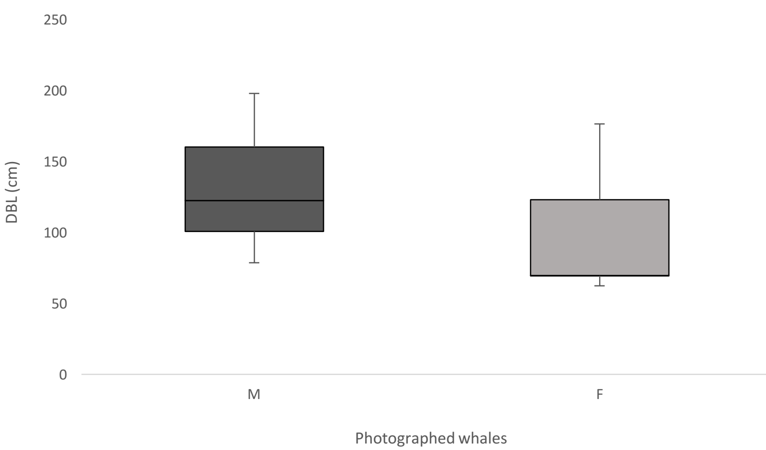


Fig 6 **DBL of photographed males (M) and females (F).**

DISCUSSION

Laser photogrammetry was used to obtain morphometric measurements of free-ranging pilot whales. Taking such measurements may have otherwise been impossible. Not only was this technique easily operable by a single researcher, but the materials involved in setting up the laser system were easily available and inexpensive.

As cetaceans are photographed in motion while their bodies are flexed, even repeated measurements of the same individual under

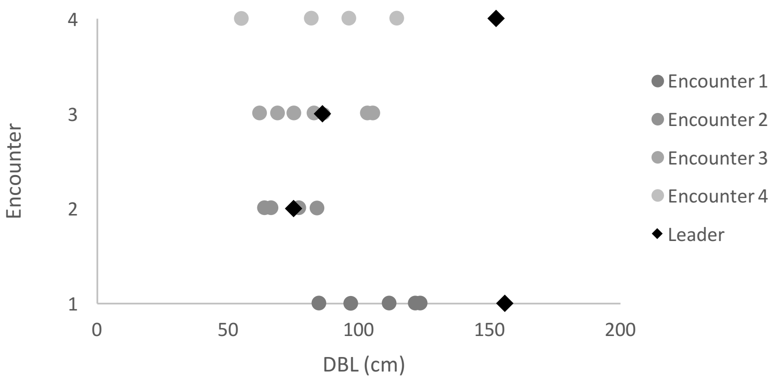


Fig 7 **DBL of four leaders in relation to other individuals in the same encounter, where each point represents one individual in the observed cluster.**

perfect conditions will not generate identical measurements (Webster *et al*. 2010). Therefore, measurement precision was assessed using ΔDBL, which quantifies the difference in measurements of DBL for the same individual. Multiple measurements from different encounters were available for 33 individuals, resulting in a mean CV of 5.09% and a median CV of 3.59% for DBL. These values are comparable to other photogrammetric techniques used to measure cetaceans. Laser photogrammetric measurement of DBL in Hector's dolphins resulted in a mean CV of 3.71% (Webster *et al*. 2010), while sperm whale fluke measurements resulted in a median CV of 1.3% (Jaquet 2006). Median CV's ranging from 1.29% to 4.56% were obtained from morphometrics of right whales, measured through aerial photogrammetry (Best and Rüther 1992). Stereo-photogrammetry on sperm whales produced a mean CV of 4.38% (Dawson *et al*. 1995), and underwater videogrammetry on humpback whale lengths yielded a mean CV of 3.08% (Spitz *et al*. 2000). The rounded angle of the anterior and posterior insertions of the dorsal fin challenge the establishment of DBL 'start' and 'end' points. Despite this, our laser structure had similar precision to that of laser photogrammetric measurements of flukes with clear points of measure. Therefore, the laser structure used in this study is considered to be reasonably precise, and even suitable for measuring difficult body sections.

The majority of individuals had a relatively small ΔDBL of less than 5 cm or 2.1% mean difference in DBL between encounters. All large ΔDBL values (median = 6.96 cm) were associated with whales photographed at a greater distance from the vessel (23 – 120 m) suggesting that an increase in distance had a negative effect on measurement precision. When laser photogrammetry was used to obtain dorsal fin height of orcas, slight changes to the parallel orientation of the lasers resulted in large variations in the location of the projected laser points, with increased variation when the whale was photographed beyond a 15 m range (Durban and Parsons 2006). Similarly, our laser structure may not have been properly aligned for long ranges of up to 120 m. Despite best efforts to align lasers in parallel, minor shifts in laser orientation may have caused laser projections to slightly converge or diverge with increasing distance from the whale. As a result, measurements of DBL were less precise. In the future, mounts should be constructed to prevent laser movement, and/or studies may be limited to situations when whales are within close range.

Based on the stranding data, BAID was shown to be a better predictor of total length in pilot whales than DBL, as indicated by a high *r* value of 0.805. Comparison of laser-estimated body lengths (based on BAID) to length measurements collected from locally-stranded pilot whales, indicated that laser-estimated lengths were significantly larger. Despite this difference, photographed whales produced length estimates (mean length: 568 cm, maximum length: 837 cm) that were similar to the mean and maximum lengths expected for free-ranging whales (mean length, male: 565 cm, mean length, female: 340 cm, maximum length: 617 cm, Sergeant 1962; maximum length: 760 cm, NOAA Fisheries 2014). There may be several potential reasons why length estimated with the lasers were greater than those of the stranded whales. First, there is likely a bias towards measuring larger whales at sea because larger individuals are more easily observed and photographed. Second, measurement via the laser method may have overestimated length; slight changes in laser alignment (i.e. physical disturbance) may have shifted laser projections out of parallel orientation, resulting in an imprecise scale. Third, stranded whales, with the exception of mass strandings and old age mortality, are typically smaller than the general population. Individuals that are young, weak or unhealthy, are more likely to beach as a result of environmental factors (Duignan *et al*. 1995, Ogle 2017, Yunus *et al*. 2017), thus morphometric measurements gathered on stranded individuals may be more representative of the smaller individuals in that population. Of the 17 stranded whales for which we had data, 65% were female, and 24% were juveniles. Adult females (340 cm) and juveniles (<200 cm) are smaller than adult males (565 cm, Sergeant 1962), which potentially suggests a bias towards smaller whales in our sample of stranded whales (mean total length: 368 cm). Fourth, the curvature of the whale's body upon surfacing could influence the measurement of the BAID, which in turn would affect the total length estimate. Furthermore, length measurements collected from strandings may not account for the curvature of the whale's body when swimming. Measurements of beached pilot whales before and after the body was straightened produced differences of up to 8 cm (Sergeant 1962). In this case, deviations between total lengths derived from free-swimming whales and those directly measured from beached whales, should be considered in future applications of this technique.

As one of the few studies that compared laser-estimated measures to locally-stranded cetaceans, potential problems and biases associated with extrapolating body length from body parts were recognized. While most of our laser-estimated lengths fell within the range of known lengths for pilot whales, this may not always be the case in laser-photogrammetry studies. Studies that estimate body length without validation using existing measurement data risk overlooking potentially stronger biases, thereby decreasing the validity of length estimates obtained this way.

In delphinids, sexual dimorphism can be expressed physically through differences in overall body size, or in traits such as dorsal fin shape and pigmentation patterns (Murphy and Rogan 2006). In bottlenose dolphins, dorsal fins of males were taller and wider at the base (larger DBL) than those of females (Rowe and Dawson 2008). Augusto *et al*. (2013) studied the sexual dimorphism of pilot whales and found no significant differences between male and female dorsal fin shape, saddle patch density, or number of mark points (nicks and notches in trailing edge of dorsal fin; Ottensmeyer and Whitehead 2003, Auger-Méthé and Whitehead 2007). However, our analysis of the DBL showed that, while laser photogrammetry cannot be used reliably to distinguish sexes, DBL may allow for the identification of large adult males. Although mean DBL's estimated using the laser system are not necessarily indicative of an individual's sex, a DBL greater than 150 cm likely suggests that the whale is male (Fig 6).

Our small sample of individuals for which we had sex information (n = 8) likely impacted our results, and future use of laser photogrammetry alongside genetic sampling may shed more light on sexual dimorphism in pilot whales.

Leaders within a cluster were not typically bigger or smaller than their counterparts, suggesting DBL may not be indicative of leadership in pilot whales. Pilot whales coexist in an extended matriline, where mothers, offspring, and recent ancestors maintain long-term associations (Amos *et al*. 1993, Ottensmeyer and Whitehead 2003, Alves *et al*. 2013, Augusto *et al*. 2017). Furthermore, pilot whales have been shown to undergo menopause – a rare post-reproductive phase experienced by only a few mammals – suggesting older females have an important social role, beyond reproduction (Marsh and Kasuya 1991, Johnstone and Cant 2010). Given this, it is not unlikely that the leader may be an older, experienced female (Brent *et al*. 2015), which might be smaller in size than the large subadult males in her cluster. Such social dynamics could explain why two of our observed leaders were not the largest in their encounter. However, the two other leaders both had a DBL > 150 cm, and were thus likely males. Adult males have been shown to stay with their mothers and remain within their natal groups long after maturity (Amos *et al*. 1993). Despite the fact that pilot whales appear to follow a "key whale" (the first individual in the group) during mass stranding events (Oremus *et al*. 2013), a set leader may not exist during regular travel. Even in killer whales, leadership by females was not absolute, despite suggested group leadership by post-reproductive females during foraging (Brent *et al*. 2015). Ultimately, the small number of identified leaders in our study (n = 4) likely impeded the significance of our results and this case study was only used to exemplify how laser photogrammetry can be used in cetacean research.

Distinguishing sex and group leaders are just two examples of the application of laser photogrammetry. Future applications of laser photogrammetry could involve differentiation between the DBL of long-finned and short-finned pilot whales (*Globicephala macrorhynchus*) where distribution overlaps in warmer waters. Short-finned and long-finned pilot whales are known to exhibit differences in flipper length, skull shape, and number of teeth (Olson 2008), but these features are unlikely to be observable above water. Thus, identifying a visible difference in dorsal fin size may improve pilot whale species identification in the field.

Several limitations challenge the application of laser photogrammetry for studying cetaceans. For example, to determine whether laser-estimated measurements are realistic requires comparison to pre-existing measurement data. As a result, this method may be limited to species that mass strand, are hunted, or those with significant bycatch (Webster *et al*. 2010). In addition, as individual identification is required to gauge laser precision, laser photogrammetry has been limited to species that surface frequently, have prominent dorsal fins, and are identifiable by natural markings (e.g. pilot whales, Auger-Méthé and Whitehead 2007, Alves *et al*. 2013; killer whales, Baird and Stacey 1988, Würsig and Jefferson 1990; bottlenose dolphins, Wells and Scott 1990; Hector's dolphins, Slooten and Dawson 1988).

We identified several potential sources of error associated with the design of our laser system. The laser pointers we used projected a laser beam that was not collimated, meaning that the axis of the laser beam may not have been parallel to the outer casing surrounding the laser. Thus, high quality laser pointers that allow for beam adjustment should be used in future studies. Furthermore, the nylon blocks used to secure the laser pointers were originally constructed to be adjustable to allow for laser alignment. However, the slightest movement of these blocks greatly altered the parallel alignment of the lasers and impeded the precision of our measurements. Future mounts should permanently hold lasers in parallel once aligned, such that physical disturbance to the structure during fieldwork does not bias the measurements.

Despite these limitations, the precision and repeatability of laser photogrammetry in obtaining morphometrics of free-ranging animals, makes it a valuable tool in cetacean research. Laser dots project a scale in every photograph, allowing measurement of any visible body proportion. Once the dorsal fin size is known for recognizable individuals, the DBL itself could be used as a reference in future photogrammetry studies to approximate the relative size of other body proportions, or other natural markings, in adults. Not only does laser photogrammetry enable simultaneous collection of photo-identification and morphometric data, but inferences about population demographics, such as growth rate, can also be made directly for individuals observed at sea, avoiding the need to rely on potentially-biased stranding or catch data (Rowe and Dawson 2008, Webster *et al*. 2010).

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DEMONSTRATING CLIMATE CHANGE IN PRINCE EDWARD ISLAND – A PROCEDURE USING CLIMATE NORMALS AND WEATHER DATA SUITABLE FOR CLASSROOM USE

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ABSTRACT

A simple method to assess climate warming is described, which is suitable for post-secondary classes in environmental sciences. This method is based on climate normals and subsequent weather data, and is demonstrated using Government of Canada archived climate/weather data from sites in Prince Edward Island including Charlottetown Airport, Alliston and New Glasgow. The method uses a simple statistical analysis based on one or two sample Student's t-tests as well as scatter plots and linear regression to highlight the direction and magnitude of changes. Statistically significant increases of annual average temperature of 0.7°C to 1.3°C were calculated for the period after the end of the 1961-1990 climate normals for Alliston and Charlottetown, and a 0.9°C change was demonstrated for New Glasgow after the 1971-2000 climate normals. These values suggest a recent rate of change three times greater than a previous estimate of up to 0.9°C per century for the Gulf of St. Lawrence region, with a major temperature increase occurring in the late 1990s. Changes were most pronounced during September and December, and two sites showed a significant increase in continuous frost-free days during the growing season, as well as a decline in the number of days with frost during spring and fall.

Keywords: Climate change, climate normals, Prince Edward Island, weather

INTRODUCTION

That the Earth is in a period of global climate change associated primarily with an anthropogenically induced warming trend caused by greenhouse gas emissions is well established (IPCC 2014). Different parts of the world are experiencing changes at different

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rates, and major changes in temperature for high latitudes in the Northern Hemisphere, including the Canadian Arctic, have already occurred (e.g. Gauthier *et al*. 2013). These changes have resulted in major declines in extent and duration of sea ice in the Arctic Ocean, major reduction in volume of the Greenland ice sheet and a decline of permafrost (e.g. Chasmer and Hopkinson 2016, Mikkersen *et al*. 2016, Ding *et al*. 2017; and references therein).

Less extreme temperature changes have been predicted for the coastal regions of eastern Canada including Nova Scotia and Prince Edward Island. Galbraith *et al*. (2010, 2012) analyzed both air and sea-surface temperatures in the Gulf of St. Lawrence back to 1873 (for air temperature), and estimated an air temperature increase of up to 0.9°C regionally. The air temperature analysis was based primarily on data from the Charlottetown Airport weather station. Here we use these data, along with temperature data from many other sites in Prince Edward Island, to focus on changes since 1961 and climate normals for the period 1961-1990.

Many of the climate changes predicted by computer modeling (e.g. IPCC 2014) refer to global warming and provide a basis for predicting future changes. Such climate change models, however, are based on computer-intensive technologies such as satellites (e.g. Garcia-Soto *et al*. 2012) and boreholes (e.g. Beltrami *et al*. 2015) that are typically not accessible to teachers or students outside of government and university research laboratories. In addition, many operate on smoothing scales of 250 to 1200 km (e.g. Garcia-Soto *et al*. 2012) that may not inform a geographic scale that might be of greater interest to students, e.g. ‘my home town’. Here I provide a simple method that facilitates a clear description of the direction and extent of temperature warming using data from Prince Edward Island.

The analysis proceeded as follows. First, the average annual temperatures for 15 sites in Prince Edward Island from 1961 to the present were used to address the question: has there been a significant change in average temperatures over that period for the island as whole? Given a positive answer, the climate normals for three sites and the associated weather data were then used to address more specific questions on climate change dealing with changes in average monthly temperatures. Because of a strong seasonal pattern to temperature increase, the analysis then addressed the issue of whether the seasonal temperature changes increased the potential growing season by way of an elongation of the frost-free period. All analyses were carried out using simple statistical tests based on archived data available from Government of Canada websites.

MATERIALS AND METHODS

Data was used from the Government of Canada website "Historical Climate Data" (climate.weather.gc.ca). Two parts of this website were used: "Canadian Climate Normals" (http://climate.weather.gc.ca/climate_normals/index_e.html) and "Historical Data" (http://climate.weather.gc.ca/historical_data/search_historic_data_e.html). In both cases Prince Edward Island was selected and the data from the relevant sites were then manually transferred to Excel (Microsoft) spreadsheets for analysis. First, I used average annual temperature values from sites across Prince Edward Island (Table 1, Fig 1) to establish the fact of temperature increase across the island over the period 1961-2016. Data from three sites (Alliston, Charlottetown

Table 1 Sites in Prince Edward Island used for climate change analysis and the years for the climate normal and subsequent data from Environment Canada.

Site	Latitude/ longitude	Years for average annual temperature	Years for climage normal	Years of weather data
Alberton[1]	46°48'N, 64°4'W	1970-2005		
Alliston[2]	46°4'N. 62°36'W	1961-2015	1961-1990	1995-2016
Bangor	46°22'N, 62°41'W	1972-2003		
Charlottetown Airport	46°17'N, 63°7'W	1961-2016	1961-1990	1991-2016
East Baltic	46°26'N, 62°10'W	1972-1999		
Ellerslie	46°36'N, 63°57'W	1966-1986		
Hunter River	46°21'N, 63°21'W	1971-1983		
Kingsboro	46°23'N, 62°7'W	2001-2005		
Long River	43°30'N, 63°33'W	1971-2002		
Monticello	46°28'N, 62°27'W	1961-2001		
New Glasgow	46°24'N, 63°2'W	1972-2016	1971-2000	2001-2016
O'Leary	46°42'N, 64°14'W	1961-2003		
St. Peters	46°25'N, 62°35'W	2004-2006		
Stanhope	46°24'N, 63°6'W	1971-2005		
Summerside Airport	46°26'N, 63°50'W	1961-2006		
Tignish	46°57'N, 64°2'W	1972-1991		
Tyne Valley	46°35'N, 63°55'W	1991-2003		
Victoria	46°13'N, 63°29'W	1994-2003		

[1] 1988 – missing data
[2] 1979, 1981-1994 – missing data

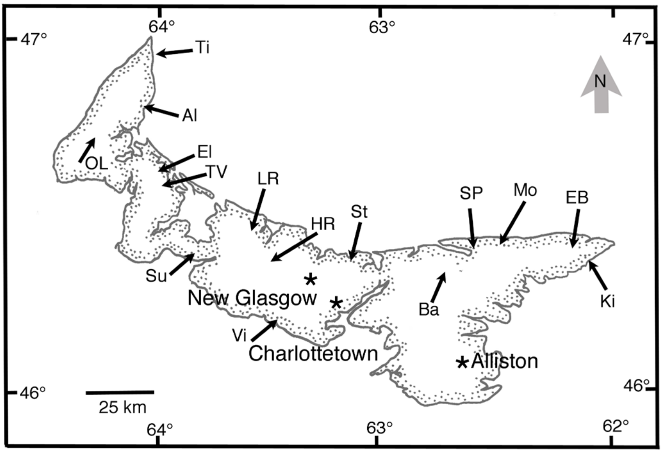


Fig 1 **Map of Prince Edward Island indicating sites used for changes in annual average temperature. Asterisks (*) indicate sites used for analyses of monthly changes in temperature and frost occurrences in spring and autumn. Arrows indicate sites used for determination of annual temperature variation 1960-present. Abbreviations: Al- Alberton; EB- East Baltic; El- Ellerslie; HR- Hunter River; Ki- Kingsboro; LR- Long River; Mo- Monticello; OL- O'Leary; SP- St. Peters; St- Stanhope; Su- Summerside; Ti- Tignish; TV- Tyne Valley; Vi- Victoria.**

Airport, New Glasgow) were then used in a more detailed evaluation (Table 1). These locations were selected because of the relative completeness of the data set relative to other sites.

Using Charlottetown Airport as the model for the procedure, the mean monthly temperatures from climate normals (in this case 1961-1990; Appendix 1) were copied into a spreadsheet with each month in a separate column. For the years 1991-2012 the monthly means were already tabulated on the website and these were copied into the appropriate column. For 2012-2016, monthly means were available only as part of 'daily' records, and the page for each month had to be inspected separately for the relevant mean value. Occasional missing monthly means were inserted by taking the mean of the previous two years.

The means and standard deviations (SD) of the monthly averages for 1991-2016 were then calculated along with the differences between the new means and the means of the climate normal. These values are shown in Table 2. The mean of the monthly differences between the climate normal and the weather data was

Table 2 Climate normals for average monthly temperature (°C) for three sites in Prince Edward Island from 1961-1990 (Alliston, Charlottetown Airport) and New Glasgow (1971-2000) and summaries of changes in average monthly temperature from weather data from 1991-2016. Comparison of annual mean temperature based on two-tailed Student's t tests; comparison of monthly means based on one-tailed t-tests. NS = p > 0.1.

Site		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean
Alliston														
Climate normal		-7.0	-7.4	-2.5	2.4	8.7	14.7	18.6	18.2	13.8	8.6	3.2	-3.0	5.7
1991-2014	Mean	-5.9	-5.3	-1.8	3.7	9.6	15.4	19.8	19.6	15.8	9.8	4.2	-1.3	6.9
	SD	± 2.1	± 3.1	± 1.9	± 1.7	± 2.0	± 1.7	± 1.1	± 1.1	± 1.3	± 1.3	± 1.1	± 2.0	
Change		1.1	2.1	0.7	1.3	0.9	0.7	1.1	1.4	2.0	1.2	1.0	1.6	1.3 ± 0.4
Significance		0.01	< 0.01	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	< 0.01	<0.01	<0.01	<0.01	< 0.001
Charlottetown														
Climate normal		-7.7	-8.0	-3.4	2.3	8.8	14.4	18.4	18.0	13.4	8.0	2.5	-4.1	5.2
1991-2014	Mean	-7.4	-7.3	-3.0	3.0	9.2	14.6	18.9	18.6	14.7	8.7	3.3	-2.5	5.9
	SD	± 2.4	± 2.3	± 2.0	± 1.5	± 1.4	± 1.0	± 1.3	± 1.0	± 1.3	± 1.4	± 1.2	± 2.1	
Change		0.3	0.7	0.4	0.7	0.4	0.2	0.5	0.6	1.3	0.7	0.8	1.6	0.7 ± 0.4
Significance		NS	0.06	NS	<0.05	<0.05	NS	< 0.01	< 0.01	< 0.01	<0.01	<0.01	< 0.01	< 0.001
New Glasgow														
Climate normal		-7.6	-7.7	-2.9	2.9	9.1	14.8	18.8	18.3	13.8	8.1	2.7	-3.8	5.6
1991-2014	Mean	-6.6	-6.8	-2.6	3.6	9.6	14.6	19.5	19.2	15.2	9.4	3.9	-1.9	6.4
	SD	± 2.4	± 2.4	± 1.9	± 1.6	± 1.2	± 1.0	± 1.1	± 0.8	± 1.2	± 1.0	± 2.0	± 0.6	
Change		1.0	0.9	0.3	0.7	0.5	-0.2	0.7	0.9	1.4	1.3	1.2	1.9	0.8±0.30
Significance		0.07	0.08	NS	< 0.01	<0.05	NS	<0.01	< 0.01	< 0.01	<0.01	<0.01	< 0.01	< 0.001

calculated, and two-tailed, single-sample Student's t-tests (GraphPad: https://graphpad.com/quickcalcs/oneSampleT1/?Format=SD) were used to determine significance. This mean was always significantly greater than the annual mean of the climate normal ($P < 0.001$).

Changes on a monthly basis were then evaluated. Based on the initial observation that an overall annual temperature increase had occurred, the monthly data were then evaluated with a question that changed from the initial: 'are the monthly means different?' (requiring a two-tailed analysis) to 'are the monthly means greater than those of the climate normal?' (requiring only a one-tailed analysis). Next, to evaluate the magnitude of the differences in the monthly means, rather than just their absolute values, a second table was constructed in which the value for each month/year for the weather data was subtracted from the mean of the climate normal for that month. This effectively normalized the differences from each month, making the size of the monthly change easier to visualize (Appendix 1, Part B). Finally, the means from the individual months were evaluated using one-tailed, single sample Student's t-tests with the GraphPad software indicated above. Annual changes in means for days of frost and frost-free days for the three primary sites were evaluated using linear regression implemented in online software from GraphPad (www.graphpad.com/quickcalcs/linear1/).

Having demonstrated an overall temperature increase and having addressed which months showed significant increases, analyses proceeded to address if there were critical times in the year where changes in temperature would impact the length of the growing season. Accordingly, the dates of the last frost in the spring and first frost in the autumn were determined, and the number of days with frost (i.e. temperatures below 0.0°C) in each month during spring (March to June) and autumn (September to December) were tabulated. Given overall temperature increases, these values provide insight into potential changes in the length of the growing season and the general amelioration of the climate. Comparisons were made between years that comprised the climate normals and the subsequent periods.

RESULTS

Spatial and temporal variation – annual variation

During the 1961-2016 period studied here, average temperature varied considerably both temporally and spatially. The warmest sites were Alliston and Stanhope and the coldest were Alberton, O'Leary and Tignish. A lack of continuous temperature records for all sites made more precise spatial comparisons difficult. Annual variation among sites was about 1°C and the SD across all sites varied from about 0.2 to 0.4. The coldest year was 1972 with a mean temperature of 4.1 ± 0.3°C (mean ± SD), and the warmest year was 2010 with a mean of 7.9 ± 0.4°C (Fig 2). The overall correlation between mean annual temperature and year between 1961 and 2016 was $r = 0.623$ (significant at $P < 0.01$).

The years 1961-2016 showed a distinct pattern in which a relatively stable temperature regime existed between 1961 and 1997 compared to the post 1997 period. The overall means for data from all sites are shown in Fig 2, and the values for the two periods were 5.3 ± 0.7°C and 6.5 ± 0.7°C. These two values with a difference of 1.2°C were highly significant (two-tailed Student's t-test, $P < 0.001$), and confirmed a major temperature increase in the last 18 years relative to the preceding period. The difference was such that the highest annual overall mean for the province for the early period (6.4°C) was always less than the mean for the subsequent period (6.4°C vs 6.5°C), and the lowest mean for the post 1997 period was always greater than the mean for the earlier period (5.7°C vs 5.3°C; Fig 2).

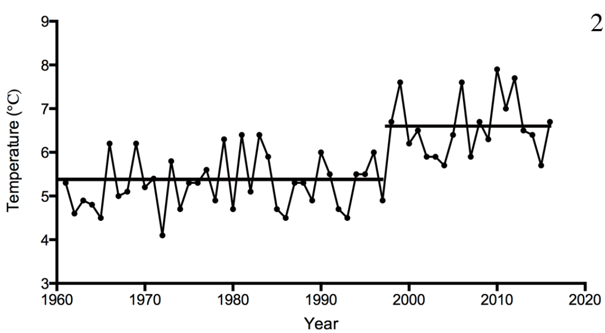


Fig 2 **Changes in average annual temperature from sites in Prince Edward Island based on all sites in Fig. 1. Note: the two lines indicate average temperature between periods 1961-1997 and 1998-2016. See Fig 1 for site locations.**

Monthly changes in temperature

A more refined analysis of temperature changes by month was done using the climate normals. The overall temperature increases were 0.7°, 0.8° and 1.3°C for Charlottetown, New Glasgow and Alliston, respectively; all were highly significant statistically (i.e. $P < 0.001$; Table 2). These increases were consistent with the changes in mean temperature for the Island shown in the previous section.

Every site/month combination had a temperature change that was in a positive direction. Of the 36 possible comparisons, 28 were significant ($P < 0.05$). All non-significant changes occurred in the first half of the year and were limited to Charlottetown and New Glasgow. Most of the non-significant changes were in the order of 0.2-0.5°C relative to climate normals. The temperature changes in the second half of the year had greater magnitude (mostly 0.7-1.6°C). At all three sites the largest increases were during September and December when increases ranged from 1.3°C to 2.0°C.

Changes in number of frost days

The increase in temperature in every month allows for the possibility of a decrease in frosts and this was evaluated for both spring and autumn months. The three sites had different patterns with respect to climate normals, with the last frost occurring 42 (Charlottetown) to 52 (New Glasgow) days after April 1 (Table 3). Allison and New Glasgow had a reduction in frost days in the period following climate normals, although only the ten-day reduction at Alliston was significant, and the six-day increase (i.e. later frosts) at Charlottetown was significant. While Alliston and New Glasgow had fewer frost days

Table 3 Climate normal and summaries of changes from weather data from 1991-2013 for days to last frost starting April 1 and number of frost days in months from March to June for three sites in Prince Edward Island. Significant differences from climate normal based on 1-tail Student's t tests: * = $P < 0.05$, ** = $P < 0.01$.

Site		Days to last frost	Number of frost days Mar	Apr	May	June
Alliston	Normal	46.0±9.9	28.2±2.5	21.6±5.4	4.4±2.8	0.05
	1991-2013	36.0±10.8**	27.1±2.7	14.9±4.8**	1.1±1.2**	0
Charlottetown	Normal	41.8±9.7	28.7±2.0	21.5±5.1	3.7±3.6	0
	1991-2016	48.1±14.2*	29.1±1.9	20.0±4.6	4.2±3.0	0.3±0.6
New Glasgow	Normal[1]	52.1±12.0	27.1±1.9	17.8±4.7	4.6±3.4	0.2±0.4
	1991-2016	48.3±11.4	26.8±5.5	16.7±4.7	3.0±1.9	0.2±0.5

[1] years 1972-1990 only

during individual months, these were significant only at Alliston with reductions during April and May of seven and three days, respectively.

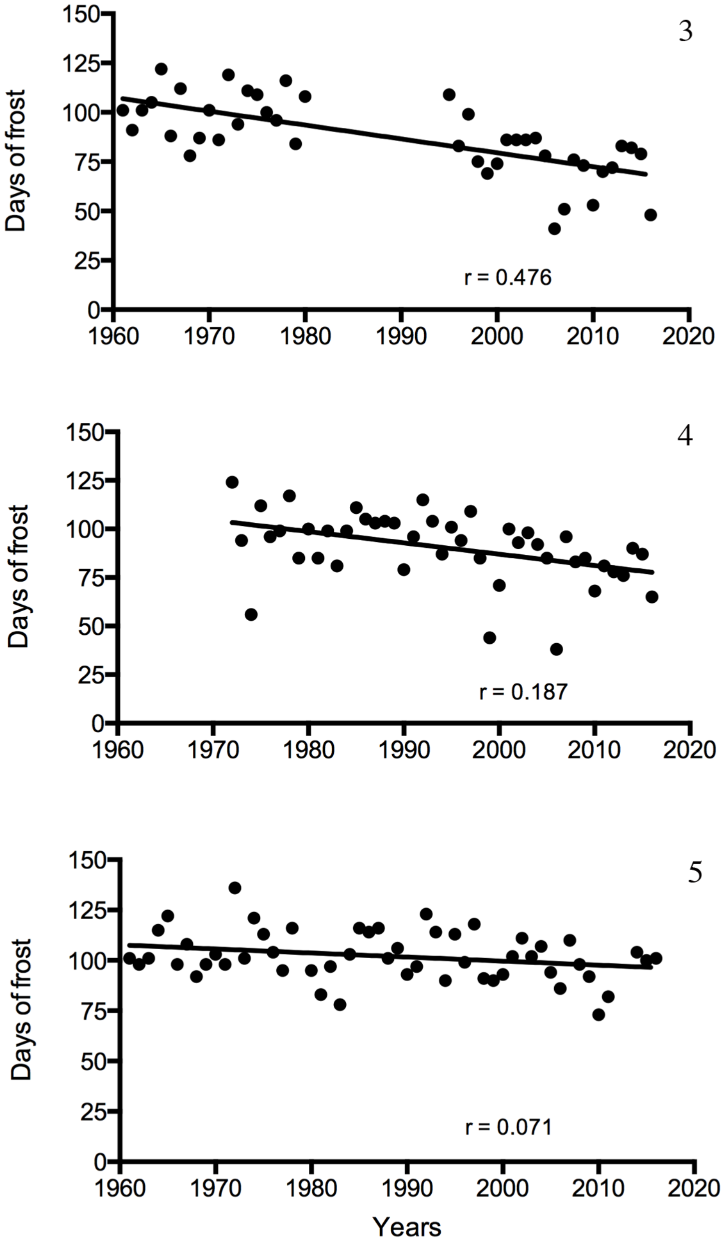
Changes in the timing and number of frosts during autumn were more apparent than in spring. Frosts during September from 1961 to present were rare, and the climate normals had the first frost occurring an average of 37 to 49 days after September 1 (i.e. early to mid-October). In the post climate normals period, there was a clear trend to a later occurrence of the first frost with later occurrences of two, six and 14 days, although this was significant only for Alliston (Table 4). Between October and December all months and sites showed fewer frost days although this was significant only for Alliston (all three months) and for New Glasgow in October.

The combination of earlier last frost in spring and later last frost in the fall led to a general trend of declining number of frost days in spring and autumn for Alliston and New Glasgow (Figs 3, 4) but not for Charlottetown (Fig 5, Table 5). This decline corresponded to an increase in continuous frost-free days for Alliston and New Glasgow (Figs 6, 7) but not Charlottetown Airport (Fig 8). The increase in the frost-free period showed a trend of about 35 days for Alliston since 1960 and about 25 for New Glasgow since 1970. The increase in the frost-free period was apparent starting in 1961 even though there was little change in average temperature over the first 35 years. For Alliston, the relationship between year and increase in continuous frost-free days was significant ($r^2 = 0.296$, $P < 0.001$). The equivalent relationship for New Glasgow was also significant ($r^2 = 0.295$, $P < 0.01$)

Table 4 Climate normal and summaries of changes from weather data from 1991-2013 for days to first frost starting September 1 and number of frost days in months from September to December for three sites in Prince Edward Island. Significant differences from climate normal: * = P < 0.05, ** = P < 0.01.

Site		Days to first frost	Number of frost days Sept	Oct	Nov	Dec
Alliston	Normal[1]	49.4±9.9	0	3.0±2.7	15.8±5.6	27.3±3.3
	1994-2015	64.0±9.4**	0	0.9±1.2**	11.9±3.9**	25.2±4.6*
Charlottetown	Normal	47.3±10.9	0	4.1±3.0	17.8±5.2	28.1±2.8
	1991-2016	49.6±10.3	0	3.6±3.3	15.3±4.2	26.9±3.5
New Glasgow	Normal[2]	37.2±11.1	0.4±0.8	6.2±2.6	16.5±4.3	27.3±3.0
	1991-2016	43.2±8.7	0.0±0.0	2.9±1.6*	13.8±3.8	25.1±3.8

[1] 1961-1981 only
[2] 1971-1990 only



Figs 3-5 Total number of days of frost for months March to June and September to December for Alliston (Fig 3), New Glasgow (Fig 4) and Charlottetown Airport (Fig 5) with lines of best fit and Pearson correlation coefficients (r).

Table 5 **Changes in frost-free days in spring and autumn months. See Tables 3-4 for significances of changes in spring and fall months. Note '+' indicates increase in days with frost.**

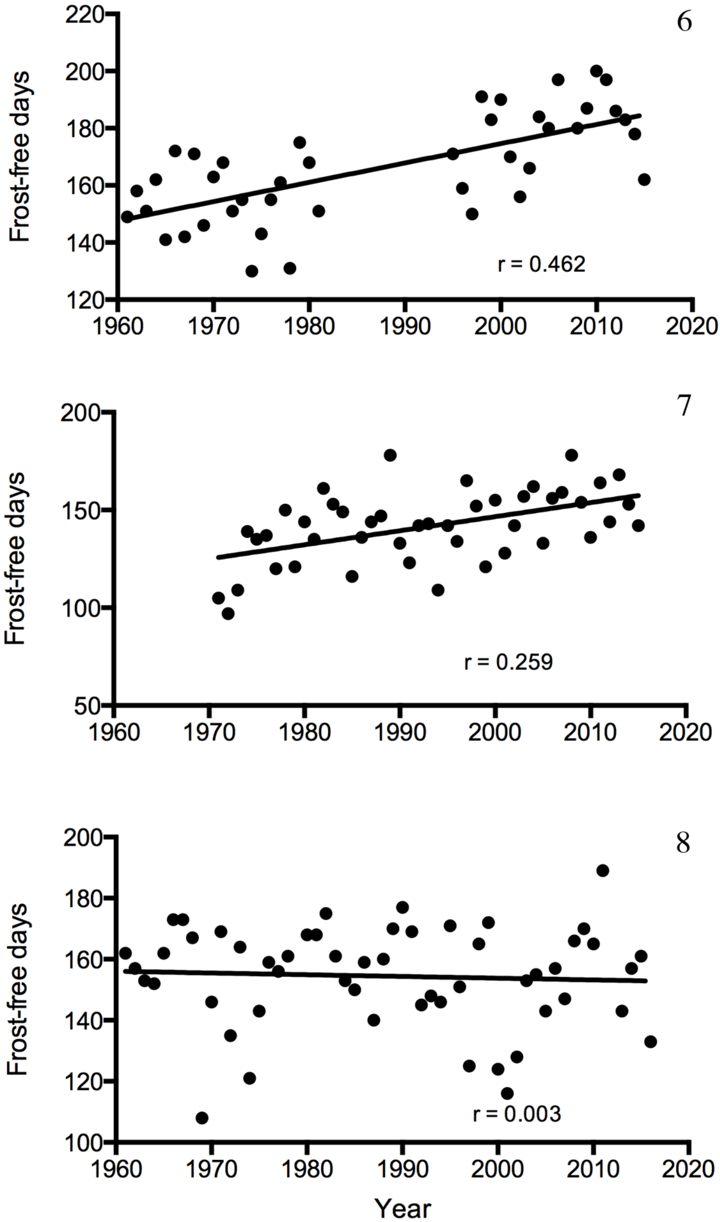
Season Spring	Reduction in days to last frost (from April 1)	March	April	Months May	June
Alliston	10.0	-1.1	-6.7	-3.3	0
Charlottetown	+3.3	+0.4	+1.5	0.5	0.3
New Glasgow	3.8	-0.3	-1.1	-1.6	0

Season Autumn	Additional days to first frost (from Sept 1)	September	October	November	December
Alliston	14.6	0	-2.1	-3.9	-1.9
Charlottetown	2.3	0	-0.5	-2.5	-1.2
New Glasgow	6.0	-0.4	-3.3	-1.7	-2.2

DISCUSSION

For purposes of this paper, the climate of an area can be defined as the 'climate normals'; these are based on weather patterns over a 30-year period and are officially updated every ten years. Here the climate normals from 1961-1990 are used because it allowed a large enough subsequent time over which changes could be generalized for statistical analysis for comparison with the climate normals. The general pattern, that the rate of change increased substantially in the late 1990s, is confirmed by the overall increase in annual temperature between the climate normals for 1961-1990 and 1971-2000, where only a 0.1°C increase for Charlottetown and a 0.4°C change for Alliston occurred in that interval. This contrasts with the more than 1°C increase for the island as a whole after the late 1990s (Fig 2).

Only one aspect of climate change was examined, i.e. temperature, and how it has changed both on an annual and monthly basis, and with respect to the occurrences of frost during spring and fall months. The latter is important because an increase in the frost-free period suggests increases in the growing season, and points to a general moderation of the cold-temperate climate of Prince Edward Island. By showing statistically significant changes from those 'normals' over a period approaching 30 years (i.e. 21 years for Alliston and 26 years for Charlottetown) climate change has been demonstrated. While the



Figs 6-8 Maximum period of frost-free days from spring to autumn for Allison (Fig 6), New Glasgow (Fig 7) and Charlottetown Airport (Fig 8) with lines of best fit and Pearson correlation coefficients (r).

primary period for New Glasgow was only 16 years, the direction and magnitude of the changes were consistent with the first two sites.

The overall pattern for Prince Edward Island was a gradual increase that suggested a temperature increase of over 1°C since the late 1990s. This pattern of a very slight increase between 1961 and the mid 1990s followed by an upward shift and subsequent stabilization, was also apparent in a similar analysis from Nova Scotia (Garbary and Hill, unpublished data). The Alliston increase of 1.3°C is larger than would be expected, and is likely an artifact of the limited data set, i.e. only 21 complete years (ca. 1995-2015). This period magnified the changes by omitting several years with lower temperatures, and concentrated the values into more recent years when the higher temperatures occurred.

Of the three primary sites, the smallest change during the 1960-2016 period was observed Charlottetown where the temperature increase was only 0.7°C relative to climate normals. Using mean annual temperatures from 1946 to 2016 gave an extremely weak correlation ($r^2 = 0.05$, $P > 0.05$). The relationship was substantially improved by using a five-year running average ($r^2 = 0.191$, $P < 0.01$) which showed the annual average after 2008 always above 6.0°C. Similarly, there was no positive trend in the increase in the number of continuous frost-free days in Charlottetown as was observed at the other sites.

The sudden rise in temperature at the end of the 1990s leading to a relatively stable subsequent regime requires explanation. While global temperatures have been rising (IPCC 2014), there was no sudden change in the late 1990s that would explain the result from P.E.I. Indeed, the average global temperature records for 2014 through 2016 do not seem to be reflected in the results for P.E.I., where the highest annual temperature occurred in 2010 (7.9 ± 0.4), with the warmest year since 2013 being only 6.7 ± 0.2. While this apparent decline is statistically significant ($P < 0.05$), it is based on limited observations and it would be premature to suggest a trend.

The sudden rise in annual temperature in the late 1990s is correlated with a decline in winter sea-ice area in the Gulf of St. Lawrence (Benoit *et al*. 2012, fig. 5.3-1); however, the dramatic increase in sea-ice in the early 1970s is not correlated with changes in the annual air temperatures for P.E.I. (Fig 3) that were relatively stable from 1961 to the mid 1990s. The onset of warmer temperatures in the late 1990s is correlated with the extreme El Nino-Southern

Oscillation event in 1998 (Trenberth *et al*. 2002). In addition to the long-term pattern of global warming (IPCC 2014), other phenomena may be acting on shorter time scales, e.g. the 20-year cycle of the Atlantic Multidecadal Oscillation (AMO- Chylek *et al*. 2011, 2016). On the one hand, a reversal of the trend of rising temperatures from the 1990s might be consistent with the AMO. On the other hand, it is reasonable to suggest that the successive global record setting years since 2014 (NOAA 2017, Gillis 2017, Su *et al*. 2017, Thompson 2017) will be reflected over the next few years in the average annual and monthly changes for Prince Edward Island.

Warmer temperatures in the spring and autumn in Nova Scotia in specific years have already been documented to cause changes in flowering phenology. This has occurred at least twice during the autumn/early winter in 2001 and 2006 when 95 and 136 species respectively were in flower after November 1, and flowering was still occurring in December in 2001 and even into January in 2007 for many species (Taylor and Garbary 2003, Garbary and Taylor 2007, Garbary *et al*. 2012). Similarly, advanced spring flowering in March-April was documented in 2012 that set early flowering records for Nova Scotia (Hill and Garbary 2013). The warming trends shown here for P.E.I. would suggest that the wild flora would have behaved as they did in Nova Scotia. As autumn temperatures continue to increase and result in longer frost-free periods, flowering periods for many species will almost certainly continue to be extended into the autumn on a regular basis.

In summary, the methodology presented here show that rising temperatures in P.E.I. have been increasing since the early 1960s with the rate of change increasing dramatically over the last 20 years (see Appendix 2 for Provincial Government websites on climate change). The temperature increase is more apparent at inland sites than at the more coastal Charlottetown. The increases at Alliston and New Glasgow are associated with increases in the frost-free period. This change was also observed in a similar analysis of climate change in Nova Scotia (Garbary and Hill, unpublished). It is beyond the scope of this work to determine the causal factors behind this more intense and rapid local change. However, more extreme changes can occur on smaller geographic and temporal scales than might be predicted for an entire region by global models. It is these local changes in mean temperature and frost-free periods that will affect human activities and the biological and physical responses of the natural world. Using this procedure in classrooms can introduce students to basic statistical concepts, and also provide clear demonstrations of climate change at a local level.

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Appendix 1 Portion of table for Charlottetown Airport (omitting 1996-2011) as an example of procedure. Part A indicates monthly mean and annual temperature in the climate normal and the monthly means from years 1991-2016. Part B indicates the normalized temperature differences between climate normal and the means in Part A. Note: the negative numbers in Part B indicate a temperature increase relative to the climate normal. Abbreviations: CN, climate normal; Diff, difference between climate normal and average of the monthly means; NS, not significant; SD, standard deviation.

Part A	J	F	M	A	M	J	J	A	S	O	N	D	Mean
CN	-7.7	-8.0	-3.4	2.3	8.8	14.4	18.4	18.0	13.4	8.0	2.5	-4.1	5.2
1991	-10.8	-7.2	-5.0	2.3	9.2	14.2	18.7	18.1	13.1	9.7	4.2	-5.1	5.1
1992	-8.5	-8.5	-6.0	1.2	8.9	14.2	15.9	18.5	15.0	7.5	1.0	-3.7	4.6
1993	-9.4	-12.4	-5.0	2.8	8.0	13.7	16.2	18.3	13.7	6.0	2.0	-3.0	4.2
1994	-12.1	-10.5	-2.6	4.2	8.1	15.5	20.3	17.9	13.0	8.6	3.7	-3.7	5.2
1995	-5.6	-9.2	-3.4	1.4	7.3	14.9	19.7	17.4	12.4	10.5	2.6	-4.9	5.3
. . .													
2012	-5.1	-6.1	-0.5	5.4	10.8	14.3	19.5	20.9	16.3	10.1	3.3	0.4	7.4
2013	-7.6	-5.4	-1.7	3.7	10.6	15.0	19.8	18.8	14.8	8.1	2.2	-6.0	6.0
2014	-7.1	-7.6	-6.5	2.9	8.1	14.3	21.3	18.2	14.5	10.7	2.6	-0.8	5.9
2015	-8.7	-12.6	-6.0	0.1	10.6	12.6	18.1	21.3	16.3	7.8	4.0	0.4	5.3
2016	-5.0	-3.7	-3.1	2.2	9.7	14.6	18.9	18.6	15.3	9.8	4.6	-3.3	6.6
Mean	-7.4	-7.3	-3.0	3.0	9.3	14.6	18.9	18.6	14.7	8.7	3.3	-2.5	5.9
SD	2.4	2.3	2.0	1.5	1.4	1.2	1.3	1.0	1.3	1.4	1.2	2.0	0.9
Diff	-0.3	-0.7	-0.4	-0.7	-0.5	-0.2	-0.5	-0.6	-1.3	-0.7	-0.8	-1.6	-0.7

Appendx 1 Cont'd

Appendx 1 Cont'd

Part B	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1991	3.1	-0.8	1.6	0.0	-0.4	0.2	-0.3	-0.1	0.3	-1.7	-1.7	1.0	0.1
1992	0.8	0.5	2.6	1.1	-0.1	0.2	2.5	-0.5	-1.6	0.5	1.5	-0.4	0.6
1993	1.7	4.4	1.6	-0.5	0.8	0.7	2.2	-0.3	-0.3	2.0	0.5	-1.1	1.0
1994	4.4	2.5	-0.8	-1.9	0.7	-1.1	-1.9	0.1	0.4	-0.6	-1.2	-0.4	0.0
1995	-2.1	1.2	0.0	0.9	1.5	-0.5	-1.3	0.6	1.0	-2.5	-0.1	0.8	-0.1
. . .													
2012	-2.6	-1.9	-2.9	-3.1	-2.0	0.1	-1.1	-2.9	-2.9	-2.1	-0.8	-4.5	-2.2
2013	-0.1	-2.6	-1.7	-1.4	-1.8	-0.6	-1.4	-0.8	-1.4	-0.1	0.3	1.9	-0.8
2014	-0.6	-0.4	3.1	-0.6	0.7	0.1	-2.9	-0.2	-1.1	-2.7	-0.1	-3.3	-0.7
2015	1.0	4.6	2.6	2.2	-1.8	1.8	0.3	-3.3	-2.9	0.2	-1.5	-4.5	-0.1
2016	-2.7	-4.3	-0.3	0.1	-0.9	-0.2	-0.5	-0.6	-1.9	-1.8	-2.1	-0.8	-1.4
Mean	-0.4	-0.8	-0.4	-0.7	-0.5	-0.2	-0.5	-0.6	-1.3	-0.7	-0.8	-1.6	-0.7
SD	2.3	2.2	2.0	1.4	1.4	1.1	1.3	1.0	1.3	1.4	1.2	2.0	0.4
P value	NS	0.1	NS	0.0	0.1	NS	0.0	0.0	0.0	0.0	0.0	0.0	<0.001

Appenidix 2 Provincial Government websites relevant to climate change in the Maritime Provinces.

New Brunswick
http://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/climate_change.html
This is the best regional website on climate change. It gives actual data on climate normals and predictions based on various climate change models. It also contains data on some sites in Prince Edward Island and Nova Scotia by providing a link "New Brunswick's Future Climate Projections: AR5 Data and Maps" — http://acasav2.azurewebsites.net/)

Nova Scotia
https://climatechange.novascotia.ca/
Brief summary of policy and general information on climate change and adaptation. Provides actual data on climate variables from around the province based on seasons (https://climatechange.novascotia.ca/adapting-to-climate-change)

Prince Edward Island
https://www.princeedwardisland.ca/en/topic/climate-change-0
A useful guide to general policy and potential impacts of climate change on various industries including agriculture, fisheries, forestry, and tourism. There is a link to an excellent manuscript on forest trees in relation to climate change (https://www.princeedwardisland.ca/sites/default/files/publications/climate_change_2010._pei_full_report.pdf)

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BOOK REVIEW

One Plus One Equals One: Symbiosis and The Evolution of Complex Life. J. Archibald. 2014. (2016 PB). Oxford University Press, Oxford, UK. 208 pp.

The Nova Scotian Institute of Science has amongst its members retired academics and government scientists, as well as those from many other walks of life with an interest in natural history and science. They have in common with high school and college students the experience of coming day to day with phrases and words such as molecular biology, molecular clocks, genetic engineering, genomes, genetic code, DNA and RNA. As well, there are terms like prokaryotes, eukaryotes, Archaea, symbiosis and endosymbiosis. Many of the older age group went to college before these became part of current vocabulary, while students with their limited focus on internet information tend to have a view that is far too narrow.

This book on symbiosis by John Archibald of Dalhousie University, also one of our NSIS speakers, provides a readable and well explained tutorial for all. The author provides on the one hand a glimpse into the historical context and, on the other, a look at impact of the latest discoveries. He weaves a narrative in fascinating details about the scientists who have made key contributions. The book is illustrated by 11 informative figures/diagrams, several of which would have been more easily understood had they used a whole page.

The book first summarizes what is known about cell structure in eukaryotes and prokaryotes and the genetic code. In the chapter "The Seeds of Symbiosis", we learn how it came to be realised that the organelles mitochondria and chloroplasts, whose ancestors were once free living microbes, became components of animal and plant cells. It seems that this was a result of being ingested but not digested by a host cell via endosymbiosis. This very ancient incorporation of cells is paralleled by more recent associations of a less intimate nature. For these, like the association of algae and fungi in lichens, we use the term 'Symbiosis', first used in a biological context by De Bary in 1878*. The eventual acceptance of the process of endosymbiosis, and the key role that it played in the evolution of eukaryotic organisms, only became recognized in the decades following the publication in 1970 by Lynn Margulis of 'The Evolution of the Eukaryotic Cell'.

Details of the follow up studies are presented and of the scientists who carried out research to test the hypothesis that endosymbiosis was really involved in the evolution of eukaryotic cells, i.e., in the evolution of all higher plant and animal cells. Part of this account includes a summary of the research carried out by Ford Doolittle and his associates at Dalhousie University. Other information came from studies on an anaerobic microbe isolated from a pond in which an elephant carcass had been dumped to decompose behind the Natural History Museum at Oxford University!

As everyone knows from grade 12 biology or first year university, the eukaryotic cell as we see it under the electron microscope is complex and as far as we know, the organisms that bridge the gap between these cells and prokaryotic cells have long gone extinct. However, the likely steps and evidence from both biology and atmospheric sciences are assembled in the book to argue a key role for endosymbiosis. A wide range of organisms are considered including odd parasites such as those found in the urogenital tracts of cats, cows and humans. In the end, the conclusion is that without the evolution of mitochondria, it is inconceivable that complex multicellular organisms like ourselves would exist today.

A chapter on the 'Green revolution' explains how the structure and function of chloroplasts are related to that 'all important' process of photosynthesis. This captures solar energy to produce sugars and release oxygen, the gas we all breath. This was dependent on the establishment of an endosymbiosis between cyanobacteria and a eukaryotic cell and genes were moved to the nuclei of the latter. The overall picture has been elucidated by molecular sequencing of the DNA and RNA in the nuclei and the chloroplasts of plant cells. However, there is biodiversity and evidence that some non photosynthetic eukaryotes, in the past, ingested but not digested whole photosynthetic eukaryotes. These evolved into the red algae, the largest of which we call the red seaweeds. Other fascinating examples of secondary endosymbioses are described, as found in the single-celled flagellate, *Euglena*. These reveal that chloroplasts are organelles that were derived from a single endosymbiotic event that occurred millions of years ago. This was part of a chain of events that 'led to the transformation of the ocean land and atmosphere'.

The penultimate chapter, 'Back to the Future', discusses a series of odd-ball organisms such as *Paulinella* and *Rhopalodi*a; these appear to have captured a photosynthetic cyanobacterium much more recently and which is in the process of becoming integrated with the host, suggesting what may have happened in the case of chloroplasts. Examples are also mentioned of organisms that steal chloroplasts and keep them functional for a period, like sea slugs, and organisms which acquire microbial endosymbionts, such as sap-sucking insects.

The final chapter, 'Epilogue', touches on advances in genetic engineering, the use of microbes like E. coli, and the achieved benefits. But there are problems. In the microbial world, genes are 'coming and going all the time' and 'the emergence of multidrug resistant bacteria by gene exchange concerns us all'. In a final postscript, two recently discovered and strange organisms are noted. One is from a hydrothermal vent in the deep ocean and another, *Monocercomonoides* has eukaryotic characteristics but apparently no trace of mitochondria. This emphasizes the fact that there is still much research to do, especially on deep-sea organisms and much to be learned about the prokaryote to eukaryote transition, the very key to our own existence.

This is a fascinating book and well-worth reading by anyone interested in our biological world.

Note: Within the last couple of years English translations of early pioneering research on Symbiosis by German Scientists have been published and make fascinating reading.

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NSIS COUNCIL

Reports from the Annual General Meeting, May 2017

AGENDA

156TH ANNUAL GENERAL MEETING

5 pm - 1 May 2017

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

1. Minutes of 155th AGM, 2016
2. President's Annual Report (Sherry Niven)
3. Treasurer's Annual Report (Angelica Silva)
4. Editor's Annual Report (Peter Wells)
5. Librarian's Annual Report (Michelle Paon)
6. Lecture Programme for 2017-2018 (Tamara Franz-Odendaal)
7. Proposed Excursions for 2017-2018 (Hank Bird)
8. Science Writing Competition Annual Report (Hank Bird)
9. Publicity Report (Nicole LeBlanc)
10. Webmaster's report (Suzette Soomai)
11. Nominating Committee for 2017-2018 (Sherry Niven)
12. Any Other Business
13. Adjournment

NOVA SCOTIAN INSTITUTE OF SCIENCE

MINUTES OF THE 155TH ANNUAL GENERAL MEETING

2 May, 2016
Dalhousie University Faculty Club

Council Members present: Patrick Ryall (President), Michelle Paon (Librarian), Angelica Silva (Treasurer), Ron MacKay, Linda Marks (Secretary), Peter Wells (Editor), Hank Bird (Excursions and Student Science Writing Competition Coordinator), Zoe Kirste (Student Representative, Dalhousie University), Ilya Kovalko (Membership Officer), Richard Singer, John Young

Members present: Tamara Franz-Odendaal, Judy Bird, Carol Morrison, David Richardson, Mike Sinclair, Robert Cook, Martin Willison, Ian Stewart

Others present: Peter Hennigar, Patricia Hinch

Regrets (Council Members): Sherry Niven (Vice President), Suzette Soomai (Webmaster), Nicole LeBlanc (Publicity Officer)

The President welcomed members and called the 155th Annual General Meeting (AGM) to order. It was noted that the reports, excluding the minutes from last year's AGM, would be passed as a unit at the end of the presentations.

1. Approval of the Minutes of the 154th Annual General Meeting of 4 May, 2015

Motion to accept the minutes of the 154th AGM with one correction and no comments:
Moved: Richard Singer
Seconded: John Young
All in favour: Carried

2. President's Annual Report (Patrick Ryall):

The President referred to the attached report and noted that he would keep his remarks brief.

The President described a successful series of Public Lectures in 2015 2016. The President, as Chair of Lecture Committee, thanked the other members of the committee: Jason Clyburn, Carol Morrison, Ron MacKay, Michelle Paon, Tom Rand and John Young.

The President thanked all Council members for their contributions in 2015-2016. The President noted that in his report he thanked several people individually but he forgot to include Hank Bird for his work on the Student Writing Contest and the NSIS Excursions.

The President reported that $5000 of Dr. Alan Taylor's bequest has been allotted to seven regional libraries. Book plates and cheques have been mailed to six of the libraries. The President will personally deliver a cheque and book plates to the Halifax Regional Library. The libraries are to use the money to purchase popular scientific books and the book plates will recognize the NSIS and Dr. Taylor's contribution. A thank you has already been received from the Cape Breton Regional Library.

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

3. Treasurer's Annual Report (Angelica Silva):
The Treasurer referred to the attached report.

The NSIS has 68 regular, 12 life, 5 student and 16 institutional members. Dues received in 2015-2016 totalled $2,660.

As of 31 March 2016, the net worth of the NSIS was $69,365.24 with $6,588.15 in cash and as of 29 February 2016 $62,777.09 in savings and investments. Details on investments are provided in the Treasurer's report. One investment will mature 15 July 2016.

In 2015 2016, expenses of $7000.82 exceeded revenue of $5002.06. Revenue included memberships ($2660); the 2015 AGM dinner fees ($1035); sales of publications ($890.91) and a royalty payment from Access Copyright ($476.15). The largest expenditures incurred to support, science fairs, the writing competition and lectures/conference sponsorships ($2000); the AGM dinner ($1307.21) and printing costs for the Proceedings, lecture posters and the brochure ($3109.46).

The maturing investment was discussed.

Motion to reinvest $7000 of the $10,000 maturing (July 2016) investment and retain $3000 in cash to cover extra expenses (website and printing):

Moved: Tamara Franz-Odendaal
Seconded: Angelica Silva
All in favour: Carried

The Treasurer's report included a budget projection for 2016 and noted that the projected expenses for 2016-2017 will be higher as the prizes (increased prize money) for the Student Writing Contest were paid after the 2015-2016 fiscal (31 March 2016) year was over. Gifts to nine regional libraries (Dr. Alan Taylor's bequest) will also be paid in 2016-2017 as will expenses to cover a planned website update.

Michelle Paon noted that the budget should also include an expense to print the very popular issue of the Proceedings, the Flora of Nova Scotia. A digital issue is readily available but students in the field require a transportable paper copy. Carol Morrison asked about the journals availability online. Michelle Paon described how to view issues of the Proceedings via Dal-Space.

Discussion arose over declining membership numbers and the payment, and non-payment, of dues among those considered members.
It was suggested that a Treasurer's Committee be formed.

4. **Editor's Annual Report (Peter Wells):**
Editor referred to the attached report.

Volume 48 (2) 2016 of the *Proceedings of the Nova Scotian Institute of Science* was published in April 2016. This volume includes papers on the lives of two distinguished scientists and former NSIS members, Dr. Leo Vining and Dr. Bill Ford. Dr. Vining was a Past President of the NSIS. This issue includes papers presented at the *Sable Island Conference* 2015 that was held at Kings College, Halifax, 1-2 May 2015. Peter Wells worked with the conference chair, Dr. Martin Willison (Dalhousie University), and others to produce the section on the conference. The Friends of Sable Island have agreed to purchase copies of this issue for their membership.

The Editor thanked Gail LeBlanc, the staff at the Killam Library and authors for their work.

Members of the NSIS and scientists in the region are encouraged to submit articles of original research, reviews of Maritime scientific accomplishments and viewpoints on current scientific issues to the Editor.

Discussion ensued concerning the production of hard vs. digital copies of the *Proceedings*. The Editor has heard from members that there is still a demand for paper copies of the journal. Carol Morrison noted that other societies ask members which version they would like to receive. Michelle Paon reported that they can request a user name and password to enable them to access the most recent issue of the Proceedings. Six months after its publication, the most recent issue becomes freely available online, as are all other past issues.

5. **Librarian's Annual Report (Michelle Paon):**
The Librarian referred to the attached report.

The Librarian reported that in 2015 2016, sales of the *Proceedings* yielded $916.46 with 18 copies of the *Birds of Brier Island* and 15 copies of the *Flora of Nova Scotia* sold. The NSIS currently 16 institutional members (one less than last year) and has 85 exchange partners, some of whom still receive print copies of the *Proceedings* (this number of partners is unchanged from last year).

The Librarian reported that she submitted the required forms to Access Copyright and received the 2015 repertoire payment to publishers for $642.37. Editor, Peter Wells, has signed a new Access Copyright agreement which now reflects the nature and online usage of the Proceedings.

The Librarian noted that the NSIS receives journals from exchange partners around the world. For example, between May 2015 and March 2016 118 publications were received.

The Librarian acknowledged and thanked Carol Richardson and the Serials Department staff at the Killam Library who process these materials and make them shelf-ready.

Ron MacKay asked if the NSIS exchange partner publications are generally available at the Killam Library. The Librarian responded that the materials are listed in Nova Net and available on the library shelves.

6. Lecture Program for 2016-2017 – Report of the organizing committee (Sherry Niven):

In the absence of the Vice-President the President presented the report of the Lecture Committee. The lectures for 2016-2017 cover biological and health topics and the lecturers are equally split with regards to gender. In recent years the Council has been endeavouring to increase the profile of the NSIS outside the Halifax area. The November lecture will be held at the Dalhousie Agricultural Campus in Truro or at Acadia University in Wolfville. As well the date for the November lecture has been changed, from the first Monday of the month, to accommodate university reading week.

3 October 2016	**Jock Murray,** Dalhousie University - Multiple sclerosis
14 November 2016	**Stephanie MacQuarrie**, University of Cape Breton - Agricultural use of charcoal or “biochar”
5 December 2016	**John Archibald,** Dalhousie University - The Evolution of cells
9 January 2017	**Hilary Moors Murphy,** Bedford Institute of Oceanography - Whale communication
6 February 2017	**Graham Dellaire,** Dalhousie University - Editing genomes
6 March 2017	**Danielle Cox,** Mount Saint Vincent University- Mathematics in the everyday world
3 April 2017	**Shashi Gujar,** Dalhousie University - Oncolytic viruses

1 May 2017	**Tara Imlay,** Dalhousie University - Declining bird populations

7. Proposed Excursions for 2016 2017 (Hank Bird):
Hank Bird reported that the membership was surveyed as to their interest in 19-20 excursions with eight selected as possible excursions during the summer and fall of 2016. Hank Bird thanked Laura Bennett, Ron Mackay, Michelle Paon, Patrick Ryall, Peter Wells for volunteering to assist in setting up and conducting the excursions.

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

Hank Bird reported that the 2016 contest drew a record number of expressions of intent (47), to submit manuscripts, with a subsequent record of 22 submitted papers (14 undergraduate and 8 graduate). Hank Bird credited the increased interest in the contest to higher awards ($500 undergraduate prize and $750 graduate prize) and the assistance of the student representatives and the Publicity officers who help spread word of the contest.

Hank Bird thanked Stuart Grossert, Ilya Kovalko, Tom Rand, John Rutherford, Patrick Ryall, Richard Singer, Don Stoltz, Peter Wells and John Young who assisted him in judging the papers. Each judge read between 8 and 22 manuscripts.

Hank Bird reported that improvements will be made the "Information to Authors" and in the judging process.

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

9. Webmaster's Report (Suzuette Soomai):
In the absence of the Webmaster, Patrick Ryall reported that at the April Council meeting $1200 was approved for the redesign of the Institute's website. The current website was designed in 2013 and a redesign, using the latest WordPress software, will improve the look and function of the site and also enhance security.

10. **Change to NSIS By-law 6 regarding Honorary Membership:** The President reported that at the last Council meeting in April, Council approved of a revision of By-Law 6 to allow for the election of non-members to honorary membership in the NSIS. This motion is subject to the approval of the AGM. This change to the by-law is sought so that the NSIS may award an honorary membership to Nobel Prize laureate and Nova Scotia born Dr. Arthur MacDonald.

    The current By Law 6:
    Any member distinguished in some branch of science or who has rendered conspicuous service to the advancement of science in Nova Scotia, or to the affairs of the Institute, is eligible for nomination and election as an honorary member. Nominations must be submitted to the Council in writing, be signed by three (3) members in good standing, and be accompanied by a document presenting the reasons for awarding the honour. Election of candidates shall require the support of a majority of Council members.

    The proposed revision of By-Law 6:
    Any Nova Scotian distinguished in some branch of science or who has rendered conspicuous service to the advancement of science, or to the affairs of the Institute, is eligible for nomination and election as an honorary member. For the purposes of this by law, a Nova Scotian is defined as someone who was either born in Nova Scotia or who conducted a substantial part of the work for which the honour is being conferred while resident in Nova Scotia. Nominations must be submitted to the Council in writing, be signed by three (3) members in good standing, and be accompanied by a document presenting the reasons for awarding the honour. Election of candidates shall require the support of a majority of Council members.

    Motion to approve a change to By-law 6:
    Moved: Hank Bird
    Seconded: Richard Singer
    All in favour: Carried

    Mike Sinclair asked about the process. Patrick Ryall referred to the by-law and noted that there are some criteria, which will change with this revision to the by-law, but the process of approval by Council will remain the same.

Council has approved an Honorary Membership to Dr. Mary Anne White.

11. NSIS Sponsorship of Local Scientific Events:
The President noted that this item of business was a carry over from last year's agenda but did report that on the 2 May Council 2016 received a sponsorship request from the Canadian Network for Ocean Education (CaNOE) for $500. CaNOE will host an ocean literacy conference in Halifax in June.

12. Report of the Nominating Committee for the 2016-2017 Council (Patrick Ryall):
The President noted that Zoe Kirste will be leaving Council and thanked her for her work as co-Publicity Officer

The President (as Chair of the Nominating Committee) referred to the attached report.

The Nominating Committee asked the AGM to elect the following to NSIS Council for 2016 2017:

President	Sherry Niven
Vice President	Tamara Franz-Odendaal
Past President	Patrick Ryall
Secretary	Linda Marks
Treasurer	Angelica Silva
Publicity Officers	Nicole LeBlanc
Membership Officer	Ilya Kovalko
Librarian	Michelle Paon
Editor	Peter Wells
Webmaster	Suzette Soomai
Councillor	Hank Bird
Councillor	Victoria Turpin
Councillor	Ron MacKay
Councillor	Donald Stoltz
Councillor	John Young
Councillor	Rick Singer

There were three calls for additional nominations from the floor. As there was "no contest" to the proposed slate of officers it was declared that the nominations be elected by acclimation.

Patrick Ryall noted that Tamara Franz-Odendaal will be new to Council and has kindly agreed to serve as Vice-President. Two student representatives are currently interested in serving on Council as Observers.

Michelle Paon noted that this was Patrick Ryall's second year serving as President.

13. Any Other Business:
Patrick Ryall invited all present to enjoy the Public Lecture at 7:30 PM, following the dinner.

There was no other business.

14. Adjournment:
Motion by Peter Wells to adjourn the 155th Annual General Meeting of the NSIS at 5:55 PM.

Respectfully submitted
Linda Marks
Secretary

REPORTS FROM THE NSIS COUNCIL NOVA SCOTIAN INSTITUTE OF SCIENCE

PRESIDENT'S REPORT 2016-2017

Welcome to the Annual General Meeting for the 156th year of the Nova Scotian Institute of Science! I would like to start the meeting by thanking the 2016-17 Council:

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

Councillors: Hank Bird (lead for Excursions and the Student Science Writing Competition); Ron MacKay; Richard Singer; Donald Stoltz; and Victoria Turpin

Observers: Laura Bennet (Nova Scotia Museum); Alexa Kirste (Student Representative); and Kara MacPhee (Discovery Centre)

It has been an exceedingly busy year for me at work and I very much appreciate Council's understanding and support! I feel honoured to have served as President of one of the oldest learned societies in Canada as the country enters its 150th year.

Public Lectures

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

Oct 3, 2016: Jock Murray (Professor Emeritus, Dalhousie University) *Changing knowledge about Multiple Sclerosis over two centuries: From leeches to the human genome*

Nov 14, 2016: Stephanie MacQuarrie (Cape Breton University) *Reaping Unsown Rewards from Biochar*

Dec 5, 2016: John Archibald (Dalhousie University) *Molecular clocks: Using DNA to infer evolution*

Jan 9, 2017: Hilary Moors-Murphy (Bedford Institute of Oceanography) *Listening in on the deep: the story that whale sounds can tell*

Feb 6, 2017: Graham Dellaire (Dalhousie University) *How to edit a genome*

March 6, 2017: Danielle Cox (Mount Saint Vincent University) *That's Math?!*

April 3, 2017: Shashi Gujar (Dalhousie University) *Oncolytic viruses*

May 1, 2017: Tara Imlay (Dalhousie University) *Where have all the swallows gone?*

Council extends thanks as well to the Museum of Natural History for hosting the October, December, February, March, and April lectures; the Agricultural Campus of Dalhousie University in Truro for hosting the November lecture; Mount Saint Vincent University for hosting the January lecture, and Dalhousie's University Club for hosting the AGM lecture and dinner this evening.

The Institute also co-hosted a lecture at the Halifax Central Library on Jan 5th, by Dr. Ken Johnson (Monterey Bay Aquarium Research Institute) entitled "A global array of robots observing the ocean".

Excursions:

Council organized excursions for NSIS members this past year to McNab's Island, the Annapolis Royal Historic Gardens, to Garrison Brewery (The Science and Art of Making Beer), and the Burke-Gaffney Observatory at Saint Mary's University. Many thanks to Hank, Michelle, and Ron!

Sponsorships and Donations:

NSIS provided financial support for a number of activities and events this past year:

- $250 sponsorship of the reception following the Dalhousie Huntsman lecture November 18, 2016 by Dr. Benjamin Halpern (University of California Santa Barbara);
- $250 sponsorship of the best student poster at the Fishermen and Scientists Research Society Conference (February 23, 2017);

- Cash prizes in our Student Science Writing Competition:

  Undergrad Winner: Zachary Sherker (SFX) *"Predator-induced Shell Plasticity in Mussels Hinders Predation by Drilling Snails"*. ($500 Prize)

  Postgrad Winner: Molly LeBlanc (SMU) "*A Literature Review on the Ecotoxicology and Species-Specific Effects of Contaminated Historical Gold Mine Sites Within Nova Scotia*". ($750 Prize);

- Contributions to nine Nova Scotia Regional Libraries (for a total of $5,000) from Dr. Alan Taylor's bequest to NSIS; and
- $200 ccontributions to three Regional Science Fairs: South Shore, Halifax, and Mi'kmaq.

Honourary Membership:

Council had the honour of granting Dr. Arthur Macdonald an Honorary Membership to NSIS at the ceremony when he was invested into the Order of Nova Scotia in October 2016.

Respectfully submitted,
Sherry Niven
2016-17 NSIS President

TREASURER'S REPORT

NOVA SCOTIAN INSTITUTE OF SCIENCE

April 1, 2016 - March 31, 2017

ASSETS as March 31, 2017	
Bank Account BMO (as of March 31, 2017)	22,993.44(*)
Investments (as of March 31, 2017)	36,389.84
TOTAL ASSETS:	**$59,383.28**

INVESTMENTS (as of March 31, 2017)	
Renaissance High Interest Savings Account (March 31, 2017) @1.0%	10,389.84
Manulife Bank Investment Certificate @2.45% due February 1, 2018	21,000.00
Equitable Trust Company GTD investment @2.15% due May 16, 2017	5,000.00
TOTAL INVESTMENTS as of March 31, 2017	**$36,389.84****

(*) Transferred $10,665.91 to BMO account on March 30, 2017

Cash and cash equivalents (GTD Feb 2, 2017 $10,000+$515.91+$150)

NOVA SCOTIAN INSTITUTE OF SCIENCE
REVENUES AND EXPENDITURES 2016-2017

REVENUE as of March 31,2016	
Membership dues Regular	$ 1,950.00
Membership Students	110.00
Membership Institutions	270.00
AGM Dinner (May 2016)	990.00
Sales NSIS Proceedings, Birds of Brier Island, Flora NS	845.00
Donations	20.00
Income/Royalties ACCESS Copyright Royalty	369.24
Field trip/Excursion	391.00
TOTAL REVENUE	**$ 4,945.24**

EXPENSES as of March 31, 2017	
Proceedings printing/ layout PNSIS	$ 2,878.75
NSIS Annual Brochure Lectures	1,202.28
NSIS monthly posters	347.44
Mail PNSIS to members	526.52
AGM Dinner (2016)	1,320.66
NSIS Dr. Taylor’s bequest to NS libraries	4,999.99
Lecture Sponsorships	1,570.09
Nova Scotia Science Fairs	1,000.00
NSIS Writing Competition	1,250.00
Rent cost MNHNS, Dalhousie	133.72
Supplies office, postage (membership, CRA)	53.00
Website	140.00
Field trip/ excursion	560.00
Bank charges	17.40
TOTAL EXPENSES	**$ 15,998.86**

Finances

The net worth of NSIS is $ 59,383.28 as of March 31, 2017 from a total of $ 22,993.44 at BMO account plus current Investments of $ 36,389.84.

For this past 2016-2017 period, NSIS had a total income of $ 4,945.24 that resulted from Membership regular, students, and institutions ($2,330); plus revenue from AGM dinner ($990), Sales of Proceedings PNSIS, Flora of Nova Scotia, Birds of Brier Island ($ 845), donations ($20), Royalties ACCESS ($369.24), Excursions ($ 391). Transference from Investments for a total of $27,464.91 were moved into BMO account after maturity to covers expenses as planned.

Total expenditures of $ 15,998.86 did result from costs associated to Printing of Proceedings of Nova Scotian Institute of Science (PNSIS) ($ 2,878.75); plus expenses related to communications and publicity that included Annual NSIS Brochures, Monthly posters, Bookplates for Donation to NS regional libraries ($1549.72), mailing PNSIS to members ($ 526.52), AGM dinner ($1,320.66), 1st year (2016) of NSIS Dr. Taylor's bequest to NS Regional Libraries ($4,999), Lecture Sponsorships ($ 1570.09), Regional Science Fairs ($ 1,000), NSIS Student Writing Competition (Molly Leblanc $ 750 and Zachary T. Sherker $500), Space rent ($ 133,72), Supplies and postage office ($ 53), website ($140), Field trip/excursion ($ 560), Bank charges ($17.40).

Membership 2016/2017 and Projected Budget 2017/2018

NSIS had a total of n= 100 individual members (n=79 regular members; n=9 student members and n=12 Life Members) and n=16 Institutional members.

A projected budget for 2017/2018 shows a projected revenue of $ 17,704. 91 and it does already include transfer of $ 10,665.91 from investments to BMO account.

Projected Expenses of $ 15,161 will include costs of printing and production of The Proceedings of the Nova Scotian Institute of Science (PNSIS); NSIS writing Awards to University Undergraduate and Graduate Students ($1,250), Regional Science Fairs (n=10 x $200- $2000); contributions to Science Lectures and Conferences in the Province; costs associated with publicity of Annual NSIS

Brochure with lectures and Membership form; publicity costs of Monthly NSIS lecture posters; Mailing costs to Institutions and NSIS members. Updates to website will also be considered at ~$ 1,500.

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

Respectfully submitted to NSIS AGM 2016-2017 on May 1st, 2017

Angelica Silva PhD
NSIS Treasurer
Angelica.Silva@dal.ca
Angelica.silva@dfo-mpo.gc.ca

EDITOR'S REPORT 2017

Prepared for AGM May 1, 2017

The 2017 Issue of the PNSIS (Volume 49, Part 1) has been published and is available in hard copy (limited printing) and on the websites of the NSIS and Dalhousie University. For the first time, it has a number of Commentaries, and two book reviews, along with regular contributions and selected student papers.

Input is continuing for the next *Proceedings*, to be produced by end of this calendar year or early in 2018.

We are also revisiting and strengthening the Instructions to Authors, and suggesting an Authors Check list, that must be filled in so as to reduce the time required at the final editing and proofing stage of production. We are also checking on the Copyright and determining whether or not to have a signed form for every contributor, to clarify ownership of the articles; the Killam Library is helping with this task.

Producing this journal is largely a volunteer operation; it takes concerted effort over a two month period to produce an issue, once enough papers and other contributions have been reviewed and accepted. We need to reduce this time commitment. As well, we do need more contributions that reflect the annual NSIS lecture program, and the work and concerns of members of the NSIS.

We rarely get feedback on the papers and especially on the Editorials, such as on the points made on the role of the *Proceedings* in the life of the Society, and the importance of the science enterprise to society in the Maritimes. The *Proceedings* are one voice piece of the Society; it would be nice to receive feedback from members and interested members of the public who attend the monthly lectures.

That said, I would like to thank everyone involved in the enterprise - the authors, the Editorial Board, and especially Gail LeBlanc, Production and Layout Editor, and Associate Editor, Dr. David Richardson.

Respectfully submitted by:
Peter G. Wells, Dalhousie University, Editor
April 12, 2017

LIBRARIAN'S REPORT 2016-2017

Prepared for AGM May 1, 2017

It has been a pleasure to serve as the NSIS Librarian during the past year. In this role, I oversee the receipt of journals from NSIS exchange partners around the world. I also work with Killam Library staff members who prepare these journals for the shelves and facilitate access to the online *Proceedings of the Nova Scotian Institute of Science*.

Proceedings of the Nova Scotian Institute of Science

During 2016/2017, sales of the *Proceedings* from the Killam Library's Reference & Research Services office generated $675.00 in revenue (see Appendix A). Of note, 18 copies of the *Flora of Nova Scotia* were sold to university students in a summer course. NSIS Council has decided to reprint this publication because the stock is close to depletion.

The fall of 2016 marked the five-year publication mark for *Birds of Brier Island*. While there remain more than 490 copies in inventory, sales have slowed in the past year. NSIS Council has reduced the price of the book from $25 to $15 to help increase turnover and will give a free print copy of the publication with each new membership. During the fall of 2016, a query from the Ocean Biogeographic Information System (OBIS) international data project prompted NSIS Council to add the *Birds of Brier Island* to the online *Proceedings*, where it can be accessed by bird researchers and enthusiasts from around the world. The electronic PDF link to the publication can be found at the following URL: https://ojs.library.dal.ca/nsis/issue/view/402/showToc

The Killam Library serves as the storage space for unsold issues of the *Proceedings*. A large overstock has accumulated, and most print issues of the journal have experienced no turnover in the past seven years. The potential for future sales of older print copies is slim because all issues of the journal are available online through the DalSpace institutional repository. Because the library is experiencing a shortage of space for its academic collections, the inventory of the *Proceedings* needs to be reduced. Since it appears that an inventory reduction would have very little impact on NSIS revenue, the NSIS Librarian will prepare a plan to address the overstock.

In the spring of 2017, the online Biodiversity Heritage Library (BHL), based at Harvard University, contacted NSIS and asked permission to redigitize the *Proceedings of the NSIS*. The goal would be to provide researchers with additional ways to search the *Proceedings* along with other publications on the BHL electronic platform. NSIS Council is interested in the BHL project and has requested further information. While discussing this opportunity, NSIS Council became aware that it may be time to revisit the Institute's publishing arrangements with its authors. The NSIS Librarian has arranged a June meeting between the Dalhousie Libraries' Copyright Librarian and the NSIS Editor and colleagues to discuss copyright, author rights and the development of a publisher agreement document for the *Proceedings*.

Institutional Members and Exchange Partners

Renewal notices were sent to institutional members in February 2017. With regard to exchange partners, in June 2016 the Institute of Systematics and Evolution of Animals of the Polish Academy of Sciences cancelled its exchange with NSIS. There are currently 16 institutional members and 84 NSIS exchange partners.

NSIS Exchange Journal Collection

NSIS receives journal issues from exchange partners around the world. As an example, from May 2016 to March 2017, 126 journal issues and society publications were delivered to the Killam Library from the Institute's exchange partners. Languages of publication include English, French, German, Italian, and Japanese. These items have been processed and added to the NSIS collection in the Killam Library. On behalf of NSIS, I would like to thank Carol Richardson and the Serials Department staff in the Killam Library who process the exchange journals and make them shelf-ready.

Access Copyright

The NSIS Librarian submitted the required forms to Access Copyright for the 2016 repertoire payment to publishers. NSIS subsequently received a payment of $369.24. Over the past three years, the royalty payment has decreased, partly due to fewer sales of the *Proceedings* and a drop in membership revenue. However Access Copyright licensing revenues have declined as well, which results in less money to distribute to publishers and affiliates. Access Copyright has projected that royalties will drop significantly in the coming year due to the decrease in licensing revenue from educational institutions.

Appendix A: Sales of Proceedings May 2016 – April 2017

Date	**Volume/Issue of *Proceedings of the Nova Scotian Institute of Science***	**# Sold**	**Price**	**Amount Received ($)**
July 2016	Flora of Nova Scotia	18	$35.00	$630.00
September 2016	Proceedings (v.48, pt. 2, 2016)	1	$15.00	$ 15.00
November 2016	Proceedings (v.48, pt. 2, 2016)	1	$15.00	$ 15.00
January 2017	Proceedings (v.48, pt. 2, 2016)	1	$15.00	$ 15.00
Total		21	---------	$675.00

Respectfully submitted by:
Michelle Paon
NSIS Librarian
May 1, 2017

WEBMASTER'S REPORT MAY 2017

Work completed for the month of April 2017 include:

1. General maintenance of the NSIS website.
2. New postings of the monthly lectures.
3. Website redesign:

   A notice for hiring a web designer to redesign the NSIS website was prepared. This process was agreed to at the NSIS Council meeting in March 2017. The notice will be circulated to NSIS members by the NSIS Secretary and posted on the Facebook page by the NSIS Publicity Officer.

   Pending the selection of a suitable candidate, the NSIS website will be redesigned over the summer months and a new website is expected to be available for the start of the 2017/2018 NSIS meetings and lectures.

   The NSIS Webmaster will oversee the redesigning of the website. It is anticipated that the new and dynamic website will require routine technical support to maintain its functions and ensure its security. To this end, the services of a new Webmaster will be sought after the new website is completed.

Submitted by
Suzuette Soomai, Webmaster

STUDENT SCIENCE WRITING COMPETITION 2017

May 2017 Report for the AGM

This year we had 32 students (25 undergrad, 7 postgrad) who expressed interest in participating, and 16 students (12 undergrad, 4 postgrad) submitted manuscripts. These were the second-highest levels of interest and submission in the history of the competition. Thanks to Nicole LeBlanc for help with publicizing the competition to students.

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

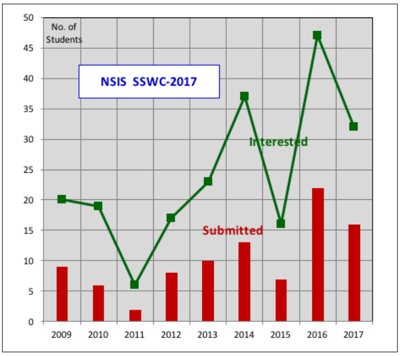
Undergrad Winner:
Zachary Sherker (SFX) *"Predator-induced Shell Plasticity in Mussels Hinders Predation by Drilling Snails"*. ($500 Prize)

Undergrad Hon.Mention:
Amélie Paulin (Dal) *"A Melting World: Consequences of Sea Ice Melt for Arctic Cetaceans*".

Postgrad Winner:
Molly LeBlanc (SMU) "*A Literature Review on the Ecotoxicology and Species-Specific Effects of Contaminated Historical Gold Mine Sites Within Nova Scotia*". ($750 Prize)

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

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



Univ.	Interest	Submitted
Acadia	2	0
CBU	0	0
Dalhousie	20	9
MSVU	1	0
SFX	3	3
SMU	6	4
Total =	32	16

Hank Bird
SSWC Coordinator

NSIS EXCURSIONS 2017
REPORT FOR AGM, MAY 2017

We did 4 excursions in late 2016 and Jan. 2017:

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

Based on a survey of the membership, we selected 5 of the more popular excursions (from a list of 14) to do in the Spring, Summer and Fall of this year. They are:

Petroglyphs and Nature Hike	(Kejimkujik)	Peter Wells
Halifax Planetarium	(Dalhousie)	Hank Bird
Joggins Fossil Cliffs	(Joggins)	Pat Ryall
Shubenacadie Canal	(Shubie Park)	Kara MacPhee
Bedford Institute of Oceanography	(Dartmouth)	Sherry Niven

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

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

Hank Bird
Excursions Coordinator

PUBLICITY REPORT
YEAR IN REVIEW

NSIS goals to increase publicity this year toward our monthly lectures, membership program, excursions, website, and the organization in general were ahieved through printed posters and social media site, Facebook.

Promotional Material

In addition to our annual lecture series brochure, each of the eight talks for the year were promoted through an events section on Facebook, and newly designed event posters which were distributed throughout HRM and via email to members.

This year, we also promoted execurions through a similarly designed poster.

Facebook

Since last May (2016), we saw an increase of 57 "likes" on our page. More recently, many of our "followers' are engaging with our posts related to community events and psychology. We celebrated our 200th like last month; our total likes is now 208.

Engagement is also enhanced by live coverge at each monthly lecture on the event page.

EventBright

A new website to promote our monthly lectures, EventBrite, has been successful in promoting NSIS and our talks while also increasing attendance at lecture events.

To Come in 2017-18

NSIS Council has started the conversation on the re-vamp of the NSIS logo, and offering a Student Ambassador Program to follow with our mission to enhance our relationship with educational instutions within HRM, and to accept volunteers to assist with publicity tasks.

The following are new additions discussed for the 2017-18 year:

1. Membership Cards for paid-members
2. Business Cards for Council Members
3. NSIS Pop-Up Banner
4. Membership Form (Brochure Insert)
5. Live video recordings at NSIS lectures

Submitted by
Nicole Marie LeBlanc
Publicity Officer

NSIS 2017 PUBLIC LECTURES

WHERE HAVE ALL THE SWALLOWS GONE?

Speaker | Tara Imlay

Department of Biology
Dalhousie University

NSIS Free Public Lecture

May 1, 2017

7:30 PM

University Club
Dalhousie University

6259 Alumni Crescent
(*Off South Street*)
Halifax, NS

Over the past 40 years, Breeding Bird Surveys have documented severe and widespread declines among species of aerial insectivores (birds that feed in flight on flying insects). The cause of this decline is unknown, but two likely drivers include changes in the availability of aerial insects during the breeding season, and/or changes in conditions on the wintering grounds and migration routes. Imlay's research focuses on understanding how these potential drivers have impacted four species of swallows that breed in the Maritimes.

Imlay discovered her passion for biodiversity conservation while completing her BSc in Zoology at the University of Guelph. The 20th recipient of the Canadian New Noah training program, Imlay received a course in Endangered Species Recovery at the International Training Centre of the Durrell Wildlife Conservation Trust, and an internship in Mauritius, working with some of the world's rarest species.

NSIS – Nova Scotian Institute of Science   nsis@chebucto.ns.ca   www.nsis.chebucto.org

NOMINATIONS FOR NSIS COUNCIL 2017/2018

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

Observers:

Discovery Centre	Kara MacPhee
Nova Scotia Museum	Laura Bennet

NOVA SCOTIAN INSTITUTE OF SCIENCE
MEMBERSHIP FORM 2018-2019

Please fill out and make copy, then forward in mail together with membership fee.

Name: ____

Address: ____

____

____

Phone: H ____________________ W ____________________

Email: ____

Memberships (please check one):

Regular member $30 _____

Student member $10 _____

Life membership $300 _____

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

Voluntary Donation (Tax receipt will be issued): __________

Mail to:

Attention: Treasurer, Nova Scotia Institute of Science
c/o Reference and Research Services
Killam Memorial Library | 6225 University Avenue
PO Box 15000 | Halifax, NS Canada B3H 4R2

INSTRUCTIONS TO AUTHORS

The Proceedings accept original research papers, commentaries, reviews of important areas of science and science history, student award papers, and book reviews.

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

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

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

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

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

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

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

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

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

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

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

Lee, G.F. (1975). Role of hydrous metal oxides in the transport of heavy metals in the environment. In: Krenkel, P.A. (ed.). Heavy Metals in the Aquatic Environment. Pergamon Press, Oxford, UK. pp. 137-147.

Nielsen, K.J., & France, D.F. (1995). The influence of adult conspecifics and shore level on recruitment of the ribbed mussel *Geukensia demissa* (Dillwyn). *Journal of Experimental Marine Biology and Ecology* 188(1): 89-98.

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

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

PLEASE NOTE:

Authors will receive page proofs and are responsible for correcting them as soon as possible after receipt from the Editorial Board and resubmit to the Assoc. Editor. Particular attention should be made to the correct formatting of references, and to the general formatting of the manuscript. **Submissions not adhering to these guidelines will be returned to the authors.** Authors are responsible for correcting and returning page proofs within 48 hours.

Authors will be provided with a printed copy of the Issue and a PDF of their article, free of charge. NSIS members are able to access the new Issue as soon as published as part of their annual membership. All new Issues of the Proceedings become open access after a six months embargo. All articles are copyrighted with the NSIS, but contributors are free to distribute their articles to interested parties as they wish.

Non-NSIS members will be charged a page charge for their articles - $25/per page, with extra charges for color printing.

Each Issue will continue to be printed for members and other associated parties. Copies of any Special Issues of the NSIS proceedings published in hard copy may also be purchased from NSIS at a charge established by the NSIS. See the website www.nsis.chebucto.org/ for details.