Fisheries and Oceans Canada
Pêches et Océans Canada

Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2023/028

Maritimes Region

Review of Baseline Monitoring within the Musquash Estuary Marine Protected Area

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May 2023

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-48111-1 Cat. No. Fs70-5/2023-028E-PDF

Correct citation for this publication:

Cooper, J.A., Jones, O. and Blanchard, M. 2023. Review of Baseline Monitoring within the Musquash Estuary Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/028. viii + 56 p.

Aussi disponible en français :

Cooper, J.A., Jones, O. et Blanchard, M. 2023. Examen de la surveillance de base dans la zone de protection marine de l’estuaire de la Musquash. Secr. can. des avis sci. du MPO. Doc. de rech. 2023/028. ix + 61 p.

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ABSTRACT

In 2015, DFO released the Musquash MPA Ecosystem Monitoring Plan (2014–2019). This plan, listed twelve indicators to monitor the ecological performance of the Musquash Estuary in support of broad conservation objectives. The objective of this review was to provide advice and recommendations as to the extent that data derived from the plan provides a baseline for detecting changes within the Musquash environment. Twenty-four data sets contained information to support at least one of the twelve indicators for productivity, biodiversity, habitat, and pressure threats. The sampling design for each dataset was reviewed in terms of spatial and temporal variability, as well as observed trends. While progress has been made to identify a baseline of information for each indicator, data gaps persist within the current ecosystem-based monitoring plan that has sought to inform on all key species, trophic groups, habitat types, and environments. The ecosystem approach to monitoring requires a diversity of data needs from multiple stakeholders. Developing a robust data management plan that can track available data and identify important data gaps for future planning and collaboration with stakeholders will improve the assessment of baseline information. This Research Document was presented and peer-reviewed at the Maritimes Region Science Advisory Process held virtually on May 11–12, 2021.

INTRODUCTION

Musquash Estuary is a coastal marine ecosystem located in the Bay of Fundy, approximately 20 km southwest of Saint John, New Brunswick. It encompasses a productive estuary and salt marsh environment that provides habitat for many species of fish, invertebrates and marine plants. It is recognized as one of only a few remaining estuaries in the region that has not been significantly impacted by human development. In addition to its natural attributes, Musquash plays an important role in the heritage of the region. It is believed that Aboriginal groups established seasonal camps along its shores, and both French and United Empire Loyalists established early settlements in the area. Today, the surrounding coastal communities continue to make use of the estuary for fishing, marine plant harvesting, and recreation.

In 1998, the Conservation Council of New Brunswick, with support from the Fundy North Fishermen's Association, proposed the Musquash Estuary and the surrounding intertidal area as a candidate Marine Protected Area (MPA) under the *Oceans Act*. On December 14, 2006, the Musquash Estuary MPA and Administered Intertidal Area (AIA) received formal designation as a protected area. The estuary's protected status reflects the cooperative efforts of community and government. Fisheries and Oceans Canada (DFO), on behalf of the Government of Canada, is responsible for managing the MPA and AIA in collaboration with the Musquash Estuary MPA Advisory Committee. Members of the Musquash Estuary MPA Advisory Committee represent government, non-government organizations, industry, First Nations and community groups that have an interest in the MPA and AIA.

VALUE OF ESTUARIES AND DEGRADATION IN THE BAY OF FUNDY

Estuaries are considered some of the most productive ecosystems on earth, hosting a range habitat types and supporting a diversity of marine life. They are often surrounded by tidal flats and low-lying coastal grasslands known as salt marshes. Tidal flats provide habitat for an abundance of salt marsh plants, fish species, and rare bird species. Salt marshes that fringe estuaries perform a variety of functions including the filtration of sediment and pollution, buffering of upland areas from storm surges and floods, and the protection of shorelines from erosion. Despite their unique biodiversity and important ecosystem function, more than 85% of the known salt marshes in the Bay of Fundy have been altered or destroyed by humans over the past 300 years.

NATURE OF THE MUSQUASH ECOSYSTEM

Musquash is characterized as large in size with expansive salt marshes and has remained ecologically intact. This estuary's location, shape, and oceanographic characteristics support multiple habitat types (Singh et al. 2000, Singh and Buzeta 2005). Rocky shores at its seaward boundary provide habitat for many fish, invertebrates, and marine plants that shelter within crevices and aggregate on stable substrate to form biogenic structures that are protected from waves and exposure of the tide. Most organisms in the tidal flats of the upper Musquash Harbour live unseen within the sediment with roles in sediment stabilization, nutrient recycling, and as food sources to birds, fish, and invertebrates species. Lastly, the expansive salt marsh that surrounds the Musquash River and smaller tributaries support a variety of plants and insects that attract both nesting and migratory birds with margins that support both fish and waterfowl.

MPA ESTABLISHMENT TIMELINE

The Musquash Estuary was designated as a Marine Protected Area (MPA) under federal legislation (*Oceans Act*) in December of 2006. The process was initiated by non-government organizations and community stakeholders interested in preserving one of the most natural estuaries in the Bay of Fundy. This interest led to the formation of the Musquash MPA Planning Group, which included participants and supporters from the Conservation Council of New Brunswick, the Fundy North Fishermen's Association, DFO, the Province of New Brunswick, and residents of surrounding communities.

MUSQUASH MPA ZONES

The Musquash MPA has been divided into three management zones (Figure 1; DFO 2008) with specific regulations afforded within each:

- MPA Zone 1 consists of the lower region of Musquash River. This habitat is species rich and surrounded by a sensitive salt marsh. Zone 1 is afforded the highest degree of protection and few activities are allowed.
- MPA Zone 2 consists of the lower region of Musquash River, upper Musquash Harbour, and Gooseberry Cove. It is subdivided into two zones. MPA Zone 2A consists of the lower reach of Musquash River and upper Musquash Harbour, and it is the largest zone in the MPA. It is characterized by a mix of soft-bottom sediment and hard-bottom substrate. MPA Zone 2B consists of Gooseberry Cove located at the mouth of the estuary. It is predominantly characterized by gravel substrate. A broader range of activities is allowed in Zones 2A and 2B compared to Zone 1.
- MPA Zone 3 consists of the mouth of Musquash Estuary between Western Head and Musquash Head, and inward to Black Beach. Bottom sediment in the zone is continually mixed by natural processes associated with tides and waves. The largest range of activities is allowed in Zone 3 compared to the other MPA zones.

The AIA consists of the expansive intertidal area that is adjacent to MPA Zones 2A and 2B, and the rocky shores that are adjacent to MPA Zone 3 (Figure 1). The intertidal areas and salt marsh adjacent to Zone 1 are not part of the lands administered by DFO. Activities within the AIA will be managed in a manner consistent with the MPA, and both provincial and federal regulations will be applied to human activities in the AIA to achieve the management objectives.

CONSERVATION OBJECTIVES

Prior to designation as a marine protected area, an ecological overview of Musquash (Singh et al. 2000) identified several key features of conservation value, including commercial and non-commercial fishes, unique habitats, and areas of high biological diversity and biological productivity. With this overview, and applying DFO's national objectives for ecosystem-based management (Jamieson et al. 2001), the management plan and conservation objectives for Musquash (DFO 2008) were adopted in broad terms to ensure *no unacceptable reduction or human-caused modification in*:

A. productivity so that each component (primary, community, population) can play its role in the functioning of the ecosystem by maintaining abundance and health of harvested species;
B. biodiversity by maintaining the diversity of individual species, communities, and populations within the different ecotypes;
C. habitat in order to safeguard the physical and chemical properties of the ecosystem by maintaining water and sediment quality.

While DFO is ultimately responsible for ensuring these objectives are being met, monitoring and protection of the Musquash Estuary MPA was to be achieved collaboratively in cooperation with other regulatory authorities and guided by advice of relevant government departments, First Nations, and local stakeholders, including members of the Musquash Advisory Committee (Cooper et al. 2011, DFO 2011, DFO 2015).

CURRENT STATE OF MONITORING IN MUSQUASH

A five-year monitoring plan was developed that identified twelve indicators for ecosystem components and human activities (Table 1). These include seven ecological indicators that align within conservation of productivity, biodiversity and habitat, as well as five pressures/threats indicators to monitor human activities. These were based on a review of available ecological data and managed activities in the area (DFO 2013b). Consensus of the review indicated that it was currently not feasible or efficient to monitor all ecological aspects of the system. Emphasis for initial monitoring was to establish baselines within existing data gathering activities, and to prioritize new monitoring aligned with perceived pressures and threats. It was recognized that continued monitoring and iterative assessment were the best approach to develop reference points for management.

OPERATIONAL TERMS AND DEFINITIONS

Terms such as *habitat type* (ecotype), *key species*, *trophic group*, and *baseline* were introduced within the Musquash Ecosystem Framework (Singh and Buzeta 2005) and are described further in context of the monitoring data in this review.

Habitat Type

Ecotypes were described by Singh et al. (2000) and used in developing an ecosystem framework for Musquash (Singh and Buzeta 2005). The concept of ecotypes was revised to habitat types listed below using a compilation of aerial photographs, light detection and ranging (LIDAR), multibeam bathymetry, and bathymetric maps (Greenlaw et al. 2014). These habitat types capture major changes in elevation (or depth) and bottom substrate, and they use a scheme that is comparable to other coastal habitats in the Bay of Fundy (Greenlaw et al. 2014). These categories do not necessarily represent water conditions or biogenic structure:

1. Salt Marsh
2. Salt Marsh Panne and Pool
3. Impoundment Salt Marsh
4. Impoundment Salt Marsh Pools
5. Intertidal Flat
6. Rocky Intertidal
7. Sand and Gravel Intertidal
8. Subtidal Mixed Substrate
9. Subtidal Soft Substrate
10. Exposed Coastline

Key Species

The term key species can be associated with a suite of indicator taxa (Pearson 1994) that exhibit criteria, such as being well-known; readily surveyed and manipulated; or have intrinsic importance economically, socially, or legally. Other desirable criteria, such as occurring over a broad geographical range; being specialized to the habitat of interest; or have patterns of change reflected in other taxa (Pearson 1994), should also be assessed if known.

A partial list of key species was developed for the MPA (Singh and Buzeta 2005) but not fully assessed for each habitat type. Further consultation was required to identify all of the key/indicator species within each type. In the evaluation of the existing monitoring data where criteria for key species information has not been assessed, the most common, dominant, or species of greatest biomass were listed as well as those of an intrinsic value (commercial, conservation concern, at-risk) for the region.

Trophic Group

Seven trophic groups were considered within the Musquash ecosystem. These are described below with example species within Musquash: Primary producers (P), Scavenger (SC), Suspension feeder (S), Deposit feeder (D), Herbivore (H), Carnivore (C), and Omnivore (O). Examples of species within these trophic groups are identified in Singh and Buzeta (2005). Key species sampled within the existing monitoring data will be categorized into these trophic groups.

Baseline

The term baseline is defined as the usual initial set of critical observations, or data used for comparison, or a control[1]. For this assessment, baseline was considered to be the measurement value(s) that represent the current state(s) or the typical state(s) when spatial and temporal variability are known. The monitoring plan (OCMD 2015) stated that triggers for management action for indicators 1, 2, 4, 5, 6, 7, 10, and 11 would be a statistically significant deviation (change) from baseline variability. These indicators are linked to natural ecosystem components, and a range of measurement values would be expected to represent a typical state.

Several research and stakeholder monitoring activities were previously reviewed and recognized as a starting point for establishing baseline information (Cooper et al. 2014). These included studies on benthic diversity, physical oceanography, sediment profiles, fish community assemblages, bird population surveys, contaminants, and other human threats. Variability within these measurement are anticipated to occur at different scales ranging from hourly/weekly (depending on diurnal cycle, tidal cycle, and weather conditions); spatially (depending on location, depth, habitat type, and habitat preference); seasonally (depending on light, temperature, growth, and species life history); and annually (aggregated changes from year-to-year). Therefore the ability of baseline data to sufficiently to capture this variation is a prerequisite for any management action (trigger) associated with each conservation objective.

OBJECTIVES

The monitoring plan recognized that periodic review and revision would be desired to incorporate new information and adjustments to indicators as required. The aim of this

[1] “Baseline.” Merriam-Webster.com Dictionary, Merriam-Webster. Accessed 14 Dec. 2020.

document is to summarize the currently available data as they could pertain to the 12 indicators listed for the MPA (OCMD 2015). This information can then be assessed against the conservation objectives. To accomplish this:

- Indicators will be compared against data with respect to availability, sampling frequency, and spatial coverage;
- Datasets for each indicator will be evaluated to access whether they are sufficient to establish a baseline for monitoring change;
- Based on observed variability, revisions to the spatial and temporal coverage of monitoring will be reviewed to provide guidance for improving sampling efficacy and efficiency.

This review will help identify data sets, indicators, and monitoring activities that are best suited to inform management on MPA effectiveness and to assess what additional information may be required to evaluate whether the MPA is meeting its conservation objectives.

DATA SOURCES

Twenty-four data sets were identified from published and unpublished sources and were evaluated for sampling frequency, spatial coverage and data availability (Table 2). Data records begin as early as 1974, but most span a period from 1999 to 2018. Many data sets are for one or two years of observation with nine data sets continuing for 5 years or more (Figure 2). Eight of these are considered ongoing and, in most instances, are part of larger-scale monitoring programs that take place both within and outside of the MPA. Fourteen data sets were limited to just one sample period during the year, usually occurring during the summer months. Some datasets sampled during all four seasons and capture seasonal variability (Figure 3). Most datasets provide measurements from more than one management zone and intertidal areas of the MPA, with several also providing comparative information from outside of the MPA (Table 2). Zone 2 was the most intensively sampled, but all zones are represented by multiple datasets (Figure 4). In some instances, the raw data were not readily accessible and a long-term data management plan for the Musquash MPA should be developed to better facilitate periodic reviews and assessment.

ASSESSMENT OF BASELINE

The extent to which each dataset can be used as a baseline for the 12 indicators will be examined through:

a. A review of data for spatial (habitat types, management zones), seasonal (intra-annual), and annual (inter-annual) frequency of sampling.
b. Identify key species (when applicable), sample variability, observed trends, data limitations.
c. Recommendations to improve as a baseline for selected indicators.

PRODUCTIVITY AND BIODIVERSITY

The data for fish, birds, and benthic infauna were applied to both productivity and biodiversity indicators, as this type of monitoring measures species presence as well as changes in abundance and/or biomass for key species. Within the monitoring plan (OCMD 2015), indicators for productivity and biodiversity are stated in context of an ecosystem framework (Singh and Buzeta 2005), with broad attention to key species and trophic levels within all habitat types.

Fish

Nearshore fish data consisted of species presence and abundance sampled twice monthly by beach seine from October 2009 to October 2010 and fyke net from June 2010 to late December 2010 (Ipsen 2013). The objective of this work was to compare year-long nearshore fish communities in three different locations within the MPA, and to assess fish community differences between the MPA and neighbouring estuaries (Ipsen 2013).

Three locations within Zone 2 including the AIA (Figure 5), plus 2 reference locations outside of the MPA at Dipper Harbour and Saints Rest Marsh were sampled (Ipsen 2013).The habitat at Five Fathom Hole was described as rock cobble beach and salt marsh channel; Black Beach as sandy beach surrounded by bedrock; Hepburn Basis as large intertidal mudflat with protected saltmarsh and an outer portion that was more exposed, consisting of rocky outcrops. Locations and description within the MPA can be matched to three of ten habitat types (Greenlaw et al. 2014): sand and gravel intertidal at Black Beach, subtidal soft at Hepburn Basin, and subtidal mixed substrates at Five Fathom Hole. The two locations outside of the MPA were both geographically close and with habitat characteristics similar to those within the MPA. The site at Dipper Harbour (35 km to the west) had sandy substratum and salinity ranging from 27–30 ppt during summer (Ipsen 2013). The site at Saint's Rest Marsh (10 km to the east) had muddy substrate and water salinity of 21–28 ppt during summer (Ipsen 2013). Substrate at Dipper Harbour site were comparable to Black Beach and Saint's Rest Marsh site comparable to Hepburn Basin. In contrast, mean salinity at Saint's Rest Marsh were closer in range to Black Beach.

Data were collected throughout the year up to twice per month for 12 months. As only one complete year of sampling was planned for this project (Ipsen 2013), the nearshore fish data does not contain information to assess annual changes (Table 3).

Prior to Ipsen (2013), twenty-three species of fish had been catalogued within the MPA (Singh et al. 2000). Most of these were associated with subtidal mud and sand ecotypes; four were also associated with the saltmarsh panne or subtidal rocky ecotypes (Singh and Buzeta 2005). At the three locations sampled by Ipsen (2013), 19 species in 6,934 specimens were observed during the entire sampling period (n = 30). Sixteen species (70%) were those previously catalogued within the MPA. Beach seine appeared to be a more effective method of capture, accounting for 90% of species and with greater abundance compared to fyke net (Figure 6). The top ten species captured by beach seine contributed to 99% of the observations (Table 4). All ten of the most common key species were classified as carnivores (Singh and Buzeta 2005), having varied diets consisting of marine worms, insect larvae, crustacean larvae, eggs, zooplankton, and other small fish.

The presence and relative abundance of these species were consistent with similar coastal studies conducted within the Northwestern Atlantic (Ipsen 2013). In terms of ecological guilds, the Atlantic Silverside was the most abundant resident estuarine species. Other species such as American Smelt, Three-spined Stickleback, Blackspotted Stickleback and Winter Flounder represent nursery species (Ipsen 2013). All ten species exhibited high variability (aggregation) in the number observed per sample. This is likely associated with changes in observed abundance throughout the sample year noting peaks in late summer and autumn (Figure 6).

Three species of conservation interest, American Eel (*Angullia rostrata*), Atlantic Cod (*Gadus morhua*), and Lumpfish (*Cyclopterus lumpus*), were recorded infrequently or rarely within the MPA (Table 5). Eight other conservation fish species listed by The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and/or listed through the *Species at Risk Act* (SARA) were not observed in this data set (Table 5). Although these species are known to occur within the Bay of Fundy coastal region, sampling location (habitat type), season, and gear type are important aspects of catchability. An absence of these within the existing nearshore fish data for the MPA should not be used as a baseline without further investigation to target these species.

Multivariate analysis of nearshore fish communities were previously conducted at several scales that considered the effects of location, gear type and season, both within the MPA as well adjacent coastal areas (Ipsen 2013). Overall, seasons were the largest source of variation for communities within the MPA (Ipsen 2013). This was associated with the noted peaks in fish abundance and richness during the summer and autumn sampling (Ipsen 2013). Within the MPA, variation in fish community composition showed significant differences across sampling location and season (Ipsen 2013). Species richness was positively correlated with temperature at Black Beach and Five Fathom Hole, and abundance was positively correlated with temperature at Five Fathom Hole (Ipsen 2013). There were no clear relationships between fish abundance and salinity at any location (Ipsen 2013). The study recognised that several unmeasured factors such as turbidity, tidal height, time of day, lunar cycle, food and habitat availability, and anthropogenic disturbances could also play a role (Ipsen 2013). With these observed trends, future fish information should consider both time of year and location of the sample. As there was only one year of data, it is uncertain as to whether the fish community information represents a typical state for these locations on an annual basis. Musquash was not found to have a unique sand and gravel intertidal fish community when compared to either Dipper Harbour of Saint's Rest Marsh (Ipsen 2013). Spatial trends in fish community were observed among Dipper Harbour (west), Black Beach (Musquash, central), and Saint's Rest Marsh (east) that were perhaps related to salinity gradient from the inner to the outer Bay of Fundy (Ipsen 2013). It was recommended that future management and monitoring of fish communities should focus on understanding annual changes through examination of historical information, include additional yearly sampling for fish communities or potential indicator species during periods of peak abundance, and in comparison with information gathered through comparable estuarine monitoring programs throughout Atlantic Canada (Ipsen 2013).

Recommendations:

As a baseline for productivity indicator 1: Total biomass, abundance, and spatial distribution of key species in each trophic level. Although biomass was not reported within this data, changes in the most abundant species, such as Atlantic Silverside, could be used to examine annual changes in productivity. Atlantic Silverside are considered an estuarine resident species and may present less variability compared to transient or migratory species. Improved baseline monitoring would expand sampling in Zones 1 and 3, conduct a survey over multiple years, focus efforts on period of expected peak abundances, and record size-age structure to evaluate annual recruitment. Such a fish sampling plan was developed for annual sampling in Musquash (Ipsen 2016). This was funded in 2018 for four years through Eastern Charlotte Waterways and DFO Coastal Environmental Baseline Program[2] under Canada's Oceans Protection Plan. Data from this project will be available in 2022 and should be assessed to determine its contribution to understanding multi-year changes in nearshore fish communities.

As a baseline for biodiversity indicator 2: Number of species per trophic level within each habitat type. Total estimated species richness was 19 based on a mathematical Michaelis-Menten estimate (Seaby and Henderson 2007) for all three locations for the entire year (n = 30). The observed accumulated number of species within the data represent 100% of the estimated number (Figure 7). This suggested that increased sampling with this method would not likely

[2] Coastal Environmental Baseline Program. Accessed 14 Dec. 2020.

reveal additional species information. However, within each location, only a portion (13 to 15 species) of the total richness was observed (Figure 8). Mathematical estimates of richness for a location is expected to be lower, but higher sample variability at Black Beach and Five Fathom Hole indicates that the number observed was only 62% and 37% of the estimate. This could be improved by increasing the number of samples at each location to the point that the species accumulation curve begins to reach an asymptote. Sampling at Hepburn Basin only occurred during months 5 to 11 and the observed species was close to the overall estimate. This suggested that sampling during periods of peak abundance in late spring to autumn (Ipsen 2013) may be sufficient to observe most of the species that are present versus sampling throughout the entire year. As with fish abundance, a multi-year sampling protocol (Ipsen 2016) is being conducted through the DFO Coastal Environmental Baseline Program to examine changes in species richness over multiple years and at other locations.

As a baseline for biodiversity indicator 3: Number of species-at-risk within the MPA (by each habitat if required). Only three of ten conservation status species were observed (Table 5). None of these are currently listed under SARA Schedule 1 and, therefore, this data does not represent a baseline for fish species-at-risk. In addition, not all of the valued species listed for this region would be expected to be captured with the methods used for nearshore fish communities. Species-at-risk monitoring should target sampling methodologies that are based on species knowledge including habitat preferences and seasonality as opposed to MPA-wide ecosystem monitoring techniques. Novel monitoring techniques such as acoustic receivers to detect tagged species and environmental DNA (eDNA) could be used as targeted but less invasive methods to test for presence or absence of these species within the MPA.

Birds

Bird productivity data has been collected by Bird Studies Canada under the Maritimes Marsh Monitoring Program (MMMP) every summer since 2013. Volunteers record abundance of bird species at fixed locations across the estuary using a standardized North American protocol (Conway 2011). Although 14 locations are identified in the data, only nine contained observations spanning multiple years for the entire time period (Figure 9). The MMMP bird data was collected within Zone 1 of the MPA. Specific habitat types are not indicated within the data, but locations coincide with both salt marsh and pannes within salt marsh habitat types (Greenlaw et al. 2014). Observations are based on combined visual and audio identification to identify cryptic and non-cryptic species. The availability of bird monitoring data within the MPA can be assessed against productivity indicator 1, and biodiversity indicators 2 and 3.

Spatially, the sampling locations are all within Zone 1. Although there are as many as nine locations sampled each year that can be associated with two habitat types, there is some uncertainty in determining a specific habitat observation based on audio only observations. Therefore, the sampling from nine locations should be treated as pooled replicates within Zone 1. Bird information in other zones and associated habitat type are not found in this data set. The sampling design provides observations during the summer only and is not suited to monitor seasonal change. The standardization of the survey using fixed season and location over multiple years offers information to assess annual changes (Table 6).

There are 237 bird species historically catalogued within the Musquash MPA (Singh and Buzeta 2005). Not all species are evenly observed throughout the MPA, in particular those with narrow niche preferences, and those that are migratory, rare, or cryptic (Deichmann 1999). From 2013 to 2017, the MMMP bird data made 1002 observations for 70 different species during 44 sampling dates. The total number of species that were observed ranged from 23 to 46 each year. The top ten most common species make up 73% of the observations (Table 7). The large variance compared to annual mean indicate aggregated data. Environmental measurements such as temperature, cloud cover, and wind were also collected during the MMMP bird monitoring program, but these data are not yet analysed to determine if correlated with changes in observations. Bird trophic types are often subdivided into fine categories depending on range of diets from seeds, nectar, aquatic vegetation, insects, invertebrates, fish, mammals, etc. These were generalized into larger categories comparable with other groups of organisms. The most common birds species observed in the MMMP data set were categorized as omnivore (70%), carnivore (30%), or herbivore (0%) (Table 7).

One hundred species catalogued as regionally “rare” have been observed within the MPA (Singh and Buzeta 2005). Additionally, twenty-four birds with distributions in New Brunswick are listed under SARA Schedule 1. Twelve of either “rare” or SARA-listed species were observed within the MMMP data (Table 8). The other SARA-listed species for New Brunswick have not been observed in Musquash through the MMMP (Table 8). Further work is needed to determine if these other species are expected to be present within the MPA or if the MMMP protocol is appropriate to record these species depending on season and location.

Recommendations:

As a baseline for productivity indicator 1: Total biomass, abundance, and spatial distribution of key species in each trophic level. The annual mean number of observations for the most common species (Table 7) can serve as a baseline of relative abundance for the combined locations in Zone 1 but does not represent productivity. With large sample variance and low sample size (n = 5) the current data would have low power to detect small changes, and additional data on nesting bird populations would be more useful to monitor productivity for these species and trophic level.

As a baseline for biodiversity indicator 2: Number of species per trophic level within each habitat type. Total observed species richness for all years was 89% of the Michaelis-Menten estimate of 79 (Figure 10). This indicated that additional sampling would slightly improve the observed species richness information. In contrast, yearly observations were only capturing 29 to 58% of the total estimated species richness over five years (2013 to 2017), but each year the sampling recorded between 86 to 97% of the annual Michaelis-Menten estimate (Figure 11). Although increased sampling would improve confidence in annual species richness estimate, the sampling appears to be sufficient to observe most of what was estimated on a yearly basis.

As a baseline for biodiversity indicator 3: Number of species at risk within the MPA (by each habitat if required). Seven “rare” and six SARA-listed species were observed within MMMP bird data (Table 8). The American Bittern is considered “rare” and was one of the top ten most common species observed. Observations for American Bittern and Virginia Rail were present every year, while observations for other rare or listed species were less frequent (Figure 12). For most of these species, it is difficult to determine if a sufficient baseline for the presence of these species was established. The MMMP provides multi-annual data on birds within Zone 1 but does not monitor bird populations over different seasons and other zones and habitat types. A survey for SARA-listed birds during known season and habitat preference would improve this baseline.

Benthic Infauna

Benthic infauna diversity and abundance was monitored by DFO Science from 2010 to 2017. Benthic infauna has an important role in nutrient cycling and habitat stabilization for intertidal and subtidal habitats. Benthic methods to study human impacts in the coastal zone (Chang et al. 2017) were adapted for this monitoring. Using a small benthic grab (0.024 m^2), the shallow intertidal flats were sampled from a small vessel three times per year to coincide with the summer, autumn, and winter seasons. Ten locations within each of three hydrographic strata (intertidal, subtidal, channel) within Zones 2 and 3 were sampled per trip. A total of 14 of 24 intended mission dates were conducted over a 6-year period resulting in 401 samples collected to a maximum depth of 18.3 m (Figure 13). This sampling recorded 328 infauna taxa (316,489 individual specimens). The average sediment composition ranged from 69 to 87% silt (< 63 um) and total organic content ranged 3.9 to 4.9% (Figure 14).

The locations that were sampled within Zones 2 and 3 and the AIA of Zone 2 coincide with four of the MPA habitat types: intertidal flat, sand and gravel intertidal, subtidal mixed, and subtidal soft. The consistent high silt composition and total organic content of the grab samples indicate that the small sized grab may be biased to soft bottom and not effective at sampling hard types with either packed sand and gravel or subtidal mixed. Most of the species information is from two softer bottom habitats (intertidal flat and subtidal soft). Seasonally, summer samples were collected most years, but autumn and winter samples were only collected periodically. As a result, there will be more uncertainty for assessing seasonal variation. Summer data were obtained for six years (excluding 2013) and provides information on annual variability (Table 9).

Previously, there were 137 benthic species catalogued within the MPA and expected to be associated with these habitat types (Singh and Buzeta 2005). It was expected that only a subset of these species would be sampled using a small benthic grab in this survey. Organisms such as marine algae, large crustaceans, and fish would have low catchability. The taxon list in the new baseline data are a combination of species and higher taxonomic levels, as often specimens were difficult to identify due to damage or have difficult taxonomy (i.e., nematodes and oligochaetes). A subset of data with valid species-level identification contained 202 species and 193,586 observations. This consisted of small infauna and juvenile epifauna. The ten most abundant species made up 90% of the observations (Table 10).

Infauna species can be loosely associated with multiple trophic groups (carnivore, herbivore, omnivore) but are appropriately categorized by feeding mode. These include filter feeders, grazers, deposit feeders, and detritus feeders. The top ten species observed in this dataset are categorized as either deposit (60%) or filter (40%) feeders, with some overlap with detritus (20%), and grazer (10%) feeding mode (Table 10).

Recommendations:

As a baseline for productivity indicator 1: Total biomass, abundance, and spatial distribution of key species in each trophic level. Abundance of the top ten species is highly variable as indicated by large variance to the mean (Table 10). This means that the data are aggregated with some samples with very high abundances and others with very little or zero. This variability can be attributed to sampling over multiple seasons and years, but sample location (hydrographic strata) would be a main source of variation as this group of organisms is known to have patchy distributions depending on sediment characteristic, currents, and water quality. Baseline information for benthic infauna within Zones 2 and 3 appears to be sufficient to assess the degree to which abundance of species changes among years, season, and sampling strata and similar baseline monitoring should be developed for the channel in Zone 1.

As a baseline for biodiversity indicator 2: Number of species per trophic level within each habitat type. Total species accumulation for all samples reached an asymptote (maximum species richness) at 202 species, greater than the Michaelis-Menten estimate of 195 (Figure 15). Additional sampling would not increase the estimate for total species richness. The accumulated number of species observed within each strata was 58 to 69% of the total observed (Figure 16). Total observed within each strata was close to, or reaching, the estimated species richness (Figure 16). The annual species richness for all species combined varied between 30 and 48% of the multi-year total observed (Figure 17). Incomplete sampling years with data from only summer (2010–11, 2012–13), summer/autumn (2014–15), or only winter (2009–10) showed steep accumulation curves and appear to be under sampled. Sampling thought to be more complete in 2015–16 and 2016–17 still observed only 41%–48% of the total multi-year estimate. This indicated that species communities may be changing from year-to-year or that only a portion of the total species richness can be observed for in a given sample period due to catchability of rare or unevenly distributed species. Combined years for benthic infauna within Zones 2 and 3 appeared to be sufficient to provide an estimate of species richness but annual, seasonal, and strata variability would need to be further assessed. Similar baseline monitoring should be developed for the channel in Zone 1.

HABITAT

Habitat data consist of geospatial characterization of shoreline, bottom type, and biogenic structure, as well as hydrodynamic regime, water quality and sedimentation.

Habitat Map and Updated High Water Boundary

A habitat map and updated high water boundary (Figure 18) was produced for the Musquash Estuary to provide a baseline for total area and location of distinct habitat types (Greenlaw et al. 2014). This map was based on a compilation of geospatial data including aerial photography (2007), light detection and ranging (LIDAR) digital elevation model (2006, 2007), multi-beam sonar (2001), and Canadian Hydrographic Services (CHS) bathymetric charts (2007). The total area and percent coverage for each habitat type was established as a baseline to support habitat indicator 4 (Table 1).

The revised habitat map and high water boundary removed one habitat type, “tidal pools”, due to absence of suitable high-resolution data. Two other habitat types were added, impoundment salt marsh and impoundment marsh pool, and one was renamed to subtidal mixed substrate from subtidal hard as bathymetric information was unable to discern between mixed sand and cobble versus a hard rock bottom. With these changes, there is some mismatch with historical information presented within the original ecosystem framework (Singh and Buzeta 2005).

Although the geospatial data give fine resolution and coverage for all three zones within the MPA and AIA, there is no seasonal or multiyear information to assess baseline variability (Table 11). New data collection with periodic geospatial analysis would assess the amount of relative change over time in order to establish a baseline to monitor the proportion and frequency that habitat is disturbed or lost.

Recommendations:

As a baseline for habitat indicator 4: Total area and location of each habitat type within the estuary and the proportion and frequency that is disturbed or lost. Data on spatial extent of habitat types based on water level and substrate are several years old and may not be represent the present conditions. In order to consider this as a baseline, an assumption would need to be made that these habitat aspects are less variable compared to species assemblages and water quality. There is currently no additional information to support this assumption. Changes in the location and extent of these habitat types should be monitored relative to changing environmental conditions, such as rainfall, sedimentation, sea level rise, storm surge, and land use.

Hydrodynamic and Sediment Regime

Five data sources were identified in assessing baseline for hydrodynamics and sediment regime (Table 2). Four of these were conducted between 1974 and 2010 and previously assessed

(DFO 2013a, Cooper et al. 2014). Additional data were derived from the benthic infauna monitoring that also measured sediment grain size and total organic carbon.

Hydrodynamic inputs into the MPA and estuary arise from several surrounding freshwater sources, ocean currents and tides, rainfall, and storm surge. Freshwater enters from a landward drainage system and exits through the mouth of the estuary. Freshwater discharge has been estimated at 9 x 10^6 cu ft per tidal cycle (Kristmanson 1974). Saltwater discharge has been estimated at 2100 x 10^6 cu ft per tidal cycle (Kristmanson 1974). Changes in freshwater flow has been historically controlled by the Musquash River Hydroelectric Development. This power station was dismantled in 2016, and water level control data have not been assessed. In addition, there are several other freshwater tributaries that contribute to the freshwater and sediment load of the estuary and Musquash Harbour. Data for these tributary sources are also not assessed. A Finite Volume Community Ocean Model (FVCOM) for Musquash (Figure 19) was previously created using sensor data at Five Fathom Hole, at the opening of the harbour, and the adjacent coastline areas (Cooper et al. 2014). The resulting model was considered preliminary with insufficient physical environmental data to determine baseline for freshwater inputs and seasonal changes in discharge. Variable environmental measurements, such as temperature, salinity, oxygen, turbidity, and chlorophyll, should also be considered within a more comprehensive hydrodynamic model (DFO 2013a).

Sediment core samples used to establish a baseline sedimentation rate were taken at three locations within Zone 2 (Figure 20). These indicated a sedimentation rate of 0.5 cm/year (Cooper et al. 2014). This was assessed to be adequate as a baseline for these locations in 2010, but it was recommended that a grain-size survey be repeated over a broader spatial scale within the MPA in order to assess changes spatially and over time (DFO 2013a).

Benthic infauna sampling for productivity and biodiversity (2010–2016) measured grain size and total organic content, as sediment characteristics are important factors to study spatial changes in species composition. This sampling showed that grain size throughout Zones 2 and 3 were predominantly fine silt (grain size < 63 um) with a percent silt fraction averaging between 68 and 82% (Figures 14A). The channel was predominantly silt with the exception of a few samples taken near Five Fathom Hole that contained more sand and gravel. Subtidal and intertidal areas along the margins of the channel exhibited lower silt content, which was replace by fine sand (> 63 um). Total organic carbon averaged between 3.8 to 4.9% (Figure 14B). Variability in both the subtidal and intertidal samples correlated with the lower silt fraction areas that were previously described (Figure 14A). These samples can offer some groundtruth information for remotely obtained multi-beam backscatter data that was used to develop the baseline habitat types (Greenlaw et al. 2014).

There are important limitations to monitoring changes in grain size and organic carbon using the benthic infauna methods. The infauna sampling employed a small grab not suited to penetrate hard mixed substrates, and the data are biased toward finer and softer sediment types. In addition, the top 5 cm of the sample is often disturbed and potentially represents an aggregate for multiple years.

Recommendations:

As a baseline for habitat indicator 5: Hydrodynamic and sediment regime within the estuary (e.g., sediment infilling). In order to establish a reliable baseline for hydrodynamic and sediment regime within the estuary (e.g., sediment infilling), it was previously recommended that a coupled hydrodynamic-sediment transport model should be developed to assess the role of physical drivers such as tide, current, and freshwater inputs (DFO 2013a). The previously assessed sediment rate for one year, is over 10 years old, and is spatially limited to only 3 locations within Zone 2. A finer-scaled hydrodynamic model and expanded sedimentation data would improve knowledge on how sedimentation and habitat could be altered by external factors, such as freshwater inputs, storm surge, rainfall, and tidal events. There is insufficient data for baseline on all scales, seasonal, spatial, and annual variability (Table 12) and insufficient monitoring to determine if there have been any physical changes in the hydrodynamics of the estuary due to either changes in managed inputs (e.g., freshwater control of hydroelectric dam) or broader environmental factors (e.g., rainfall, storm surge).

Temperature and Salinity

Temperature and salinity data have historically been recorded within several different monitoring and research activities. This periodic information has not been consolidated to establish a long-term baseline to report on anomalies or to understand variation associated with location, depth, tide, and season. Ipsen (2013) recorded temperature and salinity at each fish sample location over the course of one year from October 2009 to October 2010. During that study, water temperatures in Musquash ranged from 21°C to −1°C, which are considered more variable than the averages in the Bay of Fundy (highs of around 12°C and lows of 0°C). All seasons except autumn and spring differed significantly in pairwise comparisons (Ipsen 2013). Similarly, salinity variations were directly influenced by season in Musquash, but also by site, due to influx of freshwater (Ipsen 2013).

Since 2015, Eastern Charlotte Waterway Inc. (ECW) has conducted water quality monitoring through the Bay of Fundy Estuaries project[3]. Sampling was designed to monitor for annual changes during the same seasonal time period at 20 fixed locations within Musquash Zones 2 and 3 (Figure 21). In practice, sampling dates ranged from mid-summer to early autumn (Sept 24 2015, Sept 22, 2016, 26 July 2017, and 14 August 2018), which can contribute to variation in annual measurements. For this sampling design, multi-seasonal variability is not captured and there was insufficient data for Zone 1. Spatially Zones 2 and 3 contain 20 fixed stations that are evenly distributed, and the ECW and annual sampling could be compared with historical studies as well as relative changes throughout the Bay of Fundy (Table 13).

Temperature and salinity data had low spatial variance within a year (Table 14). Some annual variability can be attributed to time of year. Lower temperatures in July of 2017 at most locations versus higher temperatures in August 2018 and September 2015, 2016 (Figure 22). This change is typical of coastal temperature rising throughout the summer months. Salinity is variable among years for some locations (Figure 23). Salinity could be influenced by proximity to freshwater sources and rainfall events. Weather variables such as rainfall are noted in the ECW dataset but are not yet assessed for correlations with salinity and temperatures.

Recommendations:

As a baseline for habitat indicator 6: Temperature and salinity in the estuary. There is spatial coverage at 20 locations distributed in Zones 2 and 3, but there is no monitoring within Zone 1. Four years of sampling provide information on annual variability. A longer time series would be desired to monitor annual variability as statistical anomalies over a standard time frame (e.g., 10 years). In addition, these changes would also need to be reviewed against potential drivers, such as sampling season and weather. A multivariate analysis of water quality parameters would be the best approach to assess this information. As this sampling is part of a much larger Bay of Fundy Estuaries project, monitoring changes within Musquash could be compared to other locations for a relative baseline.

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[3] Eastern Charlotte Waterway Bay of Fundy Estuaries

Nutrient Concentration

Since 2015, ECW has conducted annual water quality monitoring through the Bay of Fundy Estuaries project[3]. Nutrient related measurements such as Secchi depth, dissolved oxygen, chlorophyll A, total phosphorous and total nitrogen were also monitored at 20 stations within Zones 2 and 3 (Figure 21). As with temperature and salinity, these nutrient measurements are taken on an annual basis between July and September. Spatial (Zones 2 and 3) and annual variability are captured within this monitoring data, but the significance of seasonal effects has not been evaluated. Spatial variance is generally low relative to the mean (Table 14), with variability among years. Secchi depth could be influenced by weather conditions, such as wave action and tidal state (Figure 24). Dissolved oxygen was less variable from station to station, with some annual changes noted (Figure 25). In several instances, measurement for chlorophyll a (Figure 26) and total nitrogen (Figure 27) were below detectable limits and appear as no sample data. Measurement for total phosphorous were similar among station and years with an occasional increase at some locations in 2018 (Figure 28).

Recommendations:

As a baseline for habitat indicator 7: Nutrient concentration in the estuary. There is spatial coverage at 20 locations distributed in Zones 2 and 3, but there is no monitoring within Zone 1. Five years of sampling provide information on annual variability, but this should be assessed against expected changes due to sampling time of year and weather related factors. As with temperature and salinity, a multivariate analysis of water quality would be appropriate to assess this information. As this sampling is part of a much larger Bay of Fundy Estuaries project, monitoring changes within Musquash could be compared to other locations as a relative baseline.

PRESSURES AND THREATS

Pressure and threats data are metrics associated with human use and environmental impacts related to managed activities. Presently data include records for local fishing activity, presence of aquatic invasive species, shoreline debris, contaminant metals in sediment, and bacterium in surface water.

Commercial Fishing and by-Catch

Commercial fish landings and by-catch information was accessed through the Maritime Fishery Information System (MARFIS). MARFIS collects fishing commercial logbook data for the entire Maritimes fishing region and can include species, landed weight, management zone, and GPS location depending on the logbook requirements. A geographic subset of this data was selected to assess fishing pressure within Musquash and nearby coastal areas (Figure 29). Data for the time period 2006–2018 contained 84,555 records for 30 license types (Table 15). Only 16% of the data records in 9 license types contained georeferenced (latitude, longitude) information (Table 15). The remaining logbook information for the other license types are reported by statistical fishing grid or a fishing management area.

Spatially, the commercial fishery logbook data are limited to Zone 3 and the surrounding areas outside of the MPA. Only a proportion of fisheries licenses in the area report a georeferenced location. The remaining data are at a larger scale than the MPA, either 10 minute statistical grid or fishing landing area depending on logbook requirements. This larger resolution is not appropriate to monitor changes in fishing pressure within the MPA. The MARFIS database does not provide fishery information within Zones 1 or 2, as it is a commercial fishery database and this type of activity is not permitted within these two other MPA management zones. Recreational and aboriginal fishing, that may be permitted, are not contained within MARFIS.

Seasonally, the MARFIS information is based on multiple fisheries that occur throughout the year. Seasonal changes in fishing pressure for a target species and gear types are managed with known start and end dates. As a result, seasonal changes in species and gear types are fixed to these fishing “seasons”. This is useful if pressure on certain species or threats from gear type were identified as priority for monitoring. MARFIS data have been collected over multiple years and are available for fishery pressure monitoring for the area surrounding the MPA since its establishment in 2006 (Table 16).

For the georeferenced landings data, fishing activity was reported only four times within the Musquash MPA Zone 3. This included one report of Sea Urchin landings in 2008 and three Scallop fishery landings in 2009 and 2013. Urchin landings within the MPA amounted to 0.2% of the total landings for the selected area in 2008. Scallop landings within the MPA amounted to 0.3% of the area landings in 2009 and less than 0.5% of the landings in 2013. Although by-catch of Green Crab, Irish Moss, and Monkfish were reported in the Scallop data, no by-catch was reported within the MPA.

Recommendations:

As a baseline for indicator 8: Commercial and recreational fishing catch per unit effort. The absence of georeferenced information in the fishery logs was identified in the previous review, with only the Scallop fishery required to report geographic location within the MPA (Cooper et al. 2014). A degree caution is required to interpret fishing pressures within the MPA. Currently, the MARFIS information could be used as a relative index with respect to the number of reported trips per year, number of species groups per year, and landings per species group relative to total landings for the nearby areas. However, further consultation with local knowledge keepers would help to better determine which fisheries may be of most concern versus adopting a blanket all-fishery approach.

As a baseline for indicator 9: By-catch number per impacted species. Landings of non-target species are reported at the same scale as the commercial landings. As a result, there is uncertainty in the interpretation of MARFIS data and by-catch pressure within the MPA. As with catch, the relative annual trends can be monitored for fisheries that are reported within the MPA boundaries, but further consultation may provide improved methods for evaluating this type of impact within the MPA.

Aquatic Invasive Species

Monitoring for aquatic invasive species in the coastal zone has been conducted within Musquash since 2012 through DFO’s Aquatic Invasive Species Program (Vercaemer and Sephton 2016, Sephton et al. 2017). These surveys target sampling of currently recognized invasive species such as tunicates (*Ciona intestinalis, Botryulllus schlosseri, B. violaceus, Diplosoma listeranium*), bryozoans (*Membranipora membranacea*), Skeleton Shrimp (*Caprella mutica*), and European Green Crab (*Cancer maenus*) (Martin et al. 2011, Moore et al. 2014). Presumably this program would adapt to monitoring other non-indigenous threats if identified through periodic rapid assessment (Martin et al. 2010) or other coastal multi-species surveys (Cooper and Blanchard 2016).

Invasive tunicate species were monitored within the MPA Zone 2 at Five Fathom Hole as well as 13 other locations throughout Southwest New Brunswick (SWNB) (Figure 30). Presence absence of these species is determined by colonization on passive collectors from June to October. Although the invasive bryozoan (*M. membranacea*) was observed throughout SWNB and within Musquash, from 2012 to 2015 invasive tunicates were observed everywhere except at Five Fathom Hole. This would suggested that Musquash is unique, with an absence of invasive tunicates, but further investigation revealed that the Five Fathom Hole location was exposed to low salinity conditions throughout the year due to proximity of freshwater sources (Sephton et al. 2017). Low salinity environment are thought to impact colonization of marine tunicates compared to the other locations within SWNB (Claudio DiBacco, DFO, pers comm.). To test this, tunicate collectors were deployed at new positions within central areas of Zone 2, further away from potential freshwater sources. The revised monitoring effort has yet to be reported.

European Green Crab were also monitored at three locations within the MPA Zone 2 (Figure 31). Green Crab were collected using standard Fukui traps that are deployed for 24 hours. Within SWNB from 2008 to 2013, traps were deployed at 6 to 11 stations including Five Fathom Hole in Zone 2 (2008–2013) and two other MPA locations within Zone 2 (2008–2009). Twenty-four-hour catch rates were monitored periodically throughout the entire year. Green Crab were present at all three locations within Zone 2, with a catch per unit effort that was comparable to other locations in SWNB and the Bay of Fundy area (Vercaemer and Sephton 2016).

Recommendations:

As a baseline for indicator 10: Number of non-indigenous species in the MPA. The Aquatic Invasive Species program has provided a multi-year time series for bryozoans, tunicates, and Green Crab throughout Atlantic Canada. Comparisons could be made on a regional scale, i.e., using species distribution modeling to see how the MPA compares to other areas. It is recognized in the broader program that changes in AIS distribution/abundance within the MPA should take into consideration regional environmental effects, such as temperature and salinity fluctuations/anomalies. The program is adaptive to monitoring emerging non-indigenous species for the region.

Monitoring for AIS should continue within the MPA using a design that is compatible with the broader regional program but with modifications to support the MPA indicator. Changes in monitoring stations within Zone 2 should be reviewed to understand effects of periodic low salinity and the extent to which Five Fathom Hole observations are comparable to other areas within Zone 2 and to the broader SWNB baseline. Additional monitoring for AIS should be expanded to include Zones 1, 3, and the AIA.

Seasonally, the tunicate monitoring data are recorded once per year from collectors deployed between June and October. This coincides with the peak of colonization and early growth for these invasive species. The Green Crab trap monitoring in the Maritimes Region was conducted throughout the year in order to assess seasonal variation (Table 17). The presence of invasive species are not recorded during other seasons, but it is uncertain if this is important in the monitoring design, as the current list of known invasives, if present, generally persistent throughout the year. The presence of new invasive species when observed in other locations should be assessed within the MPA and monitoring revised when appropriate.

Marine (Shoreline) Debris

Since 2010, the Conservation Council of New Brunswick (CCNB) has conducted an annual survey for shoreline debris, dumping, and littering at areas surrounding Black Beach and the shoreline at Gooseberry Cove (Figure 32). Three locations at Black Beach include the swash zone and backshore (Black Beach Proper), an area just above the beach proper, which starts at the beach berm (Black Beach Upper), and an upper hill location (Black Beach Hill). The Gooseberry Cove area encompasses the entire location from swash zone to above the berm.

Sampling for debris has been based on volunteer participation and logistical considerations for accessing shoreline areas within the MPA. Spatially, the total accumulation of debris at the three locations surrounding Black Beach (Zone 2) is different than at Gooseberry Cove (Zone 3). This is important to note as the potential sources vary depending on accessibility from water and land. The CCNB monitoring has the ability to assess changes from different sources (land versus sea). Seasonally the monitoring occurs over several dates from June until December. The data have been collected annually under the same protocols since 2010 (Table 18).

Debris is categorized into eight categories, and the number of items collected and removed are recorded for each sampling date. Due to its accessibility by road, the Black Beach area is open to both offshore debris sources as well as illegal dumping and burning of large debris and household waste. The water accessible beach area and adjacent upland and hillside are included in this data. As a result, metal has been a prevalent category of debris compared to plastics and other categories expected from an offshore source (Figure 33). Gooseberry Cove Beach is located at the west entrance of the Musquash Estuary. The cove and gravel cobble beach is open to strong wave action during stormy weather. Shore access to the beach is via a trail from a narrow gravel road. The road is in poor condition with washouts, holes and intrusive alder growth. As it is harder to access than Black Beach, Gooseberry Cove tends to experience less illegal dumping. Most debris has drifted into the cove with occasional litter from beach users, often in the vicinity of a fire pit. Plastics such as rope, rubber, and small bits of polystyrene are most common types of debris in Gooseberry Cove (Figure 33). There has been a reduction in debris observed for the Black Beach Upper area and a slight increase in debris observed at Gooseberry Cove (Figure 34).

Recommendations:

As a baseline for indicator 11: Degree of human induced habitat perturbation or loss. Sampling has been conducted annually since 2010 and offers information on long-term trends. Although observation effort (like number of sampling dates per year) should be considered in assessing the significance of trends, the ability to identify different sources of debris (i.e., ocean versus land) is an important aspect in measuring the effectiveness of MPA management versus pressures and threats that are coastal wide. There should be some standardization of observation effort as time spent or per area surveyed.

Contaminant Metals

Metals contamination within the MPA have been studied periodically between 2001 and 2012. In October and November 2001, samples were taken from biotic (American Lobster, Blue Mussel) and abiotic (sediment) components in order to establish MPA environmental quality (Chou et al. 2004). The biotic samples were taken in Zone 2 at Five Fathom Hole and Black Beach, and in Zone 3 at Musquash Head and Gooseberry Cove-. Abiotic samples were taken at 14 locations distributed throughout the subtidal areas of Zone 2, Zone 3 and just outside the MPA (Chou et al. 2004). Spatial variation within these two zones indicated higher contaminant levels in both the biotic and abiotic components for the outer harbour that indicated contaminant sources were through currents from upstream coastal activities. In December 2009, core samples were taken at three locations within Zone 2 (Figure 35) to assess sedimentation rate and trace metal concentrations. Additional sediment samples within Zone 2 taken from the benthic infauna monitoring with Eckman grab in February and August 2010 and cores taken in November 2012 (Figure 36) were used to compare against background levels established by The Canadian Council of Ministers of the Environment (CCME) for certain trace metals in the marine environment, and to assess sampling methods appropriate for this type of monitoring (Cooper et al. 2014).

Spatially, there are no metal contaminant data for Zone 1. Within Zones 2 and 3, there is information to assess variability associated with ocean current sources (Chou et al. 2004) but limited data to assess potential land-based sources throughout the MPA. Seasonal variation is insufficient as sampling periods have been sporadic from February to November over a span of several years with no consistent sampling design. Multi-year data are also from different locations using different sampling methods such that annual changes are not well measured (Table 19).

It was noted that samples taken from the Ekman grab in the winter of 2009 would tend to consolidate the upper 5 cm of sediment (Brent Law, DFO, pers. comm.). This type of sampling method would be inappropriate to monitor annual changes in sediment contaminants as the sample depth could be measuring up to a decade of deposition. Core samples taken in 2009 and 2012 would be a more appropriate method to monitor annual changes within the top 0.5 cm (Cooper et al. 2014). It has been previously recommended that methods and locations should be more consistent and monitoring of baseline concentrations can be compared against CCME background levels (Cooper et al. 2014).

Recommendations:

As a baseline for indicator 12: Contaminant (metal) concentration within the estuary. Previous assessment of the available data indicates that trace metal concentrations of bottom sediments collected in the MPA are at, or below, CCME background (Cooper et al. 2014). However, metal contaminants in abiotic and biotic components of the MPA have been measured infrequently. Recommendations for monitoring trace metals have yet to be implemented. It was recommended that four to five stations be sampled yearly as part of a long-term monitoring program (DFO 2013a). Fixed stations should be located throughout the MPA with consideration given to locations previously chosen for down-core trace metal concentrations and geochronology analysis (Cooper et al. 2014). In addition, Lithium normalization (Yeats et al. 2005, Yeats et al. 2011) should be considered to assess potential of anthropogenic sources versus natural background concentrations for this region.

Bacterium

Fecal coliform was first monitored in Musquash as part of the Canadian Shellfish Sanitation Program (CSSP) from 1992 to 2008. This sampling program was implemented to minimize potential health risks associated with consuming shellfish. The CSSP monitored surface water samples taken at 12 stations within Zone 1 and Zone 2 (Figure 37). Sampling occurred either during wet (1992–1999) or dry (1999–2008) weather conditions throughout the spring, summer, and autumn in order to assess variability caused by weather events. ECW- continued the CSSP sampling from 2015 to 2018 within Zone 2, stations 5 through 12 (Figure 37).

Spatial information is available based on several fixed locations within Zones 1 and 2, with no information in Zone 3. Although sampling within Zone 1 has not occurred since 2008, the data collected in Zone 2 over the two time periods are spatially congruent to assess variability at this scale. Seasonal changes are captured over three dates spanning spring, summer, and autumn. There are no data available for winter conditions. Several years of sampling from 1992 to 2008 and again 2015 to 2018 could be used to assess annual variability in the overall bacterium concentrations compared to CSPS shellfish harvest and consumption guidelines and consistency in the seasonal and spatial trends (Table 20).

CSSP data indicate that most locations are influenced by precipitation, with only the most seaside locations in Zone 2 (stations 9 and 10) being less influenced by rain events. Seasonal variation was also influenced by wet weather that periodically increased fecal coliform concentrations over seasonal trends associated with temperature. During dry conditions, fecal coliform concentrations were low, ranging from 2 to 23 most probable number of cells (MPN) per 100 ml and with geometric mean from 2 to 5 MPN/100 ml (Table 21). During wet conditions, concentrations were higher at all but one station ranging from 17 to 350 MPN/100 ml with geometric mean from 7 to 97 MPN/100 ml (Table 22). Under CSSP standards, all locations would be classified as uncontaminated during dry conditions but all but the outermost locations (stations 9 and 10) exceeded the contamination threshold (Median > 14 MPN/100 ml and GMean > 43 MPN/100 ml) during wet conditions. The ECW monitoring data showed similar trends with maximum counts of 5 MPN in dry conditions and 50–80 MPN in wet conditions.

Recommendations:

As a baseline for indicator 12: Contaminant (bacterium) concentration within the estuary. Annual changes in wet versus dry bacterium concentrations can be compared against the existing data, or compared against CCSP thresholds relative to adjacent areas. However, the CCSP thresholds were developed for shellfish harvest management in the coastal zone and not specifically for recreational water quality. Monitoring for this indicator should also consider thresholds that are for protection of public health and safety associated with swimming and other human contact (Health Canada 2012). Changes in bacterium concentration should be assessed against changes in salinity. Fecal coliform bacterium (gram-negative and includes *E. coli*) are known to be sensitive to salinity (Jin et al. 2004) while *Enterococci* sp. (gram-positive) are thought to provide better correlation with human source waste water in the marine environment (Levesque and Gauvin 2007).

SUMMARY

Twenty-four datasets containing productivity, biodiversity, habitat, and pressure threats information from the Musquash Estuary were assessed against twelve indicators in the Musquash MPA monitoring plan (Table 2). The primary focus of the monitoring plan was to establish baseline information for each indicator that often included several ecosystem components. Therefore, sampling design for the datasets were reviewed to the extent that the methods could measure variability for ecosystem components on spatial, seasonal, and annual scales.

This review was challenging when applying monitoring data to indicator terms such as habitat type, key species, and baseline. Improving operational definitions for these terms would facilitate periodic assessment of the monitoring data. Further study on what constitutes a baseline within a natural ecosystem is needed. Elaboration of this concept would improve data collection and interpretation by focusing on more clearly defined parameters for baseline data. This needs to be balanced with what is sufficient to discern changes in trends or status required for management.

DATA AVAILABILITY, SPATIAL COVERAGE, SAMPLING FREQUENCY, SPECIES GROUPS

The data sources were derived from different funding and research programs. As a consequence, the suite of monitoring information under review is somewhat disconnected as a comprehensive monitoring program. As it is likely that a multiple stakeholder approach for Musquash MPA monitoring will continue, the management and science team should seek to improve the MPA data management model. This would improve discoverability and access to raw data and to review changes beyond the original program application. A robust and open data management strategy would also be consistent with current Government of Canada policies on data management.

While there was at least one data source identified under each of the 12 indicators, there were gaps within the broad ecosystem context of all species groups, zones and habitat types. A research and monitoring tracking system would help communicate to stakeholders those ecosystem components that require baseline information and to plan for new or modified monitoring activities in the area.

PRODUCTIVITY AND BIODIVERSITY

Indicators for productivity and biodiversity were evaluated under an ecosystem framework (Singh and Buzeta 2005, OCMD 2015). This framework sought to gather information for key species within all habitat types, and trophic groups. The current information for fish, birds, and benthic infauna provides only partial ecosystem reporting (Table 23). Nearshore fish information covered three of eight habitat types within Zone 2 only. All species recorded in the nearshore data were classified as carnivores. Bird information was representative of four habitat types associated with marsh area (Zone 1 only) but covered a spectrum of trophic categories. Benthic infauna only examined key species in two habitat types within Zones 2 and 3 and represents suspension and deposit feeding organisms (Table 23). As sampling for different species groups requires different designs, equipment, and expertise, it is expect that data derived from a particular study would be limited in ecosystem level coverage. If an ecosystem approach is to continue as a general monitoring objective for productivity and biodiversity, new monitoring proposals should seek to complete gaps in these other habitat types and zones.

Indicator 1: Abundance of key species were used as a proxy for productivity, as biomass was not a metric used within the fish, bird, and benthic infauna datasets. In all instances the abundance data was not adequate for productivity. Abundance information was spatially aggregated with high sample variance compared to the mean. None of the information recorded age or size classes to assess production at a population level. New or revised monitoring will need to consider legitimate metrics for productivity within a marine estuarine environment.

Indicator 2: Species number was used to examine variability in species richness. For fish, bird, and benthic infauna datasets, variability in species are influenced by location and time but also sampling intensity. Species accumulation curves revealed that few samples are unlikely to record all species present. Species baseline measurements will require pooling of samples either spatially or temporally. There was also evidence that species communities are not static as samples that were pooled over long time periods produced higher species richness than what would be observed within a year of intensive sampling.

Indicator 3: Only data from the bird surveys regularly observed species-at-risk. Although the perceived conservation value of indicator 3 (Table 1) is high, assessing the available data against this indicator was problematic. The absence or reduction of species-at-risk in the data does not necessarily reflect a negative result as they may not be a component of the ecosystem. Improved species-at-risk monitoring should be based on surveys that target these species within their predicted location, habitat, and time frame.

HABITAT

Habitat related datasets included geomorphology, sedimentation, hydrodynamics, and water quality such as temperature, salinity, and nutrients. The scales of anticipated variability are different for this range of information.

Indicator 4: Habitat maps based on bottom type and tidal levels may not show significant changes over short periods of time but are probably not entirely static. Frequent monitoring of habitat type may not be necessary, but updated information should be incorporated to better assess variability with respect to indicator 4, the proportion and frequency that habitat type is disturbed or lost (Table 1).

Indicator 5: In the absence of external perturbations, hydrodynamics and sediment regime baseline may also be fairly conserved but monitoring sediment infilling would require coupled hydrodynamic-sediment model. This was previously recommended by Cooper et al. (2014) and would improve understanding of spatial and temporal variability and to pinpoint locations and seasonal periods of interest under a pressures/threats monitoring approach.

Indicator 6 & 7: Changes in water quality such as temperature, salinity and nutrients can be dynamic in a tidal estuary. Large scale changes in temperature can be predicted through seasons, but tidal and weather effects on periodic water quality measurements contribute uncertainty without a large sample. Establishing baseline water quality information in the coastal zone should employ continuous measurement techniques or a long-term standardized sampling protocol to determine the degree to which external events like tide and weather influence these measurements. Despite these challenges, the available data in Zone 2 can be used as a long-term baseline and compared against to similar measurements that are being conducted on a Bay of Fundy scale.

PRESSURES AND THREATS

Several data sources were determined to represent pressure and threats to MPA conservation objectives. These were aquatic invasive species, commercial fisheries and fisheries by-catch, debris, concentration of metals in sediment, and bacterium in surface water. Scale of influence was an important consideration for this monitoring data. Information for aquatic invasive species, fishing pressure and by-catch contained some information within the MPA but monitoring was primarily designed to observe changes on a Bay of Fundy scale. As a result, it was difficult to determine variability and trends within the MPA.

Indicator 8 & 9: Most of the commercial fisheries are reported outside of the MPA, but this is in part due to reporting requirements that are on a scale that is inappropriate for the MPA area. Improved logbooks or other methods to identify fishing and by-catch within the MPA is recommended in order to better evaluate the extent of these pressures.

Indicator 10: Invasive species monitoring should continue within the Aquatic Invasive Species program with some modification in sample location to better assess impacts from low salinity.

Indicator 11: Debris was specific to locations within the MPA, but a proportion could be identified as arriving from outside the managed zones. While the total amount of debris threatening MPA conservation objectives is of concern, management actions would need to consider different debris sources.

Indicator 12: Concentrations of contaminant metal and bacterium within the MPA are assumed to be associated with managed human interactions but also needs further investigation. The degree to which baseline concentrations change within the MPA can be assessed with regular long-term monitoring and appropriate methods. Accumulation of metal contaminants could also be monitored through biological indicators such as resident species. The Atlantic Silverside, regularly observed in the fish survey, has been identified as a candidate species for contaminant monitoring (Doyle et al. 2011). Similarly, changes in bacterium concentration can be assessed with regular sampling that accounts for the known variability in location, time of year, and rain events. Both metal and bacterium concentrations can be assessed against long-term trends within the MPA and compared to national and provincial standards.

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TABLES AND FIGURES

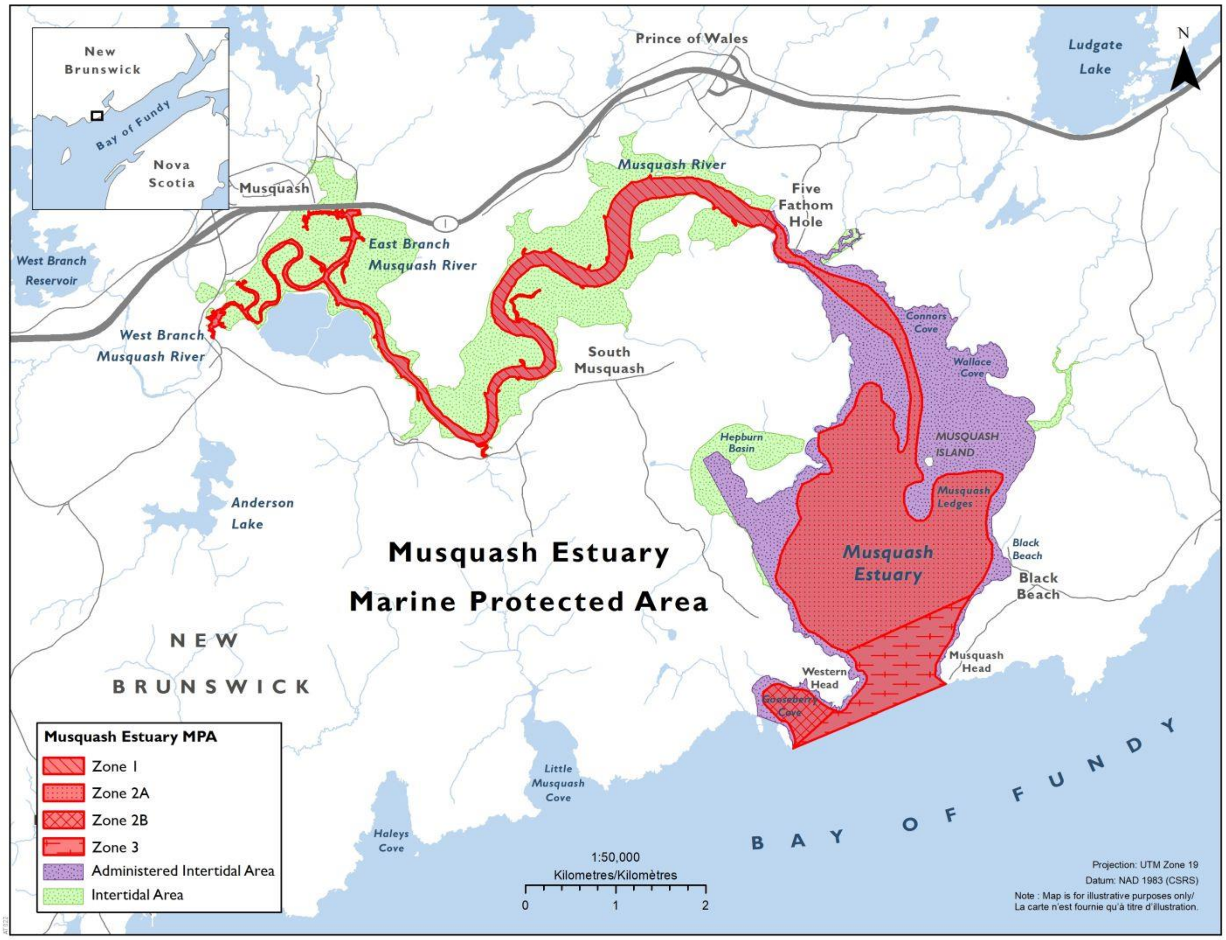

Figure 1. Musquash Estuary Marine Protected Area and its management zones, administered intertidal areas and intertidal areas.

Table 1. Twelve performance indicators were categorized under themes of ecosystem and pressures/ threats (OCMD 2015). These were proposed as a first step to monitoring within the Musquash Estuary MPA with an objective to first establish a baseline of information.

Theme	Indicator Number	Indicator Title
Productivity	1	Total biomass, abundance, and spatial distribution of **key species** in each **trophic level**
Biodiversity	2	Number of species per **trophic level** within each **habitat type**
	3	Number of species at risk within the MPA (by each habitat if required)
Habitat	4	Total area and location of each **habitat type** within the estuary and the proportion and frequency that is disturbed or lost
	5	Hydrodynamic and sediment regime within the estuary (e.g., sediment infilling)
	6	Temperature and salinity within the estuary
	7	Nutrient concentrations within the estuary
Pressures/Threats	8	Commercial and recreational fishing catch per unit effort (CPUE)
	9	By-catch number per impacted species
	10	Number of non-indigenous species in the MPA (within each habitat type if required) relative to non-indigenous species in region
	11	Degree of human induced perturbation or loss
	12	Contaminant concentrations within the estuary

Table 2. Summary of data sources corresponding to at least one of twelve indicators. Sampling duration, season, zone and data availability were reviewed to assess contribution to baseline monitoring within Musquash Estuary MPA. Year with a plus "+" indicate data that continues to be collected. Zones identify MPA management zone (1,2,3), the administered intertidal area (AIA), intertidal area (IA), and if comparative information from other areas within the Bay of Fundy are collected (Outside Zones).

Ind. No.	Dataset Name	Source	First Year	Last Year	Seasons sampled	Zones Sampled	Raw Data Accessed
1, 2, 3	Nearshore Fish Diversity	Ipsen (2013)	2009	2010	Spring, Summer, Autumn, Winter	2(AIA), Outside Zones	Y
	Benthic Infauna Biodiversity	Cooper (unpublished)	2010	2017	Spring, Summer, Autumn, Winter	2(AIA) 2, 3	Y
	Maritime Marsh Monitoring Program	Bird Studies Canada (unpublished)	2013	2017+	Summer	1(IA)	Y
3	Deichmann Bird Survey	Conservation Council of New Brunswick (unpublished)	1999	1999	Summer	1, 2, 3, AIA, IA, Outside Zones	N
4	Habitat Map and High Water Boundary	Greenlaw et al. (2014)	2006	2007	Spring, Summer	1, 2, 3, AIA, IA	Y
5	Kristmanson Tidal Study	Singh et al. (2000)	1974	1974	Spring	2, 3	N
	Law Sedimentation Rate Analysis	Cooper et al. (2014)	2010	2010	Winter, Summer	2, 3	N
	Page Hydrodynamic model	Cooper et al. (2014)	2008	2008	Summer	2, 3, Outside Zone	N
	OMG Current Mapping	DFO (2013)	2001	2001	Summer	1, 2, 3, Outside Zones	N
	Benthic Infauna Grain Size	Cooper (unpublished)	2011	2017	Spring, Summer, Autumn, Winter	2(AIA) 2, 3	Y
	Benthic Infauna Total Organic Carbon	Cooper (unpublished)	2011	2017	Spring, Summer, Autumn, Winter	2(AIA) 2, 3	Y
6	Salinity Survey	Singh et al. (2000)	1999	1999	Summer	1, 2, 3	Y
	Temperature Survey	Singh et al. (2000)	1999	1999	Summer	1, 2, 3	Y
6, 7	Bay of Fundy Estuaries Water Quality	Eastern Charlotte Waterways (unpublished)	2015	2018+	Summer	2	Y
8	Commercial Fishery Logbook	MARFIS	2006	2018+	Spring, Summer, Autumn, Winter	1, 2, 3, Outside Zones	Y
9	Commercial Fishery By-catch	MARFIS	2006	20018+	Fishery dependent	3, Outside Zones	
10	AIS Green Crab	Vercaemer and Sephton (2016)	2008	2015+	Summer	2	Y
	AIS Tunicates	Sephton et al. (2017)	2012	2015+	Summer	2	Y
11	Marine Debris	Conservation Council New Brunswick (unpublished 2012)	2010	2017+	Spring, Summer, Autumn	2(AIA) and 3(AIA)	Y
12	Fecal Coliform	Eastern Charlotte Waterways (unpublished)	2015	2017+	Spring, Summer, Autumn	2	Y
	Canadian Shellfish Sanitation Program	Environment Canada (2008)	1999	2008	Summer	1, 2, Outside Zones	N
	Contaminant Metals	Chou et al. (2004)	2001	2001	Autumn	2, 3	N
	Contaminant Metals	Cooper et al. (2014)	2009	2009	Winter	2	N
	Mackay Water Quality	Singh et al. (2000)	1974	1974	Summer, Autumn	3, Outside Zones	N

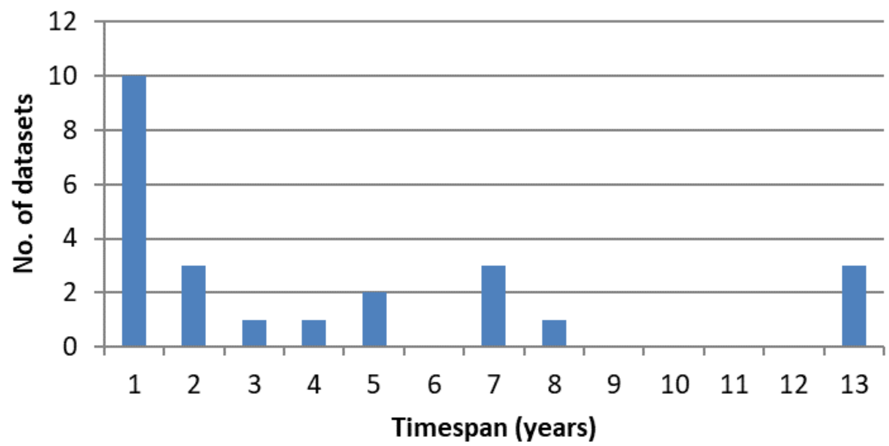

Figure 2. Number of years of sampling contained within each dataset. Note. Eight datasets are identified as annual ongoing.

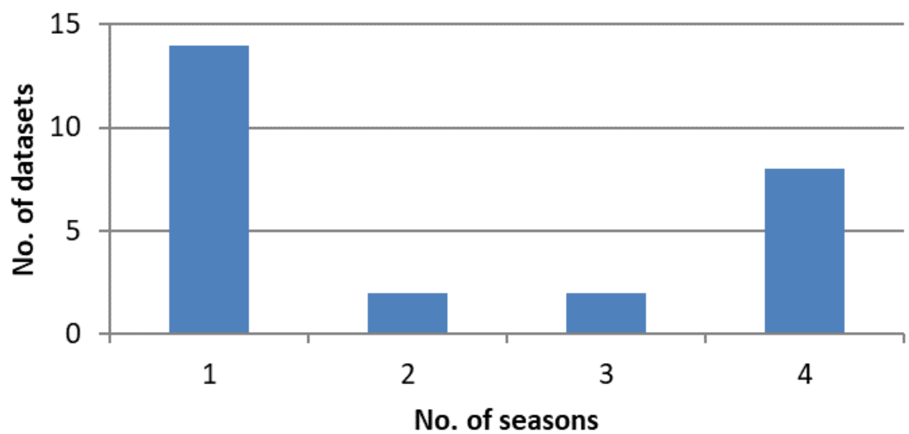

Figure 3. Proportion of datasets with information during a single time of year or multiple times of year to capture seasonal information.

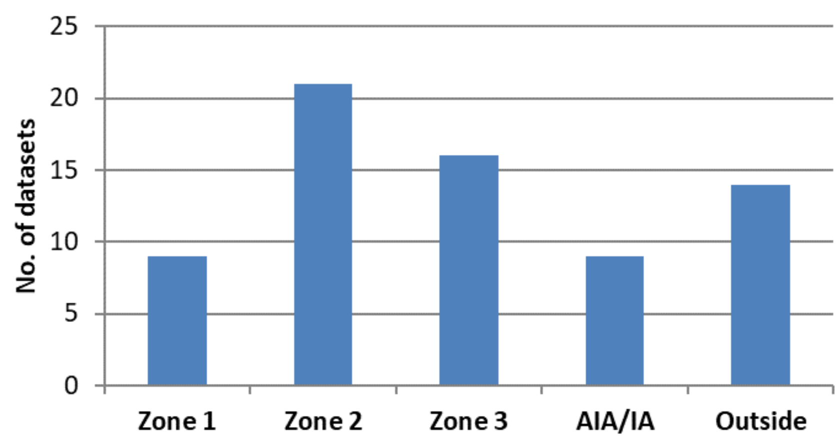

Figure 4. Proportion of datasets that sample within management zones (1, 2, 3), administered intertidal area or intertidal area (AIA/IA), and conduct comparative sampling outside of the MPA.

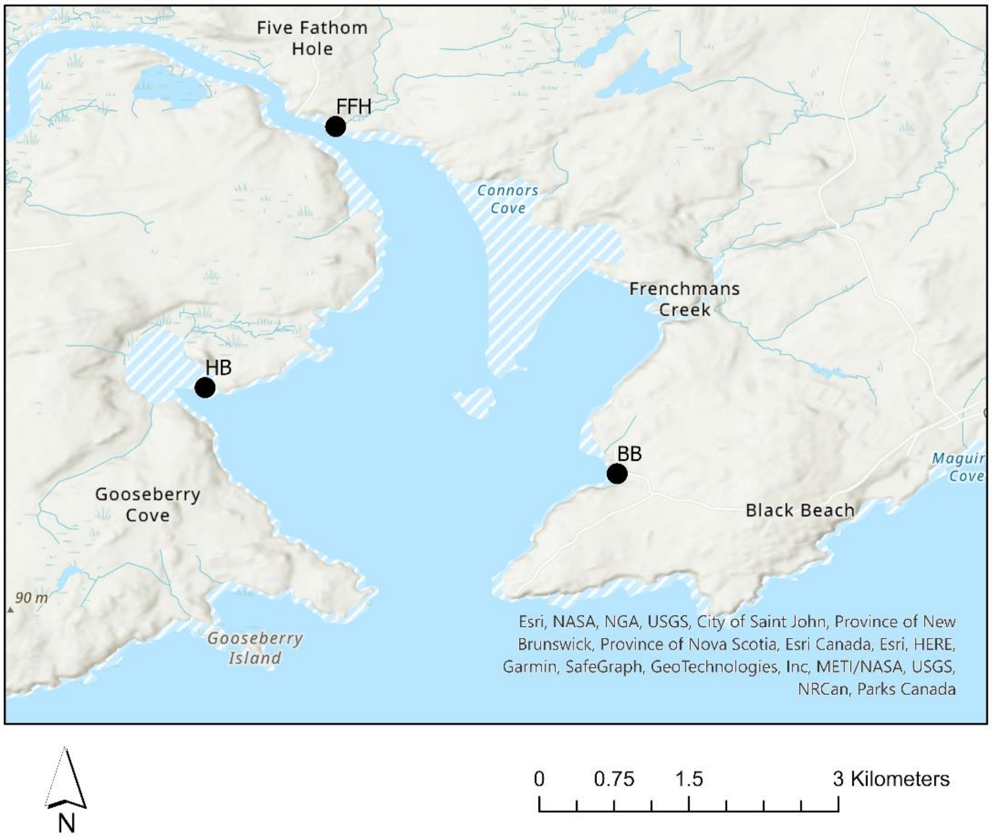

Figure 5. Nearshore fish sampling locations within Musquash (Ipsen 2013). Hepburn Basin = HB, Five Fathom Hole = FFH, Black Beach = BB.

Table 3. Summary of spatial, seasonal, and annual nearshore fish data.

Scale	Status	Frequency
Spatial	Zone 1, 3	No data
	Zone 2 (AIA): Three locations within Musquash Zone 2 (Hepburn Basin, Five Fathom Hole, Black Beach) plus two comparative sites outside of the estuary (Dipper Harbour, Saints Rest).	3 + 2 ref 3 habitat types
Seasonal	Monthly samples between 2009–2010. Sampling frequency and duration variable but sufficient to measure changes in community composition throughout the year. Minimum sample was once per month for five months (most productive months May to October). Maximum sample was twice per month for 12 months.	12 months
Annual	Only 1 year of continuous information as sampling was conducted for 16 months (15 Oct 2009 to 15 Apr 2011).	1

Table 4. Top ten species by observations for beach seine for all locations combined. Mean and variance for daily observations at all locations, n = 30.

Name	Species	Obs.	Trophic level	Mean	Variance
Atlantic Silverside	*Menidia menidia*	3496	Carnivore	116.5	5.00E+04
Blackspotted Stickleback	*Gasterosteus wheatlandi*	872	Carnivore	29.07	1.24E+04
Tomcod	*Microgadus tomcod*	715	Carnivore	23.83	9.71E+02
Smelt	*Osmerus mordax*	606	Carnivore	20.20	3.62E+03
Three-spined Stickleback	*Gasterosteus aculeatus*	591	Carnivore	19.70	6.32E+03
Winter Flounder	*Pseudopleuronectes americanus*	290	Carnivore	9.667	1.45E+02
Pollock	*Pollachius virens*	153	Carnivore	5.10	3.81E+02
Shorthorn Sculpin	*Myoxocephalus scorpius*	111	Carnivore	3.70	1.03E+02
Alewife	*Alosa pseudoharengus*	21	Carnivore	0.70	2.49E+00
White Hake	*Urophycis tenuis*	20	Carnivore	0.6667	4.58E+00

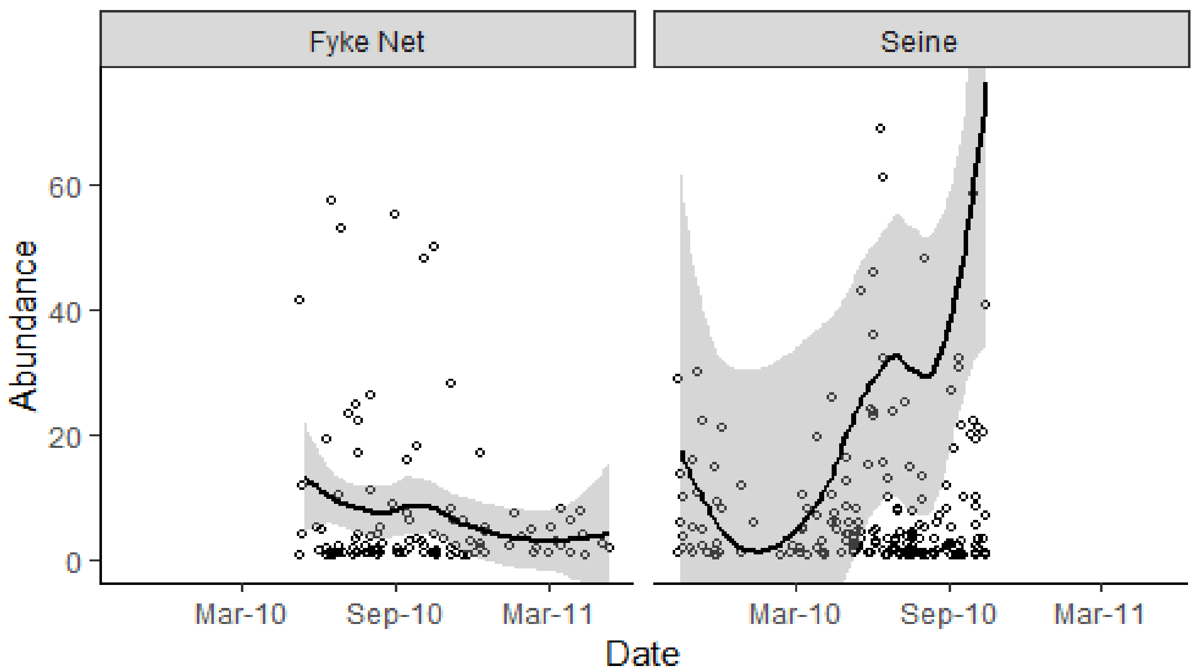

Figure 6. Comparison of Musquash fish catch abundance (individuals per species per set) between fyke net and beach seine methods (Ipsen 2013), with fitted loess smoother. Shaded areas indicate standard error.

Table 5. List of fish species with conservation concern that are known to occur within the Bay of Fundy coastal region. Three of these species were observed in the nearshore fish data with either beach seine or fyke net.

Name	Species	Observations	COSEWIC/SARA Status
American Eel	*Anguilla rostrata*	6	Threatened/No Status
Atlantic Cod (NAFO 4X)	*Gadus morhua*	1	Endangered/No Status
Lumpfish	*Cyclopterus lumpus*	1	Threatened/No Status
Atlantic Sturgeon	*Acipenser oxyrinchus*	0	Threatened/No Status
Atlantic Wolffish	*Anarhichas lupus*	0	Special Concern
Rainbow Smelt (Lake Utopia)	*Osmerus mordax*	0	Endangered/Threatened
Shortfin Mako	*Isurus oxyrinchus*	0	Endangered/No Status
Shortnose Sturgeon	*Acipenser brevirostrum*	0	Special Concern
Smooth Skate	*Malacoraja senta*	0	Special Concern/No Status
Striped Bass (Bay of Fundy)	*Morone saxatilis*	0	Endangered/No Status
Thorny Skate	*Amblyraja radiata*	0	Special Concern/No Status

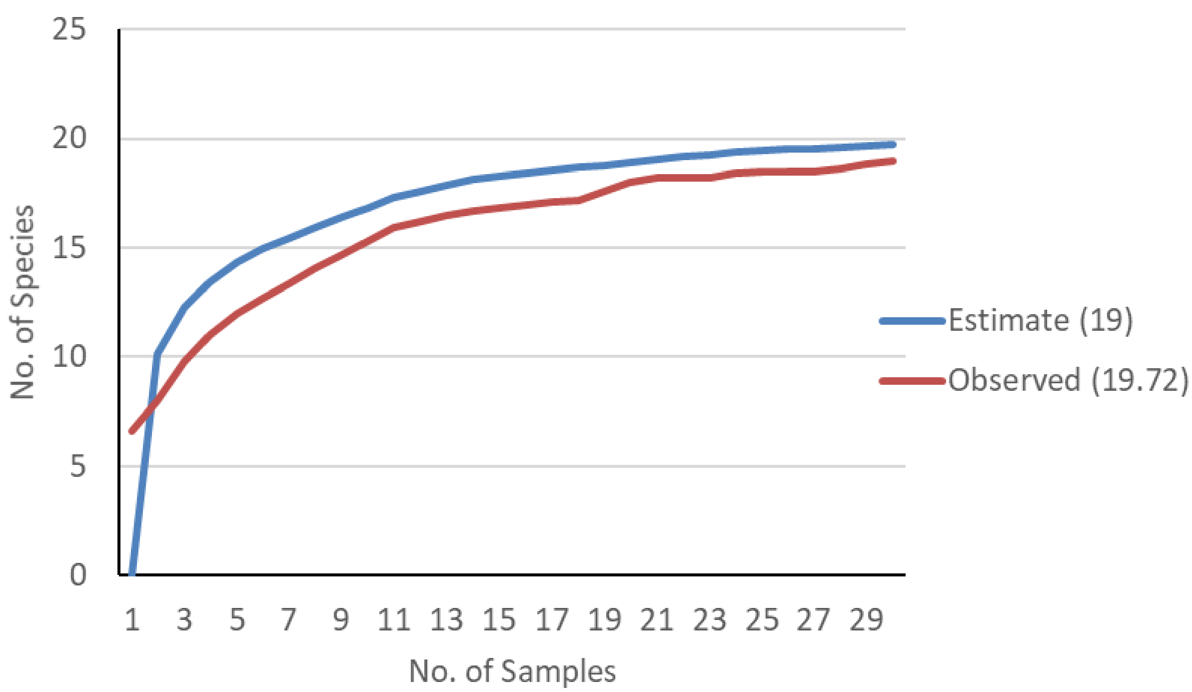

Figure 7. Accumulated total number of fish species observed compared against Michaelis-Menten estimate of species richness.

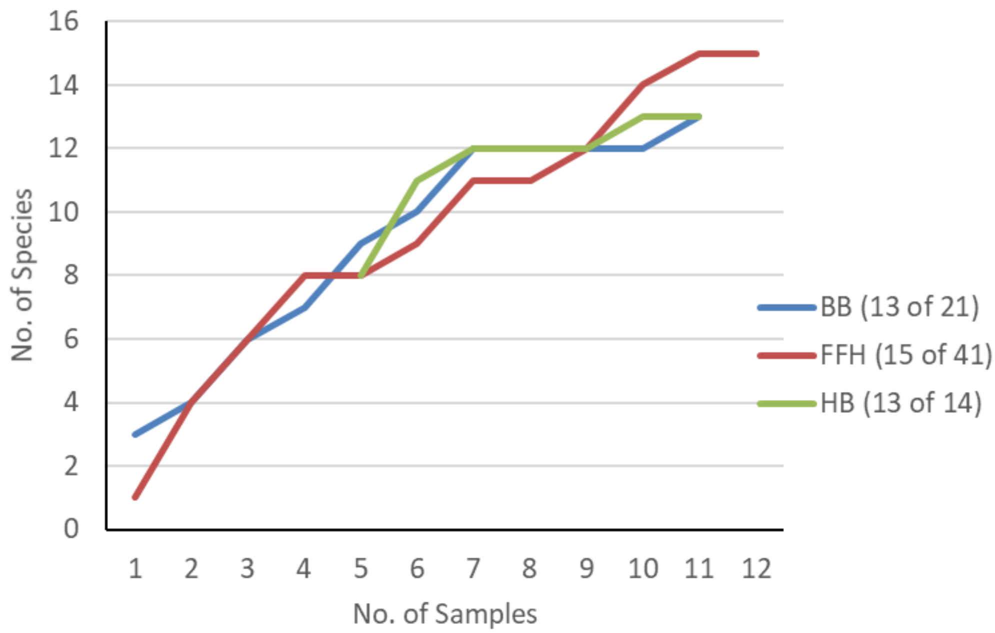

Figure 8. Accumulated number of fish species observed by month for each sample location (BB = Black Beach, FFH = Five Fathom Hole, HB = Hepburn Basin). Numbers in brackets are observed and Michaelis-Menten estimate of species richness for each location.

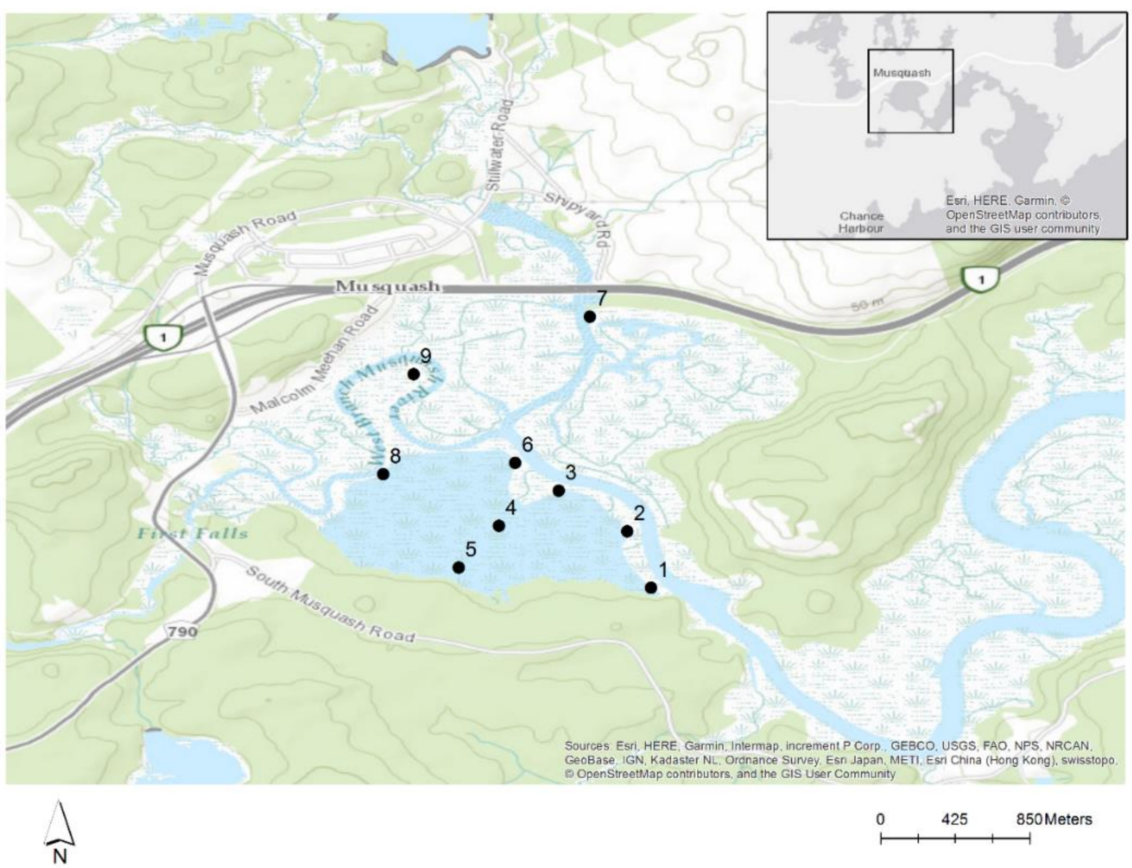

Figure 9. Observation locations for Maritimes Marsh Monitoring Program route NB-51 from 2013 to 2017.

Table 6. Summary of sample design for Maritimes Marsh Monitoring Program bird data.

Scale	Status	Frequency
Spatial	Sampling conducted across nine locations within Musquash Zone 1. Two habitat types but difficult to discern audio observations with specific habitat type.	9 locations 2 habitat types
	Zone 2, 3	No data
Seasonal	All sampling conducted in spring. Dates varied from May 17 to July 11.	1
Annual	Monitoring completed each year from 2013–2017 and is ongoing.	5+

Table 7. List of ten most commonly observed bird species from 2013 to 2017. Observations are the total recorded at all locations for the 5-year time series. Mean and variance of annual observations at all locations, n = 5.

Common Name	Species	Observations	Trophic level	Mean	Variance
Sora	*Porzana carolina*	129	Omnivore	25.8	172.7
Marsh Wren	*Cistothorus palustris*	102	Carnivore	20.4	278.8
Red-winged Blackbird	*Agelaius phoeniceus*	86	Omnivore	17.2	42.2
American Bittern	*Botaurus lentiginosus*	69	Carnivore	13.8	27.2
Nelson's Sparrow	*Ammospiza nelsoni*	69	Omnivore	13.8	65.7
Common Yellowthroat	*Geothlypis trichas*	63	Carnivore	12.6	41.8
Song Sparrow	*Melospiza melodia*	58	Omnivore	11.6	31.3
Swamp Sparrow	*Melospiza georgiana*	56	Omnivore	11.2	11.2
Yellow Warbler	*Setophaga petechia*	54	Omnivore	10.8	35.7
Pied-billed Grebe	*Podilymbus podiceps*	47	Omnivore	9.4	14.3

Table 8. Rare or SARA listed bird species in New Brunswick. Observations are the total recorded sitings at all locations within the 2013 to 2017 MMMP time series. Status is "rare" if reported in Singh and Buzeta (2005) unless SARA Status listed under Schedule 1.

Name	Species	Observations	Status
American Bittern	*Botaurus lentiginosus*	69	Rare
Virginia Rail	*Rallus limicola*	25	Rare
Barn Swallow	*Hirundo rustica*	8	Threatened
Bank Swallow	*Riparia riparia*	6	Threatened
Bobolink	*Dolichonyx oryzivorus*	4	Threatened
Cliff Swallow	*Petrochelidon pyrrhonota*	2	Rare
Least Bittern	*Ixobrychus exilis*	2	Threatened
Northern Harrier	*Circus hudsonius*	2	Rare
Northern Shoveler	*Spatula clypeata*	2	Rare
Baltimore Oriole	*Icterus galbula*	1	Rare
Common Nighthawk	*Chordeiles minor*	1	Threatened
Red-breasted Nuthatch	*Sitta canadensis*	1	Rare
Rusty Blackbird	*Euphagus carolinus*	1	Special Concern
Barrow's Goldeneye	*Bucephala islandica*	0	Special Concern
Bicknell's Thrush	*Catharus bicknelli*	0	Threatened
Canada Warbler	*Cardellina canadensis*	0	Threatened
Chimney Swift	*Chaetura pelagica*	0	Threatened
Eastern Meadowlark	*Sturnella magna*	0	Threatened
Eastern Wood-pewee	*Contopus virens*	0	Special Concern
Eskimo Curlew	*Numenius borealis*	0	Endangered
Evening Grosbeak	*Coccothraustes vespertinus*	0	Special Concern
Harlequin Duck	*Histrionicus histrionicus*	0	Special Concern
Olive-sided Flycatcher	*Contopus cooperi*	0	Threatened
Piping Plover melodus subspecies	*Charadrius melodus melodus*	0	Endangered
Red Knot Rufa subspecies	*Calidris canutus rufa*	0	Endangered
Red-necked Phalarope	*Phalaropus lobatus*	0	Special Concern
Roseate Tern	*Sterna dougallii*	0	Endangered
Short-eared Owl	*Asio flammeus*	0	Special Concern
Whip-poor-will	*Antrostomus vociferus*	0	Threatened
Wood Thrush	*Hylocichla mustelina*	0	Threatened
Yellow Rail	*Coturnicops noveboracensis*	0	Special Concern

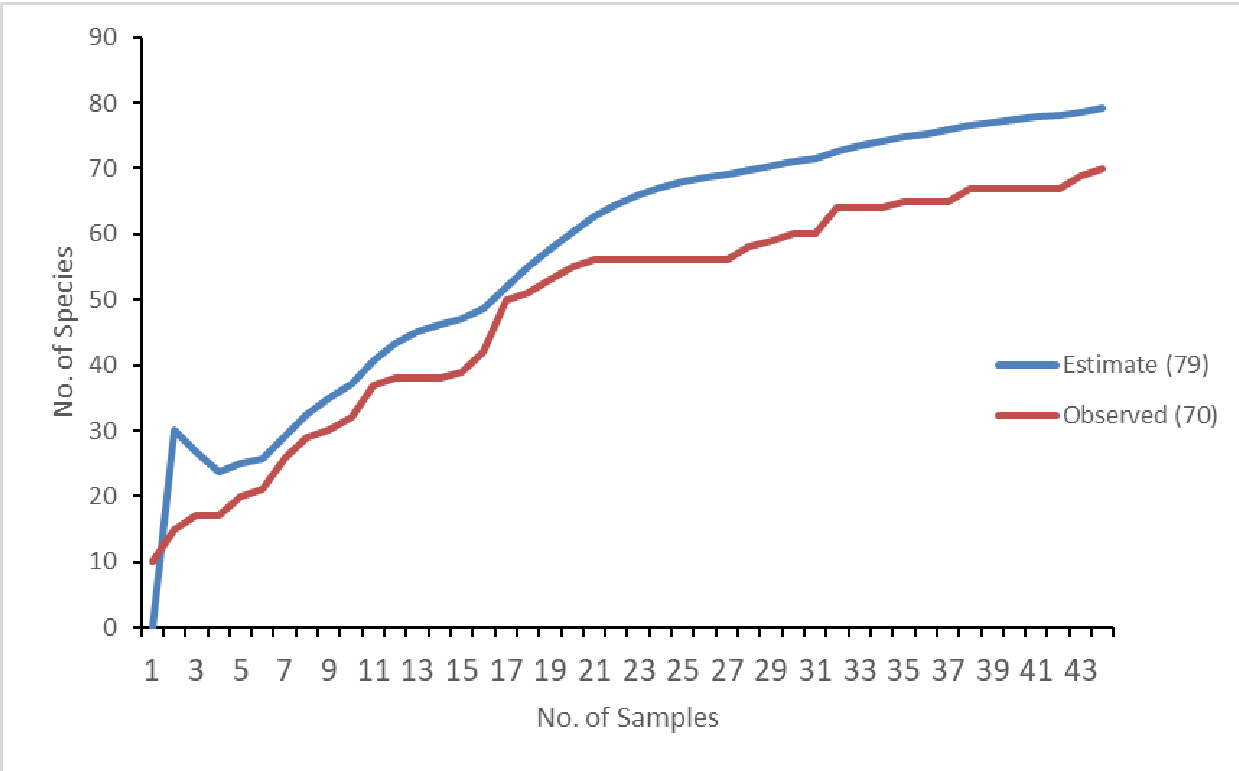

Figure 10. Accumulated total number of bird species observed versus Michaelis Menten estimate of species richness.

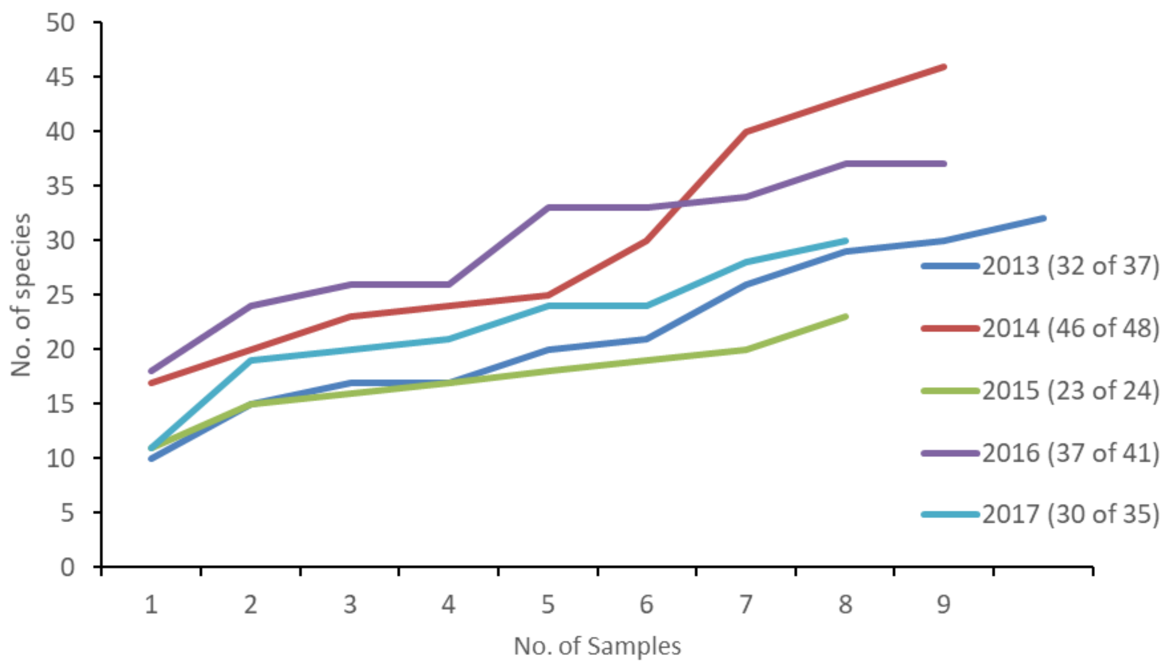

Figure 11. Accumulated number of bird species observed for each sample year, all locations combined, Number in brackets is the Michaelis-Menten estimate for species richness for each year.

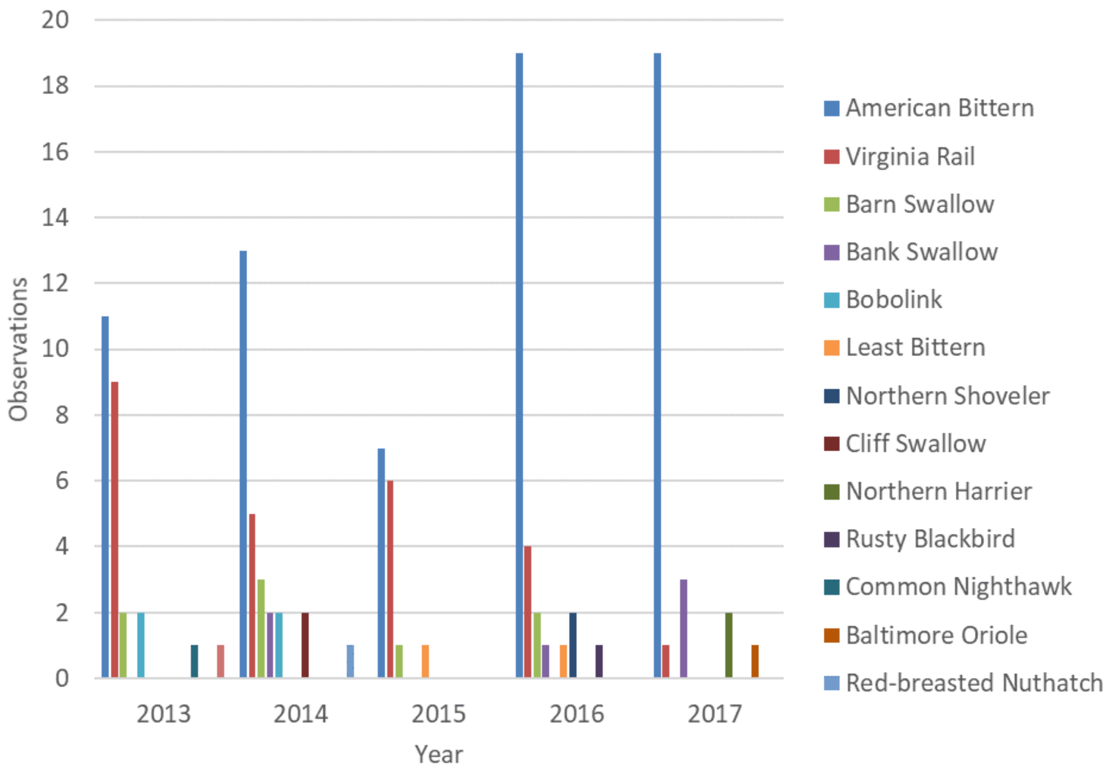

Figure 12. Annual distribution of total observations for "rare" or SARA listed birds within the MMMP data.

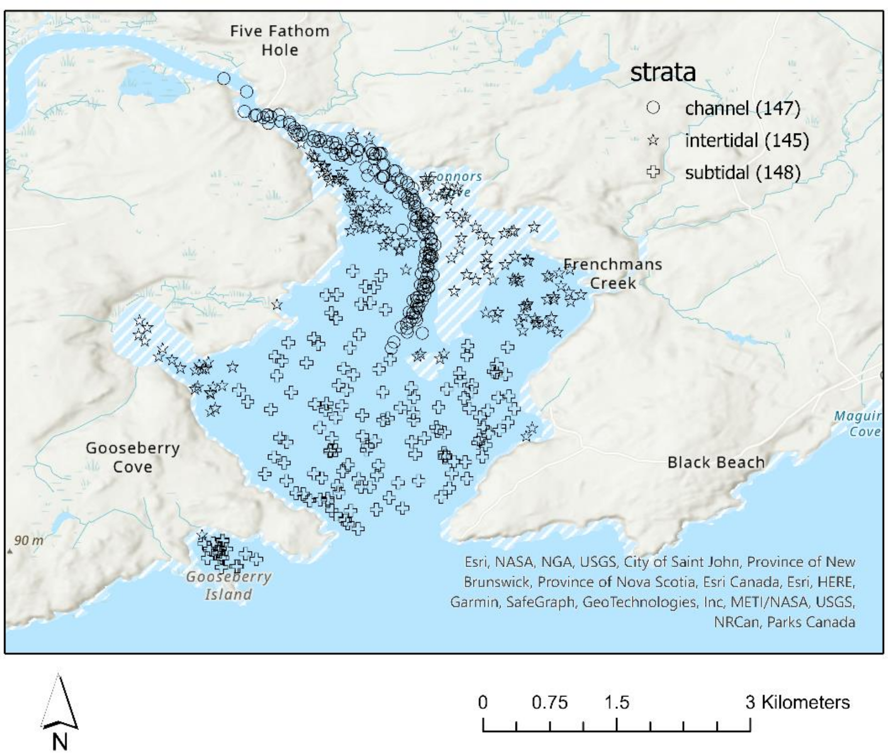

Figure 13. Sample locations for benthic infauna 2010–2017. Locations based on random sampling within three hydrographic strata. The total number of samples are reported in brackets.

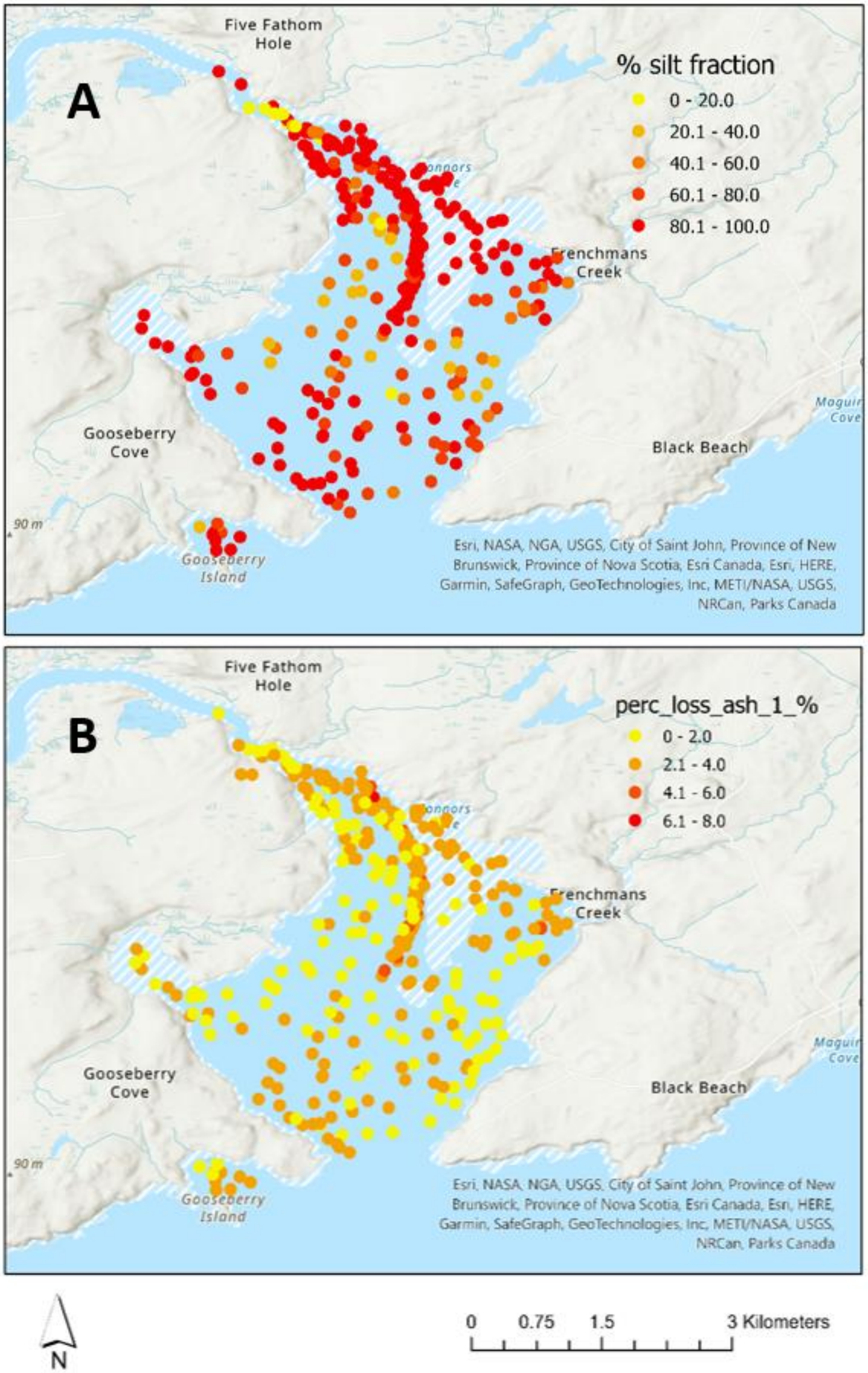

Figure 14. Distribution of sediment composition measured during benthic infauna monitoring 2010–2017. A. Distribution of grainsize expressed as percent silt fraction (< 63 um). B. Distribution of total organic content expressed as percent dry weight loss on ignition.

Table 9. Summary of data for benthic infauna sampling.

Scale	Status	Frequency
Spatial	Zone 1	No data
	Zones, 2, 3, Zone 2 AIA. Ten random locations/sampling date/hydrographic strata (intertidal, subtidal, channel). Two habitat types	30 locations/date 3 hydrographic strata 2 habitat types
Seasonal	Target was three seasonal periods each year (Summer, Autumn, Winter). Actual samples dates were variable depending on tides and weather.	3 (for two consecutive years only)
Annual	Data collected over six years spanning 2010 to 2017. Not all seasons were sampled each year.	6 summer 4 autumn 3 winter

Table 10. Ten most abundance species observed in benthic infauna survey from 2010 to 2017.

Name	Species	Observations	Trophic level	Mean	Variance
Polychaete	*Streblospio benedicti*	63020	Deposit	1616	1.86E+07
Polychaete	*Cossura longocirrata*	43410	Deposit	1113	1.23E+06
Polychaete	*Manayunkia aestuarina*	30720	Filter, Detritus	787.6	6.63E+06
Polychaete (*Pygospio* worm)	*Pygospio elegans*	11220	Deposit, Detritus	287.6	4.53E+05
Bivalve (Atlantic nut clam)	*Nucula proxima*	6647	Filter	170.4	7.14E+04
Polychaete	*Aricidea catherinae*	6414	Deposit	164.5	4.12E+04
Gastropod (minute hydrobe)	*Ecrobia truncata*	4245	Deposit, Grazer	108.8	9.60E+04
Polychaete	*Levinsenia gracilis*	4163	Deposit	106.7	7.50E+03
Crustacean (mud shrimp)	*Corophium volutator*	2780	Filter	71.28	5.45E+04
Polychaete	*Fabricia stellaris*	2142	Filter	54.92	1.17E+05

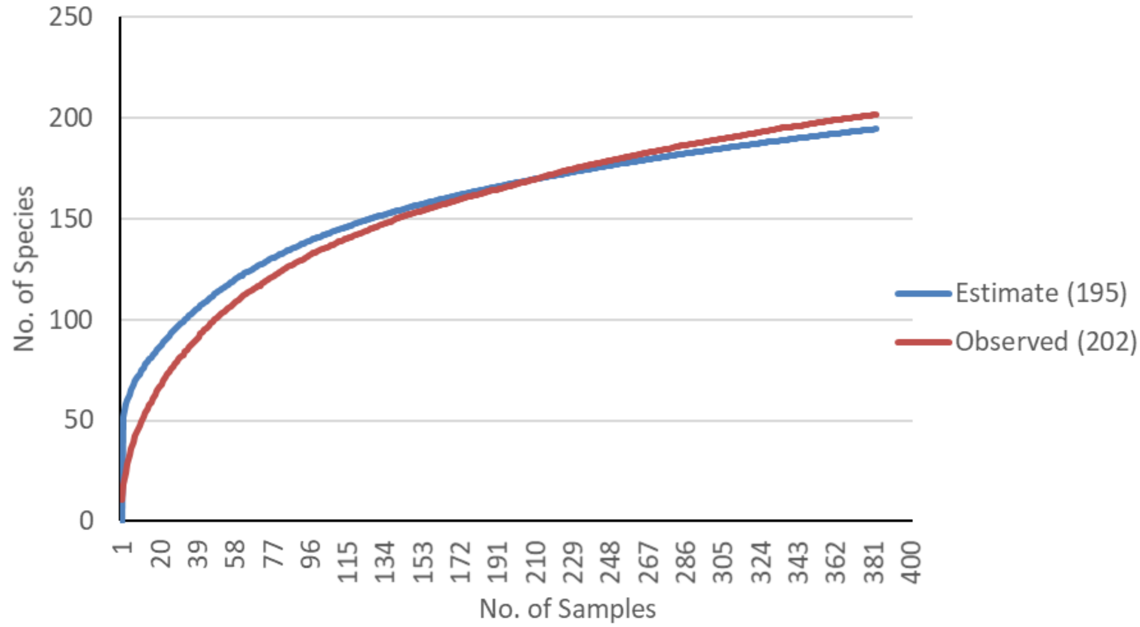

Figure 15. Accumulated total number of observed benthic infauna species (202) against a Michaelis-Menten estimate of species richness (195).

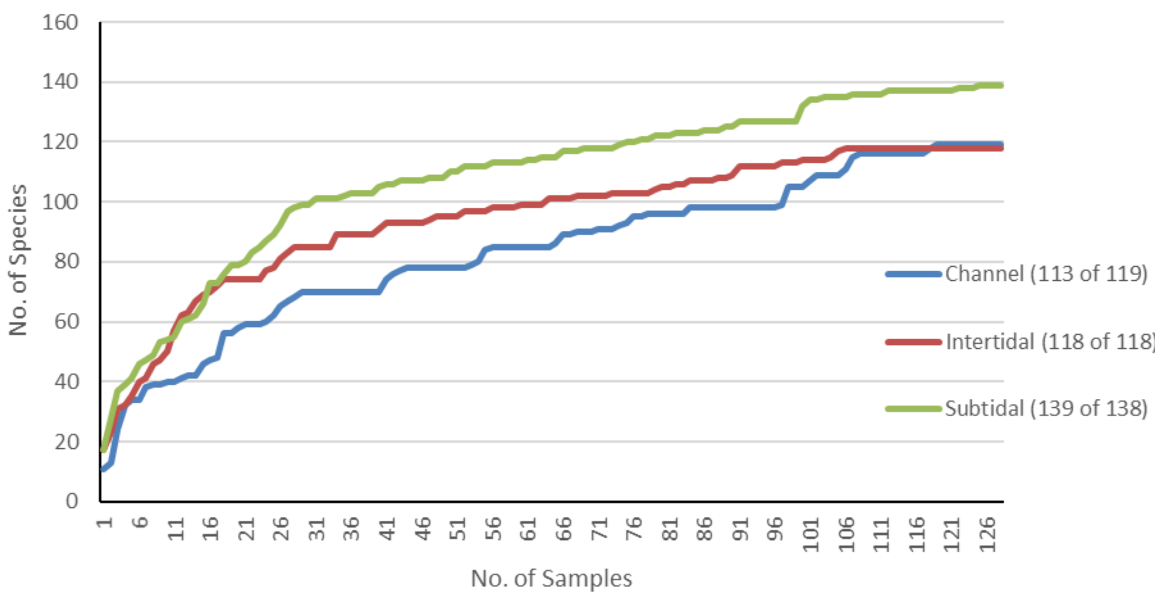

Figure 16. Accumulated number of benthic infauna species observed for each strata, all seasons and years combined. Numbers in brackets are observed and Michaelis-Menten estimate of species richness.

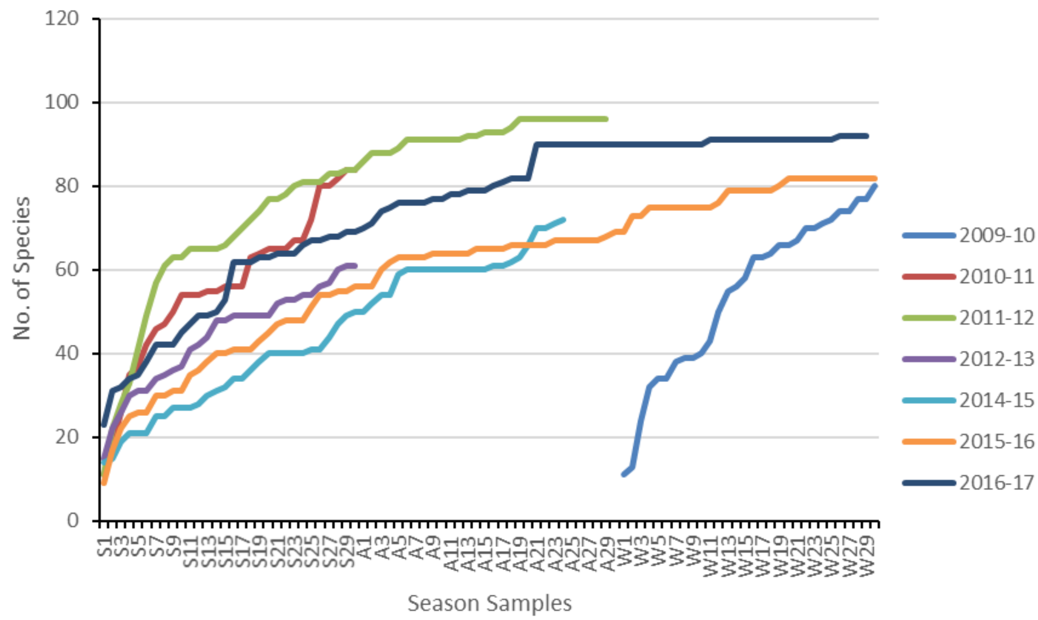

Figure 17. Annual accumulated number of benthic infauna species observed per annual cycle. Seasonal samples are ordered as summer, autumn, winter. All strata combined.

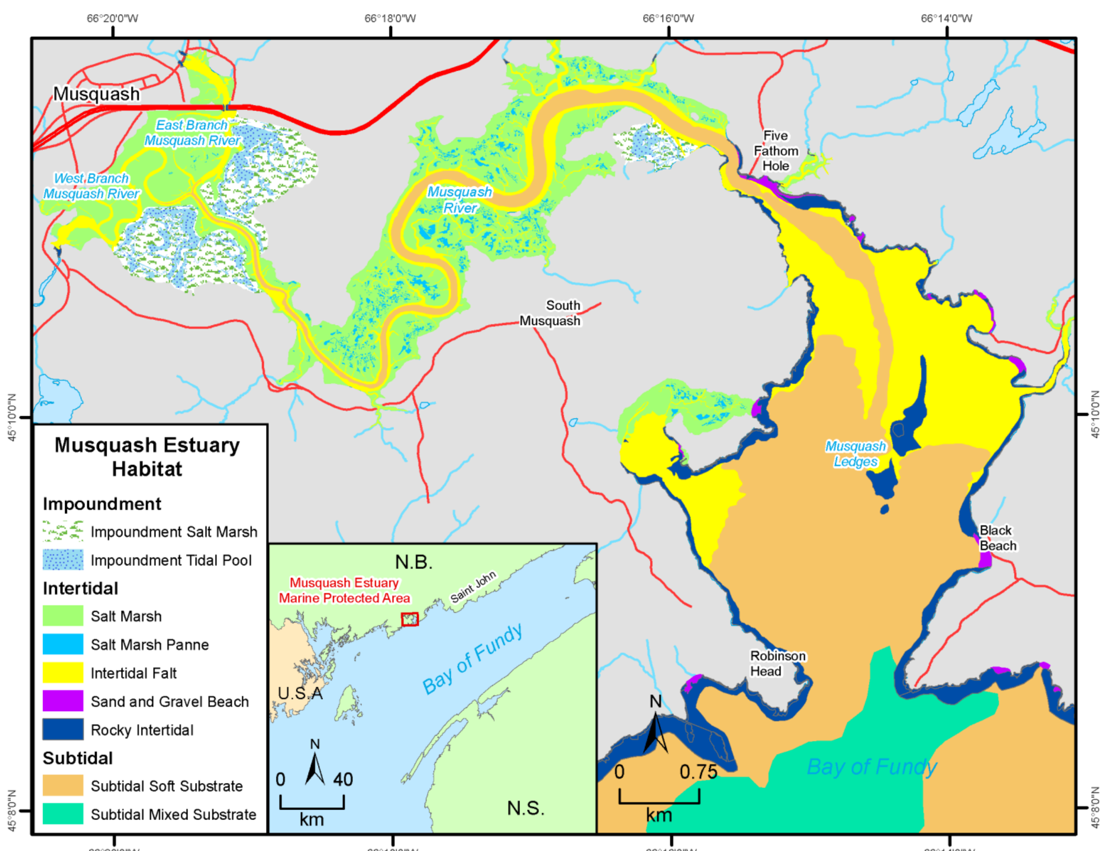

Figure 18. Revised habitat map for the Musquash MPA and Administered Intertidal Area (Greenlaw et al. 2014).

Table 11. Summary of sample design for habitat data based on shoreline, bottom type, and biogenic structure.

Scale	Status	Frequency
Spatial	Coverage for all three Zones 1,2,3. Horizontal resolution - Aerial photo (0.3m +/- 15m); LIDAR (2m), Multibeam (1m).	1
Seasonal	Geospatial data compilations represents multiple times of year.	Not Assessed
Annual	Different data collected over multiple years 2001, 2006, 2007.	Not Assessed

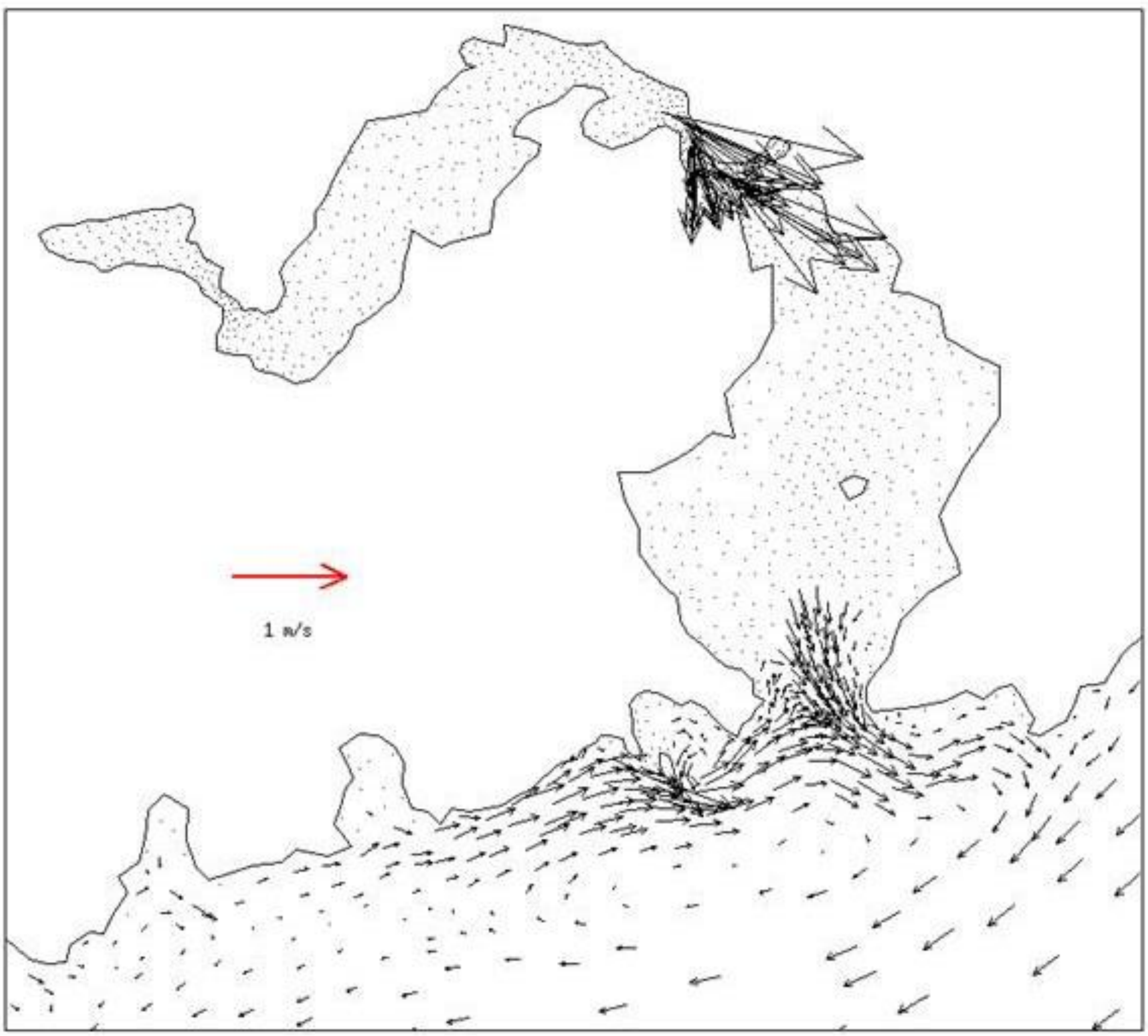

Figure 19. Preliminary FVCOM model predictions of water currents in the Musquash area with example predictions at one point in time (Cooper et al. 2014).

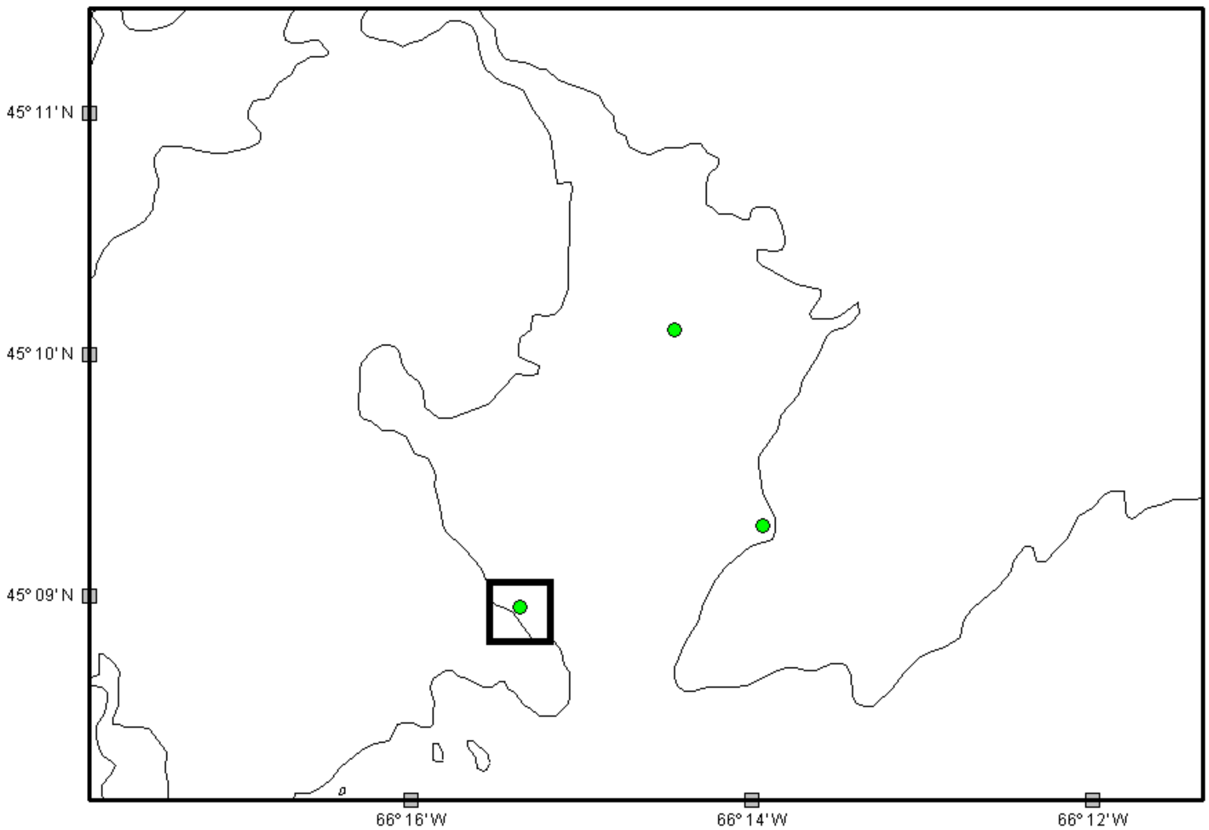

Figure 20. Location of sediment core samples taken in 2010 to assess sedimentation rate (Cooper et al. 2014).

Table 12. Summary of sampling data to monitor hydrodynamics and sediment regime.

Scale	Status	Frequency
Spatial	Zone 1	
	Zones 2 and 3 - Single baseline requires model to assess variability.	1
Seasonal	Single baseline requires model to assess variability	1
Annual	Single baseline of sedimentation requires model to assess variability.	1

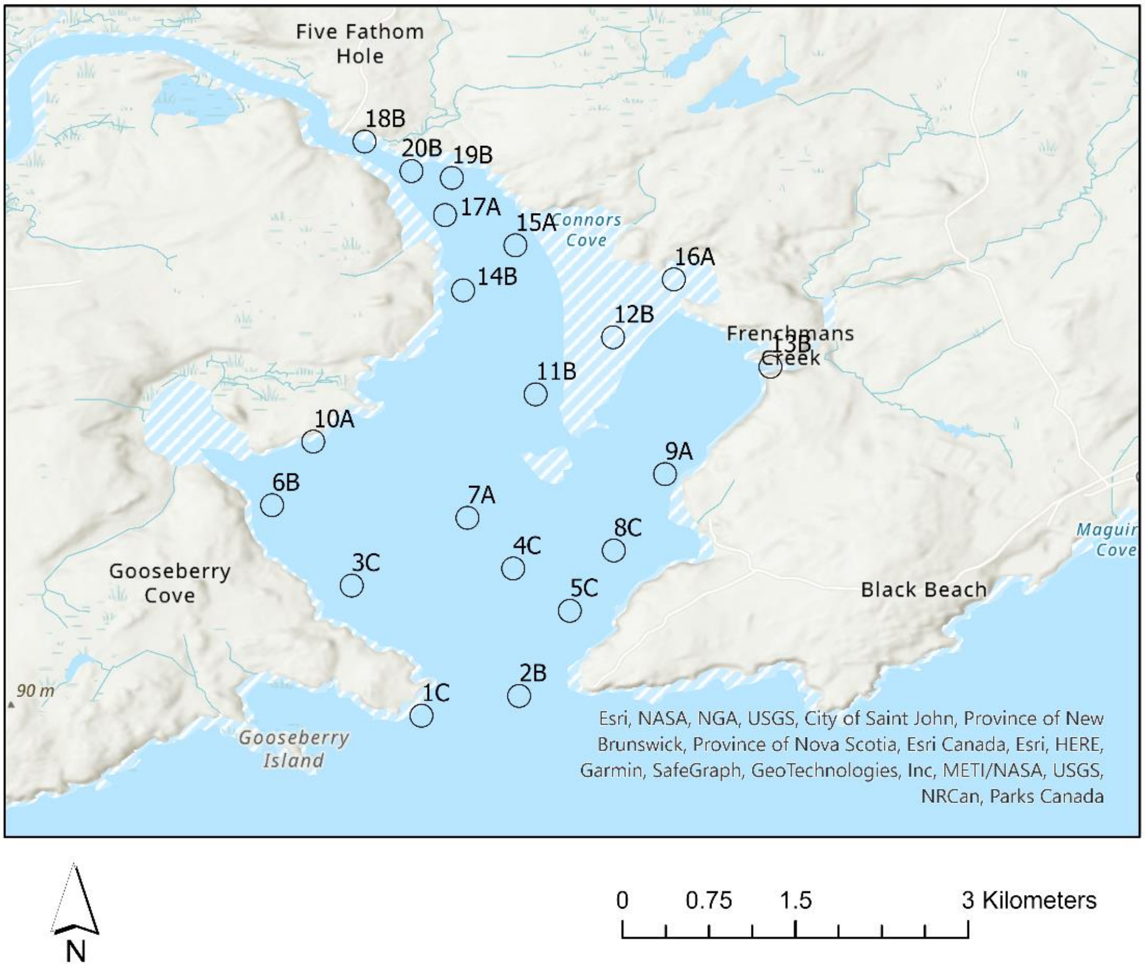

Figure 21. Fixed sample locations for water quality monitoring conducted by Eastern Charlotte Waterway Inc. through the Bay of Fundy Estuaries Project.

Table 13. Summary of sampling for habitat water quality data.

Scale	**Status**	**Frequency**
Spatial	Zone 1 Periodic measurement based on several individual research projects.	1
	Zone 2, 3 - 20 fixed sampling stations	20
Seasonal	Once per year on “summer” sampling dates (26 July–24 Sept)	1
Annual	Four years examined, ongoing. ECW (2015–2018).	4+

Table 14. Summary statistics for habitat water quality monitoring by year for all stations combined. A dash (-) indicates no data.

	2015	2016	2017	2018
Temperature (C)	20	20	20	20
min	13	13.5	11.2	12.9
max	13.7	14.6	21	13.9
mean (variance)	13.36 (0.02)	13.93 (0.03)	12.47 (0.17)	13.48 (0.02)
Salinity (ppt)	20	20	20	20
min	29.8	0.92	30	30.85
max	31.44	31.97	32	31.52
mean (variance)	30.49 (0.02)	26.92 (0.28)	31.00 (0.01)	31.24 (0.01)
Secchi depth (m)	20	20	20	20
min	2.6	1.7	0.8	1.1
max	3.9	2.2	3.5	3.5
mean (variance)	3.38 (0.12)	2.03 (0.06)	1.80 (0.49)	2.23 (0.27)
Dissolved O2 (%sat)	20	20	20	20
min	92	88	93	100.9
max	100	98	107	116.7
mean (variance)	95.70 (0.02)	92.25 (0.03)	99.55 (0.04)	108.11 (0.04)
pH	20	20	20	20
min	7.8	8.01	7.84	7.9
max	8.02	8.24	8	7.97
mean (variance)	7.96 (0.01)	8.10 (0.01)	7.93 (0.01)	7.95 (0)
Chlorophyll A (µg/L)	8	18	1	14
min	1.5	1.7	2	1.5
max	2.3	4.1	2	3.8
mean (variance)	1.90 (0.13)	2.68 (0.26)	2.00 (1.00)	2.36 (0.27)
Total Phosphorous (ppb)	20	20	20	19
min	24	25.3	15.2	10.6
max	28	41.5	27.1	164
mean (variance)	26.00 (0.04)	31.59 (0.13)	18.70 (0.18)	36.20 (1.17)
Total Nitrogen (mg/L)	0	0	11	1
min	-	-	0.5	0.5
max	-	-	0.5	0.5
mean (variance)	-	-	0.5	0.5 (1)

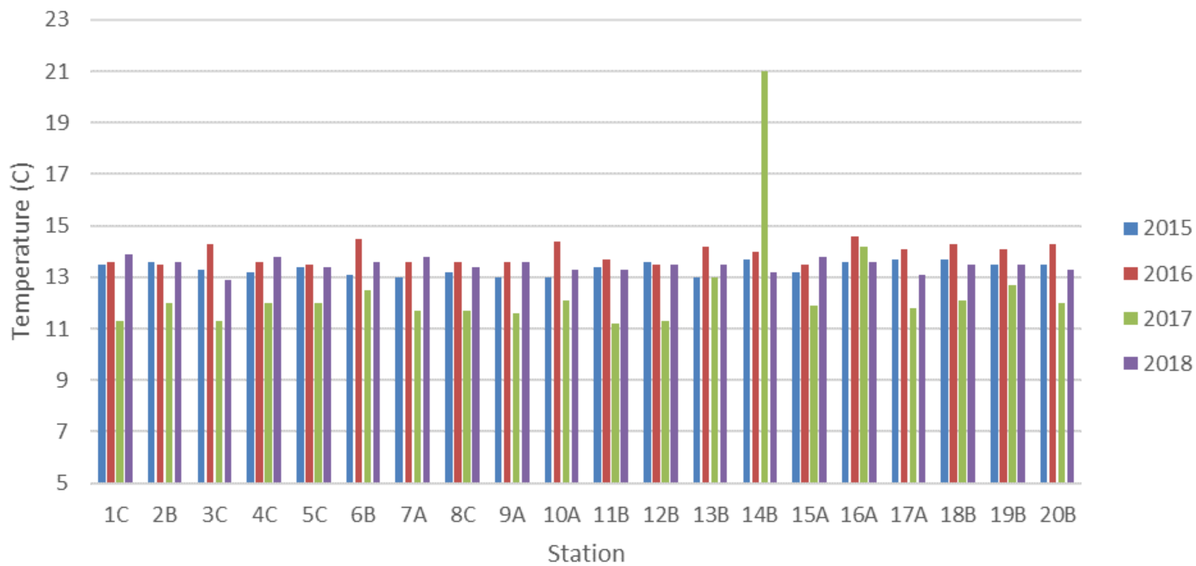

Figure 22. Annual temperature by sampling station from ECW water quality monitoring 2015 to 2018.

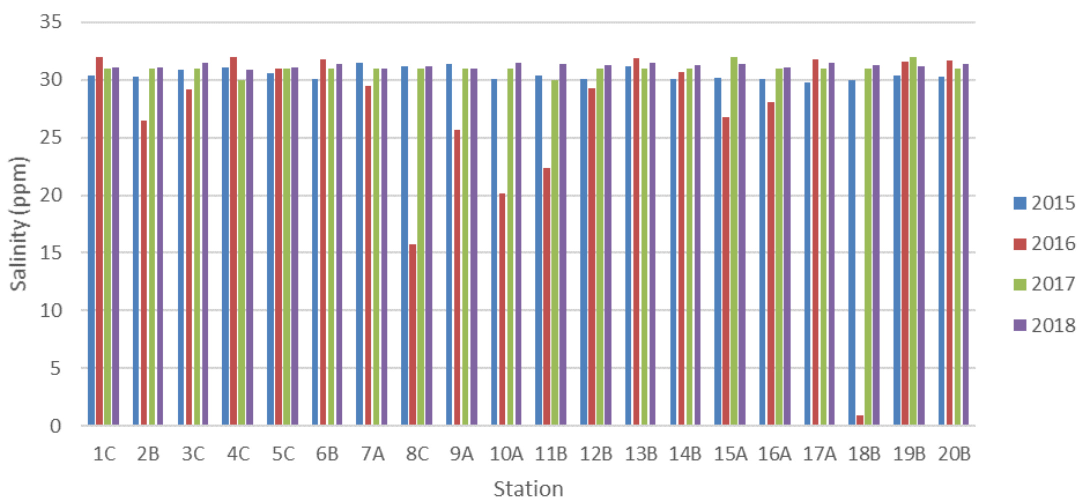

Figure 23. Annual salinity by sampling station from ECW water quality monitoring 2015 to 2018.

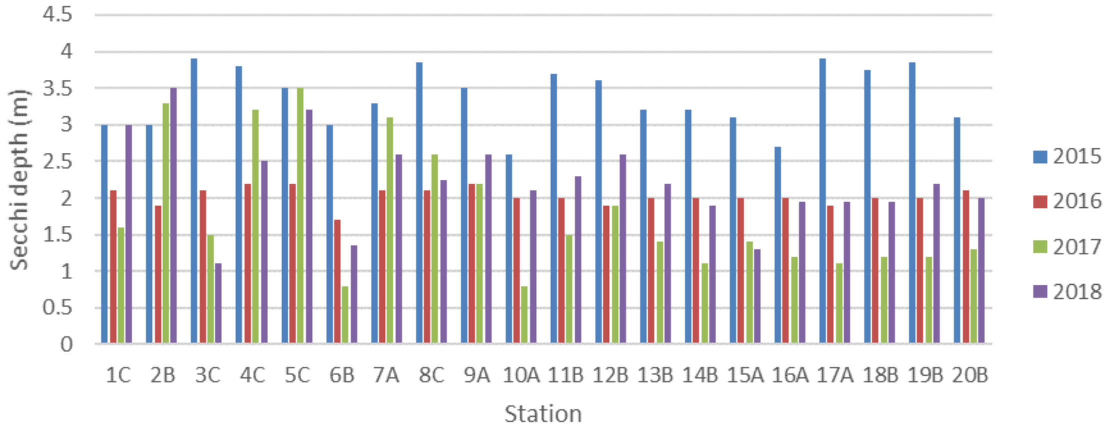

Figure 24. Annual secchi depth by sampling station from ECW water quality monitoring 2015 to 2018.

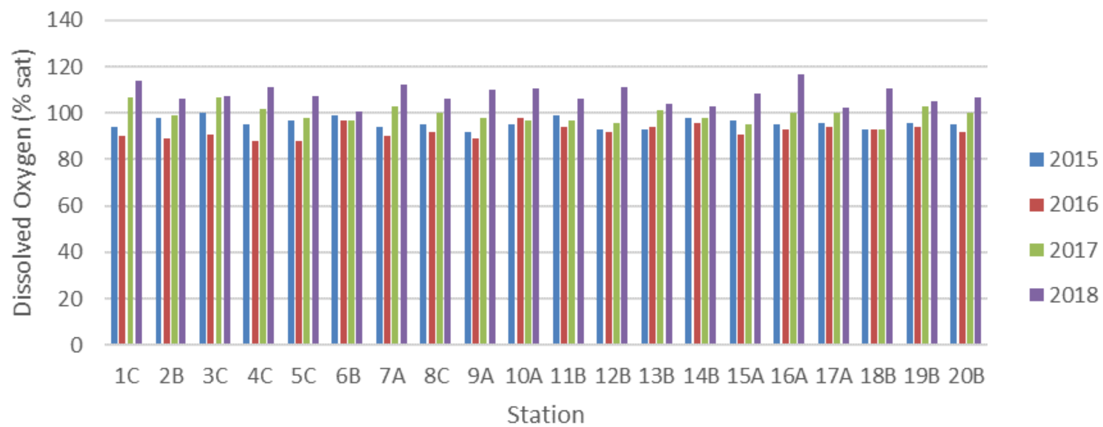

Figure 25. Annual dissolved oxygen by sampling station from ECW water quality monitoring 2015 to 2018.

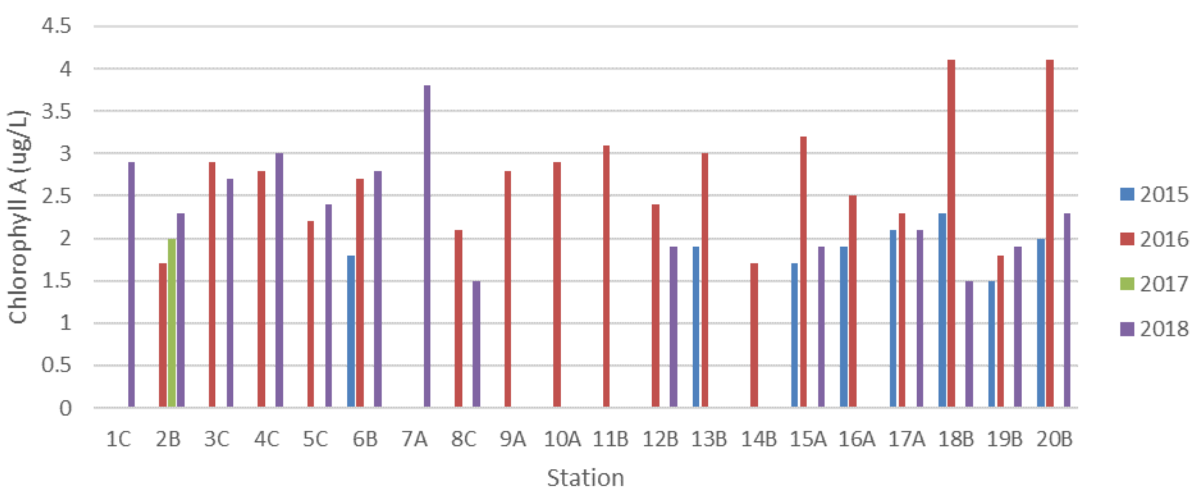

Figure 26. Annual chlorophyll A by sampling station from ECW water quality monitoring 2015 to 2018.

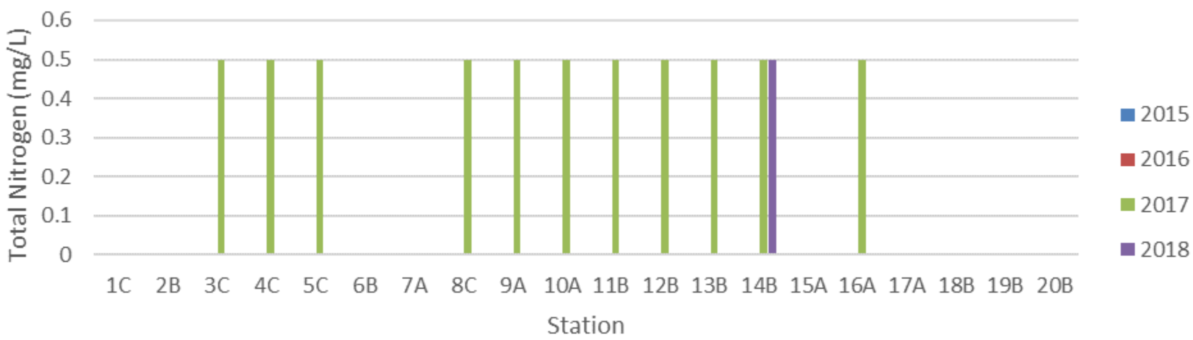

Figure 27. Annual total nitrogen by sampling station from ECW water quality monitoring 2015 to 2018.

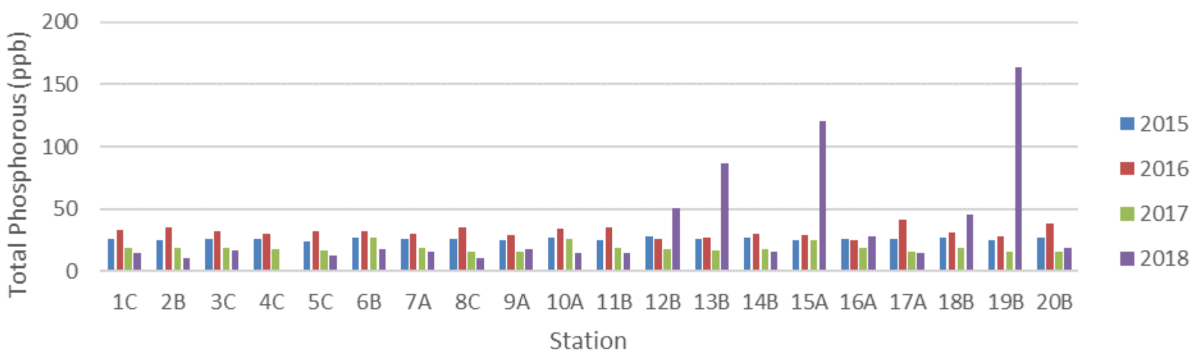

Figure 28. Annual total phosphorous by sampling station from ECW water quality monitoring 2015 to 2018.

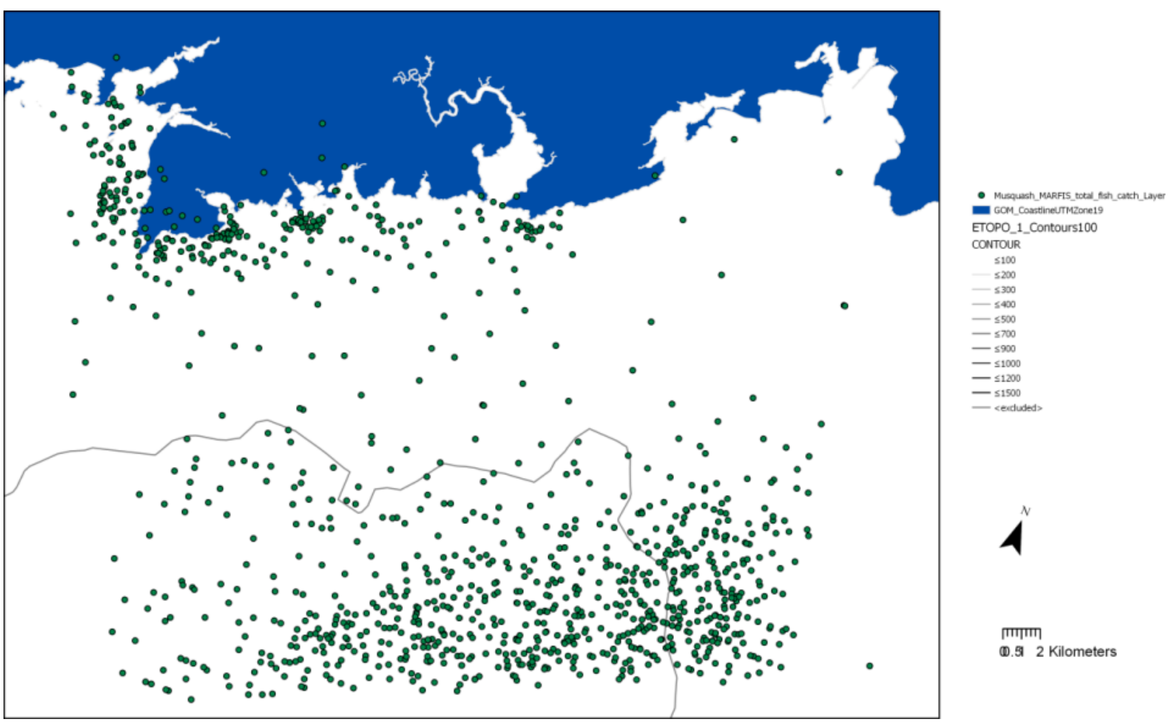

Figure 29. MARFIS reported catch locations around Musquash Estuary (2006–2018).

Table 15. Summary of active license types for fishing areas surrounding the Musquash MPA. A dash (-) indicates no data.

License type	Georeferenced	By-catch reported
Alewives/Gaspereau	-	Yes
Clams, depurated	-	Yes
Clams, unspecified	-	Yes
Crab, green	-	Yes
Crab, Jonah	-	-
Crab, Rock	Yes	Yes
Eel	-	-
Flounder, unspecified	-	-
Groundfish, unspecified	Yes	Yes
Hagfish (Slime eel)	-	-
Herring	Yes	Yes
Herring/Mackerel	-	Yes
Lobster	-	Yes
Mackerel	Yes	Yes
Marine plant	-	-
Ocean Quahaug	Yes	-
Oysters, American	-	-
Scallop, Sea	Yes	Yes
Sculpin	-	-
Sea cucumber	Yes	-
Sea urchins	Yes	-
Shad	-	Yes
Shark, unspecified	-	-
Shrimp (*Pandalus borealis)*	Yes	-
Smelts	-	Yes
Swordfish	-	Yes
Tuna, Bluefin	-	Yes
Tuna, restricted	-	Yes
Tuna, unspecified	-	-
Undetermined	-	Yes

Table 16. Summary of sampling in MARFIS data for commercial fishing logbook activities.

Scale	Status	Frequency
Spatial	Zone 1, 2 - no data. Note. Commercial fishing is not permitted within these zones.	Not assessed
	Zone 3 - Only a proportion of license types report activities within Zone 3. Many license types report landing by statistical fishing grid or fishing areas which is a much coarser resolution than the MPA.	Not assessed
Seasonal	Data is collected by commercial fishery as per license over prescribed seasons. Fishing effort (species/gear type) is therefore predictive with respect to conditions of license and managed seasons.	Not assessed
Annual	MARFIS data is collected on an annual basis.	12+

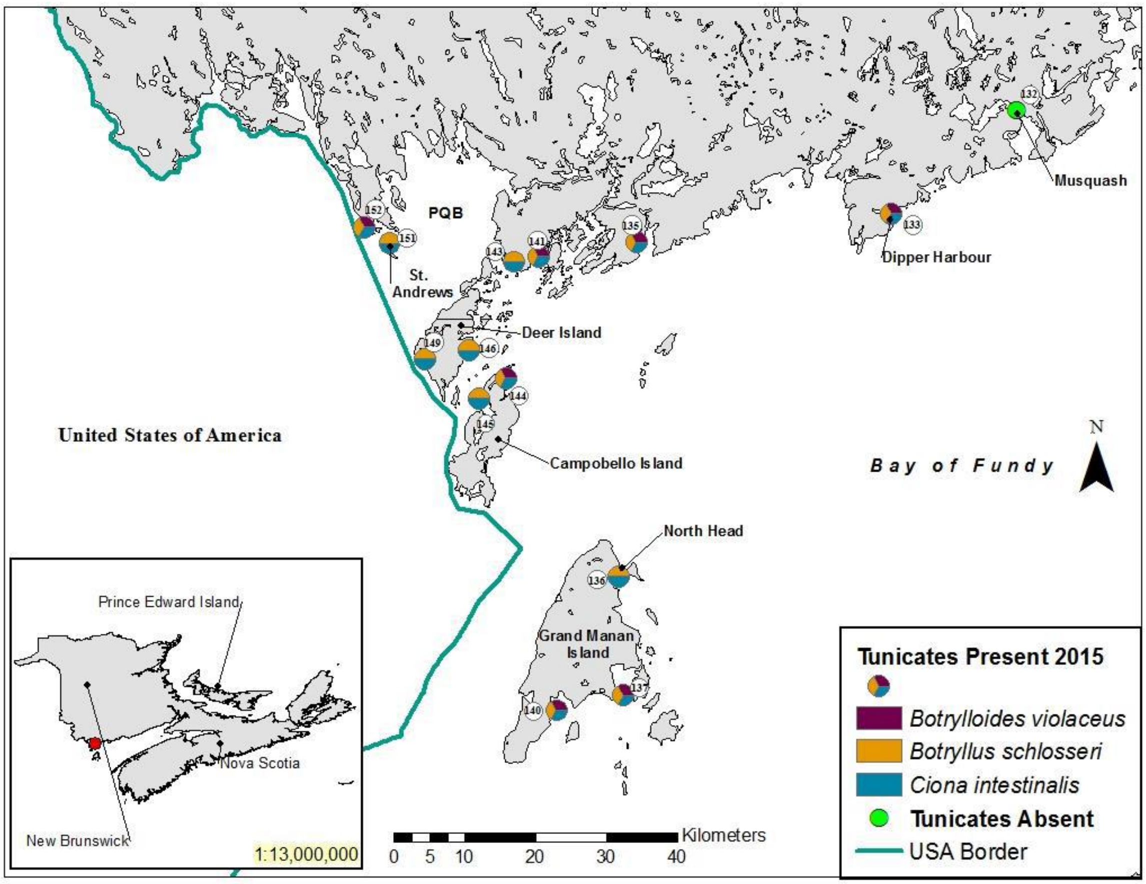

Figure 30. Location of invasive tunicate monitoring conducted in southwest New Brunswick (2012–2015). During this period invasive tunicates were observed in all locations except the Musquash MPA at Five Fathom Hole (Sephton et al. 2017).

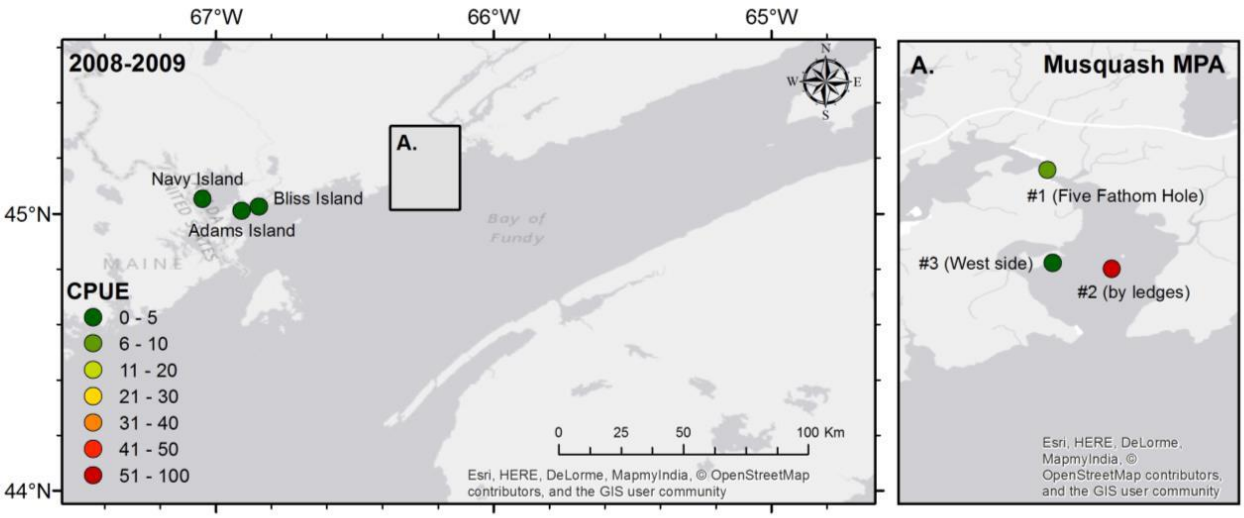

Figure 31. Location of green crab monitoring conducted in southwest New Brunswick (Vercaemer and Sephton 2016).

Table 17. Summary of sampling for aquatic invasive species monitoring.

Scale	Status	Frequency
Spatial	Zone 1, 3	No data
	Zone 2 - Tunicates 1 location suspected as not suitable?, Green crab 3 locations.	Tunicates 1 Green crab 3
Seasonal	Zone 2 - Tunicates collectors deployed in spring and retrieved in autumn. Aggregated data	1
	Green crab was monitored in 24 hour periods throughout the year (June to October) to assess seasonal variation.	Not assessed
Annual	Multi-year time series collected as part of an ongoing Aquatic Invasive Species program 2008–2015 (ongoing). Green crab 2008–2013.	Tunicates 7+ Green crab 5

Figure 32. Sample locations for Conservation Council of New Brunswick (CCNB) marine debris monitoring at Musquash. BBH = Black Beach Hill, BBP = Black Beach Proper, BBU = Black Beach Upper, GC = Gooseberry Cove.

Table 18. Summary of sampling for CCNB marine debris monitoring program data.

Scale	Status	Frequency
Spatial	Zone 1	No data
	Zone 2, 3 - Different sources of debris measured at two locations. Note. Data for Black Beach contains three areas, beach, upland, and hill. These areas should be standardized.	Zone 2 = 1 or 3?, Zone 3 = 1
Seasonal	Data collected multiple times per year ranging from March to December. The degree to which the annual changes are to be standardized by inter-annual frequency needs to be assessed.	3 to 7
Annual	Annual data collected under standard protocols 2010–2018 (ongoing).	8+

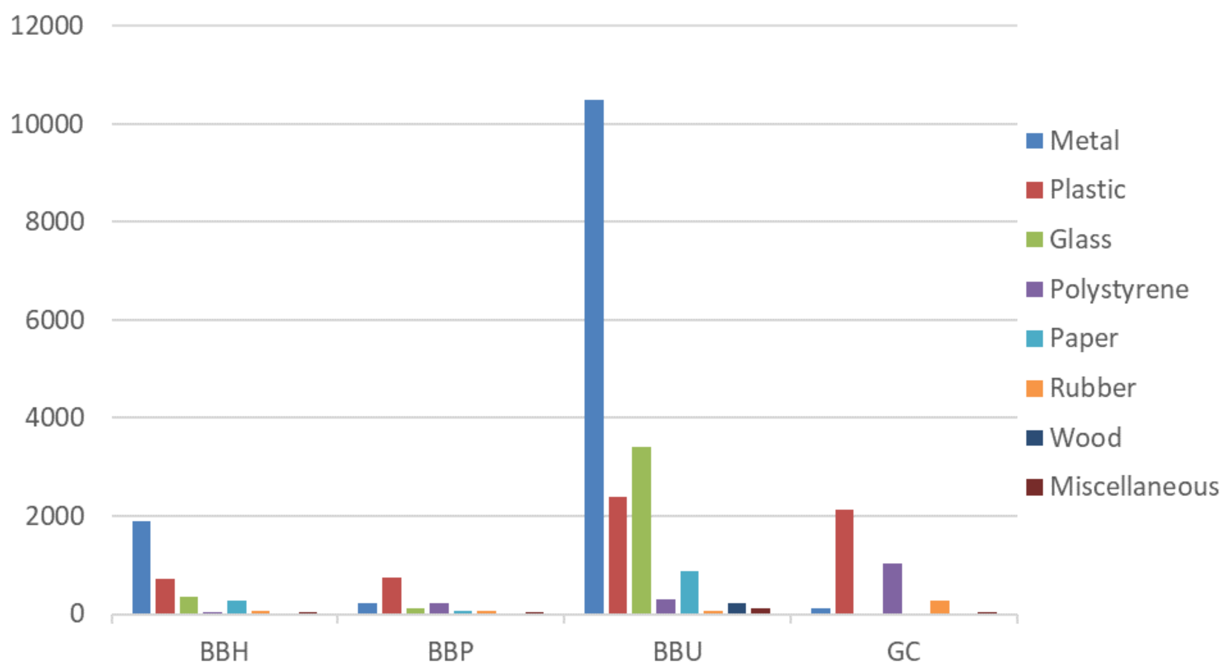

Figure 33. Total debris type observations by sample location for all years combined. BBH = Black Beach Hill, BBP = Black Beach Proper, BBU = Black Beach Upper, GC = Gooseberry Cove.

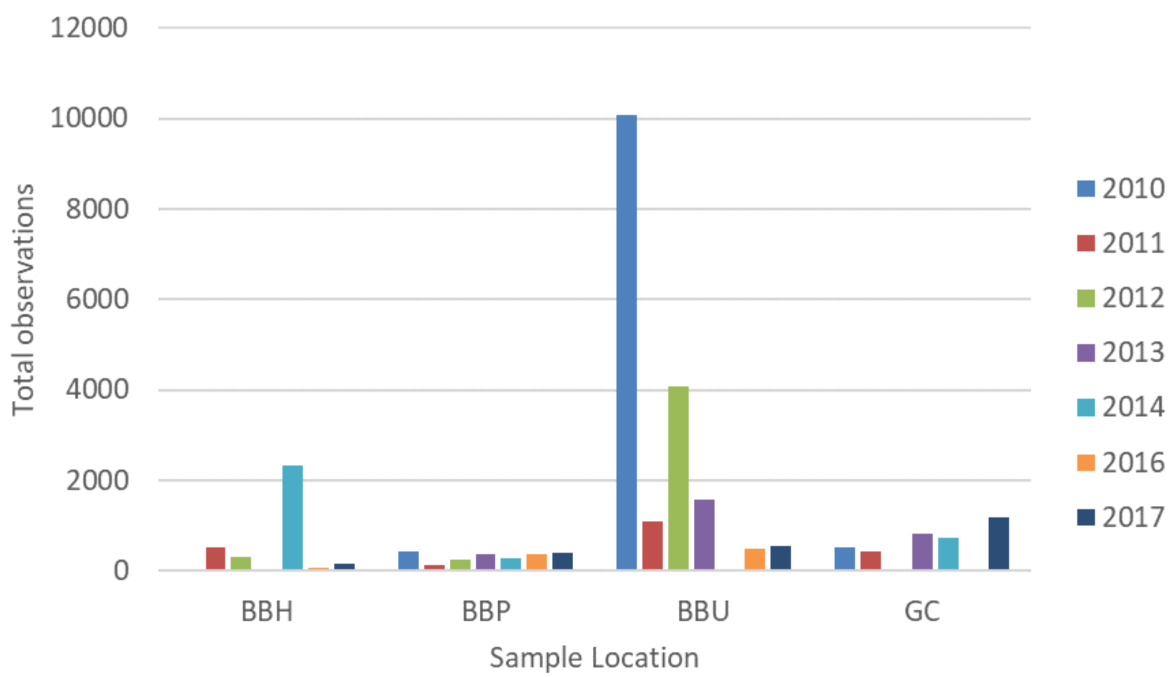

Figure 34. Total debris observations per year for each sample location. BBH = Black Beach Hill, BBP = Black Beach Proper, BBU = Black Beach Upper, GC = Gooseberry Cove.

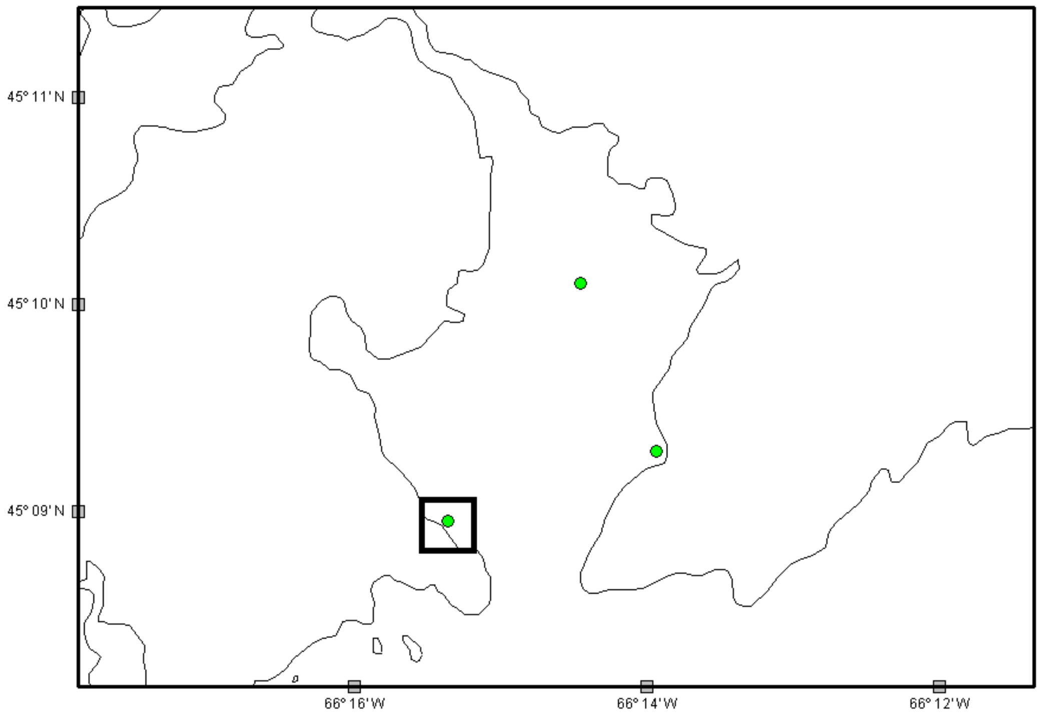

Figure 35. Location of slo-core stations collected for geochronology and trace metal analysis. The station encompassed by the black box is core station two where a sedimentation rate of approximately 0.5 cm/year was determined (Cooper et al. 2014).

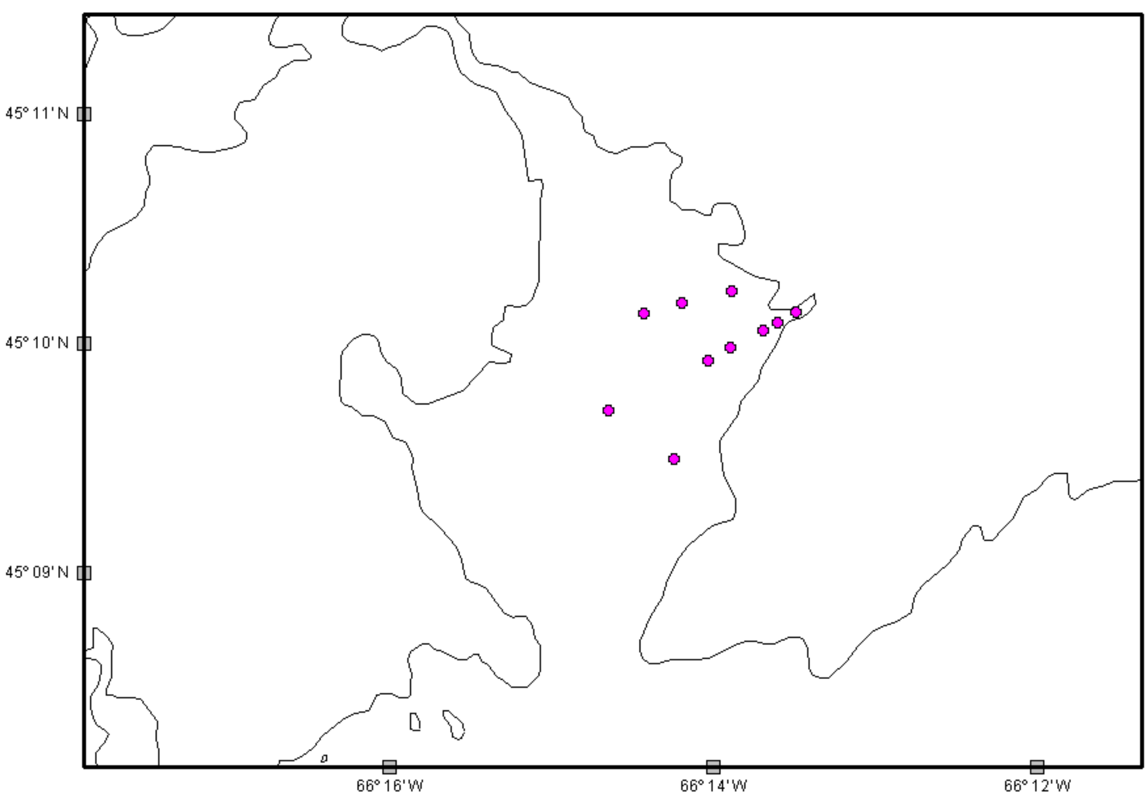

Figure 36. Location of trace metal sampling by benthic infauna Eckman grab (Cooper et al. 2014).

Table 19. Summary of sampling design for trace metal data.

Scale	Status	Frequency
Spatial	Zone 1, - no data.	
	Zone 2, 3 - Different studies applied different sediment sampling techniques. Not comparable data.	14 (Chou et al. 2004) 3 slo-core (Cooper et al. 2014) 10 Eckman (Cooper et al. 2014)
Seasonal	Samples taken during different time of year but spanning multiple years, different methods.	1
Annual	Trace metal sampling in 2001, 2009, 2010, 2012 but different locations and methodologies.	4

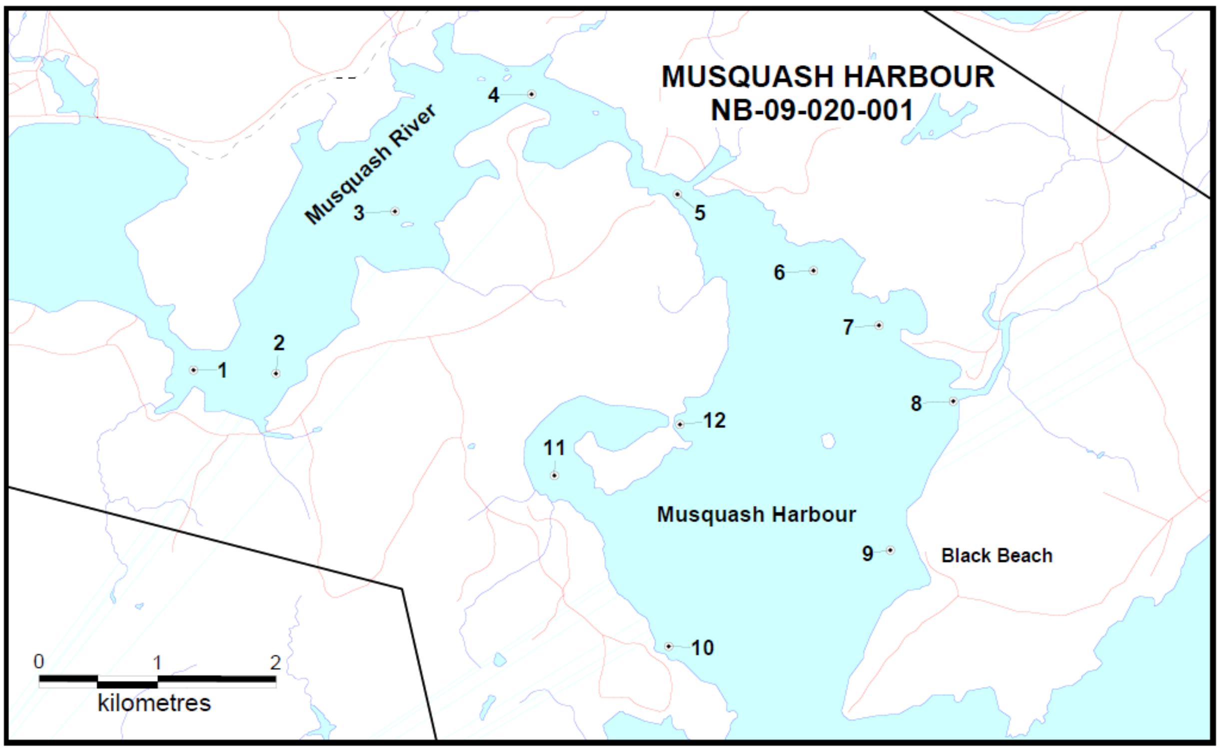

Figure 37. Location of CSSP shellfish fecal coliform monitoring.

Table 20. Summary of sampling for bacterium data.

Scale	Status	Frequency
Spatial	Zone 1, 2 - 12 fixed sample locations.	Zone 1 = 4 Zone 2 = 8
	Zone 3 - no data	
Seasonal	Samples up to three time per year (spring, summer, autumn). There is a record of wet weather events to help assess interannual variability.	3
Annual	Multiple samples taken over two time periods 1992–2008, 2015–2018.	9, 3

Table 21. Summary statistics of fecal coliform (FC) densities (MPN/100 ml) for Musquash Harbour during dry weather conditions (< 12.5 mm in 24 h and < 25 mm in 48 h). GMean = geometric mean, P90 = 90th percentile, % > 43 = percent of observations where fecal coliform is greater than 43 MPN/100 ml.

Station	Samples	Period	Min FC	Max FC	GMean	Median	P90	% > 43
1	16	1999–2008	1.9	23	5	5.0	15	0
2	16	1999–2008	1.9	13	4	5.0	11	0
3	16	1999–2008	1.9	13	3	1.9	6	0
4	16	1999–2008	1.9	5	2	1.9	3	0
5	16	1999–2008	1.9	5	2	1.9	4	0
6	16	1999–2008	1.9	5	2	1.9	3	0
7	16	1999–2008	1.9	17	3	1.9	7	0
8	16	1999–2008	1.9	7	2	1.9	3	0
9	16	1999–2008	1.9	5	2	1.9	3	0
10	16	1999–2008	1.9	13	2	1.9	4	0
11	16	1999–2008	1.9	11	2	2.0	5	0
12	16	1999–2008	1.9	13	2	1.9	5	0

Table 22. Summary statistics of fecal coliform densities (MPN/100 ml) for Musquash Harbour during wet weather conditions (> 12.5 mm in 24 h and/or > 25 mm in 48 h). GMean = geometric mean, P90 = 90th percentile, % > 43 = percent of observations where fecal coliform is greater than 43 MPN/100 ml. A dash (-) indicates no data.

Station	Samples	Period	Min FC	Max FC	GMean	Median	P90	% > 43
1	3	1992–1999	17	240	58	49	-	67
2	3	1992–1999	33	249	73	49	-	67
3	3	1992–1999	11	130	29	17	-	33
4	3	1992–1999	14	79	37	46	-	67
5	3	1992–1999	23	79	49	64	-	67
6	3	1992–1999	5	79	24	33	-	33
7	3	1992–1999	5	79	21	23	-	33
8	3	1992–1999	63	130	97	110	-	100
9	3	1992–1999	2	33	10	17	-	0
10	3	1992–1999	1.9	17	7	13	-	0
11	3	1992–1999	8	350	52	49	-	67
12	3	1992–1999	1.9	130	23	49	-	67

Table 23. Summary of ecosystem level coverage for existing monitoring data to support indicators 1 and 2. Trophic groups (P = primary producer, SC = scavenger, S = suspension feeder, D = deposit feeder, H = herbivore, C = carnivore, O = omnivore) currently monitored for species data (Fish, Birds, Benthic infauna) within each habitat type (Greenlaw et al. 2014). Trophic categories are those described in Singh and Buzeta 2005. A dash (-) indicates no data.

MPA Zone	Habitat Type	Fish	Birds	Benthic infauna
1	Impoundment Salt Marsh	-	H,C,O	-
1 AIA	Impoundment Salt Marsh Pools	-	H,C,O	-
1 AIA	Salt marsh	-	H,C,O	-
1 AIA	Salt Marsh Panne and Pool	-	H,C,O	-
2 AIA	Intertidal Flat	-	-	S,D
2 AIA	Sand and Gravel Intertidal	C	-	-
2,3 AIA	Rocky Intertidal	-	-	-
2	Subtidal Soft Substrate	C	-	S,D
2, 3	Subtidal Mixed Substrate	C (Zone 2)	-	-
3	Exposed Coastline	-	-	-