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Review of monitoring activities in Basin Head Marine Protected Area in the context of their effectiveness in evaluating attainment of conservation objectives

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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.

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ABSTRACT

The Basin Head Marine Protected Area (MPA), established in 2005 under the *Oceans Act* mandate, is a shallow marine lagoon located on the northeastern shore of Prince Edward Island (PEI). The purpose of the MPA designation is to protect and conserve a unique strain of Irish moss (*Chondrus crispus*) and its habitat. When assessed, the Irish moss biomass in Basin Head lagoon had declined by more than 99% between 1980 to 2008. The Basin Head MPA management plan identified four conservation objectives and a monitoring program was initiated for each conservation objective. Monitoring activities have included assessments of the abundance and distribution of Irish moss, assessment of blooms of sea lettuce (*Ulva spp*.), water quality indicators, and monitoring of fish and crustaceans. In recent years, there have been concerted efforts to understand threats to Irish moss-mussel clumps including heat stress, seasonal hypoxia and bottom smothering by *Ulva* (eutrophication); smothering by organic-rich silt, marsh sods and debris; storm surges and winter ice scour. Efforts to restore Irish moss in Basin Head's Northeast Arm by outplanting artificially created moss-mussel clumps, and removing Green Crab have also been initiated. Department of Fisheries and Oceans Gulf Region Marine Planning and Conservation Program requested a review and assessment of the monitoring activities undertaken in Basin Head over the last decade to determine their effectiveness in providing the information needed to evaluate whether the conservation objectives are being met. Information provided for each of the four conservation objectives include ecological indicators, monitoring regime and methods, ecological threshold if available and data analyses and results. A variety of short-term field experiments were conducted, as well as qualitative and quantitative observations over periods of 1 to 5 years. We present some preliminary findings that provide rationale for restoration activities and insights into possible monitoring approaches.

INTRODUCTION

The Basin Head Marine Protected Area (MPA), established in 2005 under the *Oceans Act* mandate, is a shallow marine lagoon located on the northeastern shore of Prince Edward Island (PEI) (Figure 0.1). The purpose of the MPA designation is to protect and conserve a unique strain of Irish moss (*Chondrus crispus*) and its habitat. Several characteristics of Irish moss in the Basin Head MPA make it distinctive, including: its complete dependence on fragmentation for dispersion and multiplication; its dependence on the Blue Mussel for substrate attachment; and, the fronds' breadth, thickness, overall shape and sustained seasonal coloration. It also is significantly larger and has a higher carrageenan yield than the outer coastal Irish moss. These characteristics are likely influenced by the environmental conditions in the lagoon but may also have a genetic basis.

Field observations in 1999 detected a decline in abundance of this distinctive seaweed in Basin Head. Subsequent annual monitoring revealed that the bottom area covered by Irish moss declined from an estimated 15,000 m^2 in 1980 to less than 2,000 m^2 in 2005 (Figure 0.2). A science advisory process was convened in 2008 to review the status of Irish moss in Basin Head. The peer review looked into factors which may have been contributing to the reported declines, and considered possible research and management actions (DFO 2009). The conclusions were that inputs of nutrients into the Basin, which may come primarily from agricultural lands, triggered annual green algal blooms which in turn resulted in deleterious conditions for Irish moss. The invasion of the Green Crab in the late 1990s, and its predation on Blue Mussel which anchor the moss, were also considered important stressors to the Irish moss population and the Basin Head ecosystem. Together, these sub-optimal conditions likely pre-dated 1999 and were not unique to Basin Head, as they were part of a wider decline in ecosystem health in many PEI estuaries.

The Basin Head MPA Operational Management Plan (DFO 2016) lists four conservation objectives and identifies research and monitoring approaches for each objective. Major monitoring activities have included assessments of the abundance and distribution of Irish moss, visual documentation of blooms of green algae (*Ulva lactuca*), water quality sampling, and monitoring of fishes and crustaceans through the Community Aquatic Monitoring Program. The four conservation objectives are:

1. Maintain the quality of the marine environment supporting the Irish moss.

The purpose of this conservation objective is to ensure that water quality indicators, including nutrient concentrations, are maintained at a level conducive to Irish moss survival and to track temperature, dissolved oxygen and identify hypoxic or anoxic conditions. Thresholds were established to indicate when management actions should be triggered.

2. Maintain the physical structures of the ecosystem supporting the Irish moss.

The purpose of this conservation objective is to maintain the integrity of the physical environment, i.e. the dune structure, the ocean opening, water depth and flushing; and to limit the erosion of land that causes sedimentation in the estuary.

3. Maintain the health (biomass and coverage) of the Basin Head Irish moss.

The purpose of this conservation objective is to monitor and quantify the biomass and/or coverage of the Irish moss and to ensure a healthy and sustainable level in the MPA.

4. Maintain the ecological integrity of the Basin Head lagoon and inner channel.

The purpose of this conservation objective is to maintain biodiversity in support of the Irish moss.

Several proposed research activities and management actions identified in the 2009 Science advice were implemented. For example, research on direct and indirect effects of Green Crab on the Irish moss, funded by the Department of Fisheries and Oceans (DFO), was undertaken by the University of Prince Edward Island (UPEI). Increased funding in 2014-2019 supported new research and monitoring efforts that aimed to strengthen management and conservation of the Basin Head MPA and to improve understanding of multiple stressors on Irish moss. Since 2015, activities have been initiated to restore Irish moss in Basin Head including artificial propagation of Irish moss – mussel clumps, restoration of eelgrass, and removal of Green Crab. Given the last science review was in 2008, and updated monitoring and research has been conducted in the interim, a new science review was considered necessary.

The objectives of the 2019 science review were to:

- determine whether monitoring activities are providing the information required to assess the attainment of conservation objectives;
- provide advice on necessary modifications to the monitoring activities and/or operating procedures that could improve their effectiveness towards meeting conservation objectives;
- assess whether the current monitoring design and collected data are sufficient to evaluate the effectiveness of ongoing restoration activities and provide advice on necessary modifications, if applicable.

The information from this science advisory process will also be used to update the Basin Head Operational Management Plan and the development of a long term monitoring plan to evaluate each conservation objective and restoration activity.

This research document is divided into five sections. Information provided for each of the four conservation objectives include ecological indicators, monitoring regime and methods, ecological threshold if available and data analyses and results. The fifth section describes the restoration activities initiated since 2015. The recommendations arising from information provided in this report appear in the Science Advisory Report for Basin Head MPA (DFO 2020).

Increased staffing in 2014 permitted year-round field observations in Basin Head MPA. A variety of short-term and largely unreplicated field experiments were conducted, as well as qualitative and quantitative observations of planted test plots over periods of 1 to 5 years. Results from these pilot projects provides insight into the physical forces driving the system and provides solid evidence for the development of new hypotheses to be tested later. Results are documented in detail in a series of field reports that will be published as part of the Basin Head Management Series. In this research document, we present some preliminary findings that provide rationale for restoration activities and insights into possible monitoring approaches.

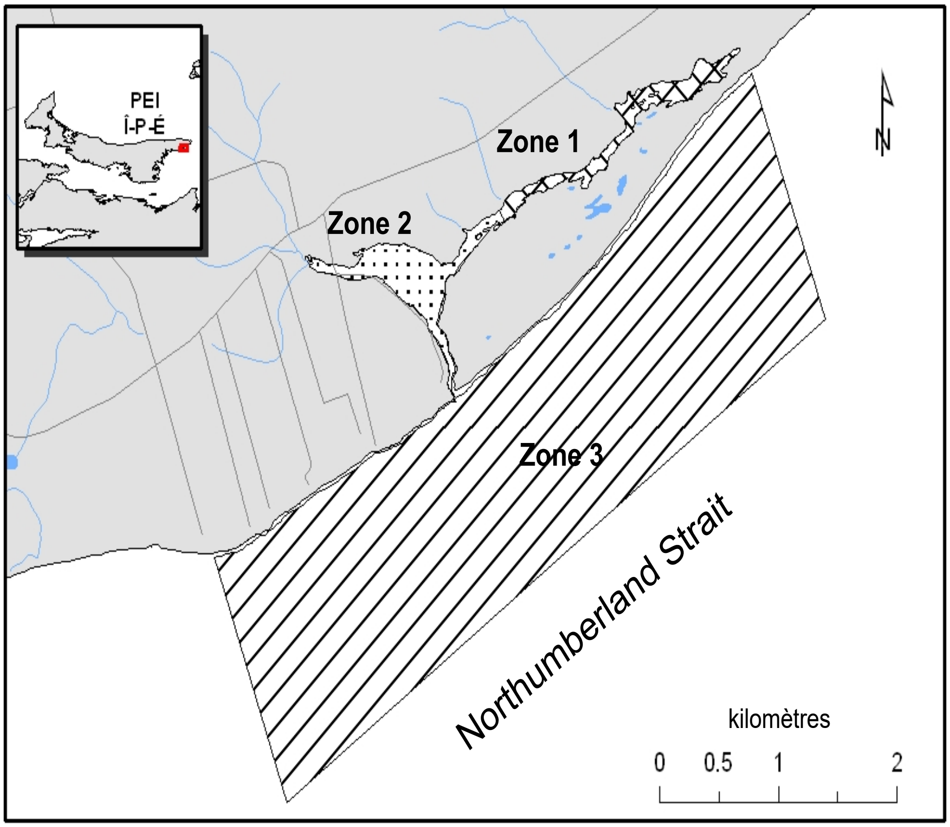

Figure 0.1. Basin Head Marine Protected Area, Gulf of St. Lawrence.

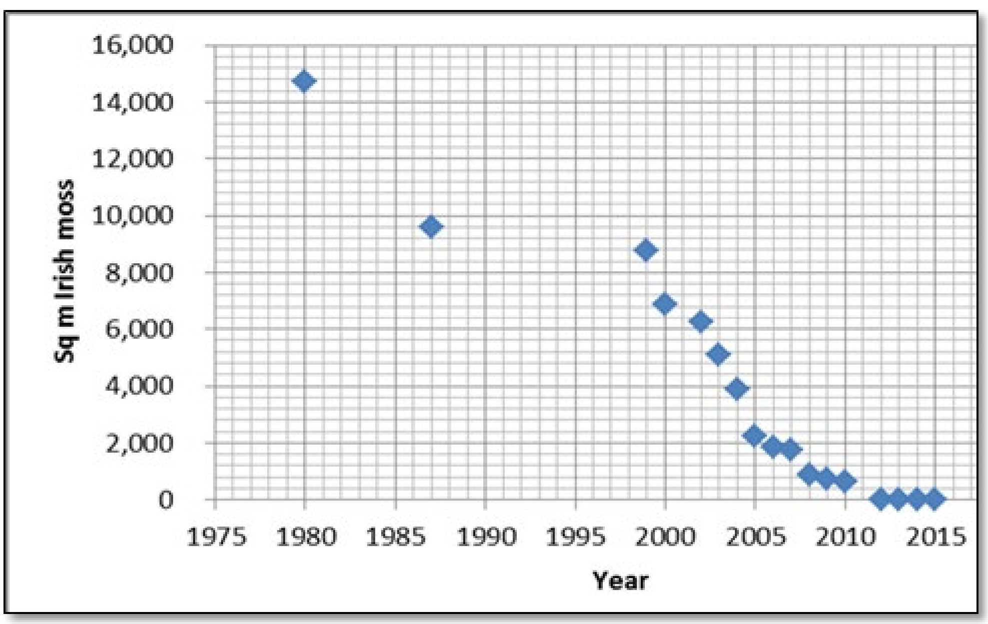

Figure 0.2. Estimated area (m^2) covered by Irish moss in Basin Head MPA during the process of decline from 1980 to 2015.

1. CONSERVATION OBJECTIVE 1: MAINTAIN THE QUALITY OF THE MARINE ENVIRONMENT SUPPORTING THE IRISH MOSS

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1.1. CONTEXT

Approximately 44% of land use in Basin Head watershed for the period 2006-2010 was agricultural. This percentage has remained stable since at least 2000 (Island Nature Trust unpublished report 2001)[1], with the predominant row crop being potatoes. Common practice for potato agriculture involves the application of nitrate-based fertilizers to potato fields. The most common potato in production, Russett-Burbank, has a high nitrogen demand and poor nitrogen uptake efficiency; thus there is a tendency for over-application of fertilizer (Zebarth et al. 2015). Nitrogen not taken up by the potato plants is susceptible to leaching into groundwater, accounting for the majority of nitrogen loading to coastal systems, and runoff into surface waters (Grizard 2013). The nitrate contained in groundwater eventually enters coastal systems via streams and rivers, or directly as freshwater seeps (springs) into estuaries. This influx of an otherwise limiting nutrient can cause eutrophication (Bugden et al. 2014; Jiang et al. 2015). The symptoms of eutrophication in coastal systems are well established and include harmful algal blooms (HABs), proliferation of macroalgae which displace seagrass, depleted dissolved oxygen levels (hypoxia /anoxia) which can result in increased mortality of fish and invertebrates, increased organic matter in sediments, and changes to aquatic community structure (Valiela 1997; Gilbert et al. 2010; Bugden et al. 2014; Coffin et al. 2018a). Prince Edward Island estuaries with high nitrogen loading are typically shallow and dominated by benthic macroalgae (notably *Ulva* spp.) as opposed to deeper systems where light does not penetrate to benthic areas and thus primary production is dominated by surface phytoplankton (Meeuwig 1999; Bugden et al. 2014). Recent work linking symptoms of eutrophication to nitrogen inputs found that nitrate, a more bioavailable form of nitrogen for plants, was a better predictor than total nitrogen (Coffin et. al. 2018b). Given that nitrate is considered more limiting than phosphorous in marine environments (Howarth and Marino 2006) and that phosphorus is consistently high in surface waters of PEI, regardless of land-use type (van den Heuvel 2009; Bugden et al. 2014; Knysh et al. 2016; Coffin et al. 2018b), nitrate concentration was investigated more thoroughly herein than other measured nutrients.

The earliest data for Basin Head are from the summer of 1979 (McCurdy 1979), when nitrate was measured in filtered water samples taken from the Irish moss bed. At that time estimated nitrate concentrations in the Northeast Arm ranged between 0.73 and 5.53 µmol per L with an average of 2.57 µmol per L (McCurdy 1979).

High summer water temperatures and low dissolved oxygen, a common symptom of eutrophication, are both threats to the sustainability of the Basin Head ecosystem. For Irish moss and Blue Mussel (*Mytilus edulis*) temperature stress occurs above 20 °C. Blue Mussel growth rates are reduced due to physiological factors associated with decreased filtration rate and higher metabolic costs (Bayne et al. 1983) at temperatures above 20ºC and lethality can occur at 28 °C (Prince and Kingsbury 1973; Lüning et al. 1986; Leblanc et al. 2010). In a study within estuaries similar to Basin Head in the southern Gulf of St. Lawrence region, it was determined that low or no dissolved oxygen (hypoxia or anoxia) influenced estuarine community

[1] Island Nature Trust. 2001. Community use of the Basin Head Lagoon, Prince Edward Island. Report prepared by the Island Nature Trust for the Basin Head Lagoon Ecosystem Conservation Committee. 26 pp.

structure (Coffin et al. 2018a). In general, hypoxic stress occurs at or below 4 mg per L for most fish, and at or below 2 mg per L for most invertebrates, and mass mortality of animals can occur if anoxia is sustained (Vaquer-Sunyer and Duarte 2008; Riedel et al. 2014). A series of monitoring activities for water characteristics in Basin Head MPA are described below and summarized in Table 1.1.

A monitoring protocol, tailored primarily to assess the concentration of nutrients (nitrate, nitrite, ammonium, phosphate, silicate), commenced in 2001 and has been conducted every year since up to the time of the writing of this document (2019). Water sampling for nutrients along with other basic water quality parameters (temperature, salinity, dissolved oxygen, chlorophyll *a*, and turbidity) were recorded weekly at multiple locations within Basin Head. Data loggers for continuous measurements of temperature and dissolved oxygen were deployed annually during the ice-free season (2011-present for temperature and 2015-present for dissolved oxygen) to better understand their variability and to capture transient high temperature and/or low dissolved oxygen events that may not be captured by point sampling.

1.2. ECOLOGICAL INDICATOR 1: WATER TEMPERATURE, SALINITY, DISSOLVED OXYGEN, CHLOROPHYLL A AND TURBIDITY

1.2.1. Methods

Water chemistry data were collected weekly, generally, from mid-May or early June through August at 11 sites (A-K) in the Main Basin and Northeast Arm (Figure 1.1). DFO collected these data from 2001-2009 and contracted the Souris and Area Branch of the PEI Wildlife Federation (SAB) to continue the water quality monitoring from 2011 to present. Data collection included taking water samples for dissolved inorganic nutrient analysis and point measurements for temperature (°C), salinity (parts per thousand, ppt), dissolved oxygen (mg per L), chlorophyll *a* (µg per L) and turbidity (Nephelometric Turbidity Units, NTU). Sampling was conducted during daylight hours but was not standardized with respect to time of day or tidal height. Water sampling start time varied from year to year depending on the resources available but was always done weekly. Sampling sites near the bridge at the inner end of the Basin (Site J) and at the top of Northeast Arm (Site A) have shifted over time because the buildup of sediments has reduced water depths, making the original locations inaccessible.

Point Sampling

Temperature, salinity and dissolved oxygen were measured with a hand held multi-meter (YSI 85®). Time, tide state, wind speed and direction as well as precipitation within 24 h of the time of sampling were also recorded, though not analyzed. Chlorophyll *a* and turbidity were measured with a fluorometer from Turner Designs®. The fluorometer detects how much light is reflected from particulate matter in a cuvette; this is dependent upon properties of the particles such as shape, color, and reflectivity. Surface water was collected into a clean, rinsed cuvette and inserted into the handheld fluorometer to read chlorophyll *a* and turbidity. Chlorophyll *a* concentrations collected from 2011 to 2015 were calibrated in the laboratory using water samples having known concentrations of chlorophyll *a* (Gary Bugden DFO pers. comm.). However, from 2015 to present, a new fluorometer was used and unfortunately this instrument was not calibrated. The differences between instruments preclude direct comparison (Table 1.2), but both reflect intra- and inter-annual trends in chlorophyll *a* concentrations even if the absolute values are uninterpretable.

Continuous Probes

In 2011, Vemco® classic V12 Minilog temperature loggers, set to record hourly, were deployed at two Irish moss beds in the Northeast Arm, Corduroy Road (T1) and Main (T2), and at one site in the Basin (T3) (Figure 1.2). The loggers at sites T2 and T3 were removed and downloaded in October 2012. The logger at site T1 could not be found, thus no temperature data exists for site T1 for 2012. From October 2012 on, data were collected from all three sites using Vemco Minilog II® units. These temperature loggers are downloaded and redeployed annually.

Continuous temperature loggers deployed in Main Bed provide insight into the influence of tidal flushing on water temperature in Northeast Arm. Given that values for temperature stress and lethality (20°C and 28°C, respectively) are similar for Irish moss and Blue Mussel, temperature data are presented according to these temperature thresholds to highlight their biological relevance (Table 1.3)

In August 2014, DFO deployed an Onset Hobo® optical dissolved oxygen logger set to record hourly at the Corduroy Road Irish moss bed within the Northeast Arm (Figure 1.2). In 2015 dissolved oxygen loggers were deployed from June-December at three locations: Corduroy Road Irish moss bed, Main Bed and at the Mouth of the Northeast Arm. Dissolved oxygen loggers were purchased new and were within specifications for the instrument, i.e., factory calibrated. Although loggers were cleared of fouling periodically throughout their deployment, the loggers at Corduroy Road and Main beds were buried in anoxic silt and *Ulva* in 2015. Data are unreliable for that period and therefore not presented.

A pH logger was deployed in the Northeast Arm but the combination of poor data quality, fouling, and natural variation associated with pH in freshwater-influenced tidal systems prevented meaningful interpretation of data. However since 2017, as part of a wider ocean acidification program to determine pH in bays, estuaries and the Gulf of St. Lawerence, water samples from Basin Head are collected, sealed in glass bottles with a preservative and sent for pH analysis in the laboratory. Results from this project are not yet available for the coastal areas sampled.

1.2.2. Results and Discussion

Temperature

Temperature readings taken with the handheld YSI 85® in the 9 estuarine sites were, on average, warmer than the readings from the two freshwater sites (Table 1.2). Temperatures within the estuary also reached higher maximum temperatures (28.1°C at site A) than in freshwater (22.9°C at Site H).

In the summer months of 2012-2017, average temperatures over the Irish moss beds (as measured by the continuous temperature data loggers located at T1 and T2) exceeded the threshold for stress (20°C) on 44 – 63 days per year (Table 1.3). Temperatures reached the lethal limit of 28°C for 0 – 12 days per year for the same period. Over the course of the entire deployment for these loggers, the maximum duration of exposure to temperatures over 28°C was 5 consecutive hours. This occurred only at one site, T1, and was observed a total of four times in 2013, once in 2014, and once in 2016. At T2, four consecutive hours of high temperature were observed twice in 2013 and once in 2014. Acute high temperature exceeding 30°C was observed on occasion (Table 1.3 and Table 1.4). The average temperature in the Basin (T3) was not as high as in Northeast Arm and there were fewer days over 20°C (11-33 days) and temperatures never reached 28°C.

Although high water temperatures have been observed in these areas previously; 24.5°C on July 20, 1979, and 26°C on August 6, 1980 in the Northeast Arm (McCurdy 1979, 1980), there isn't sufficient data to compare between the data collected herein and previous decades. A rise in sea surface temperature has been observed more generally in the southern Gulf of St Lawrence (DFO 2010a), though it is unclear if this warming translates to higher temperatures within Basin Head. If temperature increases within Basin Head lagoon it could be detrimental for both Irish moss and Blue Mussels.

Salinity

Based on DFO water quality samples, salinity ranged between 9 and 32 ppt at most Basin Head sampling sites. The exception is site J which is under the influence of a surface wedge of fresh water from Stream 3. Salinity sometimes dropped to 4 ppt at site A (under the influence of streams 1 and 2 likely) but remained between 9.5 and 31 ppt over the Main Bed (Site C) and Corduroy Road (Site B) Irish moss beds (Table 1.2).

Salinity varied spatially within the estuary and was affected by tidal flux and stream inputs. Salinity was lowest during low tide in areas near the main inflows of fresh water at sites in the Basin, and at site A at the top of Northeast Arm. The two freshwaters sites (H and I) were on average 0.92 and 0.37 ppt respectively.

Dissolved oxygen (DO)

Annual average dissolved oxygen concentrations measured punctually during daylight hours with a hand-held multi-meter (YSI 85®) ranged between 7 and 10 mg per L at all sites (Table 1.2). Freshwater sites H and I had higher average DO values (9.68 and 10.30 mg per L, respectively). All sites had highly variable DO concentrations (maximum 19.89 mg per L, minimum 0.03 mg per L). All sites experienced minimum dissolved oxygen values less than 4 mg per L and Irish moss beds (sites B and C) experienced hypoxic stress that was at times less than 2 mg per L.

Continuous dissolved oxygen data loggers at three locations (Corduroy Road, Main Bed and Mouth of the Northeast Arm) indicate that average dissolved oxygen concentration from June to October ranged from 7-11 mg per L (Table 1.5). The logger at the east end of Corduroy Road Irish moss bed recorded DO at a concentration less than 4 mg per L about 10% of the time between June and September and less than 2 mg per L about 2% of the time in 2016 (Table 1.6). In 2017, DO concentrations of 4 and 2 mg per L occurred 8.0% and 5.4% of the time, respectively. The dissolved oxygen logger at Main Bed and at the Mouth of the Northeast Arm recorded DO concentration below 2 mg per L less than 1% of the time.

The Basin Head Operational Management Plan dictates that action be taken when persistent hypoxic or anoxic conditions exist and these conditions expand towards the Irish moss bed. Main Bed, where much of the Irish moss exists, experienced dissolved oxygen < 2 mg per L, this dissolved oxygen concentration is considered hypoxic and has negative consequences for biota. For the sustainability of Irish moss it is critical that the Blue Mussel that anchors the Irish moss survives, lest the Irish moss becomes detached. If anoxia becomes more prevalent, or is sustained, the risk to community functioning increases as many species of fish and invertebrates may die. The absence of dissolved oxygen also promotes the growth of anaerobic bacteria which may be the ultimate cause of mortality for species such as Blue Mussel, which is otherwise insensitive to short periods of low dissolved oxygen (Babarro and De Zwaan 2002, 2008). In any case, hypoxic conditions within the Northeast Arm are occurring and warrant that management action be taken, based on the aforementioned Operational Management Plan.

Chlorophyll *a*

Chlorophyll *a* is generally used as a proxy for primary productivity in marine systems that are dominated by pelagic production (i.e., phytoplankton) (Bugden et al. 2014) and at high values are a coarse indicator of nutrient impact alone. However for shallow, well-mixed estuaries that are dominated by benthic production, such as in Basin Head, chlorophyll *a* represent only a portion of total production and/or nutrient impacts in general (Coffin et al. 2018b). The fluorometer readings (average for each site) were extremely high for all years (2001-2017 combined) (Table 1.2). In other eutrophic estuaries on PEI annual averages for chlorophyll *a* of ~ 21 ug per L were observed from May-November, with the highest value recorded of 64 ug per L at the most eutrophic site (Coffin et al. 2018b). For the period of time when the fluorometer was calibrated, chlorophyll *a* values were far in excess of 21 ug per L. Given this disparity there is some question whether data collected by the fluorometers are directly comparable to chlorophyll a values measured in a laboratory setting in an absolute sense. However, it is likely that data are comparable to each other in a relative sense, at least when comparing data from the same instrument.

Turbidity

Measurements of turbidity were conducted since 2011 and were a by-product of the fluorometer readings. Nevertheless, turbidity is a potentially influential variable as it can be related to plankton abundance, suspended sediment and other materials in the water column. In this case, unfortunately, the turbidty measurements were not calibrated to a specific variable, e.g., suspended sediment, and therefore the values do not correlate to quantitative measures. Furthermore, turbidity readings were occasionally negative throughout data collection, which is not possible, and these readings were attributed to instrument error and therefore excluded from analyses.

A review of field data collected since 2000 revealed that elevated turbidity readings were associated with windy weather and precipitation.Two of the most likely mechanisms for the observed variability in turbidty are rain-eroded soil entering via streams and suspension of sediments by wave activity. Indeed, turbidity varied geographically within the lagoon, being greatest (average 11.3 NTU) at site A (Table 1.2), at the top of Northeast Arm. Site A is also where there is substantial contribution from two freshwater streams and where *Ulva* accumulates and eventually decomposes, releasing plumes of organic matter (silt and/or bacteria) sufficient to be visible in aerial photographs.

Aside from the aforementioned lack of calibration there are a variety of other factors through which the turbidty data should be considered. Because most water samples prior to 2015 were taken between late May and early September, the spring and fall sediment plumes associated with spring snow melt and late fall storms were not recorded. Furthermore, given that the majority of sediment loading to estuaries occurs outside of the regular sampling period or after high intensity rain storms (Alberto et al. 2017) and that sampling was accomplished under calm conditions, the turbidity readings contained herein likely do not reflect the full range of conditions to which Irish moss are exposed. Ultimately though, it is probable that water clarity has declined in recent years given that eelgrass attenuates wave action and maintains sediment stability (Hemminga and Duarte 2000) and that it was basically extirpated from the Northeast Arm of Basin Head during 2006-2008. Unfortunately, no turbidity readings from the Northeast Arm were available from the time before eelgrass declined.

1.3. ECOLOGICAL INDICATOR 2: DISSOLVED INORGANIC NUTRIENTS

1.3.1. Methods

From 2001-2017, weekly water samples were collected without filtration at two freshwater and nine estuarine sampling sites located in the Basin and Northeast Arm (Figure 1.2). Samples were collected in duplicate (2) in acid washed 30 ml HDPE bottles. Bottles were rinsed with surface water several times and collected with gloved hands at the surface. Samples were then placed in an insulated container and frozen immediately upon return from the field.

Water samples were shipped to the Bedford Institute of Oceanography in Dartmouth, Nova Scotia where all analyses for dissolved inorganic nutrients were performed: nitrate, phosphorus, nitrite, ammonium and silicate. For this paper, only the results for nitrate and phosphate will be reported. The results for nitrite and ammonium will not be presented because they add very little to the total nitrogen loading. Furthermore, silicate, which is critical for diatom growth and can be limiting in systems dominated by pelagic production, is not directly relevant to Irish moss health and is therefore not discussed. Samples were excluded whenever anomalies were flagged by the laboratory technician as cases of possible contamination or mislabeling of water samples. In 2010, for example, water samples had to be discarded because they thawed in transit to the laboratory, thus no nutrient data exist for 2010. Similarly in 2006, values of ammonium were extremely high (1000 µmol per L which is acutely toxic to animals), likely due to contamination, and these samples were therefore also excluded. Finally, in 2011 the relative amount of nitrite at all sites was inexplicably high, which likely influenced the overall amount of nitrate for that year. These data were retained and analyzed, given that nitrite only represented a small component of total nitrogen.

1.3.2. Results and Discussion

Nitrate

Nitrate varied seasonally, with the highest levels generally occurring in spring and fall, when agricultural fields are ploughed. Because samples were not always collected in April and early May or after September, inter-annual trends were assessed using only data from June-August (Figure 1.3). Nitrate concentrations as measured in 9 estuarine sites were generally below 10 µmol per L. However, at the two estuarine stations closest to freshwater streams (site A and site J) elevated nutrient levels were recorded on occasion (Figure 1.3). The lower nitrate concentration observed in estuarine samples outside the influence of freshwater streams was likely due to rapid uptake of nitrate by fast growing macroalgae (such as *Ulva* spp. and filamentous algae) growing close to stream mouths (Burkholder et al. 2007).

Nitrate concentrations at the freshwater nutrient sampling sites H and I are highly variable. Ranging from 125 – 225 µmol per L and 150 – 275 µmol per L, respectively (Figure 1.4), these values are an order of magnitude higher than estuarine nutrient concentrations.

The graph of annual average nitrate concentrations for the two freshwater sites (H and I) and estuarine site J (which is affected by freshwater influence) suggests a slight decline in nitrate concentrations over the 2001-2017 period (Figure 1.5). However the fits of the lines (r-square values) were extremely low and there is limited confidence in this trend. In essence, concentrations at these sites were highly variable, as would be expected from snapshot sampling affected by dry periods, random high rainfall events, and differences in concentration associated with surface water runoff. Thus, it is difficult to determine any trends in the record of nutrient concentrations in Basin Head for 2001-2017. To assess whether nutrients inputs are increasing or decreasing it may be more effective to monitor nitrogen loading (i.e. product of concentration and flow) which is the actual quantity of nitrogen entering the system and not simply the concentration of surface water (Gilbert et al. 2010). The contribution of groundwater seeping into the estuary has not been quantified but springs do enter Northeast Arm (I. Novaczek pers. obs.) and their influence may be substantial.

Phosphate

Phosphate levels in estuarine and freshwater sites were similar and generally remained below 2 µmol per L (Figure 1.6 and Figure 1.7). Phosphate loads are high and considered stable on PEI and are not associated with agriculture, unlike nitrogen (van den Heuvel 2009; Bugden et al. 2014). Given that phosphate levels are high there appears to be nutrient sufficiency, meaning that its addition does not result in a stimulus of primary production.

Table 1.1. Mointoring activities for water characteristics in the Basin Head MPA.

Parameter (units)	Sampling type	Instrument	Frequency	Season	Number of sites	Annual coverage
Temperature (°C)	Point measurement	Hand-held meter	Weekly	Mid-May to end of August	11	2001 - 2009
	Point measurement	Hand-held meter	Weekly	Mid-May to mid-November	11	2010 - 2017
	Continuous	Probe (data logger)	Hourly	Year-round	3	2011 - 2017
Salinity (ppt)	Point measurement	Hand-held meter	Weekly	Mid-May to end of August	11	2001 - 2009
	Point measurement	Hand-held meter	Weekly	Mid-May to mid-November	11	2010-2017
Dissolved oxygen (mg L^{-1})	Point measurement	Hand-held meter	Weekly	Mid-May to end of August	11	2001 - 2009
	Point measurement	Hand-held meter	Weekly	Mid-May to mid-November	11	2010 - 2017
	Continuous	Probe (data logger)	Hourly	June to December	3	2014 - 2017
Chlorophyll *a* (ug L^{-1})	Point measurement	Hand-held meter	Weekly	Mid-May to end of August	11	2001 - 2009
	Point measurement	Hand-held meter	Weekly	Mid-May to mid-November	11	2010 - 2017

Parameter (units)	Sampling type	Instrument	Frequency	Season	Number of sites	Annual coverage
Turbidity (NTU)	Point measurement	Hand-held meter	Weekly	Mid-May to end of August	11	2001 - 2009
	Point measurement	Hand-held meter	Weekly	Mid-May to mid-November	11	2010 - 2017
Dissolved inorganic nutrients (μmol L^{-1})	Point measurement	Water samples (lab analyses)	Weekly	Mid-May to end of August	11	2001 - 2009
	Point measurement	Water samples (lab analyses)	Weekly	Mid-May to mid-November	11	2010 - 2017

Table 1.2. Comparison of chlorophyll a (ug per L) calibrated data pre 2015 (n = 122 to 131 per site) and non-calibrated data post 2015 (n = 80 to 82 per site).

	Calibrated 2001-2014			Non-calibrated 2015-2017		
Site	Average	Max	Min	Average	Max	Min
A	134.7	1301.0	0.0	161.4	989.6	50.7
B	92.5	743.6	0.2	127.0	745.0	35.5
C	83.1	754.6	0.3	115.5	280.6	32.3
D	70.7	444.8	0.1	109.7	337.1	20.6
E	66.8	461.2	0.3	97.7	246.8	25.9
F	52.7	208.1	0.0	100.2	257.4	18.3
G	58.4	278.3	0.0	101.9	255.0	20.5
H	67.1	243.1	0.2	177.4	3306.7	34.0
I	60.2	331.7	0.0	121.1	334.7	28.1
J	62.1	405.9	0.1	107.2	410.3	24.0
K	62.8	370.6	0.1	106.6	536.8	14.6

Table 1.3. Average, maximum and minimum values of temperature, salinity, dissolved oxygen from hand held YSI (2001-2017) and chlorophyll a and turbidity values from fluorometer (2001-2017) for months May to November. Temperature (n=249-289), Salinity (n=216-273), dissolved oxygen (n=214-257), chlorophyll a (n=204-213) and turbidity (n=69-72). Sites H and I are freshwater.

	Temperature (℃)			Salinity (PSU)			Dissolved Oxygen (mg/L)			Chlorophyll a (ug/L)			Turbidity (NTU)		
Site	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min
A	16.4	28.1	1.4	21.66	28.60	4.00	7.58	19.89	0.03	145.1	1301.0	0.0	11.3	31.7	0.1
B	15.9	24.8	2.3	24.09	30.39	9.50	7.61	19.74	0.38	105.8	745.0	0.2	9.6	73.2	1.1
C	15.6	26.5	2.5	24.48	30.76	12.37	7.74	18.14	1.53	95.6	754.6	0.3	8.4	19.3	0.8
D	15.4	27.0	4.2	25.42	31.23	14.19	8.01	17.87	2.80	85.6	444.8	0.1	8.0	19.7	0.7
E	15.4	26.8	4.7	26.34	31.34	15.40	7.98	16.04	2.96	78.7	461.2	0.3	7.6	23.0	0.4
F	14.9	26.6	4.1	27.01	31.50	17.00	8.08	14.84	1.51	71.0	257.4	0.0	7.0	22.3	0.0
G	14.7	26.6	3.5	27.56	31.86	16.40	8.21	17.02	1.06	75.1	278.3	0.0	7.4	21.0	0.3
H	10.7	22.9	3.7	0.92	26.20	0.00	9.68	19.22	3.16	110.2	3306.7	0.2	11.0	73.9	0.1
I	10.2	20.3	4.9	0.37	26.60	0.00	10.30	17.03	3.89	83.7	334.7	0.0	10.0	25.3	0.6
J	15.1	26.8	4.8	23.07	31.04	0.00	8.51	16.20	2.76	79.4	410.3	0.1	7.4	22.6	0.4
K	14.8	27.1	4.0	27.08	32.15	0.04	8.32	17.46	3.50	80.5	536.8	0.1	7.8	21.6	0.2

Table 1.4. Number of days where average daily temperatures exceeded 18°C. Daily average temperatures are from continuous probes in the Northeast Arm sites (T1 and T2) over the Irish moss beds and in the Basin site (T3). No data (-) are available for site T1 in 2012 because the data logger was lost.

		Average daily water temperature														
Site	Year	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
T1	2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T1	2013	82	75	57	41	29	16	7	4	0	0	0	0	0	0	0
T1	2014	81	70	63	51	31	20	8	3	0	0	0	0	0	0	0
T1	2015	83	64	47	36	20	10	9	5	0	0	0	0	0	0	0
T1	2016	78	65	51	35	22	6	3	0	0	0	0	0	0	0	0
T1	2017	89	77	59	41	23	12	10	3	0	0	0	0	0	0	0
T2	2012	90	74	59	43	31	19	7	2	0	0	0	0	0	0	0
T2	2013	79	68	47	35	18	8	3	0	0	0	0	0	0	0	0
T2	2014	57	54	49	34	20	11	4	1	0	0	0	0	0	0	0
T2	2015	81	54	44	28	11	9	8	2	0	0	0	0	0	0	0
T2	2016	72	59	42	26	8	3	0	0	0	0	0	0	0	0	0
T2	2017	85	67	49	26	17	10	5	0	0	0	0	0	0	0	0
T3	2012	68	53	37	18	10	1	0	0	0	0	0	0	0	0	0
T3	2013	57	43	23	4	0	0	0	0	0	0	0	0	0	0	0
T3	2014	55	41	28	20	5	1	0	0	0	0	0	0	0	0	0
T3	2015	51	23	11	9	7	2	0	0	0	0	0	0	0	0	0
T3	2016	57	42	23	3	0	0	0	0	0	0	0	0	0	0	0
T3	2017	63	52	33	14	7	1	0	0	0	0	0	0	0	0	0

Table 1.5. Number of days where maximum daily water temperatures exceeded 18 °C range. Daily average temperatures are from continuous probes in the Northeast Arm sites (T1 and T2) over the Irish moss beds and in the Basin site (T3). No data (-) are available for site T1 in 2012 because the data logger was lost.

		Maximum daily water temperature														
Site	Year	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
T1	2012	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T1	2013	119	109	93	84	72	59	47	38	30	23	12	8	5	0	0
T1	2014	119	108	95	83	74	65	58	48	38	18	10	6	4	0	0
T1	2015	119	111	96	79	65	51	39	30	24	17	10	5	4	0	0
T1	2016	105	100	93	81	69	50	77	21	12	6	5	3	3	0	0
T1	2017	111	104	92	78	68	56	42	26	17	11	6	2	1	0	0
T2	2012	123	111	105	88	71	65	55	38	26	19	8	5	0	0	0
T2	2013	113	96	87	76	61	52	42	33	22	10	7	5	0	0	0
T2	2014	82	78	72	67	62	53	47	38	21	12	5	5	0	0	0
T2	2015	117	104	87	74	60	45	36	30	21	13	4	4	0	0	0
T2	2016	101	98	88	70	55	34	25	14	6	5	2	1	0	0	0
T2	2017	106	99	86	72	57	45	28	18	15	6	1	0	0	0	0
T3	2012	100	88	73	57	38	25	17	2	0	0	0	0	0	0	0
T3	2013	80	68	55	43	29	14	5	2	0	0	0	0	0	0	0
T3	2014	85	75	60	49	30	20	11	2	0	0	0	0	0	0	0
T3	2015	72	48	28	18	16	11	5	2	0	0	0	0	0	0	0
T3	2016	74	62	48	73	15	9	0	0	0	0	0	0	0	0	0
T3	2017	86	67	56	40	25	12	4	2	0	0	0	0	0	0	0

Table 1.6. Average monthly dissolved oxygen concentrations (mg per L) from continuous probes over Irish moss beds and at the Mouth of Northeast Arm from 2015-2017. Data for Corduroy Road and Main Bed in 2015 are not included (-) due to probe likely being buried in silt.

Year	Month	Corduroy Road	Main bed	Mouth
2015	June	-	-	10.7
	July	-	-	9.0
	August	-	-	7.7
	September	-	-	7.6
	October	-	-	8.3
2016	June	10.6	10.8	9.3
	July	6.9	8.6	7.7
	August	7.1	8.1	7.3
	September	7.9	7.7	7.7
	October	9.4	9.0	9.3
2017	June	10.9	10.8	10.2
	July	7.0	8.7	8.6
	August	7.6	7.8	7.9
	September	8.2	8.1	7.8
	October	9.6	9.3	8.9

Table 1.7. Percentage of time (June through September) dissolved oxygen concentrations from continuous probes over Irish moss in the Northeast Arm and mouth of Arm were below thresholds of 2, 4 and 6 mg per L, or greater than 10 mg per L.

		Dissolved oxygen concentration (mg per L)			
Year	Site	< 6	< 4	< 2	> 10
2015	Corduroy Rd.	-	-	-	-
	Main bed	-	-	-	-
	Mouth	15.1	3.4	0.6	23.4
2016	Corduroy Rd.	26.5	10.4	2	26.4
	Main bed	6.2	0.5	0	25.2
	Mouth	16.5	3.8	0.8	22.6
2017	Corduroy Rd.	21.3	8	5.4	30.4
	Main bed	9.1	0.7	0	26.5
	Mouth	9.4	1.7	0.4	25.3

Figure 1.3. Water quality sampling sites in Basin Head from 2001-2017. The 11 estuarine sites are lettered from A to K and the 2 freshwater sites are H and I.

Figure 1.4. Location of temperature loggers and dissolved oxygen probes in the Main Basin and Northeast Arm.

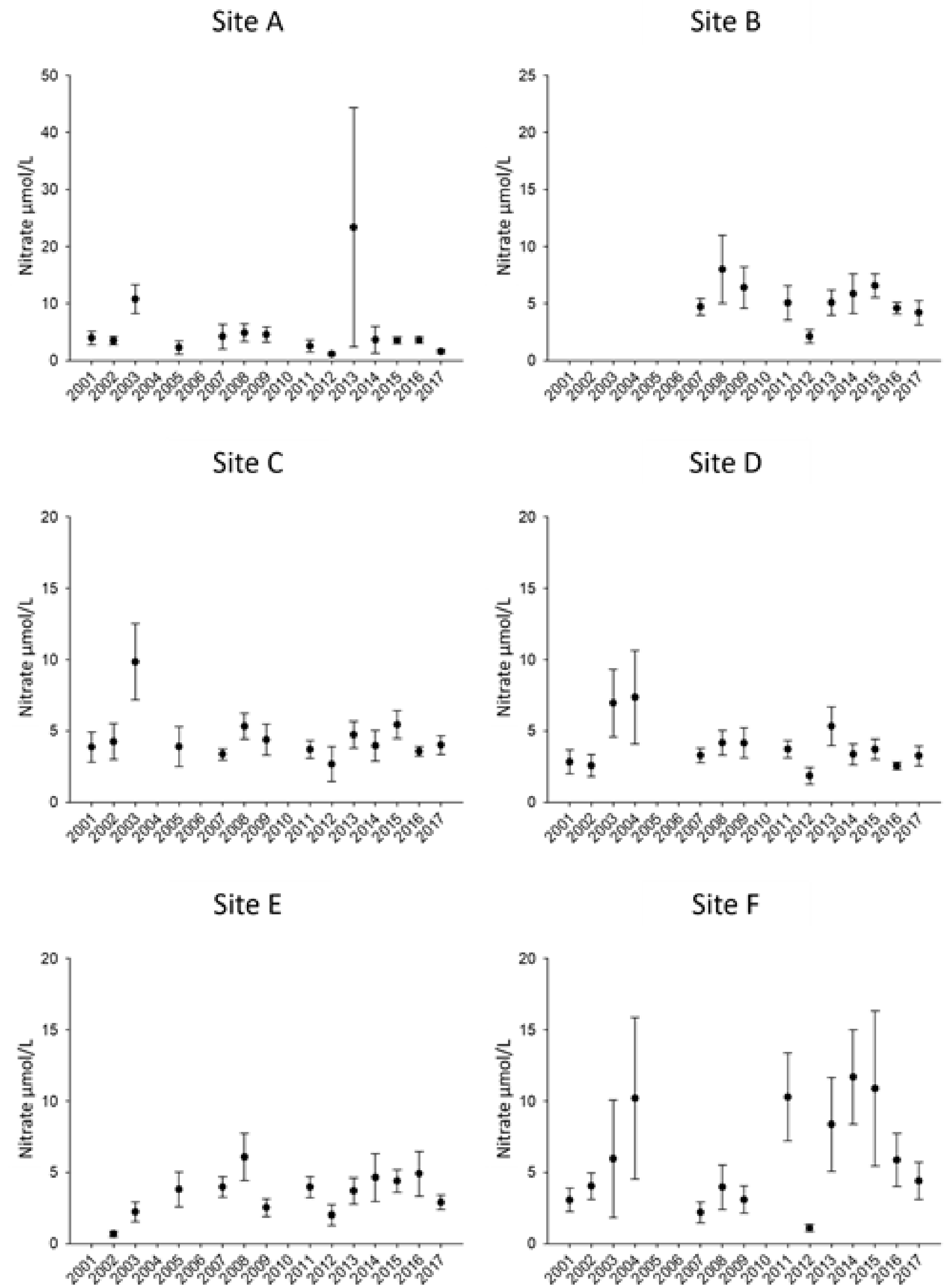


Figure 1.5. Mean (with one standard error bars) annual nitrate concentrations (µmol per L) from June, July and August samples collected from nine estuarine water quality monitoring sites in Basin Head from 2001 to 2017. Data from 2006 and 2010 are not presented due to sample loss or contamination. Note changes in scale of the y-axis.

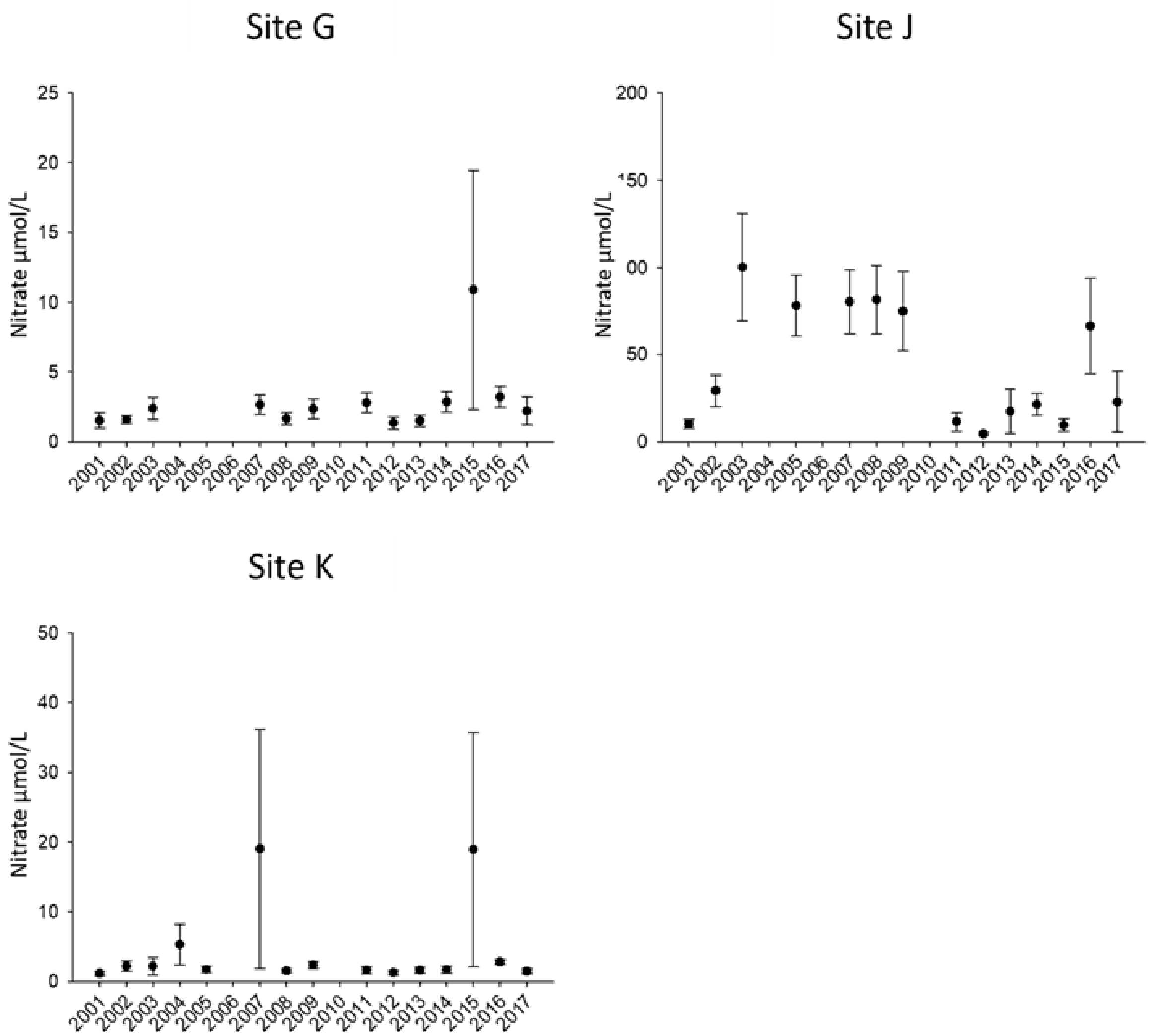


Figure 1.6. (continued). Mean (with one standard error bars) annual nitrate concentrations (µmol per L) from June, July and August samples collected from nine estuarine water quality monitoring sites in Basin Head from 2001 to 2017. Data from 2006 and 2010 are not presented due to sample loss or contamination. Note changes in scale of the y-axis.

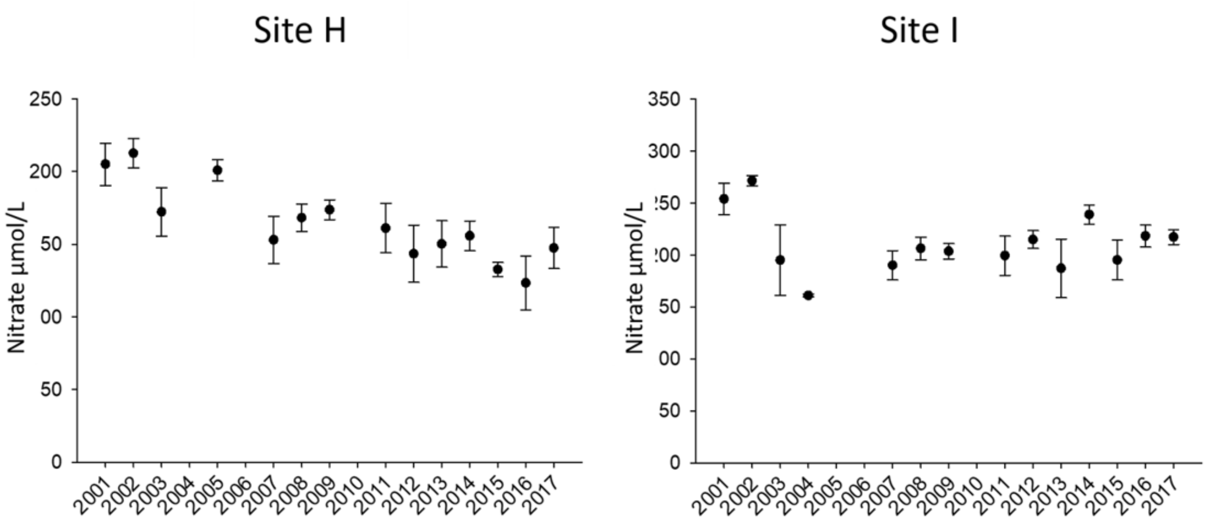


Figure 1.7. Mean (with one standard error bars) annual nitrate concentrations (μmol per L) from June, July and August samples collected at two freshwater water quality monitoring sites in Basin Head from 2001 to 2017. Data from 2006 and 2010 are not presented due to sample loss or contamination. Note changes in scale of the y-axis.

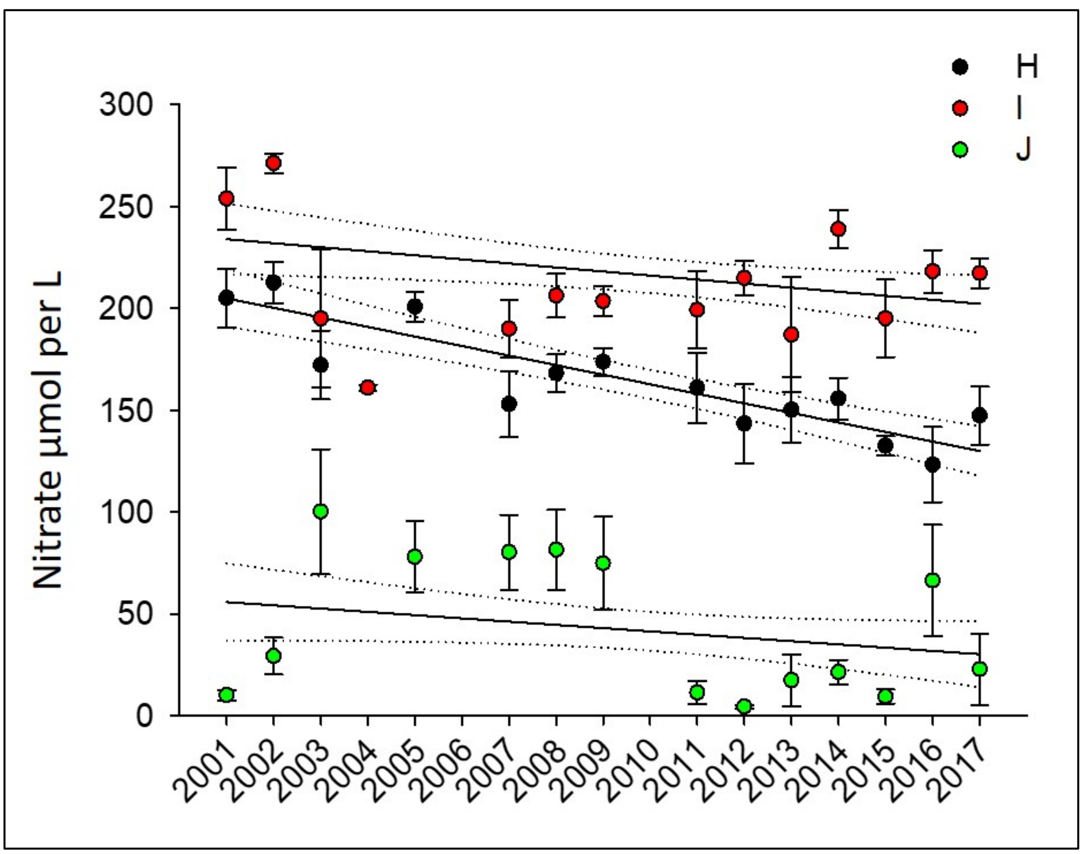


Figure 1.8. Annual trend in nitrate concentrations (umol per L) for freshwater sites H and I, and estuarine site J in Basin Head for 2011 to 2017. The dashed lines show the 95% confidence interval for the mean trend. The relative fits expressed in terms of r-square values are as follows: Site H = 0.23; site I = 0.04, and site J= 0.02

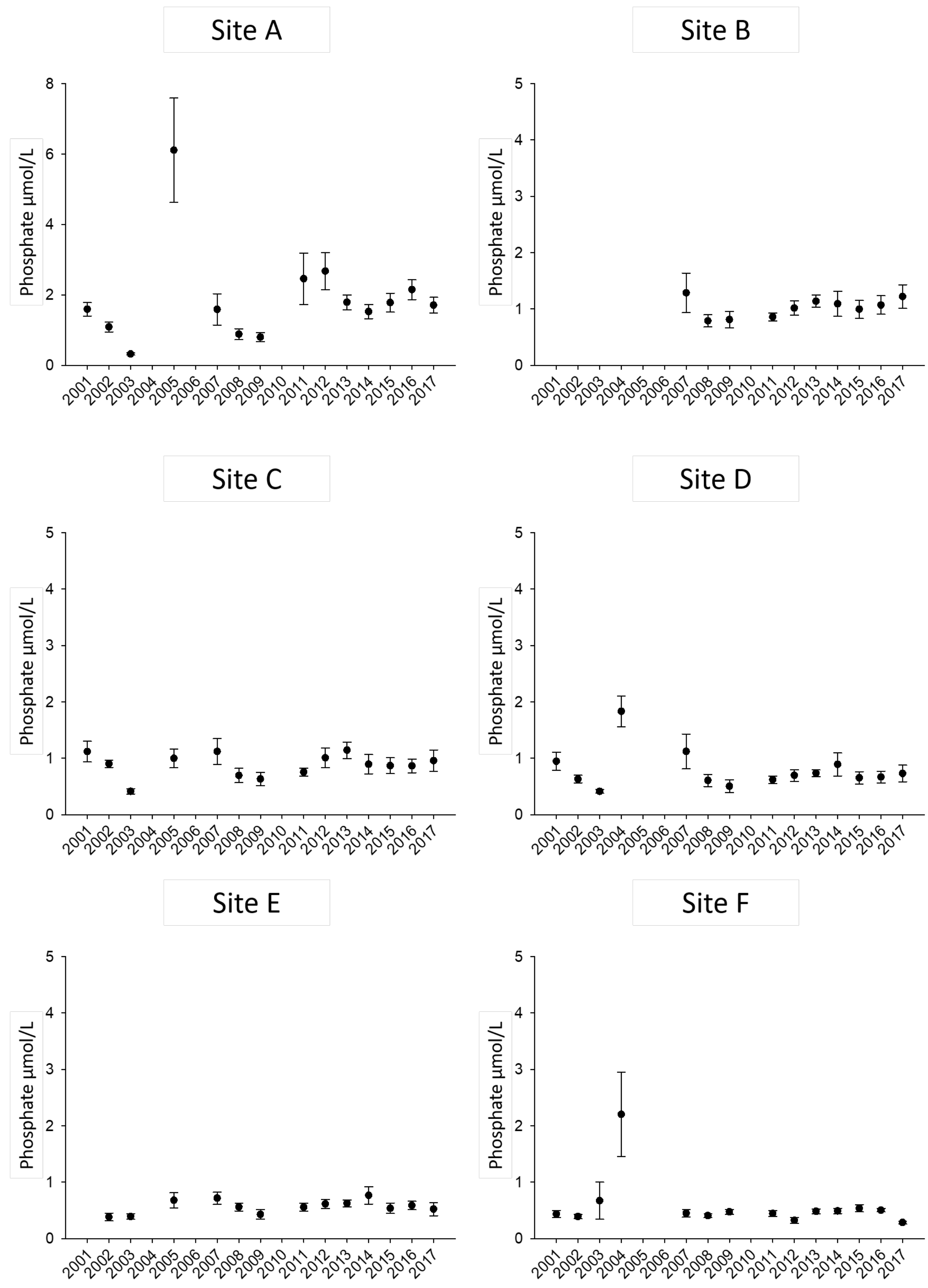
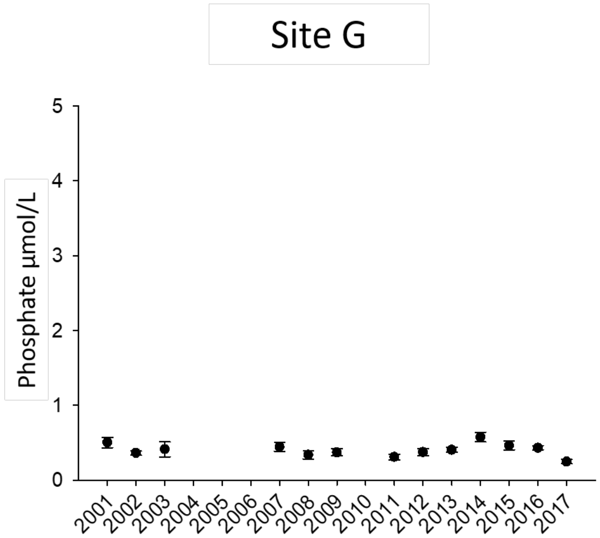
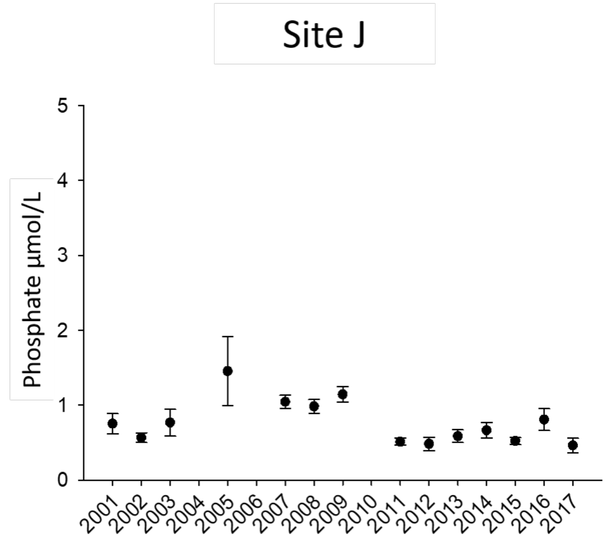


Figure 1.9. Mean (with one standard error bars) annual phosphate concentrations (μmol per L) from June, July and August samples collected from nine estuarine water quality monitoring sites in Basin Head from 2001 to 2017. Note changes in scale of the y-axis.





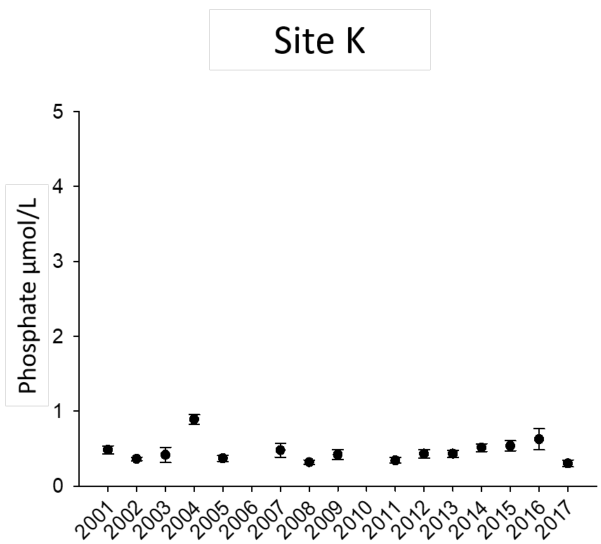


Figure 1.10. (continued). Mean (with one standard error bars) annual phosphate concentrations (μmol per L) from June, July and August samples collected from nine estuarine water quality monitoring sites in Basin Head from 2001 to 2017.

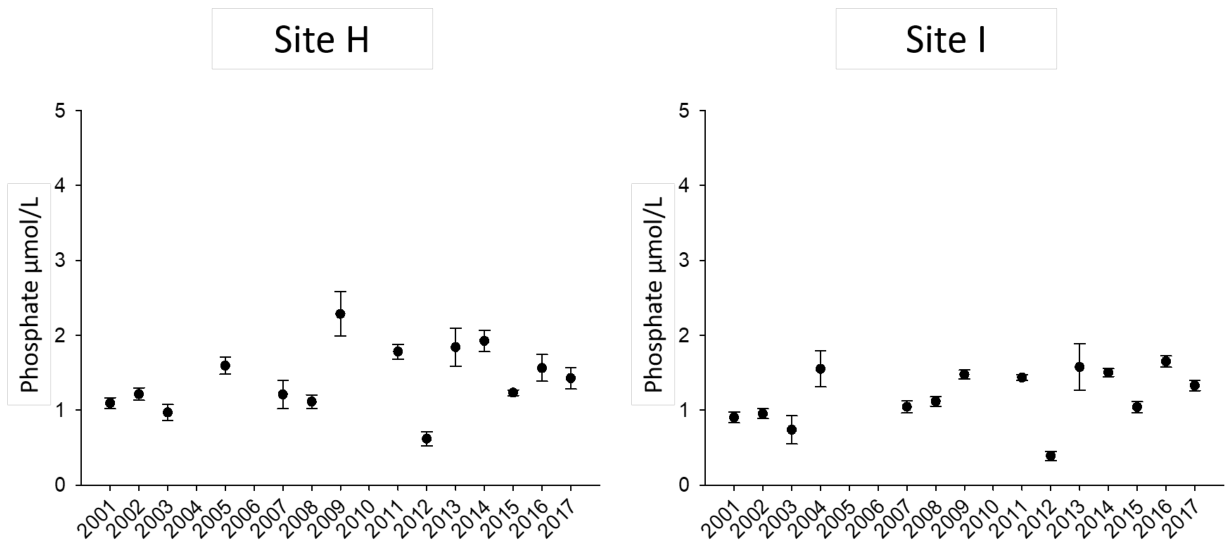


Figure 1.11. Mean (with one standard error bars) annual phosphate concentrations (μmol per L) from June, July and August samples collected from two freshwater water quality monitoring sites in Basin Head from 2001 to 2017.

2. CONSERVATION OBJECTIVE 2: MAINTAIN THE PHYSICAL STRUCTURES OF THE ECOSYSTEM SUPPORTING THE IRISH MOSS

Author: I. Novaczek

2.1. CONTEXT

The purpose of this objective is to maintain the integrity of the physical environment, i.e. the dune structure, the ocean opening, water depth and flushing; and to limit the erosion of land that causes sedimentation in the estuary. Although the stated purpose is broad, the ecological indicator monitored to meet this conservation objective concerns only land use related impacts. There has not been any systematic monitoring of the dune structure or the opening to the Northumberland Strait by DFO. Other key physical features of the estuary that affect physical structure but have no explicit indicators include the salt marsh, natural oyster reefs and eelgrass beds. The thresholds for triggering management action that are listed in the 2014 Operational Management Plan lack specificity. For example, the Plan calls for mitigation in the event of a breach in the barrier sand dune system, or changes in flushing rates compared with baseline data.

A major land use impact is soil erosion into the estuary and subsequent accumulation of loose sediments on the bottom. This reduces water depth, which increases the potential for winter ice scour and may affect current speeds and the rate of flushing. In the present Operational Management Plan, there are no thresholds for action related to impacts of sediment loading into Irish moss habitat.

A series of monitoring activities and short term studies of the physical structures supporting the Irish moss were conducted in recent years and are described below and summarized in Table 2.1 and Table 2.2. Physical structure of eelgrass beds will be discussed in Section 3.

2.2. MONITOR IMPACTS OF LAND USE PATTERNS IN THE WATERSHED

2.2.1. Methods

Dune structure

There has been no monitoring of the dune structure but the aerial photo series available from the provincial geomatics division could be used to establish a baseline for dune width. The top of Northeast Arm (site of the pre-1936 entrance to the estuary) is where the dune is relatively low and narrow and where a breach may be most likely to occur.

Ocean opening

There has been no monitoring of the ocean opening by DFO. The only annual monitoring conducted is by the province of PEI, monitoring water depth in the Basin Head run between the two wharves to ensure the safety of persons jumping off the wharves into the water. Over recent centuries, the shape and size of Basin Head Lagoon have changed due to natural forces (Giles 2002). Starting in 1936 a man-made opening and fishing wharves were constructed at the southwestern corner of the system, replacing the previous, shallower opening at the northeastern end of Northeast Arm. For the first time since (at least) 2000, the run had to be dredged in 2019 because a storm surge in November 2018 brought sand into the system that caused more than 1 m of shallowing between the wharves. Impacts further up the channel, and the effect this has had on hydrodynamics, are as yet unknown.

Land use

Basin Head watershed covers 17.5 km^2 while the estuary covers an additional 0.6 km^2 (Chassé pers. comm.). The Province performs aerial photography every 10 years to document land use, with the last one conducted in 2010. Yearly satellite image analyis of crops on agricultural land is performed by Agriculture and Agri-Food Canada (AAFC) and these data, which are publicly available online, have also been examined. Souris and Area Branch of the PEI Wildlife Federation (SAB) staff visited all farm fields in the watershed in the fall of 2013 to produce a map of crops per field for that year. A land use study initiated by DFO and SAB in winter 2017 documented land use from 2010 to 2015 based on interviews with eight farmers who collectively owned or leased a majority of the agricultural land in the watershed. Data collected included the type and area of crops planted per field; the timing of ploughing; the type, amount and timing of fertilizer applications; acreage used for livestock pasture; use of chemicals to kill potato foliage; land conversions since 2009; and erosion mitigations in place. Crops planted on fields not covered in the interviews were determined from the 2013 field survey performed by SAB and federal land use data based on annual satellite image interpretation (Figure 2.1).

Soil erosion

Soil erosion from unvegetated land in the watershed (including the dunes) can be caused by rainfall or wind with eroded sediments deposited directly or carried by streams into the estuary. The availability of stream flow and sediment load data for Basin Head is limited. Connolly (2002) measured concentrations of sediment in three streams identified in Figure 1.1 in the summer of 2000.

Using the provincial land use layers to identify agricultural areas, every farm field in the watershed was assigned a soil erosion vulnerability code based on average slope and proximity to water (Figure 2.2).

Anecdotal evidence indicates a shallowing of the water in the estuary since the 1950s (SAB 2015)[2]. Water depths were first measured along survey transects by Connolly (2002) who calculated a flushing rate for the estuary. Subsequently, current measurements allowed development of a hydrodynamic model (Martec Ltd. unpublished report 2005a and 2005b[3] ; Chassé pers. comm.). During wading surveys to document the size (frond diameter) and position of Irish moss plants in the period from 2014 to 2015, bottom conditions (water depth, sediment thickness) around each clump were recorded, allowing us to quantify conditions under which the remnant population of clumps had survived. Twenty cross-channel transects were surveyed to map areas of Northeast Arm having the water depth and firm substrate suitable for survival of Irish moss-mussel clumps. Eleven transects located in Irish moss beds were also established at permanent survey benchmarks of known elevation so that future surveys can be used to determine how water depth and penetrable sediment thickness in these areas change over time as a result of sediment loading and redistribution. Changes may limit or expand the area of bottom suitable for Irish moss.

Sediment thickness was monitored at 11 sites along the edges of the Arm in October 2016 and in May, July and October 2017 (Figure 2.3). On each occasion, sediment samples were collected and analyzed for wet pH, grain size, % organic matter and nutrient composition (% nitrogen, % sulfur, % carbon and ppm ammonium on a dry weight basis; analysis by PEI Soil Lab). During various field experiments (2014 to 2018), impacts of sediment accumulation on Irish moss-mussel clumps were documented.

Winter ice

Clump survey data from 2014 to 2018 were analyzed to determine if movement of clumps or loss of Irish moss from mussel clumps varied with season or water depth. Field observations were made in February 2016, December 2016 and March 2017 to document ice development, ice thickness and the time of melting. Photographic monitoring of ice movement was initiated in January 2017 using time lapse cameras strapped to a mast anchored in the marsh, and to a tree at Main Bed. The Main Bed camera is still in place (2019). Bricks were set out at 2 m intervals across the eastern end of Main Bed to observe their movement over the winters of 2017 and 2018.

Current speed and flushing

Within the Northeast Arm, survival and retention of Irish moss-mussel clumps is highly dependent on current speeds, as areas of minimal current are depositional zones where the clumps are killed due to smothering by mobile sediments, organic debris and *Ulva*. In 2017, two initiatives aimed to characterize current speeds. On a small scale, a Global FP211 current flow meter was used to explore the current environment around high tide and low tide at Main Bed. At the estuary-wide scale, monitoring was conducted to collect oceanographic data (tidal elevation, currents, water temperature and salinity) using loggers placed in various locations within the Basin Head system. This information was used to support the development of an updated version of the Basin Head hydrodynamic model, which also made use of high

[2]Souris and Area Branch of PEI Wildlife Federation (SAB). 2015. Basin Head Local Knowledge Report. 47p

[3] Martec Ltd. 2005a. Effect of entrance configurations on water quality at Basin Head, PEI. Contract report to PEI Transportation and Public Works, Technical Report no TR-05-16, March 2005, 21p. & Martec Ltd. 2005b. Effect of entrance configurations on water quality at Basin Head, PEI. Addendum 1 to contract report to PEI Transportation and Public Works, Contract no TR-05-16, Addendum 1 August 2005, 5p.

resolution bathymetric data collected in summer 2017 through a lidar survey conducted for the Canadian Hydrographic Service. Flow speed and direction time series were collected at 4 locations in the Main Bed area, using Sontek Argonaut-ADV acoustic current meters deployed on the bottom to characterize the current regime in this region and serve as model validation.

2.2.2. Results and Discussion

Ocean opening

A destructive storm surge damaged the ocean entrance to Basin Head on December 27, 2004 (DFO 2008; Sharp et al. 2010) and resulted in strong flushing of the system that removed a significant proportion of Irish moss from the estuary. In 2016, another storm surge hit Basin Head which also caused an increased dislocation of clumps and scouring away of surface sediments. In contrast, the storm surge during high tide at the end of November 2018 filled the entrance channel with sand, reducing water depths. The effect of climate change may impact the severity and frequency of storm surges, making it important to monitor the only ocean opening more closely.

Land use

Land use in the Basin Head watershed has been stable since 2000, with roughly 3 Km^2 of agricultural land being used for growing crops. Prior to the MPA establishment, roughly 40% of the land was dedicated to agriculture (Island Nature Trust unpublished report 2001)[1]. Land use documented by the province for the period 2006 to 2010 indicated little change (44% agricultural).

In all years, information provided by farmers sometimes differed from the assessments provided by AAFC annual crop inventory. In our report, information from farmers is assumed to be most reliable. AAFC and Provincial data should, nevertheless, reflect major changes in land use over time. Figure 2.1 illustrates the main farmland use in Basin Head in 2013 showing potatoes as being the major crop on the northern side of Northeast Arm.

The farmer interviews revealed that the proportion of farmed land dedicated to potatoes varied from year to year between 55% and 80%. Several varieties of barley and a Timothy-clover hay crop were typically used in the three-year potato rotations, while soybeans and Samson wheat were occasionally planted. Fertilizers were applied as early as the first week of May, and applications continued until end of June. Potatoes were usually harvested in October. Land devoted to livestock was limited; woods, marshes, dunes and residential properties occupied most of the uncropped land base.

Soil erosion

Many fields abutting Northeast Arm are extremely vulnerable to erosion (Figure 2.2), and 86-92% of the most vulnerable properties (codes 5 and 6) are in some phase of potato rotation in any given year. Four varieties of potato were planted in the watershed in the period from 2010 to 2015, with Russet Burbank being the most common. These potatoes are very inefficient in terms of nitrogen absorption, are heavily fertilized, and leach more nitrates into waterways than other varieties (Zebarth et al. 2015).

In any one year, between 17% and 67% of the fields most vulnerable to soil erosion are planted with Russet Burbank potatoes, which require a long growing season. In consequence, fields are ploughed in the fall before planting, so as to ensure an early start in spring, and there is no time in autumn to grow a cover crop after harvesting the potatoes. The bulk of eroded sediment entering the lagoon likely comes from fields that are left bare all winter. In spring, thick soil deposits can be seen coating the banks of the estuary below such bare fields. Extremely turbid water conditions follow rain events in months when farm field soils are exposed.

On PEI generally, soil erosion into estuaries has been a serious environmental issue for decades (Environment Canada 1999). Regulations and incentives have been established that aim to reduce erosion, but the problem persists. Connolly (2002) measured the sediment load in three of the largest streams entering Basin Head, which carried an estimated 145 tonnes of soil into the estuary over 3 months (i.e. June-August 2000). However, 2000 was the driest summer in the period 2000 to 2015 and is not representative of average conditions. Less than 100 mm of rain fell in July to September 2000. In other years between 2000 and 2015 rainfall ranged between 134.4 mm (2011) to more than 500 mm (2012) during the same summer months (Source: Environment and Climate Change Canada). Also, no sediment load measurements were made in the spring and fall when fields are bare and more prone to erosion. Therefore we can expect total annual loading to be greater than indicated by Connolly's data.

Another potential source of sediments to the system is wind erosion of the nearby dunes, but the dunes are well vegetated and wind-blown sand from that direction has not been observed.

More work is required to understand how much sediment is entering Basin Head estuary from the watershed, especially during the spring snow melt and during extreme rain events when the water in Northeast Arm can be seen to turn red. Because phytoplankton blooms also influence turbidity readings, turbidity is, by itself, not an appropriate measure of sediments in the water. Therefore direct sampling of suspended sediment concentrations in streams, and of rates of sedimentation in the Arm, are required.

We also do not know what proportion of sediment gets swept out by the tide, but over time there has been a net retention, leading to shallowing of the estuary. The east end of Northeast Arm used to be navigable by fishing boats in the 1950s, but now there is not enough water depth for a canoe when the tide is low (SAB 2015)[2]. What used to be a deep channel at the mouth of stream 3 (near Ching's bridge) is now filled in and turning into a marsh (F. Cheverie pers. comm. 2014). Because the shallowing of the estuary will increase summer thermal stress and winter ice scour, monitoring soil erosion and developing mitigation strategies are important gaps to be filled in the Operational Management Plan.

Pockets of loose sediments 20 to 50 cm thick were measured along the relatively stagnant edges of Northeast Arm. In addition to soil and sand from the watershed (wind borne, stream borne or cascading directly over the banks), these areas receive organic-rich silts released by the decomposition of seasonal *Ulva* blooms and salt marsh debris. Eelgrass beds that once would have stabilized such sediments disappeared from Northeast Arm prior to 2014. Sediment monitoring at 11 sites in Northeast Arm in 2016 to 2017 showed that % organic matter and % nitrogen were higher at the top of the Arm under the *Ulva* bloom and lower in the increasingly sand-dominated (terrigenous) sediments to the west (Figure 2.3). Variability was least under the *Ulva* bloom (site 1), and greatest within Irish moss beds (sites 3 and 4 at Corduroy Road, 6 and 7 at Main Bed).

In field experiments, mobile sediment in Northeast Arm settled not only along the stagnant edges and in deep channels but also wherever there were groups of Irish moss-mussel clumps present in areas of less than maximum current speed. Where severe, sedimentation killed Irish moss and damaged the shells of mussels, making them rough. Soft silt, coarser sediments and organic debris including marsh sods and *Ulva* mats accumulated to a greater extent on clumps that had been placed on or close to relatively soft bottom. In extreme cases, smothering killed all the Irish moss in test plantations of multiple clumps and the annual rate of mussel mortality also increased relative to that of clumps planted on current-swept sand.

Surviving Irish moss-mussel clumps located in 2014 were concentrated on relatively hard bottom (< 20 cm penetrable sediment) in water that ranged from 10 to 60 cm depth at low tide (Figure 2.4). The twenty cross-channel transects that were surveyed to map Irish moss habitable areas in Northeast Arm estimated a potential suitable habitat amount of 16,000 m^2 (Figure 2.5), which is within the range of estimates of area occupied by Irish moss-mussel clumps in 1979-1980. To generate this map, interpolation of bottom conditions between transects were based on changes in the texture and colour of the bottom in the 2016 base map developed using drone-based aerial imagery.

Winter ice

Field and camera observations showed that thin ice may form in December or (in the case of 2018) in November, but this generally thaws and reforms several times until freezing temperatures become continuous in January or February. Snowfall and winter ice formation were heavy in the winters of 2013 to 2014 and 2014 to 2015. Structures left in the water over the winter of 2014 to 2015 were crushed or pounded into bottom sediments. Water temperature records indicated that the ice did not melt until late April. Ice scour marks were visible on intertidal and shallow subtidal mud in the spring of 2015. In the following winters, freeze-thaw cycles caused the ice to partially melt, crack and refreeze throughout January-February and melt away before the end of March. In the winter of 2016 to 2017, nearshore ice reached a maximum thickness of 20 cm in February, was thinner in mid-channel, and was underlain by a layer of low salinity water (0.4 to 12.5 ppt) that could be detrimental to stenohaline benthic fauna and flora. During spring low tides of 0.1 to 0.2 m, the shoreward edges of such thin ice would come into contact with subtidal bottom. When 24 bricks were placed at 2 m intervals across Main bed in 2016 and 2017, only those along the shallow edges were significantly disturbed. Along the stagnant edge, bricks were buried in sediments over winter, while along the current swept edge, bricks were shifted several meters east or disappeared entirely. Monitoring of tagged Irish moss-mussel clumps showed that these often moved. In Main Bed in 2014 (before clumps were stabilized by adding mussels) 17.5% of clumps moved during the field season, and a further 42.1% moved over winter. From 2014 to 2018, clump movement was greatest in shallow and intertidal areas. Ice scour that removes clumps from intertidal and shallow subtidal areas poses a threat to clumps not because it kills them directly, but because most firm bottom in Northeast Arm is surrounded by areas of deep silt and any lateral movement will take clumps into areas where they could be smothered.

In a winter with relatively thin and mobile ice (2017-18), Irish moss was sheared off mussel clumps in shallow portions of permanent survey transects, reducing overall cover in most cases by 27 to 55%, but leaving the mussels behind intact. Climate change will likely bring ice-free winters to the Gulf of St. Lawrence and in the meantime, any increase in mobility of ice may increase losses of fronds from shallow bottom during winter.

Current speed and flushing

Inside the estuary the tidal amplitude is less than on the outer coast, indicating a restricted degree of flushing. Connolly (2002) estimated mean flushing time of water in Basin Head to be 2 days, with a range between 0.79 and 6.82 days, depending on stream discharge and tidal inputs. Martec Ltd (unpublished report 2005a, 2005b)[3] estimated flushing time of water in Basin Head in 2005 as follows: 2.5 days in the Basin; 2.6 days in the mid-Northeast Arm; and 2.9 days in the upper arm. Chassé (pers. comm.) estimated average flushing time to be only 1 day but an alternate model (Drozdowski pers. comm.) indicated widely variable flushing times ranging from 0.25 days to more than 5 days. An updated version of the model (Guyondet pers. comm.) using the 2017 lidar bathymetry dataset and including intertidal areas confirms the wide range of flushing times going from less than a day close to the inlet, to 1 to 1.5 days in the Main Basin, and more than 3 days at the head of the Northeast Arm.

In 2014, remnant Irish moss clumps were largely confined to particular areas of firm, shallow subtidal bottom (10 to 60 cm water depth at low tide, penetrable sediment < 20 cm). These areas also experienced maximum depth-averaged current speeds of 30 cm s^{-1} or greater (Chassé pers. comm.; Figure 2.6). We conclude that for Irish moss to survive, tidal flushing must be strong enough to remove smothering sediments and debris from the clumps. Current measurements taken in Main Bed with the Global FP 211 flow meter demonstrated the following characteristics of the current speed: reduced by friction at the water-sediment interface, increasing where the channel narrows, peaking when the tide is rising, and least around high tide. Bricks set on edge in a line across Main Bed usually fell over to the east, demonstrating the greater power of the rising tide. However, surveys performed to detect and map movement of clumps showed that although clumps could migrate east or west, the general trend of movement over time was to the west (downstream), perhaps because the falling tide occupies a greater length of time per day. For example, during the period of July 18 to 21 2016, the spring tide spent 4 to 6 hours per cycle rising in Northeast Arm, but took as long as 9 hours to drain out (Figure 2.7).

2.3. OTHER KEY PHYSICAL STRUCTURES SUPPORTING IRISH MOSS

2.3.1. Methods

Salt marsh structure and rate of erosion

Provincial aerial photos dating back to 1935 were georeferenced and analyzed using GIS to trace changes in the location of marsh edges and develop estimates of marsh erosion rates over time. In January 2017, 15 rebar rods were inserted at 5 m intervals, along a transect running east-west at a distance of 30 cm from the marsh edge. The distance of each post from the edge of marsh was monitored periodically to determine rates of erosion. This study is on-going.

Ten marsh sods removed from the marsh by ice and left on the marsh or rafted into the Arm were tagged and measured in 2017, then located and re-measured in 2018. Samples from sods and surrounding sediments were collected for analysis of grain size distribution and % organic matter (analysis at DFO Moncton), and duplicate samples went to the PEI Soil Lab for analysis of wet pH and nutrient concentrations (% carbon, % nitrogen, % silicate, ppm ammonium). During various field experiments the impact of coarse marsh debris settling on top of clumps was documented.

Vulnerability of the marsh to erosion may be elevated in Basin Head because of the negative impact of high nitrogen concentrations on marsh grass roots (Burkholder et al. 1992, 1994; Deegan et al. 2012). In 2017 three cores were taken from the marsh behind Main Bed to document the thickness and composition of the live root zone and underlying peat layers. Marsh pore water samples were collected, pushed through a 0.45 µm filter, then frozen and sent to Bedford Institute of Oceanography for analysis of salinity and nutrients (nitrate, phosphorus, silicate and ammonium).

Oyster reefs

Although transect surveys to document water depth and sediment thickness also recorded whether shell litter was present on the bottom, no monitoring of the full extent of shell-covered bottom or living oyster reefs has ever been done in Basin Head. Oyster shell is currently being incorporated in planted Irish moss clumps to increase its weight and stability. Live oyster demographics were recorded from animals found on 0.5 m^2 areas sampled at 5 m intervals along transects at Main Bed and Corduroy Road in 2015.

2.3.2. Results and Discussion

Salt marsh structure and rate of erosion

Marsh edge erosion close to the Mouth of Northeast Arm was elevated following the construction of the new opening at the southeast end of the Basin in 1936 to 1937. Compared to the 1935 to 1968 period, rates of marsh erosion over the period 1968 to 2000 were less, and the marsh changed very little from 2000 to 2010. On average, the marsh edge at Main Bed eroded by 0.8 cm per month between January 2017 and May 2018, with a higher erosion rate over the winter and spring of 2018 when there were more frequent freeze and thaw cycles.

The floating marsh behind Main Bed was found to be up to 63 cm thick. Dead *Spartina alterniflora* roots (peat) underlaid the live *S. patens* roots, indicating that the marsh elevation has risen over time relative to mean sea level. Marsh pore waters were so highly sulfuric and anoxic that the analytical column was stripped and only one measurement of nitrate concentration was possible. Relative to estuarine waters, marsh pore waters were enriched with nitrite, phosphorus, silicate and ammonia.

By late summer, marsh sods torn from the marsh in winter and rafted into the channel of Northeast Arm in spring were falling apart, releasing mud and organic debris. Sods declined in volume from year to year and some smaller sods disappeared from their recorded location over winter, either because they disintegrated or moved. Sods had lower carbon:nitrogen (C:N) ratios than surrounding bottom sediments, and when grass was growing on them, sods were relatively rich in nitrogen, ammonium and carbon. The composition of relatively large sods (> 150 cm long) was quite uniform but the chemical profile became more variable as sods broke down into smaller units. Sediments collected from immediately upstream and downstream of sods were similar in composition to other benthic sediments.

Small sods and detritus moving along the bottom with the tide got snagged on Irish moss - mussel clumps. Irish moss quickly died when covered in marsh debris, whereas mussels often survived from year to year. Year-long monitoring of the thickness of penetrable sediments in Northeast Arm revealed that sediments may pile up during calm spring and summer months (increasing by as much as 29 cm) or be scoured out by storms between autumn and the following spring (decreasing by as much as 46 cm).

Oysters reefs

Mussels have a strong affinity for oyster shell. In the Irish moss beds, clumps were often found attached to shells, and mussels in suspended cultivation in mesh bags produced byssal threads through the mesh to pick up oyster shells from the bottom. Mussel clumps that include oyster shells are heavier and less likely to drift onto unsuitable bottom. The shells also act as platforms that help prevent clumps from sinking into soft sediments.

In 2015, oysters were present in 59% of bottom samples collected in Irish moss beds. Densities ranged from 0 to 22 (average 6) per m^2. The population included a cohort of animals less than 40 mm long which formed a disconnected peak indicating recruitment in the previous year that survived predation (Figure 2.8).

Storms in the autumn of 2016 scoured areas of bottom, exposing layers of oyster shell that had been covered in unconsolidated sediment. In 2017, not only had old reefs been uncovered, there had also been a significant development of new reefs of young oysters in Northeast Arm. Filter-feeding by oysters will help reduce turbidity, benefitting eelgrass by improving light penetration (Tallis et al. 2009). Oyster shell litter will help stabilize loose sediments and provide anchorage for mussel clumps. Irish moss could benefit from having access to a more stable and healthy mussel clump population. Benthic infauna that require a stable environment would also benefit from shell litter that “armours” otherwise mobile sediments.

On the other hand, sediment trapping by oyster reefs may exacerbate the shallowing of the system, and oysters may compete with mussels for food, and with eelgrass for space on the bottom.

Table 2.8. Monitoring activities and short term studies of the physical structure of the Basin Head lagoon.

Metric	Information collected	Sampling frequency
Land use	Quantification of land use from satellite images	Annual
	Interviews with land-owners covering the period of 2010-2015	2017
	Ground truthing by surveyors	2013
Soil erosion	Soil erosion vulnerability code, based on average slope and proximity to water, assigned to individual farm fields in the watershed	Static
Water depth and sedimentation	Water depth at low tide and penetrable sediment thickness beside each Irish moss-mussel clump	2014, 2015
	Mortality of Irish moss and mussels under different bottom conditions, condition index of Irish moss exposed to different bottom conditions	2015-2018
	Water depth at low tide, sediment thickness and bottom cover at 2 m intervals along 20 cross-channel transects in Northeast Arm.	2016
	Sediment thickness at 11 sites along the edges of the Arm; sediment samples analysed for wet pH, grain size, % organic matter and nutrient composition	Four times between October 2016 and October 2017
Winter ice	Field observations of ice development, thickness and melting	February 2016, December 2016 and March 2017
	Photographic monitoring of ice movement using time lapse photographs at fixed locations	January 2017 – 2019
	Bricks set out at 2 m intervals across the eastern end of Main Bed to observe their fates over the winter	Winters of 2017 and 2018
Current speed and flushing	Current flow meter in the largest of three beds of Irish moss (Main Bed)	Sept. 27 to Oct. 7 2017
	Tidal elevation, temperature and salinity using a continuous recording pressure, temperature and conductivity loggers	Open water season 2016-2018
	Continuous vertical profiles of current speed and direction at the provincial wharf/boat slip, recorded with Acoustic Doppler Current Profiler	June 26 to Aug. 1, 2017

Table 2.9. Short term studies of additional physical structures of the Basin Head lagoon conducted in recent years.

Metric	Information collected	Sampling frequency
Salt marsh structure and rate of erosion	Georeferenced analyses of available provincial aerial photos to trace changes in the location of marsh edges and develop estimates of marsh erosion rates	1935, 1958, 1968, 1974, 1990, 2000, 2010
	Rods inserted at 5 m intervals along a transect running east-west at a distance of 30 cm from the marsh edge to monitor erosion rates	January 2017 to present
	Movement and fate of marsh sods displaced into Northeast Arm. Core samples from sods and surrounding sediments analysed for wet pH, grain size distribution, % organic matter, and nutrient concentrations.	2017, 2018
	Core samples to document thickness and composition of the live root zone and underlying peat layers, analysis of salinity and nutrients (nitrate, phosphorus, silicate and ammonium)	2017
Oyster reefs	Oyster demographics from animals found on 0.5 m^2 samples at 5 m intervals along transects at Main Bed and Corduroy Road.	2015

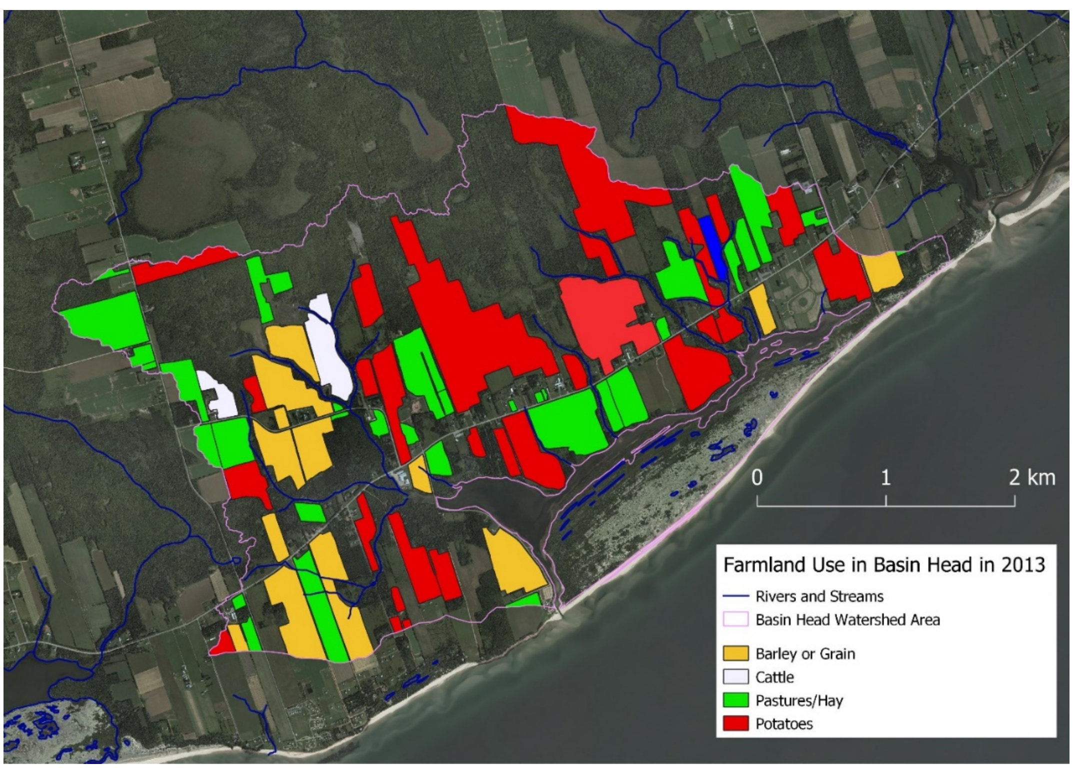


Figure 2.12. Agricultural land use in Basin Head watershed in 2013, based on farmer interviews, direct observation of crops in fields, and federal satellite image analysis.

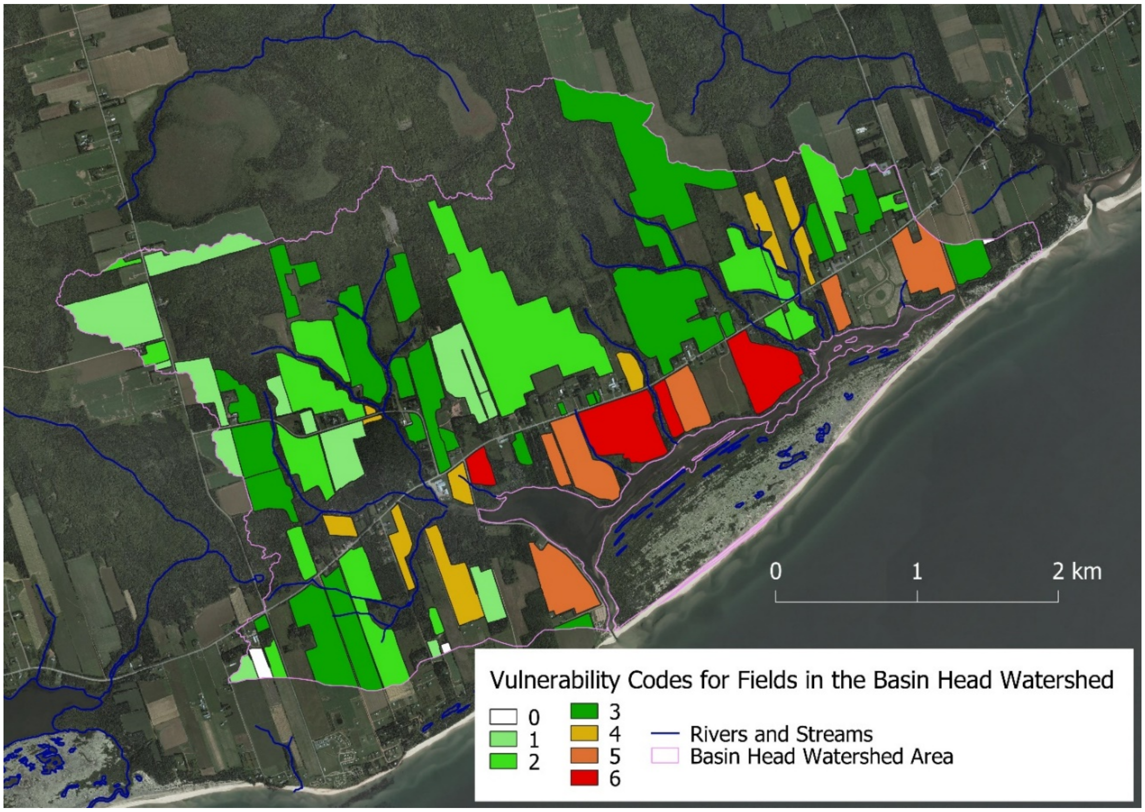


Figure 2.13. Watershed with all agricultural fields coded 1-6 for soil erosion vulnerability defined as the sum of slope (low=1, medium=2, high=3) and contact with surface water (0=none, 1=stream only, 2-estuary only, 3=stream + estuary).

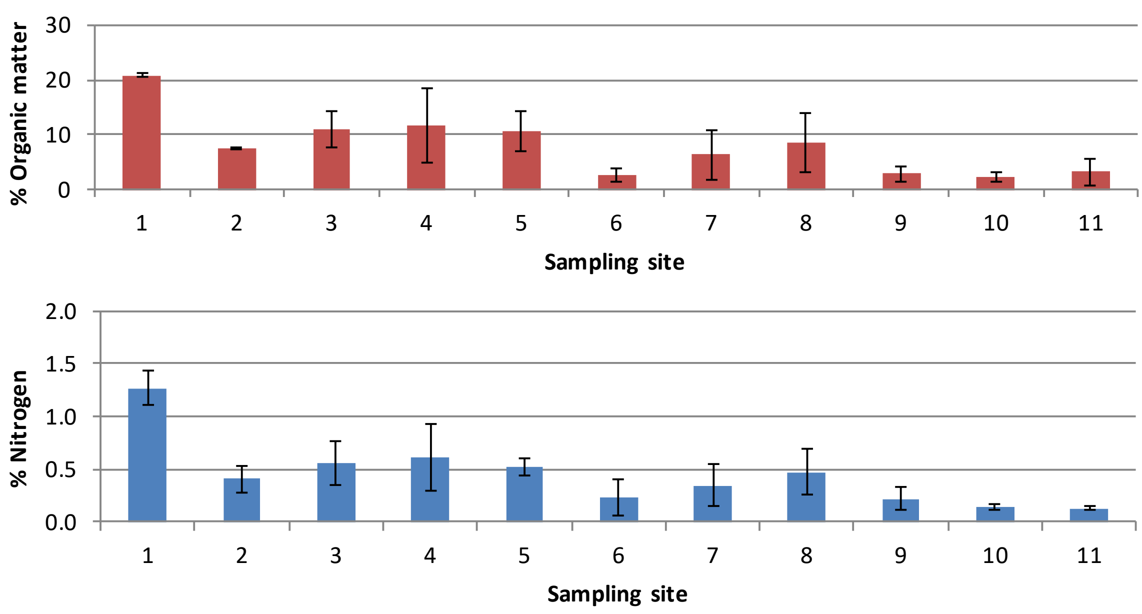


Figure 2.14. East to west trends in % organic matter and % nitrogen (mean, +/- 1 standard deviation error bars) in sediments collected along the edges of Northeast Arm, 2016 to 2017 (See Fig. 3.4 for sampling site locations). Site 1 is at the eastern tip of the Arm (Elliott Marsh) and site 11 (Clam Bed) is located west of Fireweed Bank.

Figure 2.15. Sediment sampling sites and corresponding sediment thickness values in October 2016.

Figure 2.16. Survey Transect locations in Northeast Arm of Basin Head MPA (summer 2016), and the estimated extent of potential Irish moss habitat (purple).

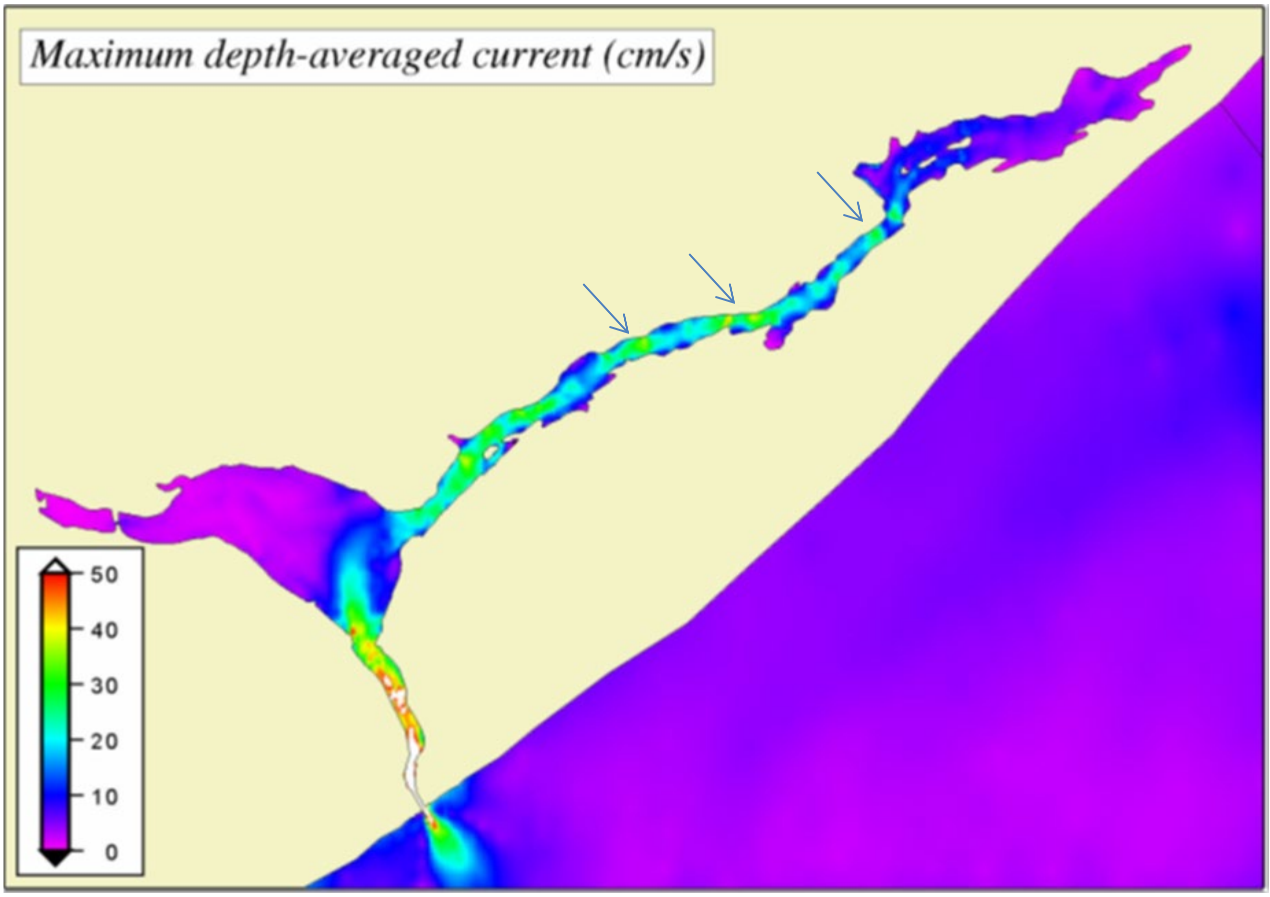


Figure 2.17. Estimated depth-averaged maximum current speeds in Basin Head lagoon (Source: Chassé pers. comm. 2008). Arrows indicate locations of Irish moss beds, west to east as Fireweed Bank, Main Bed and Corduroy Road.

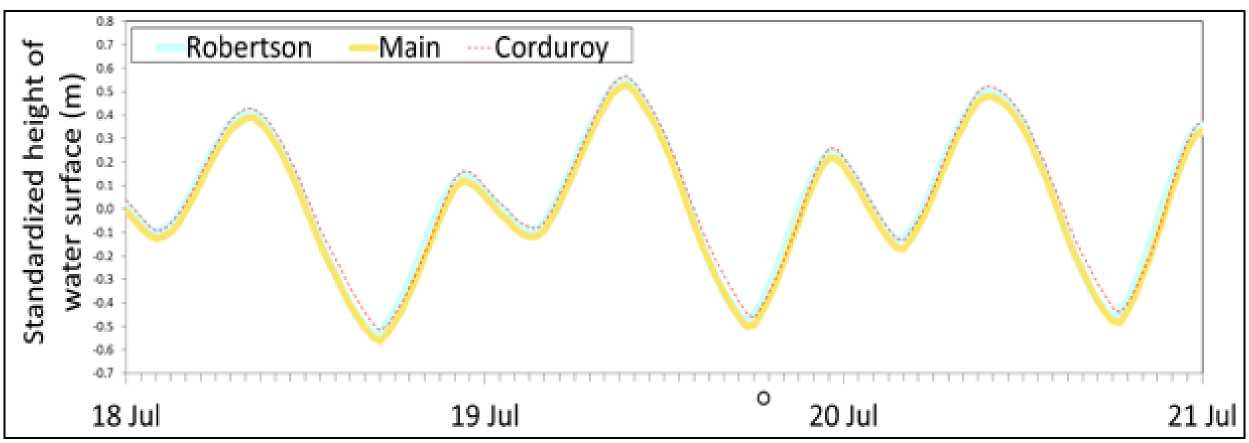


Figure 2.18. Tidal cycle, expressed as standardized height of water surface around full moon at three sites in Northeast Arm, July 18 to 21, 2016.

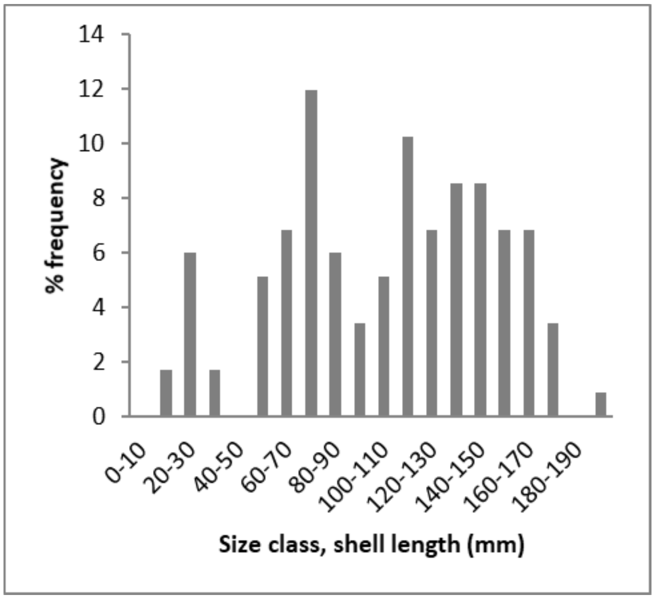


Figure 2.19. Demographics of oysters sampled from transect quadrats across Irish moss beds in 2015, expressed as percentage frequency of each shell length size class.

3. CONSERVATION OBJECTIVE 3: MAINTAIN THE HEALTH (BIOMASS AND COVERAGE) OF THE BASIN HEAD IRISH MOSS

Author: I. Novaczek

3.1. CONTEXT

In 1979 an estimated 15,000 m^2 of bottom was occupied by Irish moss-mussel clumps (McCurdy 1979). Irish moss biomass was estimated at 100,000 lbs. By the time the MPA was established at Basin Head in 2005, the bed had already shrunk to cover an estimated 2,500 m^2 and it continued shrinking, approaching extirpation (1.88 m^2) by 2013 (Figure 1.2). The monitoring of macroalgae has always focused on the Basin Head Irish moss but following the Science advice in 2008, it was recommended to also monitor *Ulva* blooms. This was initiated and will be reported under this conservation objective. A search for a third form of submerged aquatic vegetation, eelgrass, was undertaken by a swimming survey in 2014 and the presence of eelgrass was always noted while conducting field work during 2014 to 2018. These observations will also be reported in this section. Figure 3.1 illustrates locations within the MPA that are referenced in the sections below. Monitoring activities associated with assessing abundance and distribution of Irish moss in Basin Head are described below and summarized in Table 3.1.

3.2. ECOLOGICAL INDICATOR 1: EXTENT OF IRISH MOSS BED

3.2.1. Methods

Irish moss wading and swimming surveys

The Operational Management Plan for Basin Head calls for aerial photography to document the estuary, or at minimum the Northeast Arm, once every 3 years. Aerial surveys to monitor Irish moss were conducted annually from 2001 to 2010 but were discontinued when the population was too fragmented to be reliably identified. As of 2012 the population has been monitored using a wading survey method (D. Cairns and R. Melanson pers. comm.). As of 2015, drone-based photography has been used to develop base maps for visualizing the distribution of clumps documented by wading surveys.

The wading surveys of 2012 and 2013 collected data on the number and diameter of Irish moss fronds discovered while wading over the northern shallows of Main Bed guided by survey posts placed at 4 m intervals. The transects surveyed were 2 m wide and contiguous, so that all intertidal and subtidal areas of the bottom in the survey area were inspected and all Irish moss clumps were measured and counted. Attempts were also made to document clumps in deeper water using a glass-bottomed boat but this was not successful.

In June 2014, the wading survey method was applied over a 100 m long section in the middle of Northeast Arm (Main Bed) including both shallow and deep areas. The same comprehensive wading survey method was used in every year from 2014 through 2017. Field workers waded along contiguous 2 m transects, locating and measuring the diameter of every visible Irish moss frond in Northeast Arm to provide an estimate of Irish moss cover (m^2). Mussel clumps lacking Irish moss were also counted. Flags and uniquely numbered tags were initially used to mark the position of each clump. While the number of clumps was in the hundreds (i.e. from 2014 to 2016), we resurveyed all beds during every workable spring and neap low tide throughout the summer months. Rates and patterns of clump movement were established by recording when a clump moved away from its flag, and the appearance of clumps in unflagged locations. Bottom conditions (water depth, sediment thickness) around each clump were also recorded.

A swimming survey in July 2014 searched for eelgrass and Irish moss outside of Main Bed by snorkeling diagonally along nine transects that crossed between the north and south banks of Northeast Arm, starting east of Corduroy Road and ending at Robertson field, thereby encompassing all areas occupied by the historical Irish moss and mussel bed (McCurdy 1979, 1980). The end of each cross-Arm transect became the start of the next, and notes were taken using a pencil and underwater slate. A 1 m ruler was used to measure water depths and thickness of soft sediment. Presence of plants, animals and rocks on the bottom were recorded for each transect.

Methods for geolocation of clumps evolved over time. In 2014 we used a method (developed by D. Cairns and R. Melanson pers. comm.) to document the distance of each clump from the edge of salt marsh vegetation in terms of the number of steps out from shore within numbered transects. In 2015, we tested a rangefinder for triangulating clump positions relative to permanent survey markers, which increased accuracy but was cumbersome. Subsequently, we used a hand-held GPS to geolocate plants (± 3 m horizontal accuracy) but this was still not accurate enough to allow us to quickly find particular plants that were being monitored. In 2016 and 2017 a survey grade Trimble Geo 7 GPS provided positional data ± a few cm. Using drone-based photography and GIS, base maps were produced on which positions of surveyed clumps were mapped.

Restoration efforts (see Section 6) quickly increased the number of clumps to the point where comprehensive wading surveys and individual tagging of clumps were no longer practical. In 2018, wading surveys were restricted to 2 m wide swaths in each of three Irish moss beds (Main, Corduroy Road and Fireweed Bank). Where clump density was sparse, we surveyed two contiguous swaths. Clump location, size and condition were recorded and the numbers of clumps per square meter were compared with the estimated density in that area in 2017. The 2017 clump density baseline was derived using GIS to query a map showing where clumps had been located (by wading survey) or subsequently planted in 2017.

Drone-based mapping

A method for developing photomosaics of images collected using a drone-based camera was established in 2015 to 2016. Ground control point (GCP) locations were measured by a survey-grade GPS. Photos were taken by DJI Phantom 2 and 3© quadcopters in calm weather during the lowest daytime low tides of summer. Preparation of maps from drone images required photogrammetric adjustment for radial photo distortion, assembly of images into mosaics, and georegistration to the earth's coordinate grid. The quality of mosaics generated by five photostitching programs were compared, using images pre-corrected for radial distortion. Mosaics were georegistered in QGIS using GCPs visible in the images. A photostitching method using Adobe Photoshop© produced outputs that matched or exceeded the output quality of other software, at lower cost. Drone images obtained in 2015 were used to prepare a composite map for the central part of the Northeast Arm, and images obtained in 2016 were used to prepare a composite map for the full Northeast Arm (Figure 3.2). In most images, resolution was sufficient to show objects 2 cm or smaller in size. Resolution improved with lower flight altitude and sunny conditions.

Drone-based reconnaissance using more sophisticated cameras (DJI Mavic Pro Platinum© and a DJI Matrice 100© equipped with a Zenmuse X5© camera) was attempted in August 2018 (AGRG 2019). The aim was to collect superior images and feed the resulting georeferenced mosaics into two different software programs (eCognition© and ESRI ArcMap©) to determine whether image analysis could find and measure Irish moss clumps and generate m^2 coverage data.

Manual photo interpretation using GIS was also initiated, using images collected in 2017 from low altitude, slow drone flights that were taken under better atmospheric conditions than 2018 and repeatedly dehazed using Photoshop©.

3.2.2. Results and Discussion

Wading and swimming surveys

In 2014, wading and swimming surveys located more clumps than were detected in 2013 and 2012 because of the larger area surveyed and the discovery of a second population at the east end of the Arm (Corduroy Road) (Table 3.2). In 2014, there were 292 Irish moss-mussel clumps: 227 at Main Bed (4.2 m^2) and 65 at Corduroy Road (1 m^2) (Table 3.3). The Irish moss fronds were anchored by no more than five individual and old mussels. In most cases there were fewer than three mussels attached, and some fronds were weighed down only by periwinkles or dead shell litter. The majority were found on shallow, relatively sandy and firm bottom (Figure 3.3 and Figure 3.4). Clumps often moved around, sometimes landing in thick soft sediments where they were in danger of being smothered. The larger plants (> 15 cm diameter) became fragile as water temperature peaked, and in August, September and October some fragmented. Regrowth of plants from fragments that had not been visible earlier in the season was observed in the autumn.

The threshold for action (reduction in the population) had been exceeded to the point where the population was in danger of extirpation. Therefore, in 2015 adult mussels (> 50 mm long) procured from cultivated stock harvested from Tracadie Bay (PE) were brought into Basin Head to be added to existing clumps. Artificial clumps were also made using giant Irish moss grown on cultivation lines in Basin Head. These were planted in Main and Corduroy Road beds. The number of mussel clumps and the Irish moss cover are now increasing from year to year because of continuing restoration efforts (see Section 6). For the period 2014 to 2016, estimated clump losses were 7% at Main Bed and 13% at Corduroy Road (Table 3.4). In subsequent years, plantings tested the less suitable habitat in each bed and as a result, estimated losses of Irish moss over winter increased (based on limited samples, not comprehensive surveys). However, mussel clumps survived even where Irish moss was removed or died, and the pace of planting ensured continued net increases in the Irish moss population.

Drone-based mapping

Drone based photography during spring low tides in calm weather is a powerful technology for monitoring changes in fundamental structures that support Irish moss in the Basin Head MPA. The 2018 tests using more powerful drone-based sensors failed to provide images suitable for automated analysis of Irish moss clump density because of unfavorable weather (AGRG 2019). Calm dry weather, clear water and sunshine are essential to successful imaging. Although taken with more basic equipment, the 2017 images were acquired close up at low speed in calm conditions and therefore were of high quality, suggesting that it might be possible to use the photomosaics not only as base maps but as sources of data to come up with a reasonable estimate of Irish moss cover. Interpretation of processed images (Figure 3.5) is in progress and results so far are promising in terms of clump identification and the ease and speed of data generation using GIS tools. The technique works best in the shallows, where most clumps are located. Under calm, sunny conditions, a shadow is cast by the high profile of an *Ulva* mat that is sitting on top of a clump, whereas *Ulva* by itself is too flat to cast a shadow. This can be used to discern clumps covered by *Ulva* provided the mat is not too thick. However, the shadows are only visible in relatively shallow water and after mid-afternoon when the sun is at a low enough angle to cast the shadow. Removing *Ulva* prior to drone flights is possible but slow and labour-intensive. Clearing also involves wading and swimming through the beds, stirring up sediment and potentially damaging the clumps.

Drone-based surveys require ground truthing. This was initiated in 2018 by surveying selected swaths of bottom in each bed, but the drone images for that year were not suitable for use. The same swaths were surveyed in 2019 to support another drone survey. Swath surveys have margins of error related to GPS accuracy, inexact geolocation of planted clumps, and year-to-year differences in the exact area surveyed. However, they should detect a catastrophic change in Irish moss abundance, and be adequate for ground-truthing interpretation of images from drone-based, full bed surveys.

Eelgrass beds, oyster reefs, *Ulva* blooms and marsh edge erosion may also be amenable to drone-based photographic monitoring. Higher altitude, rapid drone flights could be used to document changes in dune width and the entrance channel.

In future, as the climate becomes less stable, there may be fewer opportunities to fly drones safely and effectively during the narrow windows of daytime spring and neap low tides.

3.3. ECOLOGICAL INDICATOR 2: EXTENT OF ULVA BLOOMS

3.3.1. Methods

When the giant Irish moss population was first surveyed (McCurdy 1979) the presence of *Ulva* that smothered and killed Irish moss along the edges of the bed was documented. Sharp et al. (2003) mapped the extent to which the bottom was covered in *Ulva,* Irish moss or eelgrass and later conducted experiments to document *Ulva* growth rates and explore relationships between nutrient loading and *Ulva* blooms (Sharp et al. 2010). Monthly sampling by the Community Aquatic Monitoring Program (CAMP) in May to August could be inhibited by accumulation of *Ulva* in the beach seine; therefore, occurrences of abandonment of seining due to *Ulva* fouling was proposed as a monitoring metric.

Beginning in 2011, pictures were taken at weekly intervals during the summer months as a way of monitoring *Ulva* bloom development. Sampling sites included Elliott Marsh, Foul Bay and Ching's Bridge. A qualitative analysis of the Elliott Marsh photo record was undertaken in 2017 to 2018, taking into consideration the possible influence of the timing of ice-out, seawater temperatures and rainfall-driven loading of nutrients into the estuary.

Photographs taken at 30 min intervals during daylight by a time-lapse field camera attached to a tree at Main Bed were reviewed to detect patterns of *Ulva* development on the intertidal mud. Percent cover of *Ulva* was estimated from images showing the intertidal during low tide.

Since 2015, monitoring of Irish moss plantations documented impacts of *Ulva* mats on planted clumps. Data collected included % cover and/or biomass (g wet weight) of *Ulva* in test plots, % mussel mortality, wet weight of Irish moss and condition index of Irish moss. Sampling of test plots was conducted systematically over months or years.

3.3.2. Results and Discussion

Many images taken for *Ulva* monitoring were considered not useful because the high tide obscured the *Ulva* bloom. This was especially true for Foul Bay which, unlike the other two sites, could not be conveniently photographed from the road during low tide. The full extent of the *Ulva* bloom was not visible in any photos from Foul Bay.

The *Ulva* bloom at Elliott Marsh was always well developed by May, bleached and rotted in mid-summer and likely flushed out of the estuary by storms in October. The rate of *Ulva* development and the timing of bloom collapse differed somewhat year to year; this appeared to be driven by weather patterns. The bloom was larger in May in years when the ice melted early (i.e. in March rather than April). Hot dry conditions limited *Ulva* development, more rapid senescence occurred during very hot summers and the bloom was larger and more persistent during cool, wet weather.

In 2016, after a winter in which ice cover and snow had been relatively light and there was no long period of sub-zero water temperature, the bottom of Northeast Arm, including Main Bed, was already infested with young *Ulva* by April 22. In 2017, the intertidal bloom at Main Bed that was photo-monitored became conspicuous later than the bloom at Elliott Marsh, and went through pulses of development and senescence between spring and autumn.

Each year, mats of loose *Ulva* were seen floating back and forth throughout the Arm from spring until at least mid-August and these snagged on any object protruding from the bottom, including Irish moss clumps. By late August *Ulva* blades were soft and falling apart.

In the Oyster Cross plantation established in 2016, there were areas of relatively firm, current-swept bottom and others where sluggish water movement encouraged deposition of sediments. *Ulva* and other fast-growing algae covered the plantation from early spring through summer. By monitoring and sampling the different areas of the plantation it was confirmed that in areas of relatively slow current flow, silt accumulated beneath the *Ulva* mats. This eventually killed most of the Irish moss in the affected areas, while other, more current-swept portions of the plantation maintained their Irish moss cover. It is concluded that *Ulva* smothering in combination with sediment accumulation is deadly for the giant Irish moss population.

Predation of mussels by invasive Green Crab has been assumed to be a key factor in the decline of the Irish moss (Cairns et al. pers. comm.). Due to the 90% decline in Green Crab numbers after the harsh winters of 2013 to 2014 and 2014 to 2015 (Figure 3.6) there is now an increased chance that mussels recruited in spring will survive their first year and outgrow their vulnerability to Green Crab predation. Factors that are presently most affecting the Irish moss population may be the *Ulva* smothering in combination with the sedimentation and not so much the Green Crab population.

3.4. ECOLOGICAL INDICATOR 3: EXTENT OF EELGRASS BEDS

3.4.1. Methods

McCurdy (1979) described Basin Head lagoon as an “eelgrass dominated system”, and local informants have described how, in the 1950s, fishing boat propellers would get tangled in and brought to a stop by dense eelgrass (SAB 2015)2. Available evidence from unpublished field reports and archived databases suggested that eelgrass declined dramatically over the period 2006 to 2008. Eelgrass disappeared from the CAMP sampling site in western Northeast Arm in 2009 (see Section 5). A search for eelgrass throughout Northeast Arm was conducted in July 2014 via a swimming survey. During field work conducted since 2014, staff always looked for eelgrass.

3.4.2. Results and Discussion

In the 2014 Operational Management Plan, the stated management trigger calls for mitigation when decreasing coverage of eelgrass occurs but fails to indicate what baseline should be used for eelgrass cover (DFO 2016). Eelgrass cover in Basin Head was sampled between 2001 and 2008 as part of the annual Irish moss population assessment process. Up until 2008, patches of 100% eelgrass cover existed within the Irish moss bed. During field work and in the swimming survey of 2014 no eelgrass was detected in Northeast Arm. In 2015 and 2016 a very small (< 0.5 m^2) patch of eelgrass was found west of Corduroy Road. When scouting for a location for eelgrass restoration planting in 2017, a small number of individual blades of eelgrass were found along the shore below Robertson field. In 2018, patches of eelgrass became visible in many parts of Northeast Arm, all the way east to Corduroy Road. There was a similar resurgence observed in other estuaries of eastern PEI including Souris Harbour (Fred Cheverie pers comm.). Because of the recent decline in Green Crab (Figure 3.6) there is an increased chance of eelgrass recovery, provided that water clarity allows adequate light penetration. Once re-established, eelgrass beds could help to stabilize bottom sediments and thereby improve water clarity further (Ferriss et al. 2019), but sediment retention may also increase the rate of shallowing. Eelgrass may also play a role in stabilizing clumps and preventing them from being washed out of the system (Reusch and Chapman 1995). However, patches of eelgrass will also slow down currents and catch *Ulva* mats, potentially smothering the surrounding bottom.

Benson et al. (2013) determined that eelgrass survival requires ≥ 100 µMol photons m^{-2} s^{-1} of light (roughly 4350 lux of natural daylight) and tidally-averaged total nitrogen concentrations less than 0.34 mg L^{-1} (24.3 µMol L^{-1}). During every field season since 1999, nitrate concentrations in water samples collected over the Irish moss beds (nutrient sampling Sites B and C, refer to Figure 1.1) have generally remained below 24 µmol per L except during spring, when runoff from the watershed can temporarily boost nitrate concentrations to 50 µmol per L or more (see Section 2). In Basin Head, light reaching depths typical of Irish moss beds was at best 7500 lux in mid-July. Daytime readings were usually less than 3000 lux on bottom that was 30 cm deep at low tide (Figure 3.7). Therefore, although ambient nitrate concentrations appear not to be a problem for eelgrass, light limitation caused by *Ulva,* siltation and turbidity could impair eelgrass recovery.

Table 3.10. Monitoring activities associated with assessing abundance and distribution of Irish moss in Basin Head.

Method	Information collected	Sampling frequency
Wading and snorkel survey	Number and diameter of Irish moss fronds along contiguous, 2 m wide transects over the northern shallows of Main Bed.	2012 – 2013
	Number and diameter of Irish moss fronds along contiguous, 2 m wide transects throughout all areas of the Northeast Arm known to contain Irish moss.	2014 – 2017
	Wading surveys, 2 m wide swaths (3 to 5 per bed) in each of three Irish moss beds.	2018
Drone based mapping	Aerial images to develop a composite map for the Northeast Arm.	2015 – 2018
	Aerial image mapping of Irish moss distribution and quantification of area.	2017

Table 3.11. Results of Irish moss surveys in Main Bed conducted in 2012 and 2013, compared with the results from 2 days of field work in June 2014. By the end of the 2014 field season we had surveyed more bottom and detected a larger number of clumps. IM=Irish moss. SD = standard deviation.

Survey dates	Predicted low tide height (m)	Number of Irish moss clumps recorded	Diameter (cm) of Irish moss clumps (mean; +/- 1 standard deviation)	Estimated area (m^2) of Irish moss clumps	Survey notes (extent, conditions)
2012; Sept. 28	0.6	28	11 ± 4	1.63	7 transects parallel to shore, covering 18.7% of Main Bed. Good visibility. Green crabs abundant.
2013; July 25, Aug. 20-21	0.3	38	17 ± 7	1.88	24 cross-channel transects covering 33% of Main Bed. Deep part of the channel too deep for wading. Limited visibility.
2014; June 12-13	0.2 to 0.3	61	14 ± 8	1.39	41 cross channel transects covering 76% of Main Bed, excluding deep channel and thickly silted areas.

Table 3.12. Number of Irish moss clumps recorded, planted, that moved, and estimated area (m^2) of all clumps in Main Bed and Corduroy Road Bed during 2014 to 2017. In the table, nd represents no data.

Feature	Year	Main Bed	Corduroy Bed
Number of Irish moss clumps documented after overwintering	2014	227	65
	2015	201	55
	2016	314	140
	2017	657	356
Number of Irish moss clumps planted	2014	0	0
	2015	144	96
	2016	528	330
	2017	1,613	548
Percentage of clumps that moved (May to Nov.)	2014	14.5	30.0
	2015	15.0	12.0
	2016	4.0	9.0
	2017	nd	nd
Estimated number of clumps present in November	2014	194	45
	2015	300	139
	2016	838	428
	2017	2,270	904
Estimated area of Irish moss (m^2) in November	2014	4.2	1.0
	2015	5.2	1.9
	2016	14.7	8.6
	2017	39.7	15.5

Table 3.13. Calculated loss (attrition) of Irish moss - mussel clumps in Main Bed and in Corduroy Bed over the period 2014 to 2016.

Characteristic	Main Bed	Corduroy Road
Original number of clumps in 2014	227	65
Clumps planted 2015	144	96
Clumps planted 2016	528	330
Expected number of clumps in November 2016	899	491
Actual number of clumps in November 2016	838	428
Difference (percentage difference)	61 clumps (- 7%)	63 clumps (-13%)

Figure 3.20. Locations within the Basin Head MPA referred to in text.

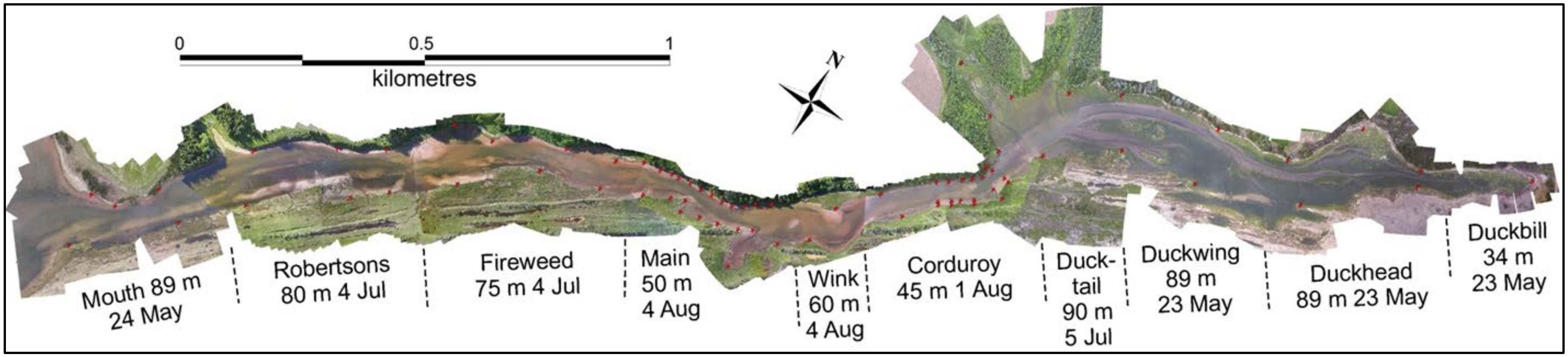


Figure 3.21. Georeferenced photomosaic of Northeast Arm portion of Basin Head. The red dots are the positions of the ground control points.

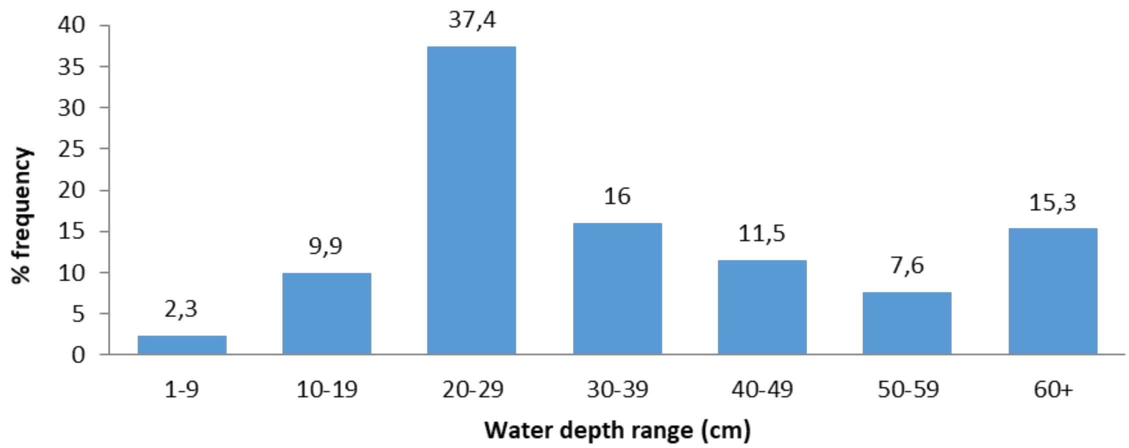


Figure 3.22. Relative (%) distribution by water depth of native (not planted) Irish moss - mussel clumps in Basin Head in 2015.

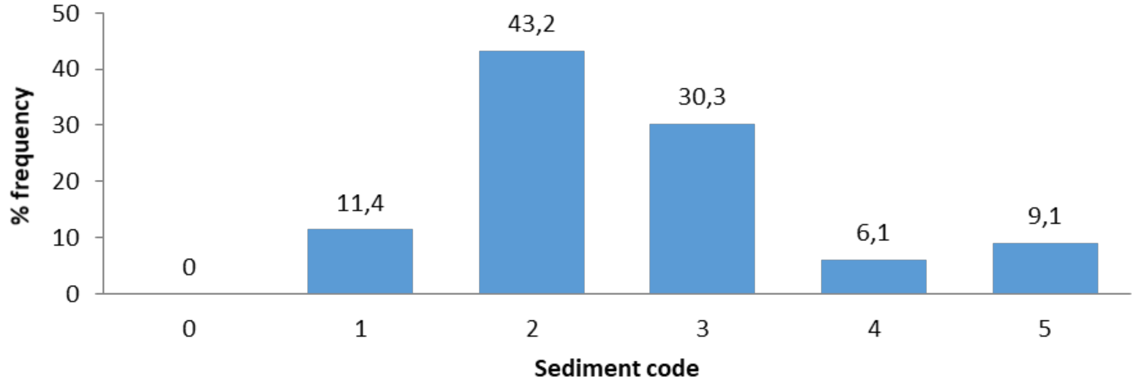


Figure 3.23. Relative (%) distribution by sediment type of native (not planted) Irish moss clumps in Basin Head in 2015. Sediment type is defined and coded as follows: 0 = rock, 1 = clean hard sand (rod penetrates less than 10 cm), 2 = firm bottom (10-14 cm penetration), 3 = moderate silt (15-19 cm penetration), 4 = deep silt (20-24 cm penetration), and 5 = very deep silt (≥25 cm penetration).

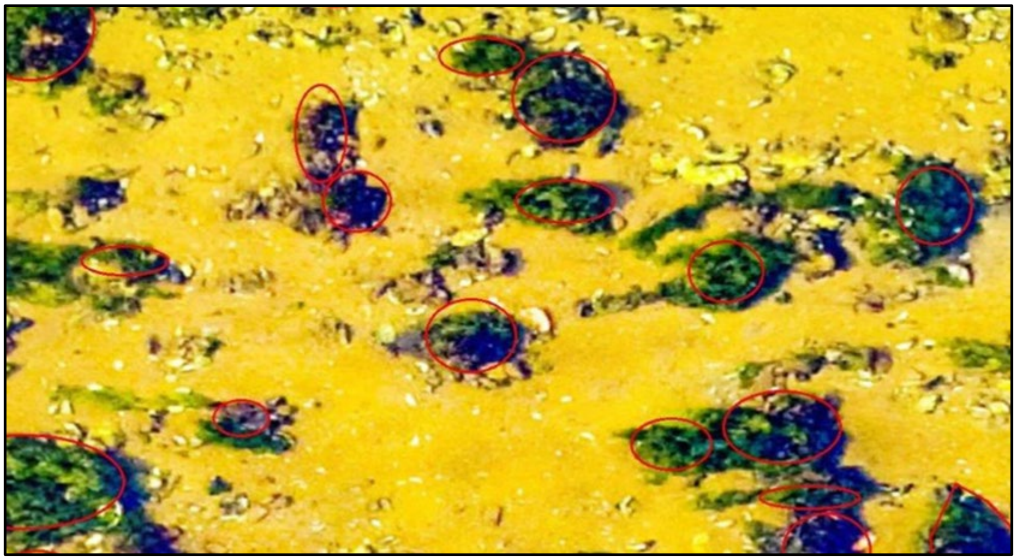


Figure 3.24. Example of a drone-based photo of the bottom of Main Bed showing Irish moss clumps that have been circled to allow calculation of bottom cover using GIS tools.

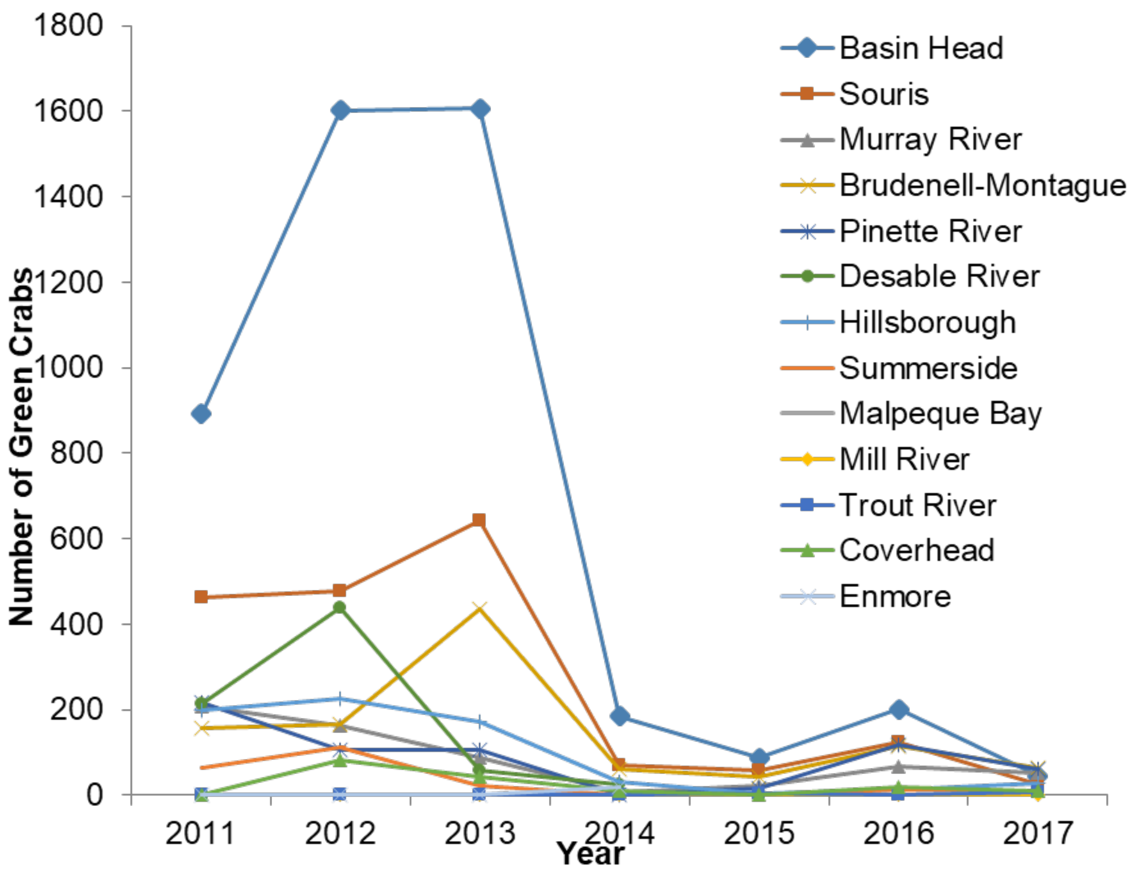


Figure 3.25. Time series of number of Green Crab captured in the seining samples in PEI estuaries by CAMP, during 2011 to 2017.

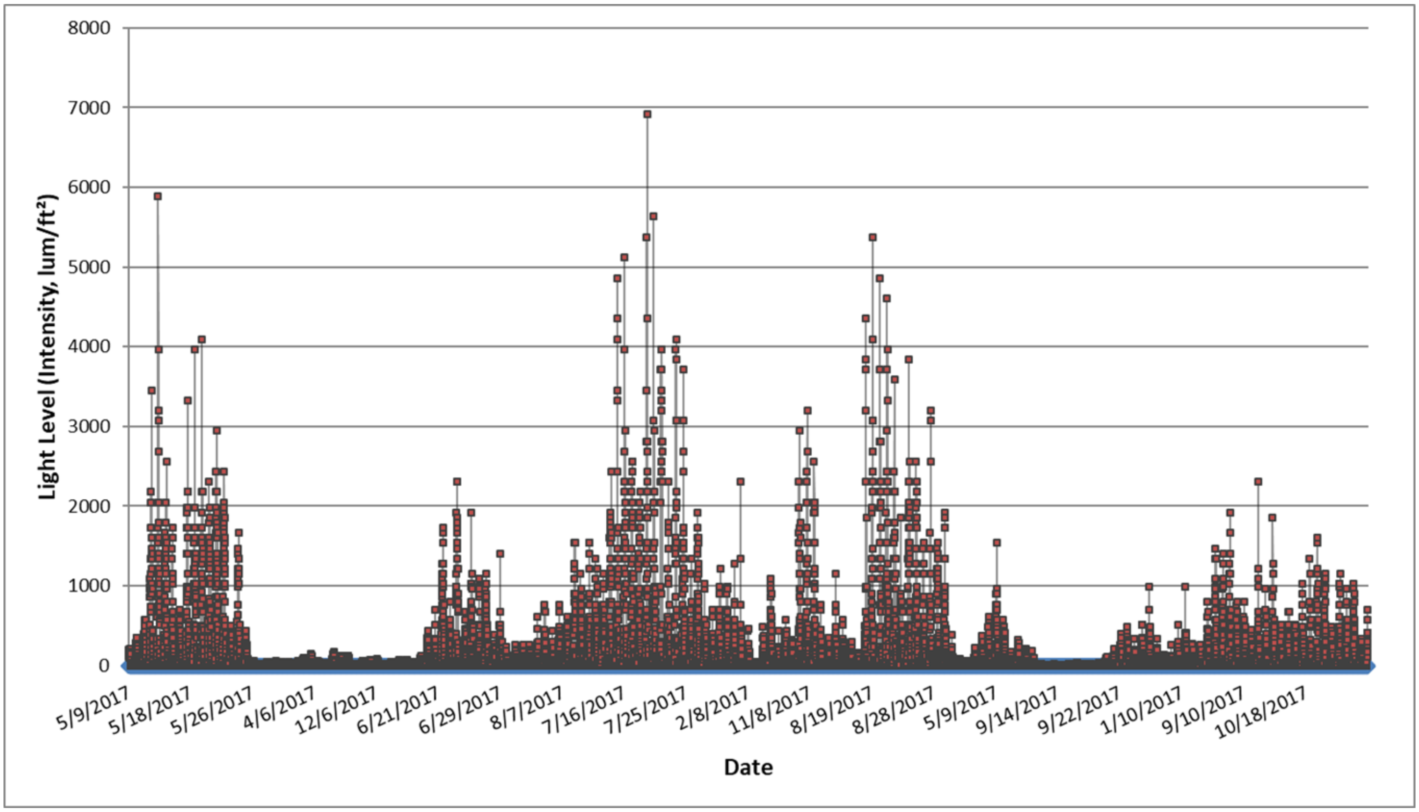


Figure 3.26. Light levels (lux) on bottom (depth 50 cm at low tide) in Northeast Arm measured by a light logger (every 15 min) from May 11 to October 22 2017. Periods when little light reached the sensor reflect smothering by sediment, debris and/or Ulva.

4. CONSERVATION OBJECTIVE 4: MAINTAIN THE ECOLOGICAL INTEGRITY OF THE BASIN HEAD LAGOON AND INNER CHANNEL

4.1. ECOLOGICAL INDICATOR 1: TRENDS IN COMMUNITY ABUNDANCE AND DIVERSITY OF FISH AND BENTHIC INVERTEBRATES WITHIN THE BASIN HEAD LAGOON

Author: M. Boudreau

4.1.1. Context

The Community Aquatic Monitoring Program (CAMP) employs beach seine surveys in estuaries throughout the southern Gulf of St. Lawrence (sGSL) to assess changes in coastal fish communities. Launched in 2004, the objectives of CAMP are:

- determine if a relationship exists between the health of estuaries and the diversity and abundance of nearshore fish communities;
- provide an outreach program for Fisheries and Oceans Canada (DFO) to interact with Environmental Non-Governmental Organizations (ENGOs) to raise awareness of the ecology of estuaries in the sGSL, and;
- collect baseline data on the abundance, diversity and coastal community assemblages for future comparisons.

CAMP is a collaboration between DFO and approximately 30 ENGOs. Since it began in 2004, CAMP has expanded from 16 to 33 estuaries in 2018. With a growing dataset, monthly sampling frequency which was originally May to September, was reduced to June to August in 2011 and, since 2018, is now conducted only once a year, in June.

The objective of conducting CAMP in Basin Head is to address the fourth conservation objective for this MPA, to maintain diversity of indigenous fauna by monitoring the diversity and abundance of the fish community over time. However, the main focus for maintaining biodiversity in Basin Head is the area where Irish moss is present, in the Northeast Arm. Because CAMP utilizes a beach seine that could harm the Irish moss, no CAMP stations are located in the Irish moss beds. Therefore, the biodiversity assessment is not conducted in the priority area of this MPA.

4.1.2. Method

Sampling is conducted at six stations within each estuary. Sampling stations in Basin Head (Figure 4.1) were chosen to be easily accessible by canoe without disturbing the Irish moss in Northeast Arm with the beach seine. Therefore, all sampling stations are located in or near the Main Basin. Nearshore fish communities (fish, crabs and shrimps) are collected with a 30 m x 2 m beach seine, placed in an aerated tub, identified and counted, and released live back into the water. Additional parameters are monitored at each sampling station to understand how habitat features, such as submerged aquatic vegetation (SAV), sediment composition, water temperature, salinity, dissolved oxygen, and nutrient concentrations, can influence the fish community structure. Percent cover of SAV is estimated by randomly throwing a 50 x 50 cm quadrat three times within the area sampled. SAV is divided into 9 categories to facilitate identification (1: Eelgrass (*Zostera marina*), 2: Widgeon grass (*Ruppia maritima*), 3: green algae (*Ulva* sp., *Monostroma* sp.,*Cladophora* sp.), 4: brown filamentous algae (*Pilayella littoralis*), 5: rockweed (*Fucus* sp), 6: common red algae (*Chondrus crispus*, *Polyides rotundus*, *Gracilaria tikvahiae*, *Dasya baillouviana*, *Polysiphonia* sp.), 7: common brown algae (*Stilophora rhizodes*, *Sphaerotrichia divaricata*, *Scytosiphon lomentaria*, *Chorda tomentosa*), 8: kelps (*Saccharina latissima*, *Laminaria digitata*) and 9: Green fleece (*Codium fragile*)). A surficial sediment sample (10 cm deep) was collected in August and now is collected in June at each of the stations to assess sediment humidity content, organic content and grain size distribution. Two 15 ml water samples per station were collected to quantify nitrate (NO_3), nitrite (NO_2) and phosphate (PO_4) starting in 2006 but will no longer be collected as of 2019 because Basin Head MPA has its own nutrient monitoring. Water temperature (°C), salinity (ppt) and dissolved oxygen (mg per L) are measured with a YSI Professional Plus handheld probe. For the purpose of the current review, CAMP data from 2004 to 2017, from June to August only, were assessed. Further details on the CAMP methodology in Basin Head are available in Thériault and Courtenay (2010).

To determine the effectiveness of CAMP to monitor the diversity and abundance of indigenous fauna in Basin Head, analyses were performed to determine if changes in the Basin Head fish community have been occurring since the start of the program in 2004, and if so, to explore the potential causes of these changes. Also included are the results of a comparison of the Basin Head fish community to those at CAMP reference sites in the sGSL (Table 4.1). The latter analyses were conducted by Trefor Reynoldson (GHOST Environmental Consultants) in 2017 and included June data only from 2010 to 2015.

Statistical Analyses

Basin Head Fish Community

Changes in fish community structure from 2004 to 2017 were assessed using Plymouth Routines in Multivariate Ecological Research (PRIMER) version 7 with PERMANOVA+

(PRIMER-E Ltd, Plymouth) and followed procedures outlined in Clarke and Gorley (2006), Anderson et al. (2008) and Clarke et al. (2014). Prior to the analysis, the developmental stages (adult and young-of-the-year) were combined to obtain the total abundance per species. Categories that could not be identified to the species level were removed, i.e. *Gasterosteus* (all stickleback species) and flounder (all flounder species). The abundance data were square root transformed prior to producing Bray-Curtis similarity resemblance matrices. These matrices were used to perform repeated measures PERMANOVAs, testing year as a fixed factor and station as the random factor, i.e. the unreplicated sampling unit repeatedly examined every year. Because the fish community was assessed each month from June to August, each month was tested separately to determine if the community structure changed over the course of the summer. After significant differences were identified in the PERMANOVAs, a similarity percentage routine (SIMPER) tested which species within the community contributed the most to the dissimilarities observed among years and stations. To visualize the dissimilarities among groups, Principal Coordinates Analyses (PCO) were created for each month using the Bray-Curtis similarity resemblance matrices. Vector overlays on the PCOs were used to show Pearson's correlations between species or environmental parameters and the PCO axes ($r > 0.3$ for species and $r > 0.2$ for environmental parameters). Prior to including vector overlays of environmental parameters in the PCOs, draftsman plots were utilized to choose appropriate data transformations. Skewness was corrected using a square-root transformation. Because the environmental parameters are on different scales, these data were also normalized following transformations.

Comparison of Fish Communities within Basin Head vs CAMP Reference Sites

Basin Head is impacted by high loadings of nutrients and sediments (see Section 1 and 2). These stressors were impacting this system prior to the start of CAMP. Therefore, to have a better understanding of the health of the fish community in Basin Head, a comparison of this community with other CAMP sites is also included. These comparisons were done to determine if a relationship exists between physical conditions in estuaries and the diversity and abundance of nearshore fish communities, specifically, whether eutrophic estuaries possess a particular assemblage of fish when compared to oligotrophic estuaries. The approach utilised to investigate this relationship was the Reference Condition Approach (RCA) which is Environment and Climate Change Canada's Canadian Aquatic Biomonitoring Network's (CABIN) method for assessing differences in animal community structure (Reynoldson et al. 1997). This method uses a range of reference sites to capture the natural variation in the animal community structure in different geographic regions. Reference conditions are developed using subsets of reference sites based on specific habitat conditions. Considering the habitat conditions at the test (exposed) site, a model is generally used to select the appropriate group of reference sites to compare to this test site, but such a model was not available for CAMP, therefore, the entire set of reference sites (a "null" model) was used (van Sickle *et al.* 2005) (Table 4.1). Non-reference sites were either nutrient impacted, impacted by point-source discharges or were considered to have different habitat parameters (usually higher salinity) compared to other CAMP sites, as determined from documented nutrient concentrations, salinity, and field observations. To test the Basin Head CAMP data against CAMP sites considered to be in reference condition, two different analyses were performed. The first, analysis of similarity (ANOSIM), was used to determine if the fish community at Basin Head sampling stations was significantly different than those at reference sites (PRIMER version 7 with PERMANOVA+; PRIMER-E Ltd, Plymouth). The second, Environment Canada's assessment bands, were used to make an overall comparison of the fish community at Basin Head sampling stations to fish communities at reference sites. To detect departure from reference, the BEAST approach was utilised. This measures the similarity of exposed (test) samples to reference sites by plotting the two sets of sites in ordination space. Probability ellipses constructed around the reference sites provide an indication of the degree of difference. This is analogous to using P values in univariate statistics. The bands used are those recommended by Reynoldson et al. (1997) and Rosenberg et al. (2000) and by the Environment and Climate Change Canada's CABIN program:

- Band 1: inside the 90% reference ellipse – equivalent to reference sites;
- Band 2: between the 90-99% ellipses – possibly different from reference sites;
- Band 3: between the 99 and 99.9% ellipses – different from reference sites;
- Band 4: outside the 99.9% ellipse – very different from reference sites.

To visualize the dissimilarities among groups, non-metric multi-dimensional scaling (MDS) was created using the Bray-Curtis similarity resemblance matrices. Vector overlays were used to show correlations between species or environmental parameters and the MDS axes. Environmental parameters are as mentioned in the previous section except for nitrate levels which were assigned to three categories: 1) low (≤ 0.1 mg per L), 2) medium (> 0.1 – < 1.0 mg per L), and 3) high (≥ 1.0 mg per L).

4.1.3. Results

Basin Head Fish Community

When assessing each month individually, significant differences were observed in the fish community for both factors tested (year and station) (Table 4.2). Species identified by SIMPER as contributing to more than 10% of the dissimilarity between years for each month are listed in Table 4.3. Because comparing each year from 2004 to 2017 resulted in 91 pairwise comparisons, detailed results could not be included. Therefore, Table 4.3 only provides the list of species that were identified at least once as contributing > 10% of the dissimilarity between years. This table also includes how often a species contributed the most to the dissimilarity of pairwise comparisons. SIMPER results for pairwise comparisons of August data from station 3 and reference stations, are included in Table 4.4. Station 3 is the sampling site located inside the Mouth of the Northeast Arm and therefore closest to the Irish moss beds. PCO ordinations for all months are included in Figure 4.2 and correlations of species with PCO axes are included in Table 4.5. In each month, three main community groupings could be observed in Basin Head. This grouping varied per month but was mainly composed of stations 3, 4 and 6 for years prior to 2010. The fish community at these stations was dominated by Mummichog. The fish community in the larger group of stations, including stations 1, 2 and 5 in earlier years, and most stations after 2010, were dominated by Sand Shrimp. The fish community in a third, smaller group of stations, mainly stations 3 and 5 between 2004 and 2007, were dominated by Three-spined Stickleback in June. In July, this third grouping was mainly composed of stations 4 and 5 for the years 2004 to 2007, and was dominated by Green Crab. In August, the community in a much larger group stations (which included stations 1, 3 and 5 from 2004 to 2016) was associated with Green Crab. The Mummichog dominated community was accompanied by Four-spined Stickleback and Nine-spined Stickleback in all months, with the addition of Three-spined Stickleback in July and Atlantic Silverside in August (Figure 4.2). At stations 1, 2 and 5, the Sand Shrimp dominated community also included Winter Flounder in June, Grass Shrimp and Smooth Flounder in July, and Smooth Flounder in August. Around 2010, a shift occurred in the stations previously dominated by Mummichog, they also became dominated by Sand Shrimp. This shift was observed in all months. Vectors showing the association between fish communities and environmental parameters were also included in the PCOs (Figure 4.2). In June, the Mummichog dominated community was associated with eelgrass while the Sand Shrimp dominated community was associated with common brown algae, common red algae, *Fucus*, brown filamentous algae and kelp. In July and August, there were no environmental parameters that were associated with the Mummichog or Sand Shrimp communities. In June, Three-spined Stickleback was associated with temperature. In July, the Green crab community was associated with green algae, and in August, with temperature.

Comparison of Fish Communities in Basin Head vs CAMP Reference Sites

Utilising the BEAST approach, of 34 stations sampled to assess the fish community in Basin Head from 2010 to 2015, 64.7% were in reference condition (Table 4.6). More detailed examination (Table 4.6 and Figure 4.3) revealed the community at stations 2, 4 and 6 to be most "disturbed" (Table 4.7), and more than half of the sampled stations were out of reference. However, two more recent years (2014 and 2015) showed that the fish community at only one station was out of reference. These two years, as well as 2010 and 2011, were not significantly different from reference (Table 4.7).

To examine the specific effects of nitrogen enrichment, we compared the fish community at stations in the three enrichment categories with the reference sites (Figure 4.4). Although all the Basin Head sites are situated at the high end of a nitrate concentration gradient, it is noteworthy that the community at stations in the highest nitrate category are in fact more similar to reference sites and those in the low and medium enrichment categories are more similar to enriched sites (Figure 4.4; Table 4.7). Therefore, it is suspected that factors other than nitrate concentration may be causing these effects.

The change in the fish community at stations in Bands 2 and 3 results in a dissimilarity from reference sites in more than 80% of Basin Head stations, mainly because of an increase in numbers of Sand Shrimp. At the reference sites, Sand Shrimp average 280 individuals per sample compared to 2,258 in Band 2 and 4,365 in Band 3 (Table 4.8; Figure 4.5). This suggests an overall response to enrichment at stations in Bands 2 and 3. However, the species that is causing this change in the community (Sand Shrimp), is not usually present in areas considered enriched. Mummichog are most often present in high numbers in areas considered enriched (Schein et al. 2011).

An initial examination of the habitat factors that may be associated with these changes was also conducted. It is acknowledged that the differences in spatial and temporal scales means that any conclusions have to be judiciously considered; nevertheless, the analysis may provide an indication of cause. As with the fish community data, the reference site habitat data are the June averages for the sites documented per sampling year. The habitat vectors have been plotted in biological ordination space, and of the nine habitat variables, particle size, nitrate, nitrite and temperature seem to be associated with the biological gradient (Figure 4.4 and Table 4.9).

4.1.4. Discussion

The fish community in Basin Head's Main Basin is presently dominated by Sand Shrimp. However, prior to 2010, the fish community at some of the sampling stations, mainly stations 3, 4 and 6, was dominated by Mummichog. Around 2010, a shift occurred in the fish community at these stations during which Sand Shrimp became the dominant species. This shift was observed for all months. Within this same timeframe, from 2006 to 2008, there was a significant loss of eelgrass habitat in Basin Head (see Section 4). Before this decline, dense eelgrass habitat dominated this system (McCurdy 1979). This decline in eelgrass may explain the shift in the community at these stations. Studies show that fish are generally more abundant in eelgrass habitats whereas decapods, such as Sand Shrimp, are as abundant in eelgrass or unvegetated sandy habitats (Joseph et al. 2006). This is in agreement with our results which showed an association between eelgrass and Mummichog in June (Figure 4.2).

The large abundance of Sand Shrimp in Basin Head is quite different from the community structure observed at other nutrient impacted CAMP sites (DFO 2011a; Schein et al. 2011). At these sites, Mummichog often dominate the community. Although Mummichog can be associated with eelgrass habitats, at nutrient impacted sites the abundance of Mummichog is associated with large amounts of *Ulva* (Schein et al. 2011). In Basin Head, *Ulva* productivity occurs mainly at the eastern end of Northeast Arm and at Ching's Bridge in the Main Basin. Although there is some accumulation of *Ulva* in other parts of the Main Basin, it is not abundant at any of the CAMP stations. Nutrient impacted sites also have fewer Sand Shrimp than CAMP reference sites. This is the opposite of what is observed in Basin Head where some sampling stations had 10-20 fold increases in Sand Shrimp compared to CAMP reference sites (Table 4.8). At most CAMP sampling stations, the lack of eelgrass and *Ulva*, which results in bare sandy habitat, may explain the abundance of Sand Shrimp and low numbers of Mummichog.

In this assessment of the Basin Head fish community, caution should be taken when considering the relationship between nitrate categories and the fish community (Figure 4.4). The nitrate categories were based on the CAMP nutrient data which are collected at the CAMP sampling stations within the estuary. In estuaries, complex nutrient cycling occurs (Kellogg et al. 2014). Consequently, nutrient concentrations may not reflect nutrient impacts which is why CAMP will no longer collect samples to measure nutrient concentrations. A more effective way to assess nutrient impacts on fish communities within estuaries is to document the amount of *Ulva* or other opportunistic green algae that result from high nutrient loads. These changes in habitat are what cause changes in the animal community (Coffin et al. 2018a) and not the nutrient concentrations per se.

Table 4.14. CAMP reference sites in the southern Gulf of St. Lawrence.

CAMP reference sites
Antigonish, NS
Pugwash, NS
Tatamagouche, NS
Mabou, NS
Bouctouche, NB
Caraquet, NB
Cocagne, NB
Neguac, NB
Tabusintac, NB
Tracadie, NB
Cap-Pelé, NB
Richibucto, NB
Malpeque, PEI

Table 4.15. Results of repeated measures PERMANOVA to assess differences in the fish community in Basin Head among years (fixed factor) and stations (random factor) for June, July and August. Summary statistics shown include: df, degrees of freedom; SS, sums of squares; MS, mean squares; Pseudo-F, Pseudo-Fisher-Snedecor distribution; P (perm), probability value calculated through permutations; unique perms, unique permutations.

Month	Source	df	SS	MS	Pseuso-F	P (perm)	Unique perms
June	Year	13	36 777	2829	4.150	0.001	997
	Station	5	6811	1362	1.998	0.003	998
	Residual	63	42 951	682	-	-	-
	Total	81	86 757	-	-	-	-
July	Year	13	51 492	3961	4.210	0.001	999
	Station	5	13 535	2707	2.877	0.001	999
	Residual	64	60 217	941	-	-	-
	Total	82	1.25×10^5	-	-	-	-
August	Year	13	62 699	4823	5.007	0.001	999
	Station	5	13 868	2774	2.879	0.001	997
	Residual	64	61 651	963	-	-	-
	Total	82	1.38×10^5	-	-	-	-

Table 4.16. Summary of species identified with an X in the similarity percentages (SIMPER) analyses as contributing to at least 10% of dissimilarity in fish communities between years in Basin Head for each month. Also included in parenthesis is the percentage of comparisons for which a species accounted for the largest percentage of dissimilarity.

Species	*June*	*July*	*August*
Sand Shrimp	*X (95.0%)*	*X (84.6%)*	*X (51.6%)*
Mummichog	*X (5.0%)*	*X (7.7%)*	*X (20.9%)*
Green Crab	*X*	*X (1.1%)*	*X*
Four-spined Stickleback	*X*	*X (6.6%)*	*X (4.4%)*
Atlantic Silverside	-	*X*	*X (23.1%)*
Three-spined Stickleback	*X*	*X*	*X*
Blackspotted Stickleback	*X*	*X*	-
Nine-spined Stickleback	-	-	*X*
Grass Shrimp	-	-	*X*
Winter Flounder	-	-	*X*

Table 4.17. Species identified in the similarity percentages (SIMPER) analyses contributing to the dissimilarity in fish communities for pairwise comparisons between station 3 located at the edge of Northeast Arm and other sampling stations in Basin Head for the month of August.

	Average relative abundance						Average	% of
Species	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	dissimilarity	contribution
Mummichog	4.72	-	6.34	-	-	-	8.47	19.81
Four-spined Stickleback	9.62	-	3.27	-	-	-	7.07	16.53
Sand Shrimp	14.66	-	14.79	-	-	-	6.65	15.56
Nine-spined Stickleback	4.97	-	0.99	-	-	-	4.54	10.62
Atlantic Silverside	3.92	-	1.33	-	-	-	3.57	8.36
Sand Shrimp	-	11.53	14.79	-	-	-	9.42	23.22
Mummichog	-	3.84	6.34	-	-	-	8.00	19.71
Atlantic Silverside	-	3.80	1.33	-	-	-	5.85	14.42
Green Crab	-	2.47	5.28	-	-	-	4.84	11.93
Four-spined Stickleback	-	2.26	3.27	-	-	-	3.87	9.53
Sand Shrimp	-	-	14.79	15.32	-	-	12.04	26.19
Atlantic Silverside	-	-	1.33	9.13	-	-	10.09	21.94
Mummichog	-	-	6.34	4.01	-	-	5.99	13.03
Four-spined Stickleback	-	-	3.27	2.45	-	-	5.01	10.89
Mummichog	-	-	6.34	-	10.61	-	8.77	23.03
Sand Shrimp	-	-	14.79	-	16.04	-	8.12	21.32
Atlantic Silverside	-	-	1.33	-	8.86	-	7.53	19.78
Nine-spined Stickleback	-	-	0.99	-	3.97	-	3.59	9.42
Mummichog	-	-	6.34	-	-	17.46	12.22	28.92
Sand Shrimp	-	-	14.79	-	-	13.22	10.25	24.27
Atlantic Silverside	-	-	1.33	-	-	7.02	6.25	14.78
Grass Shrimp	-	-	0.84	-	-	3.71	3.02	7.16

Table 4.18. Variation explained by the individual PCO axes and Pearson's correlations between species and each PCO axes for June, July and August for species with vector correlations of r > 0.3 (Figure 4.2).

	June		July		August	
Characteristic	PCO1	PCO2	PCO1	PCO2	PCO1	PCO2
Variation explained (%)	42.1%	18.2%	31.4%	19.9%	24.9%	19.3%
Sand Shrimp	0.87	0.38	-0.86	-0.16	0.77	0.46
Mummichog	-0.56	0.58	0.11	0.73	0.52	-0.50
Four-spined Stickleback	-0.30	0.43	-0.13	0.71	0.28	-0.49
Tree-spined Stickleback	0.01	0.37	-0.12	0.52	-	-
Nine-spined Stickleback	-0.18	0.30	-0.17	0.51	0.43	-0.32
Smooth Flounder	-	-	-0.41	0.08	0.40	0.24
Atlantic Silverside	-	-	-	-	0.25	-0.47
Winter Flounder	0.24	0.24	-	-	-	-
Green Crab	-	-	-0.47	0.44	0.66	0.018
Grass Shrimp	-	-	-0.31	0.05	-	-
Northern Pipefish	-	-			0.29	-0.09

Table 4.19. Assignment of individual Basin Head stations by year to each BEAST quality band (NS – no sample). Stations in Band 1 are inside the 90% reference ellipse and are equivalent to reference sites; stations in Band 2 are between the 90-99% ellipses and are possibly different to reference sites; stations in Band 3 are between the 99 and 99.9% ellipses and are different to reference sites.

Year	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
2010	NS	1	1	2	1	1
2011	1	1	2	1	1	2
2012	2	2	1	2	2	2
2013	1	3	1	3	1	1
2014	1	2	1	1	1	1
2015	1	1	1	1	1	2

Table 4.20. Comparison of ability of variables (nitrate categories, years, stations, and quality bands) to discriminate test stations from reference sites based on ANOSIM r values.

Effect	Pairwise r	Significance
Nitrate Low (≤ 0.1 mg per L NO_3)	0.416	0.006
Nitrate Medium (> 0.1 – < 1.0 mg per L NO_3)	0.301	0.001
Nitrate High (≥ 1.0 mg per L NO_3)	-0.054	0.576
2010	0.038	0.355
2011	0.229	0.031
2012	0.560	0.001
2013	0.444	0.003
2014	0.066	0.254
2015	0.249	0.020
Station 1	0.223	0.051
Station 2	0.391	0.002
Station 3	0.225	0.048
Station 4	0.308	0.008
Station 5	0.106	0.158
Station 6	0.324	0.007
Band 1 (90% reference ellipse)	0.132	0.013
Band 2 (90 to 99% ellipses)	0.578	0.001
Band 3 (99 to 99.9% ellipses)	0.805	0.001
Band 4 (outside the 99.9% ellipse)	NA	NA

Table 4.21. Comparison (SIMPER) of biota in BEAST quality bands to reference sites for taxa contributing to differences from reference sites. Stations in Band 1 are inside the 90% reference ellipse and are equivalent to reference sites; stations in Band 2 are between the 90-99% ellipses and are possibly different from reference sites; stations in Band 3 are between the 99 and 99.9% ellipses and are different from reference sites.

Species	Reference	Band 1	Band 2	Band 3
Sand Shrimp	279.85	864.36	2258.60	4365.00
Mummichog	82.41	27.09	95.80	-
Black-spotted Stickleback	19.34	30.59	-	-
Four-spined Stickleback	22.25	9.64	-	-
Green Crab	4.18	20.45	-	-

Table 4.22. Correlation of nine habitat variables with biological ordination axes.

Variable	r
Temperature	0.448
Salinity	0.289
Dissolve oxygen	0.268
Sediment humidity	0.428
Sediment organic carbon	0.017
Sediment particulate size	0.587
Phosphate (PO_4)	0.159
Nitrate (NO_3)	0.508
Nitrite (NO_2)	0.403

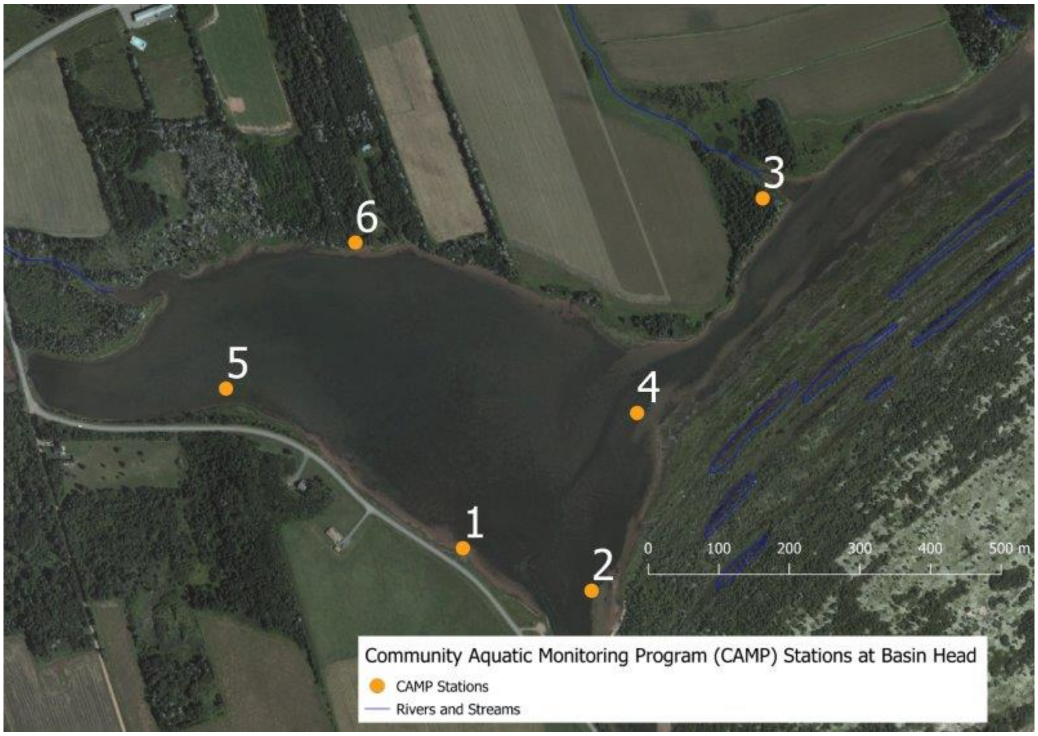


Figure 4.27. Location of CAMP sampling stations in Basin Head.

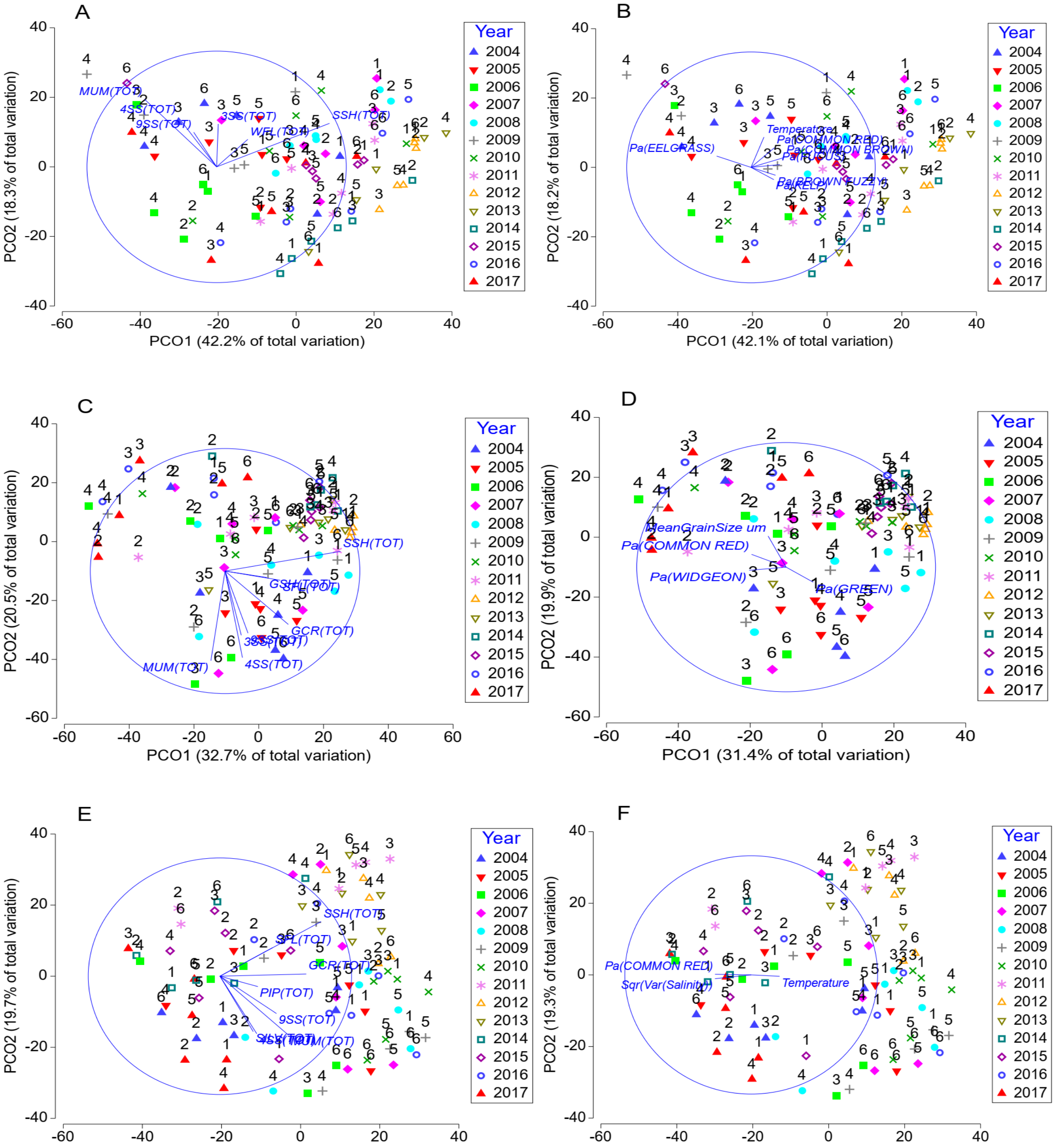


Figure 4.28. Principal Coordinates Analyses (PCO) for June (panels A, B), July (panels C, D), and August (panels E, F) showing the dissimilarities among fish communities at CAMP stations in Basin Head from 2004 to 2017. PCOs were created with S17 Bray-Curtis similarity resemblance matrices on square root transformed data. Vector overlays show correlations between species for r > 0.3 (panels A, C, E) or environmental parameters for r > 0.2 (panels B, D, F) and the PCO axes. Species acronyms are: SSH, Sand Shrimp; GSH, Grass Shrimp; MUM, Mummichog; 3SS, Three-spined Stickleback; 4SS, Four-spined Stickleback; 9SS, Nine-spined Stickleback; BSS, Blackspotted Stickleback; SILV, Atlantic Silverside; GCR, Green Crab; SFL, Smooth Flounder; WFL, Winter Flounder; PIP, Northern Pipefish.

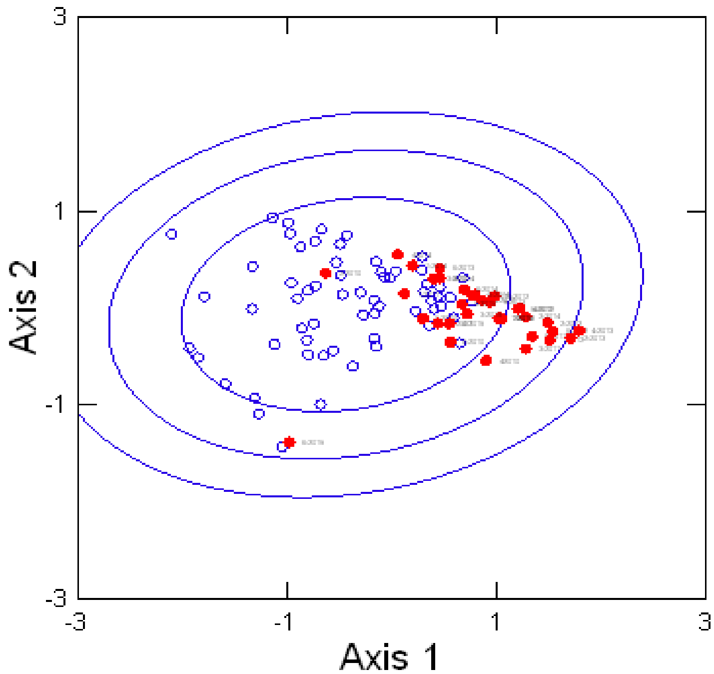


Figure 4.29. BEAST plot of reference (open) sites (with 3 probability ellipses representing 90, 99, and 99.9% coverage) and the Basin Head stations (red solid) for 2010 to 2015.

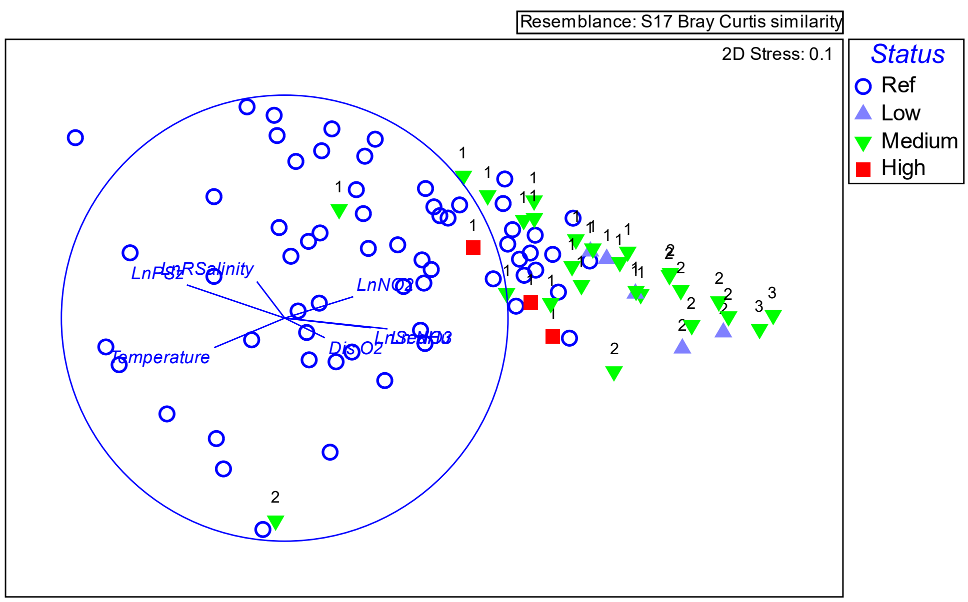


Figure 4.30. Ordination (MDS) of reference sites and Basin Head stations indicating the nitrate enrichment categories (low, medium, high) and habitat vectors. Acronyms are: Dis O2, dissolved oxygen; LnRSalinity, natural logarithm of salinity; LnSed Hu, natural logarithm of sediment humidity; LnPSz, natural logarithm of sediment particule size; $LnNO_3$, natural logarithm of nitrate; $LnNO_2$, natural logarithm of nitrite.

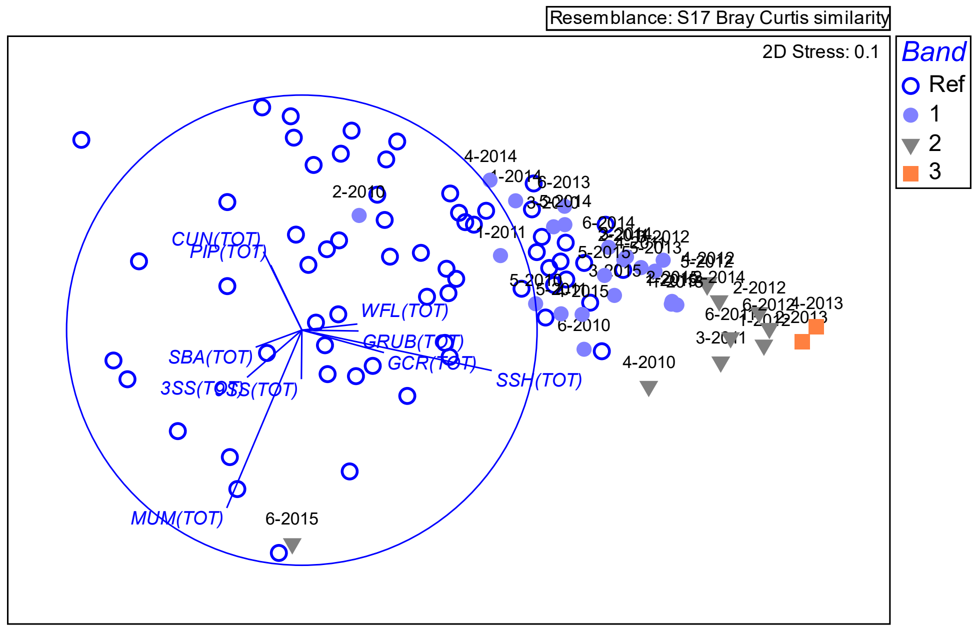


Figure 4.31. Ordination (MDS) of reference sites and Basin Head stations indicating the BEAST quality Bands (1, 2, 3) and species vectors. Species acronyms are: SSH, Sand Shrimp; MUM, Mummichog; 3SS,Three-spined Stickleback; 9SS, Nine-spined Stickleback; GCR, Green Crab; WFL, Winter Flounder; CUN, Cunner; PIP, Northern Pipefish; GRUB, Grubby; SBA, Striped Bass. Included after each species acronym is TOT for total, indicating that both life stages (adults and juveniles) were included in the analysis.

4.2. ECOLOGICAL INDICATOR 2: TRENDS IN COMMUNITY ABUNDANCE AND DIVERSITY OF FISH AND BENTHIC INVERTEBRATES IN NORTHEAST ARM OF BASIN HEAD (OTHER SURVEYS)

Author: I.Novaczek

4.2.1. Context

Biodiversity in Northeast Arm of Basin Head was sampled by McCurdy (1979, 1980) using an Ekman grab sampler. The different species found in four zones of the Arm were recorded, and the many species associated with the Irish moss-mussel clump population were explicitly documented. McCurdy (1979, 1980) reported 43 benthic taxa, including at least 17 different polychaetes, 2 ribbon worms, unidentified round worms, 6 gastropods, 6 bivalves (including mussels), 1 isopod, 9 amphipods, mysids and Rock Crab (*Cancer irroratus*). Smaller infauna were commonly present at densities of more than 100 per m^2, or more than 1000 per m^2 in the case of the worms *Hediste diversicolor* and *Polydora cornuta*. McCurdy (1979, 1980) also listed 6 fish, one ctenophore, 3 cnidarians, and 20 algae. A limited species list was generated from sampling performed in 1999 (Sharp et al. 2003) that included 2 gastropods and 3 isopods not listed by McCurdy (1979, 1980).

Griffin's (1973) thesis on the Basin Head salt marsh recorded two species along the lower marsh edge that may be ecologically important. The free-living macroalga *Ascophyllum nodosum* forma *mackii* is like the giant *Irish moss* as it lacks holdfasts and reproduces only by fragmentation. It may be one of the most abundant macroalgae in the estuary but its prevalence has never been documented. The ribbed brown mussel *Geukensia demissa* is at its northern geographic limit in the southern Gulf of St Lawrence. In warm temperate salt marshes *Geukensia* may mitigate marsh edge erosion (Reusch and Chapman 1995). It is not numerous in Basin Head, but may increase in numbers as the climate changes. No census has ever been done on this mussel.

Other than the biodiversity assessments described above, there has been no systematic, on-going monitoring for biodiversity since the MPA was established in 2005 except for the CAMP program, which documents small mobile species that can be captured by beach seine. Recent field studies to document biodiversity in the Basin Head MPA follow.

4.2.2. Methods

Benthic biodiversity assessment

Transect surveys of benthic organisms in Main Bed and Corduroy Road were conducted during the lowest workable tides between July 29 and August 11, 2015. The bottom appeared to be almost devoid of life over large areas, especially along the edges of the Arm where thick deposits of sediment have built up. Our intent was to obtain a quick glimpse of benthic diversity and productivity, with the effort being limited by lack of in-house taxonomic expertise and the brief periods of suitable daytime low tide conditions in which workers wearing waders could reach the bottom of the deeper channels. Because of the brief slack time of low tide and the rapid rise of incoming tides, sampling had to be abandoned and then picked up again on a different day in several cases. Some channels were so soft or deep even at low tide that field staff were unable to collect any samples. Using permanent survey posts as endpoints, samples were collected (if possible) at 5 m intervals along three cross-channel transects at Corduroy Road and four transects at Main Bed (Figure 4.6 and Figure 4.7). At each sampling point, water depth and penetrable sediment thickness were documented. The percentage cover of Irish moss, *Ulva* and eelgrass were assessed using a 1 m^2 quadrat. Half of the quadrat was cleared by hand of all surface organisms. Oysters and mussels were counted; up to 10 oysters and 10 mussels per sample were measured (length and height in mm); other animals were assigned an abundance category (0, 1 to 10 or 11 to 50). A 10 cm deep, 15 cm diameter sediment core was removed from the center of the quadrat. Sediment cores were poured into a 400 µm mesh sieve bucket. After sieving out the sediment, all organisms retained by the mesh were dumped onto a small table to be sorted by taxonomic unit and assigned an abundance category. All animals were returned alive to the sampling area. Identification was sometimes possible to species level, but many organisms could only be identified to genus (*Littorina spp*.) or as members of an ecological group (annelid worms, tube worms, hard shell clams).

Green crab bycatch

Trapping has been performed in Basin Head since 2016 using a variety of traps. Bycatch from these traps provide some insight into what large mobile species are present in the estuary.

Species populating Irish Moss

Researchers from the UPEI explored the community of invertebrates that naturally colonize giant Irish moss clumps and focused on the potential effects of its most abundant grazers. Transects with artificially created clumps were deployed for two weeks in the Northeast Arm. Four distinct types of clump that simulated giant Irish moss clumps in its natural *in situ* state were deployed: a) Irish moss clumps suspended near the surface, b) Irish moss clumps on the bottom, c) Irish moss mixed with large mussels (>4 cm shell length) suspended near the surface, and d) Irish moss mixed with large mussels on the bottom. The purpose of these transects was to identify which species, in addition to Green Crab, were colonizing the clumps and potentially using them as refuge or as a source of food.

4.2.3. Results and Discussion

Benthic biodiversity assessment

A total of 46 samples were taken from the surface of transect sampling sites, and 43 core samples from the sediment (Table 4.10). *Irish moss* was found on only three occasions, and eelgrass was absent, but 59% of surface samples contained *Ulva*. On average, there were 4 mussels per m^2 and 3 oysters per m^2. The only gastropods found on the surface were periwinkles, which were present in 63% of surface samples. In all but one sample, periwinkle numbers were low (< 10). In sediment core samples, nereid worms in the abundance category of 1 to 10 occurred in 72% of samples (usually only 1 to 3 per sample). Tube worms in the abundance category of 1 to 10 were recorded in 14% of the samples (usually 1 per sample). Soft-shell clams (*Mya arenaria*) and hard-shell clams (species of *Macoma* and/or *Mercenaria*) in the 1 to 10 abundance category were found in 7% and 2% of samples, respectively. Fast-moving species were not usually captured by the sampling equipment but we did pick up one Sand Shrimp and one Hermit Crab. No other organisms were found.

Species lists compiled for Basin Head in previous decades showed that biodiversity varied from place to place within the lagoon, with fewer taxa evident at the inner end of Northeast Arm and in the Main Basin, and higher diversity in the central Northeast Arm where Irish moss and eelgrass were dominant (McCurdy 1979, McCurdy 1980). An assessment in 1999 concentrated on documenting biodiversity in the Irish moss bed, where 52 animal and 42 marine plant species were recorded (not including plankton) (Sharp et al. 2003). Therefore, a profound decline in numbers of species and biomass of benthic organisms occurred between 1999 and 2015. Once restoration trials were initiated in 2015 and 2016 using experimental plantations of Irish moss – mussel clumps, periodic monitoring showed that over time, the types and numbers of benthic organisms increased in the planted areas.

Green Crab bycatch

In 2015 to 2018, researchers from UPEI who were doing a Green Crab census using baited minnow traps and Fukui traps also caught 18 different species of fish, lobster, 2 species of mud crabs, Hermit Crab, 2 species of shrimp, 2 gastropods and unidentified jellyfish and starfish (Table 4.11).

Species populating Irish moss

A diverse array of invertebrates (31 taxa) was collected from Irish moss reintroduced into the MPA, and these are summarized in Table 4.12. Species composition and abundance of these assemblages were compared between the four types of clumps. Gammarid and Corophiid amphipods were the most abundant taxa, with four species making up 91.5% of the abundance of all organisms found: *Gammarus oceanicus, Gammarus mucronatus, Gammarus lawrencianus, and Corophium volutator.* These results indicate the kind of increase in biodiversity to be expected as restoration of the Irish moss-mussel population continues.

Table 4.23. Summary table for the benthic survey of July 29 to August 13, 2015.

Species type	Number of samples	Taxa	Sampling unit	Percentage of samples with taxa	Number of individuals	Adundance type	Mean abundance over all samples (range)
Epibenthic	46	Irish moss	Quadrat ($1\ m^2$)	6.5%	3 (floating fronds)	Percentage cover	0.31% (0 – 5%)
Epibenthic	46	*Ulva*	Quadrat ($1\ m^2$)	59%	-	Percentage cover	4.80% (0 – 25%)
Epibenthic	46	Mussels	Quadrat ($0.5\ m^2$)	54%	231	Number per sampling unit	4.27 (0 – 32)
Epibenthic	46	Oysters	Quadrat ($0.5\ m^2$)	59%	137	Number per sampling unit	3.04 (0 – 22)
Epibenthic	46	Periwinkles	Quadrat ($0.5\ m^2$)	63%	-	Abundance category per sampling unit	< 10
Infauna	43	Annelids	Core ($0.017\ m^2$)	72	-	Abundance category per core	< 10
Infauna	43	Tube worms	Core ($0.017\ m^2$)	14	-	Abundance category per core	< 10
Infauna	43	Soft shell clams	Core ($0.017\ m^2$)	7	-	Abundance category per core	< 10
Infauna	53	Hard shell clams	Core ($0.017\ m^2$)	2	-	Abundance category per core	< 10

Table 4.24. By-catch species caught in Basin Head Lagoon in traps set for Green Crab by UPEI researchers in 2015 to 2018.

Latin name	Common Name
Alosa sp. (A. pseudoharengus)	Gaspereau (Alewife)
Anguilla rostrata	American Eel
Apeltes quadracus	Four-spined Stickleback
Dyspanopeus sayi	Mud Crab
Rhithropanopeus harrisii	White-fingered Mud Crab
Ecrobia truncata (Hydrobia minuta)	Mud Snail
Gasterosteus aculeatus	Three-spined Stickleback
Gasterosteus wheatlandii	Blackspotted Stickleback
Homarus americanus	American Lobster
Menidia menidia	Atlantic Silverside
Microgadus tomcod	Atlantic Tomcod
Morone americana	White Perch
Myoxocephalus aenaeus	Grubby Sculpin
Nassarius spp.	Snail
Osmerus mordax	Rainbow Smelt
Paguridae (family)	Hermit Crab
Pleuronectes americanus	Winter Flounder
Pleuronectes putnami	Smooth Flounder
Salvelinus fontinalis	Brook Trout
Scopthalmus aquosus	Windowpane Flounder
Tautogolabrus adspersus	Cunner
Urophycis tenuis	White Hake
Crangon septemspinosa	Sand Shrimp
Palaemonetes vulgaris	Grass Shrimp
Fundulus spp.	Mummichog / Killifish
Syngnathus fuscus	Pipefish
Scyphozoa (class)	Jellyfish
Asteriidae (family)	Starfish

Table 4.25. Species composition and density (mean +/- 1 SE) of organisms per clump that colonized the four types of giant Irish moss clumps deployed in Basin Head. Acronyms for Irish moss clumps are: IM, Irish moss; IMBM, giant Irish moss combined with Blue Mussels. Species groups identified in parenthese are: A, amphipod; I, isopod; D, decapod; G, gastropod; P, polychaete; B, bivalve.

Species (Taxonomic group)	IM Suspended	IM Bottom	IMBM Suspended	IMBM Bottom
Gammarus oceanicus (A)	60.50 ± 6.89	39.70 ± 6.41	44.10 ± 3.94	95.60 ± 7.75
Gammarus mucronatus (A)	47.10 ± 6.52	4.70 ± 1.20	41.90 ± 6.53	16.70 ± 4.57
Gammarus lawrencianus (A)	84.80 ± 14.45	36.60 ± 9.26	18.90 ± 4.60	15.10 ± 6.30
Corophium volutator (A)	35.30 ± 10.07	5.40 ± 1.10	117.70 ± 17.73	52.50 ± 5.72
Caprella linearis (A)	0.60 ± 0.25	0.07 ± 0.07	1.13 ± 0.45	0.07 ± 0.07
Paracaprella tenuis (A)	2.60 ± 0.80	0.13 ± 0.09	2.80 ± 0.95	0.07 ± 0.07
Unciola serrata (A)	0 ± 0	0 ± 0	1.40 ± 0.56	0.07 ± 0.07
Jaera marina (I)	0.07 ± 0.07	0.67 ± 0.27	0.07 ± 0.07	1.13 ± 0.41
Idotea balthica (I)	0 ± 0	0.07 ± 0.07	0.07 ± 0.07	0 ± 0
Idotea phosphorea(I)	0 ± 0	0 ± 0	0.33 ± 0.19	0 ± 0
Carcinus maenas (D)	0.14 ± 0.09	0.07 ± 0.07	0 ± 0	0 ± 0
Cancer irroratus (D)	1.00 ± 0.41	0.40 ± 0.19	0.07 ± 0.07	0.93 ± 0.33
Panopeus herbstii (D)	0 ± 0	0.73 ± 0.15	0 ± 0	0.47 ± 0.13
Littorina obtusata (G)	0 ± 0	2.40 ± 1.20	0 ± 0	0 ± 0
Littorina littorea (G)	0.40 ± 0.24	36.00 ± 7.70	0.20 ± 0.20	1.87 ± 0.49
Lacuna vincta (G)	0 ± 0	0.13 ± 0.09	0 ± 0	0 ± 0
B totteni (Boonea bisuturalis) (G)	0 ± 0	0 ± 0	1.27 ± 0.30	0.67 ± 0.23
Neptunea decemcostata (G)	0 ± 0	0 ± 0	0.80 ± 0.24	1.53 ± 0.43
Nassarius trivittatus (G)	0 ± 0	0 ± 0	0.07 ± 0.07	0 ± 0
Hydrobiidae (G)	0 ± 0	0.07 ± 0.07	0 ± 0	0 ± 0
Nereidae (P)	0.60 ± 0.24	0.27 ± 0.15	0.93 ± 0.32	0.13 ± 0.13
Scolelepsis squamata (P)	0.20 ± 0.11	0.07 ± 0.07	0.07 ± 0.07	0 ± 0
Phyllododocidae (P)	0 ± 0	0.47 ± 0.19	0 ± 0	0 ± 0
Harmathoe extenuata (P)	0 ± 0	0.27 ± 0.18	0.07 ± 0.07	1.27 ± 0.25
Harmathoe imbricata (P)	0 ± 0	0.07 ± 0.07	0.13 ± 0.13	0.07 ± 0.07
Eusyllis blomstrandi (P)	0 ± 0	0 ± 0	0 ± 0	0.13 ± 0.13
Platyhelminthes (unknown)	0 ± 0	0 ± 0	0 ± 0	0.07 ± 0.07
Oligochaeta (unknown)	0 ± 0	0 ± 0	0 ± 0	0.07 ± 0.07
Periploma leanum (B)	0 ± 0	0 ± 0	0.27 ± 0.15	0.47 ± 0.27
Lyonsia hyalina (B)	0 ± 0	0 ± 0	0.07 ± 0.07	0 ± 0
Crassostrea virginica (B)	0 ± 0	0.07 ± 0.07	0 ± 0	0 ± 0

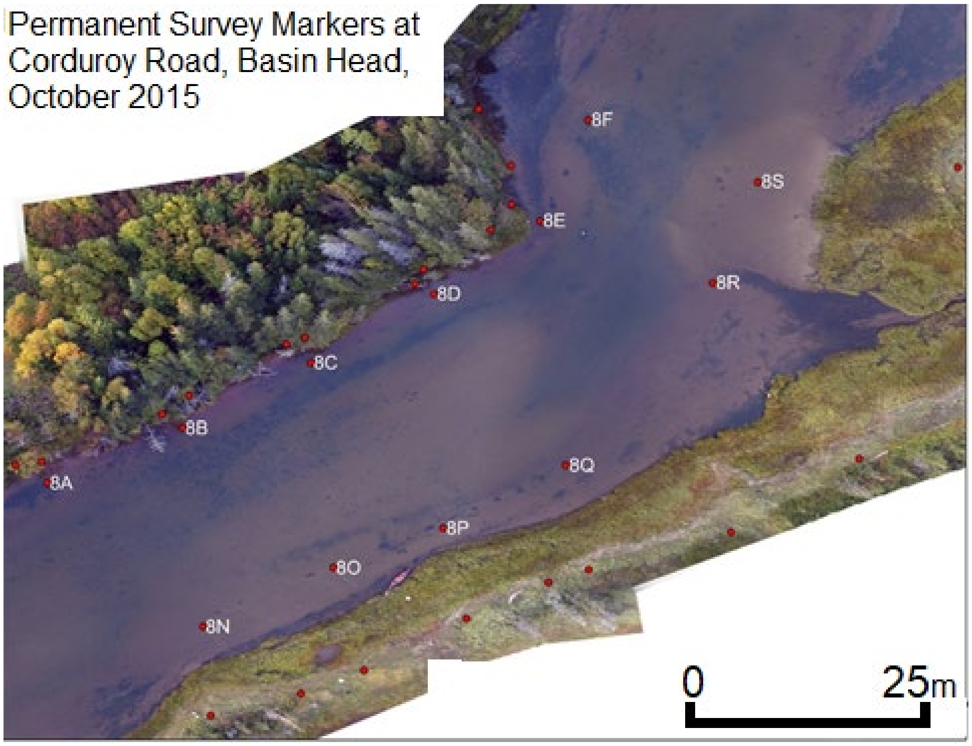


Figure 4.32. Placement of Corduroy Road transects defined by survey posts 8A to 8N, 8B to 8O, and 8C to 8P.

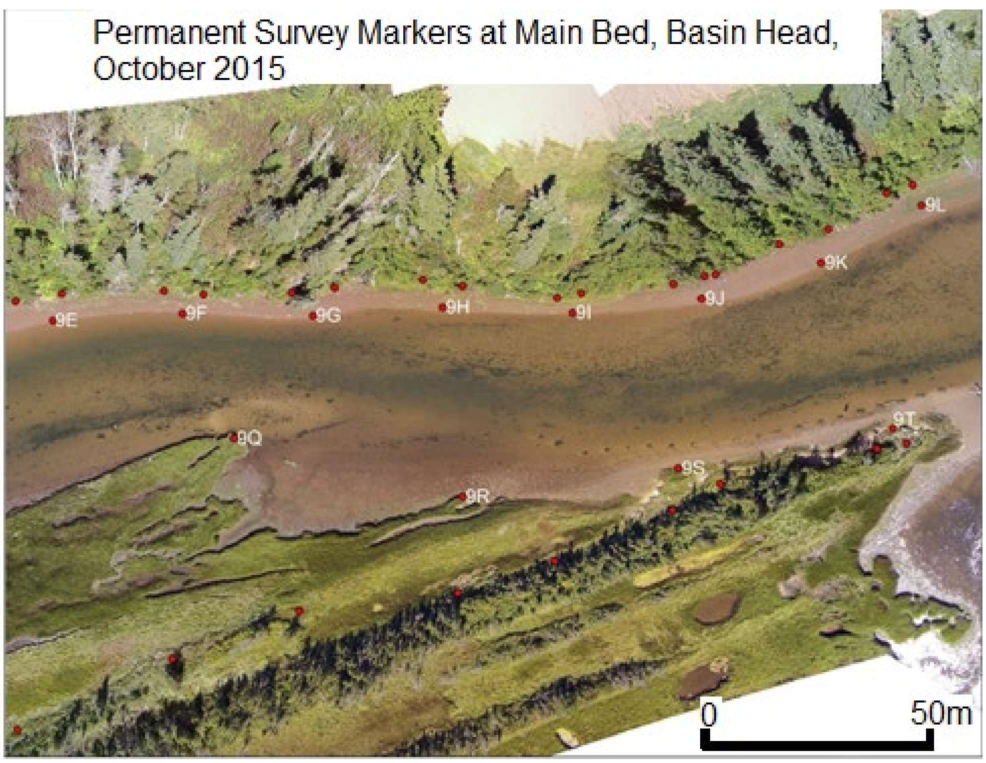


Figure 4.33. Placement of Main Bed transects defined by survey posts 9F to 9Q, 9H to 9R, 9I to 9S, and 9K to 9T.

5. RESTORATION EFFORTS

Authors: I. Novaczek, M-H. Thériault, M-A. Plourde, P.A. Quijon, and P. Tummon Flynn

5.1. IRISH MOSS-MUSSEL CLUMP RESTORATION

5.1.1. Context

On-land cultivation of the Basin Head Irish moss was initiated in 2008 in tanks at the National Research Council (NRC) marine laboratory in Sandy Cove, Nova Scotia (NS). The objective was to provide a source of viable material for research and potentially for transplantation into Basin Head. Because of near extirpation of the Basin Head Irish moss and increased funding for management and conservation of the Basin Head MPA, research into restoration strategies was performed. Different test planting of artificially constructed Irish moss - mussel clumps began in 2015. Multiple short term studies, reported below, were conducted to better understand the fate of artificial clumps in different conditions. These were monitored to provide information for designing further restoration, which is ongoing.

5.1.2. Methods

Conservation of existing stock (2014 to 2016)

Plastic mesh bag cages and rigid Vexar rings were used to stabilize floating Irish moss fragments and Irish moss - mussel clumps in 2014 to compensate for the small number of mussels remaining in Northeast Arm. Commercially grown PEI mussels, that were cleansed for 24 hours in running fresh water at 7-8ºC (i.e., ambient groundwater temperature) to eliminate any invasive species, were placed around existing clumps in 2015 in an effort to reduce clump mobility that could lead to death in pockets of deep silt. Gill nets stretched across the Arm at Robertson field, Main Bed and Corduroy Road were used in 2015 and 2016 to determine whether or not Irish moss fragments were being swept out to sea with the falling tide, or into the the muddy, seasonally anoxic zone east of Corduroy Road with the rising tide.

In autumn 2016, 200 kg of individual mussels were spread on the seafloor in designated areas of Main Bed and Corduroy Road. The following year, wading survey data from these areas were compared to data from adjacent areas to see whether small mussel clumps (with or without Irish moss attached) were more abundant where mussels were added.

Production and planting of artificial clumps (2015 to 2018)

To perform field experiments, giant Basin Head Irish moss grown in tanks on-land at the NRC Marine Station in Sandy Cove, NS was brought to Basin Head. As mentioned above, commercially grown Blue Mussels from PEI were also brought to Basin Head to create artificial clumps. In most cases, there was about 10% mortality of mussels observed within a week of the treatment, which is in accordance with a study by Bailey et al. (1996) where mussels exposed to distilled water (0 ppt) for a week had low mortalities. Irish moss-mussel clumps of various sizes and shapes were tested and through trial and error, an efficient method for clump production and planting was developed as follows. A minimum of 20 adult mussels were placed in a mesh bag (PEI Bag Co©) with two large oyster shells at the bottom (used to prevent clumps from sinking into soft sediment) and a small handful of cultivated Irish moss. Bags were hung on a cultivation line for 48 hours or until firmly clumped. When water temperatures peaked, mussel byssal thread production was impaired and clumping required more time.

Clumps were transported in fish pans to the planting areas. Initially, clumps were set out by hand at low tide, at 30 to 50 cm intervals in gaps between the existing clumps at Main Bed and Corduroy Road. As of 2018, planting has been more intensive and rarely performed during low tide, so clumps are simply released over the side of a canoe. The total number of clumps planted per area is recorded and a handheld GPS unit is used to determine the general location of the newly planted clumps. These data are then added to a map showing approximate locations of all the clumps, including previously present and newly planted ones (Figure 5.1).

The planting of clumps in 2015 and 2016 concentrated on filling gaps at Main Bed and Corduroy Road. Restoration planting was expanded in 2017 and 2018 to include Fireweed Bank, which had been the center of dense Irish moss biomass prior to 2004 (Sharp et al. 2003).

Green crab inclusion/exclusion cage experiments (2015)

Field experiments explored the positive and negative relationships that exist among Irish moss, Blue Mussel, and Green Crab under various conditions of water depth and bottom sediment thickness. In 2015, 14 experimental plastic mesh cages, each containing two Irish moss - mussel clumps, were placed on a mid-channel sand bank west of Main Bed. Water depth at low tide ranged from 47 cm to 67 cm. Penetrable sediment thickness surrounding each cage ranged between 7 and 32 cm. Seven cages each contained one Green Crab of known size, and the other seven did not include crabs. Mussel mortality and Irish moss condition were assessed by removing and documenting the clumps from each cage after 2 days and again after 6 days. This experiment was repeated in August using clumps of mussels only (i.e. no Irish moss) to populate the same 14 cages. In this case, the crabs used in the 7 crab inclusion cages were larger (average 62 mm), and clumps were removed from the cages after 3 days and 10 days.

Fate of clumps in small open plots (2015 to 2016)

In summer 2015, five 1 m^2 plots of mussels and Irish moss were set up; three at Fireweed Bank (firm bottom) and two at Gazebo, close to Oyster Cross (soft bottom). In each case, 400 mussels of known size (ranging from 30 to 65 mm in length) were evenly spread out on each plot. Three small Irish moss–mussel clumps having known numbers of mussels and a known wet weight of Irish moss were also added to each plot. Objectives were to observe how mussels clumped up or disappeared from the plot, the % mortality of mussels, whether new clumps of mussels captured fragments of Irish moss, and the change in weight, position and condition of Irish moss over time. Plots were monitored occasionally to detect whether they were being smothered by silt, *Ulva* or debris, and to determine whether the Irish moss was still present. One plot from each site was harvested after two months, while the remaining plots remained untouched for approximately one year. When harvested, all living and dead organisms in each quarter of the plot, and from adjacent 0.25 m^2 areas of the sea floor were hand-collected, separately bagged, and taken to the lab for processing. Processing involved measuring all living mussels and dead shells, weighing the Irish moss and *Ulva* present, identifying and counting all other plants and macrofauna present, and noting the presence of accumulated silt, marsh sods and organic debris.

Test plantations (2015 to 2018)

Test plantations of various sizes were initiated and subsequently monitored for Irish moss and mussel survival and *Ulva* cover. In September 2015, at Oyster Cross (area west of Main Bed), 320 Irish moss–mussel clumps were placed along two 40 cm wide strips of oyster shell, in a cross shape. The east-west strip was 17 m long and the north-south (cross channel) strip was 13 m long. Each strip of the cross was distinctive in terms of water depth and sediment thickness. In 2017, a total of 13, 0.25 m^2 benthic samples were harvested from all arms of the cross, using a box sampler. The % *Ulva* cover, wet weights of *Ulva* and Irish moss, Irish moss condition, numbers and sizes of living and dead mussels (including spat), and numbers of other species were documented for each sample. The sampled areas were subsequently restocked with Irish moss–mussel clumps and annual surveys documented subsequent changes in the numbers of mussel-only and Irish moss–mussel clumps along each arm.

To check for potential planting sites in other parts of Northeast Arm, Irish moss–mussel clumps were seeded at 2 m intervals along seven benthic survey transects where firm sandy bottom was encountered in 2016. These transects were monitored annually in 2017 and 2018 to determine whether mussel clumps and Irish moss persisted over time.

Clump dynamic on Fireweed Bank (2017)

In May 2017, an experiment was set up on a 10 m^2 area of clean sandy bottom at Fireweed Bank, which was historically at the center of dense Irish moss cover. This plot was divided into three sections for sampling purposes (shallow edge, center and deep edge), and each section was stocked with equal numbers of mussel-only and Irish moss-mussel clumps. Each clump contained 15 large mussels that were > 48 mm long and five smaller mussels that represented a size susceptible to Green Crab predation. Loose mussels of known sizes were spread on the bottom between rows of clumps at a rate of 10 per 0.25 m^2 (seven large and three small mussels). Samples of clumps with and without Irish moss were hand-collected from each section of the plot in July, August and September 2017. In addition, all shells and debris that might host spat were collected from areas lacking clumps using a 0.25 m^2 box sampler. Data collected from each sample included: mussel size (length and height); number and size of dead mussels, number and size of mussel spat on clumps and benthic litter; and Irish moss wet weight and condition. Mussel meat dry weight, condition index and gonad index were assessed in May and September. Green Crab and Rock Crab were counted in the plantation on each sampling date. Numbers of crabs were also counted in an adjacent 10 m^2 area devoid of clumps, and the results compared.

Irish moss-mussel interactions in suspended cultivation (2017)

Interspecies interactions include not only competition and predation, but also positive interactions and facilitation. Because experiments in cages placed on the sea floor were confounded by siltation, a series of experiments to check for positive interactions were attempted using enclosures suspended in the water column of Northeast Arm. From May to September 2017, suspended Vexar mesh cages housed either mussels, Irish moss or combined clumps (9 replicates per treatment) to determine whether either species gained a detectable benefit from growing together. Because of fouling of the vexar cages by mussel spat, *Ulva* and filamentous algae, this experiment was repeated once in the fall (from September to November 2017), with replicates (Irish moss alone, mussels alone or Irish moss–mussel clumps) confined in mesh socks without protective cages. At the end of each trial the change in wet weight and condition of Irish moss, mussel mortality and the length and height of individual mussels from each treatment were documented and compared. Size and number of mussel spat that settled on the experimental Irish moss and mussels were also noted.

5.1.3. Results and Discussion

Conservation of existing stock (2014 to 2016)

Protecting Irish moss fragments in plastic mesh cages placed on the bottom in 2014 failed because of siltation within the cages. Protecting Irish moss-mussel clumps using open Vexar rings reduced clump mobility over the summer, but the structures were crushed by ice or filled with silt over the winter. All cages and rings were removed as soon as possible in 2015. As an alternative, we placed adult mussels around existing clumps in 2015. This increased their stability over the summer, without any appreciable negative impacts. The 2016 clump survey showed that once stabilized with additional mussels, the clumps retained their positions in the beds over the winter.

Gillnet sampling for mobile Irish moss fronds showed that very little Irish moss was floating out of the estuary with the tide and no fronds were detected moving east into the seasonally anoxic zone.

In areas of Main Bed and Corduroy Road where mussels had been scattered on the bottom in autumn 2016, greater than average numbers of small mussel-only clumps and clumps that held small fragments of Irish moss were found. Specifically, in spring of 2017, 182 mussel-only clumps were found in Main Bed while 131 were found in Corduroy Road. These clumps likely resulted from the combined effects of removal of Irish moss by winter ice and new clump formation by mussels that were added to the beds. Survey data showed that the majority of the mussel-only clumps (62% in Main Bed and 61% in Corduroy Road) were found in areas that had been seeded with unattached mussels. These seeded areas comprised 45% of Main Bed and 56% of Corduroy Road. Survey data were also checked for evidence of newly formed mussel clumps capturing fragments of Irish moss during the winter. Assuming that newly-captured Irish moss fragments are 5 cm or less in diameter, we counted the proportion of clumps that fit into this size category. In Main Bed, 53 Irish moss - mussel clumps held less than 6 g of Irish moss, 33 (62%) of which were located in areas seeded with loose mussels. At Corduroy Road, there were 32 clumps with less than 6 g of Irish moss including 28 (88%) within areas seeded with loose mussels. These findings suggest that seeding may promote development of new mussel clumps and increase the possibility of Irish moss fragments being captured by mussel clumps.

Production and planting of artificial clumps (2015 to 2018)

Clumps planted on current-swept bottom within existing Irish moss beds had a 90% retention rate between 2015 and 2017. Survey data collected from selected transects in 2018 and 2019 indicated more serious losses of Irish moss over winter among clumps that were dropped from a canoe rather than hand-planted. This reflects the greater likelihood of mass-planted clumps landing on unsuitable (i.e. silty or very shallow) bottom. By the end of 2018, there was an estimated 90 m^2 of Irish moss (7398 clumps) in Northeast Arm (Figure 5.2).

Green crab inclusion/exclusion cage experiments (2015)

Observations of Irish moss-mussel clumps that were made during surveys indicated that fronds died within days when placed close to thick unconsolidated sediment. In cage experiments, Irish moss condition declined most in cages where siltation was heavy. In the first experiment, mussel mortality ranged from 6.5 to 24.8% in heavily silted cages, compared to 2.5 to 4% in cages with little to no siltation. Siltation effects on mussel mortality were not evident in experiment 2, when accumulations in the cages were mostly of coarse organic debris rather than fine silt. Mussel mortalities remained below 11%. One crab died during experiment 2 and that occurred in the inclusion cage that accumulated the most sediment.

Whether they attacked Irish moss–mussel clumps (experiment 1) or mussel-only clumps (experiment 2), Green Crab primarily consumed the smaller mussels (mostly < 38 mm and occasionally 38-43.9 mm). However, the larger crabs used in experiment 2 also successfully attacked and consumed a small number of mussels that were 44-47.5 mm long. Siltation stress can cause mussels to gape (Novaczek pers. obs.), and may be responsible for making larger mussels vulnerable to predation.

Fate of clumps in small open plots (2015 to 2016)

Within two months, the 1 m^2 plantations that were each seeded with 400 individual mussels and 3 Irish moss–mussel clumps were populated by oysters, periwinkles, mud crabs, slipper limpets and annelid worms. After 11 to 12 months, these had been joined by soft-shell and hard-shell clams, Rock Crabs, hermit crabs, amphipods and Sand Shrimps. Sticklebacks were commonly found around clumps that retained their Irish moss. Surrounding bare sand remained barren. Oysters moving along the bottom with the tide collected in patches of clumps, as did loose sediments and organic debris. The greatest mussel mortality occurred within the first two months, and overall mortality was greater at Gazebo (softer bottom) than at Fireweed Bank (firmer bottom) (Figure 5.3). After a year on the bottom, the weight of Irish moss was reduced by at least 90% in all plots and at Gazebo, almost all the Irish moss was gone. This is consistent with the cage experiments in which loss of Irish moss was correlated with heavy siltation.

Test plantations (2015-2018)

After 320 Irish moss–mussel clumps were planted at Oyster Cross in 2015, up to 100% of Irish moss and 50% of mussels died within a year on those parts of the cross that were surrounded by thick deposits of loose sediment. On firmer bottom, clumps managed to persist and thrive from year to year despite annual smothering by *Ulva* and other ephemeral algae. We observed the fusion of clumps leading to a decrease in clump numbers in 2016 and 2017, and also the fragmentation of large clumps when mussels in the center died, which resulted in an increased number of clumps being counted in 2018. Periwinkles were the dominant recruits into the plantation but at least four species of annelid worms, soft shell clams, oysters, mud crabs, hermit crabs, tube worms, Slipper shells and two macroalgae (*Ascophyllum* and *Gracilaria*) were also detected in samples gathered in 2016. When surveyed in 2018, the number of mussel clumps on Oyster Cross had built back up to 320, but only 61 (19%) had Irish moss attached and these were concentrated in areas of firm sand.

Along the seven survey transects, only the transect at Fireweed Bank retained all of its mussel clumps and a high proportion of Irish moss over the winter. In other areas, especially where surrounding bottom sediments were thickest, most clumps disappeared. As a result, Fireweed Bank was selected as an experimental site and as a restoration area.

Clump dynamics on Fireweed Bank (2017)

Samples taken from the Fireweed test plantation consistently showed more mussel spat settlement on Irish moss-mussel clumps than on mussel-only clumps or shell litter. This may be because the Irish moss fronds “catch” the spat before they can be filtered out of the water column by the mussels (Davenport et al. 2000). Growth of spat was most rapid on Irish moss, possibly because increased turbulence in the boundary of moving fronds increases the likelihood of encountering prey (Commito and Rusignuolo 2000; Hurd 2000; Johnson 2001). Spat may also benefit from consumption of Irish moss exudates (Sieburth 1969). Retention of spat on Irish moss–mussel clumps may be enhanced because mussels spin more byssal threads and therefore create tighter clumps when Irish moss is present (I. Novaczek pers. obs.), and this in turn may make it difficult for crabs to find and extract small mussels from the clump. Spat retention must be very important to Irish moss survival, as it guarantees continued attachment to the bottom after older mussels die.

The Irish moss fronds grew from 10 g wet weight to as much as 180 g between May 11 and September 19, 2017 (132 days). Growth was greatest in the middle of the plot and along the deep edge. Irish moss was smaller along the shallow edge where herbivory (likely by amphipods) reduced the average condition of the growing tips.

In addition to the species previously observed populating the small open plots and the Oyster Cross plantation (see above), limpets and whelks also moved into Fireweed Bank. As the Fireweed plantation was on firmer bottom than the other test sites, this may indicate that limpets and whelks require relatively clean bottom conditions.

Possibly because crabs were being trapped throughout the summer, there were few Green crabs (23 in total) and even fewer Rock crabs (3) detected during the three surveys of the experimental site. The majority of Green Crabs counted (13) were present in July. On the adjacent 10 m^2 of bottom where clumps were not planted, the numbers of crabs were even lower: a total of 5 Green Crabs and 2 Rock Crabs were seen in July and August; and none in September.

Irish moss–mussel interactions in suspended cultivation (2017)

We hypothesized that Irish moss might benefit from nitrogen released by mussels. However, there was no measureable benefit for either Irish moss or mussels when grown together rather than separately. In experimental socks and cages suspended in the water column, Irish moss grew better when cultivated alone, (Table 5.1) as mussel byssal threads tended to cover growing tips. Light-limited Irish moss in cages suffered from herbivory by amphipods, and became covered in epiphytes. Mussel and oyster spat settled and were retained more abundantly on Irish moss than on mussel-only clumps, and spat grew more rapidly in cages suspended over a current-swept sandy bottom compared to those suspended over a softer bottom (Table 5.2).

5.2. GREEN CRAB REMOVAL PROGRAM

5.2.1. Context

It has been suggested that the current status of Irish moss in Basin Head is the result of cumulative effects of a number of stressors, including the invasion of Green Crab in the late 1990s (DFO 2008). The giant Irish moss can only persist in Basin Head if it is anchored to the bottom by the byssal threads of the native Blue Mussel and since evidence suggests that the mussel population has been reduced by Green Crab predation, inevitably, the Irish moss population has been indirectly impacted as well. Of all the stressors thought to have led to the significant decline in Irish moss abundance, the Green Crab may be the most readily amenable to a management intervention.

The complete eradication of an invasive species in an aquatic environment is virtually impossible once the organism has become established (Bax et al. 2003; Lodge et al. 2006). In Basin Head, the eradication of Green Crab is no longer considered an option; therefore, efforts are now focused on mitigation to suppress the Green Crab population, slow its spread and minimize its negative impacts. Mitigation studies have found that the direct removal of Green Crab through focused trapping is an effective control technique, which has become the standard method of mitigation on the east and west coasts of Canada (DFO 2010b; DFO 2011b; Duncombe and Therriault 2017). In Basin Head, trapping to reduce the Green Crab population was first attempted by DFO in 2009 and 2010. This was a pilot project to evaluate the feasibility for the management of Green Crab, with the objective of facilitating the re-establishment of a healthy Irish moss population. Specifically, the project aimed at reducing the Green Crab population below an abundance threshold where predation would no longer prevent recruitment of susceptible size classes of mussels. Green Crab were trapped in the Main Basin with Fukui traps and harvested manually in the Northeast Arm using snorkeling gear. This project was not extended pass the 2010 season because of a lack of capacity and the substantive efforts required to successfully reduce the Green Crab population.

In 2016, Green Crab trapping was re-initiated in Basin Head as a pilot project (8 weeks) using a slightly different method than what was used in 2009 and 2010. This pilot project led to an extension of Green Crab trapping as a control measure for up to four years (2017 to 2021). The objectives were to: 1) remove as many Green Crab as possible and reduce their size (carapace width < 35 mm); 2) increase the mussel population and size structure; and, 3) increase biodiversity. SAB was contracted by DFO to conduct the trapping and reporting of data.

5.2.2. Method

Since the pilot project was initiated in 2016, there have been a number of variations in the trapping regime, including varying types and numbers of fishing traps, deployment locations, soak times and total fishing days. In 2018, traps were submerged for an extended period of time (210 days) compared to 2016 and 2017 (50 and 92 days, respectively) (Table 5.3). The number of days that the traps were fished (i.e. Green Crab removed) varied from one month to another in 2017 and 2018. For example, in 2018 traps were fished (i.e lifted, emptied, re-baited and re-deployed) a total of 8 times per month in June, August, September and November, while they were fished 21 times in May and July and 15 times in October. The number of traps increased in 2018 from 35 (2016 and 2017) to 45 at the beginning of the season (May) and to 53 in September, at which point a total of 15 individual Luke traps were placed in the Northeast Arm and 12 sets of three Luke traps, one Russel trap and one Delbert trap were placed in the Main Basin (Table 6.3; Figure 5.4). Fukui traps used in the initial phase of the project were gradually replaced with a new type of trap (Luke trap) that is comparable to a smaller version of a snow crab trap. Initial trials with Luke traps suggested that they were more efficient at catching Green Crab than Fukui traps, since they retained more crabs for longer periods of time, had the ability to catch smaller crabs due to a smaller mesh, and greatly reduced by-catch. Traps in the Main Basin were fished in sets of three, tied approximately three meters apart, while traps in the Northeast Arm were fished individually to avoid damage to the seabed.

When the traps were fished, Green Crab and by-catch were removed and the traps re-baited with frozen herring. All by-catch was counted and recorded during the fishing process and released live on site. The most frequent by-catch was Rock Crab and the occasional flounder. Rock Crab were released at the mouth of the lagoon to deter them from re-entering the traps. Green Crab were counted per trap and one third of the total catch was measured and sexed. All Green Crab were euthanized in a fresh water bath and disposed of in a landfill.

Over the first three years (2016 to 2018), many trials were conducted in an attempt to maximize catch rates and to determine the best trapping regime. Because initial trapping strictly focused on the control of the Green Crab population, no effort was directed towards monitoring the population (i.e. trapping efficiency), which resulted in a highly variable fishing protocol (as discussed above). Consequently, the current dataset does not allow for statistical analyses or yearly and/or seasonal comparisons. Moving forward, the intention is to establish a standardized trapping protocol for the purpose of evaluating the effectiveness of the Green Crab removal program and wheather the program is having a beneficial impact on the mussel population and biodiversity in general.

5.2.3. Results and Discussion

A total of 33,799 Green Crab were captured in 2016 (October and November), 32,821 in 2017 (August to November), and 45,578 in 2018 (May to November) (Figure 5.5). Monthly size class distributions in subsamples are presented in Figure 5.6. In general, more males than females were captured, except for May and October 2018, when more females were captured (Figure 5.7). Sex ratios obtained through trapping can be influenced by several factors, including reproductive behavior (e.g. ovigerous females tend to be inactive/unresponsive to bait to avoid predation), molting activity, intimidation (females tend to avoid traps containing large males), and environmental conditions. It is likely that the increased number of females in the spring and fall of 2018 is a result of foraging behavior (i.e. increased feeding in the spring in preparation for reproduction, and in the fall prior to winter quiescence).

Numbers of Green Crab captured per site in 2018 are shown in Figure 5.8. Traps at sites 5 and 6 in the Main Basin seemingly captured more crabs and yielded 26% of the total Green Crab catch for 2018. Most were small to medium sized crabs. These two sites also captured the least amount of Rock Crab. These observations are consistent with 2017 data, and could be related to the tendency of Green Crab to stay close to the mouth of streams in brackish water, probably to avoid predation by taking advantage of salinity tolerances (Klassen and Locke 2007).

5.3. GREEN CRAB POPULATION ASSESSMENT

5.3.1. Context

Research conducted by the UPEI was done in Basin Head to better understand the Irish moss and Green Crab interactions. One of the objectives of this research was to assess the Green Crab population densities and to develop an index of population density for areas near Irish moss beds and in the Main Basin of Basin Head.

5.3.2. Method

From 2015 to 2018, Fukui traps were deployed overnight (24 h) at an approximately bi-weekly frequency in order to collect information on Green Crab numbers and population structure. Two sites within Basin Head were sampled: the Main Basin and the western end of the Northeast Arm, in proximity to where Irish moss was originally found. Traps were deployed on similarly shallow, subtidal bottoms, and accessed using a canoe or by wading from the shoreline. Two additional sites in Murray Harbour (PEI) were concurrently monitored with the goal of having a reference area at a location outside of Basin Head; in this area, Fukui traps were used following the same protocol and frequency of deployments as in Basin Head.

During the 2017 field season, additional information on Green Crab in Basin Head and Murray Harbour was collected, including male to female ratios and ovary/egg development. The goal was to monitor aspects of the life history of the Green Crab populations that could be potentially relevant for future management decisions. Male to female ratios are informative because most of the Green Crab impacts described in the literature are directly associated with the behavior of large males, broadly considered the most aggressive and potentially the most detrimental to prey populations and habitats (Pickering et al. 2017). There is also a reproductive advantage associated with size, as larger males can fertilize more eggs either by transferring a greater amount of spermatophores to a single female, or by mating with more females.

5.3.3. Results and Discussion

Table 5.4 and Table 5.5 summarize the yearly mean densities (number of crabs per trap per day) of Green Crab and Rock Crab (main by-catch), respectively, that were captured in Basin Head and Murray Harbour from 2015 to 2018. Overall, mean densities of Green Crab were higher in the Northeast Arm than in the Main Basin. The density of Green Crab ranged widely in the Northeast Arm, with mean values between 0 and ~88 crabs per trap per day. The overall mean (all samples from the four years) was 23.6 crabs per trap per day. Given the high level of variation between years, the overall median and 25th and 75th percentile values for each year are also presented in Table 5.4 and Table 5.5. Mean densities of Green Crab in the Main Basin were between 0 and ~25 crabs per trap per day, with an overall mean value of 3.4 crabs per trap per day.

Mean densities of Rock Crab in the Northeast Arm were lower than those recorded for Green Crab, ranging between 0 and ~52 crabs per trap per day, with an overall mean value of 14.8 crabs per trap per day. In the Main Basin, Rock Crab mean densities were slightly higher than in the Northeast Arm, and much higher than those recorded for Green Crab. Mean values ranged between 0 and ~58 crabs per trap per day with an overall mean of 17.0 Rock Crab per trap per day.

Over the four sampling years (2015 to 2018), a reduction in the number of large males was observed in Basin Head, which is likely due to the Green Crab removal program. Such a drop in the fraction of large male crabs was not observed in Murray Harbour. Female Green Crabs in Basin Head exhibited only minor changes in size range over the course of the four years. An examination of size classes for female and male Rock Crab in Basin Head indicates the existence of only minor changes in size and no major decline. During the 2017 field season, the number of females in Basin Head was highest in May (Figure 5.9). The estimated male to female ratios in 2017 showed a predominance of male Green Crab in all subsequent samples (after May). Furthermore, females with ovary/egg development at stage 4 (the stage just before extrusion) were predominant early in the field season (May to June) and late in the fall (mid-October). Early stages, primarily stage 1 females, were mostly observed during the summer months.

5.4. EELGRASS RESTORATION PROGRAM

5.4.1. Context

Eelgrass was previoulsy abundant in Basin Head, but available evidence from unpublished reports, databases and field observations suggests that eelgrass declined drastically between 2006 and 2008. Eelgrass is a key physical structure of the estuary that improves environmental quality by stabilizing sediments and offering habitat such as nursery areas for many species (DFO 2009). Therefore, we explored the potential of restoring eelgrass by planting eelgrass plots using a technique that was developed by SAB and proven successful in Souris Harbour, PEI.

5.4.2. Method

From 2017 to 2018, eelgrass shoots were transplanted in three 10 m x 10 m experimental plots in the Main Basin and Northeast Arm, where eelgrass had historically thrived and new shoots had been observed in 2017. Viable shoots were collected from the wrack line in Souris Harbour, where washed-up plants accumulate during strong autumnal winds. Following a 24 h fresh water bath in breathable lock-tech containers to ensure eradication of invasive tunicates, shoots of various diameters were threaded through holes drilled in oyster shells to stabilize the eelgrass shoots on the seafloor and planted at designated sites. Oyster shells were chosen because they are easy to obtain, have negative buoyancy and do not fragment when drilled.

5.4.3. Results and Discussion

Field observations indicated that the plot created in 2017 was still viable in 2018 and growth of eelgrass was ongoing. Two additional plots were planted in fall of 2018 and will be monitored for the first time in June 2019. Success of the plantations will be evaluated at the end of the 2019 field season, and the potential for planting additional plots in the future will be considered at that time. Before investing time and money into planting additional plots, it is important to monitor the success of the three existing plots to evaluate eelgrass survival under current conditions of poor water quality, high summer water temperatures, light limitation (turbidity), *Ulva* smothering, sedimentation and Green Crab abundance. Field observations indicate that eelgrass is making a natural recovery in the Northeast Arm and a similar re-establishment has been observed by SAB fieldworkers restoring eelgrass in other estuaries, including Souris Harbour. A reproductive event in an eelgrass bed along the east coast of PEI, or the uprooting of eelgrass and subsequent entrainment into the estuary by a storm event, such as the storm surge of late autumn 2016, may have precipitated the resurgence. The recent cold winters that likely had a role in reducing the Green Crab population may have also contributed to successful re-establishment of eelgrass. Ongoing efforts to reduce the Green Crab population in Basin Head should increase the chances of further recovery of eelgrass.

*Table 5.26. Average final weight (g) and condition of Irish moss (IM) after being in suspended cultivation for 96 days, alone or with a mussel clump (N = 9 replicates per treatment). Significance level based on Analysis of Variance interpreted as: ** = <0.01, *** = < 0.001.*

Characteristic	Final fresh weight (g); Mean (one SE)	IM Condition Index; Mean (one SE)
Irish moss alone	12.3 (0.58)	9.42 (0.31)
Irish moss with mussels	4.56 (0.47)	8.28 (0.46)
p-value	0.002**	1.9 E-08***

Table 5.27. Results of two-way ANOVA indicating significant differences in spat growth with treatment (mussel clumps with or without Irish moss attached) and type of bottom under the cultivation line (hard sand or thick silt). df: degrees of freedom; F: F-test: p: probability.

Variance terms	Sum of squares	df	Mean square	F	p
Treatment	180.8	2	90.4	17.99	5.41E-08
Line	209.9	2	104.9	20.88	4.52E-09
Interaction	28.8	4	7.2	1.432	0.22
Within	1175.9	234	5.0	-	-
Total	1560.7	242	-	-	-

Table 5.28. Results of Tukey's Test p-values of pairwise differences in spat growth with treatment (mussel clumps with or without Irish moss attached) and type of bottom under the cultivation line (hard sand or thick silt).

Main Effect	Pariwise comparison		p-value
Treatment	Irish moss only	Mussels+Moss	0.25
Treatment	Irish moss only	Mussels only	4.24E-08
Treatment	Mussels+Moss	Mussels only	0.0001
Line	A	B	0.038
Line	A	C	2.42E-09
Line	B	C	0.0003

Table 5.29. Green Crab trapping protocols and activities during the 2016 to 2018 directed removal program.

Year	Month	Number of traps	Types of traps	Number of sites	Number of days fished	Number of days in water
2016	Oct	35	34 Fukui, 1 Russell	15	16	27
	Nov	35	34 Fukui, 1 Russell	15	16	23
2017	Aug	35	33 Fukui, 1 Russell, 1 Luke	15	11	22
	Sept	35	33 Fukui, 1 Russell, 1 Luke	15	12	30
	Oct	35	33 Fukui, 1 Russell, 1 Luke	15	19	31
	Nov	35	33 Fukui, 1 Russell, 1 Luke	15	4	9
2018	May	45	21 Fukui, 22 Luke, 1 Russell, 1 Delbert	23	21	31
	Jun	45	21 Fukui, 22 Luke, 1 Russell, 1 Delbert	23	8	30
	Jul	45	21 Fukui, 22 Luke, 1 Russell, 1 Delbert	23	21	31
	Aug	45	21 Fukui, 22 Luke, 1 Russell, 1 Delbert	23	8	31
	Sept	53	51 Luke, 1Russell, 1 Delbert	29	8	30
	Oct	53	51 Luke, 1Russell, 1 Delbert	29	15	31
	Nov	53	51 Luke, 1Russell, 1 Delbert	29	8	26

Table 5.30. Density of Green Crab (number of crabs per Fukui trap per 24 h) by location and site for each year and overall (all data combined). Values presented include mean, median, 25th and 75th percentiles.

Location	Site	Year	Mean	Median	25th percentile	75th percentile
Basin Head	Northeast Arm	2015	16.3	11.0	3.0	20.5
		2016	20.6	14.0	4.0	32.0
		2017	33.2	24.0	16.5	40.0
		2018	26.0	14.0	3.0	40.5
		Overall	23.6	16.0	4.0	34.0
	Main Basin	2015	7.5	3.0	0.0	8.0
		2016	3.9	1.0	0.0	5.0
		2017	4.8	2.0	0.0	8.0
		2018	1.9	0.0	0.0	3.5
		Overall	3.4	0.0	0.0	4.0
Murray Harbour North	Marsh area	2015	2.7	0.0	0.0	1.0
		2016	9.2	6.0	1.0	13.5
		2017	35.4	32.0	14.0	50.0
		2018	36.4	27.0	10.0	52.0
		Overall	21.9	12.0	2.0	32.0
	Wharf area	2015	4.9	2.0	0.0	6.0
		2016	3.6	2.0	1.0	6.3
		2017	22.7	21.0	11.0	31.0
		2018	16.4	17.0	6.5	22.5
		Overall	11.9	7.0	1.0	19.0

Table 5.31. Density of Rock Crab (number of crabs per Fukui trap per 24 h) by location and site for each year and overall (all data combined). Values presented include mean, median, 25th and 75th percentiles.

Location	Site	Year	Mean	Median	25th percentile	75th percentile
Basin Head	Northeast Arm	2015	11.7	7.0	0.5	15.5
		2016	7.4	3.0	0.0	9.0
		2017	26.0	18.0	9.0	39.5
		2018	15.4	12.0	3.0	20.0
		Overall	14.8	9.0	2.0	21.0
	Main Basin	2015	15.4	11.0	4.5	22.5
		2016	8.1	5.0	1.0	11.0
		2017	22.3	18.0	9.8	29.3
		2018	24.4	20.0	9.0	32.0
		Overall	17.0	12.0	5.0	24.0
Murray Harbour North	Marsh area	2015	5.2	4.0	1.0	7.0
		2016	0.6	0.0	0.0	1.0
		2017	0.8	0.0	0.0	1.0
		2018	0.7	0.0	0.0	0.0
		Overall	1.9	0.0	0.0	3.0
	Wharf area	2015	9.2	8.0	3.0	13.0
		2016	1.9	1.0	0.0	3.0
		2017	3.9	2.0	0.0	5.0
		2018	4.6	2.0	0.0	8.0
		Overall	5.0	2.0	0.0	8.0

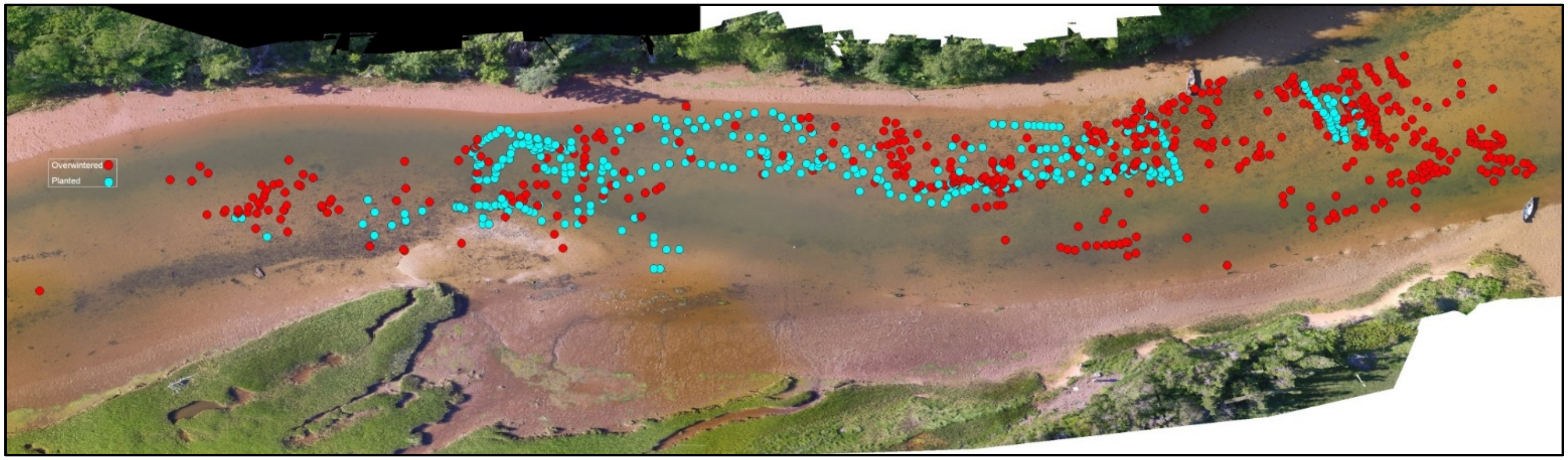
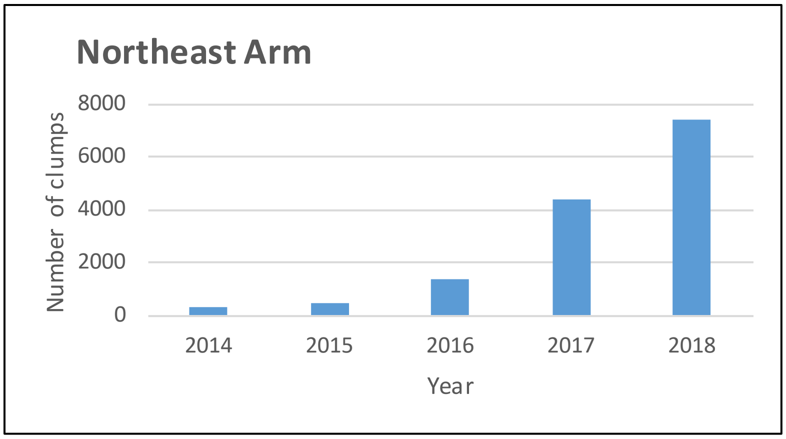


Figure 5.34. Clump locations in Main bed at the end of 2017, showing those that were present in 2016 (red) and those planted in 2017 (blue).



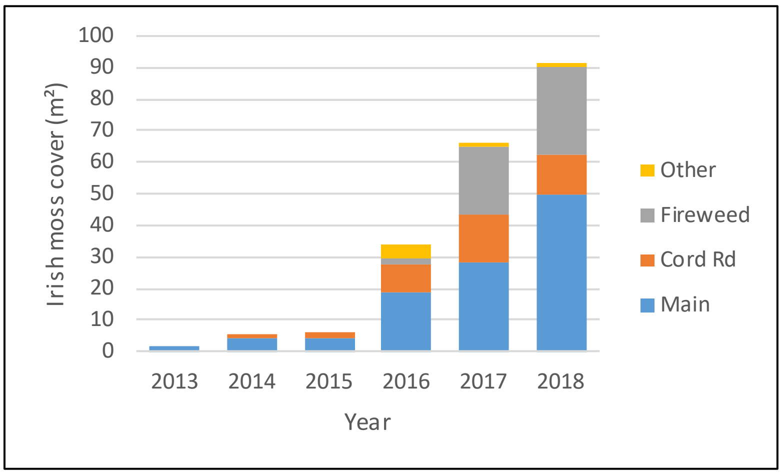


Figure 5.35. Number of Irish moss-mussel clumps in the Northeast Arm from 2014 to 2018 (top panel) and the estimated Irish moss cover (m²) in the Northeast Arm between 2013 and 2018 (bottom panel). In 2018, estimated coverage is based on a survey of selected transects rather than a comprehensive survey.

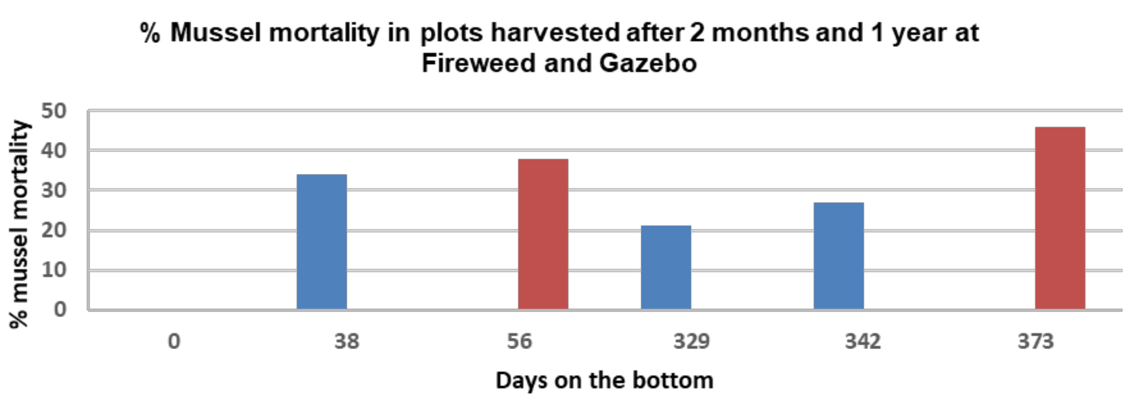


Figure 5.36. Mortality of mussels in the experimental plots at Gazebo (red) and Fireweed Bank (blue) was high (between 30% and 40%) in plots harvested after the first 2 months. In plots sampled in the following year (after 329 – 373 days on the bottom), mortality was greater at Gazebo (over 40%) but less on the firmer bottom at Fireweed Bank (under 30%).

Figure 5.37. Location of traps used to capture Green Crab in the Main Basin and Northeast Arm as of September 2018. In Main Basin, 12 sets of 3 Luke traps, 1 Russel trap (location 2) and 1 Delbert trap (location 13) were deployed. In Northeast Arm 15 individual Luke traps were deployed.

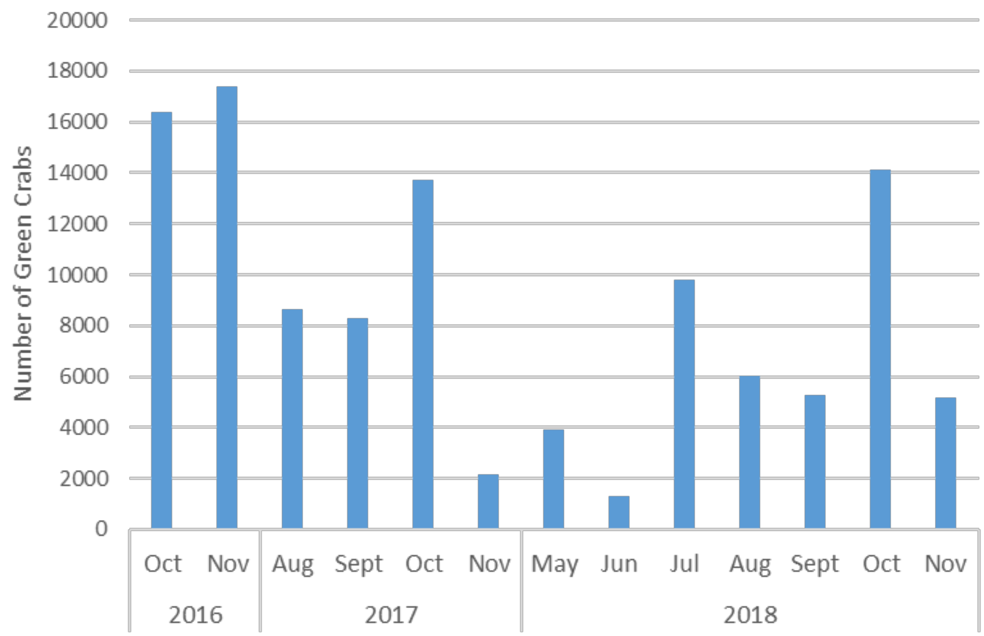


Figure 5.38. Total number of Green Crab captured by month in Basin Head Marine Protected Area during the 2016 to 2018 field seasons.

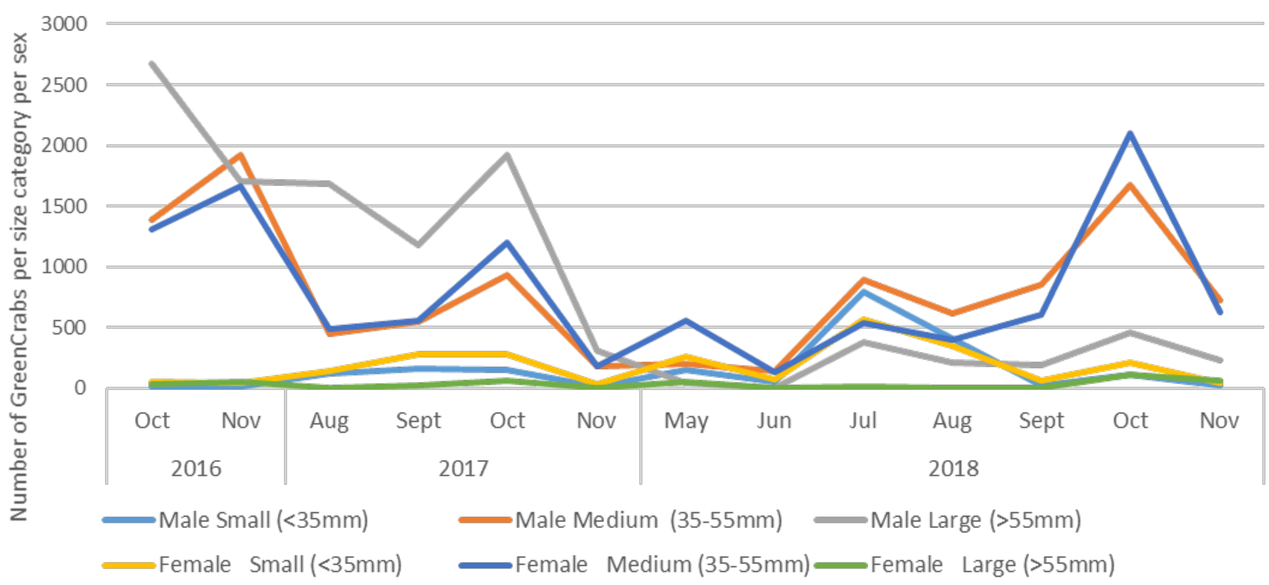


Figure 5.39. Number of Green Crab, by size category and sex, by month and year. The data are based on subsamples of one third of the total catch of Green Crab in each trap or sets of traps.

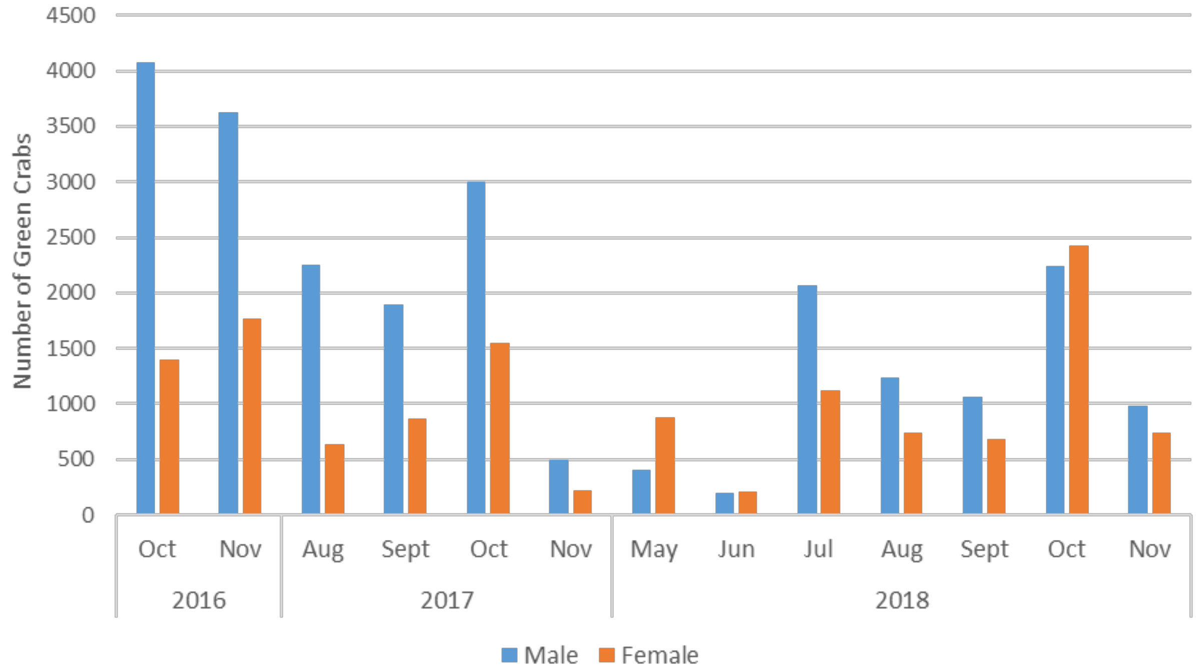


Figure 5.40. Number of Green Crab per sex for each sampling month from 2016 to 2018. The data are based on subsamples of one third of the total catch of Green Crab in each trap or sets of traps.

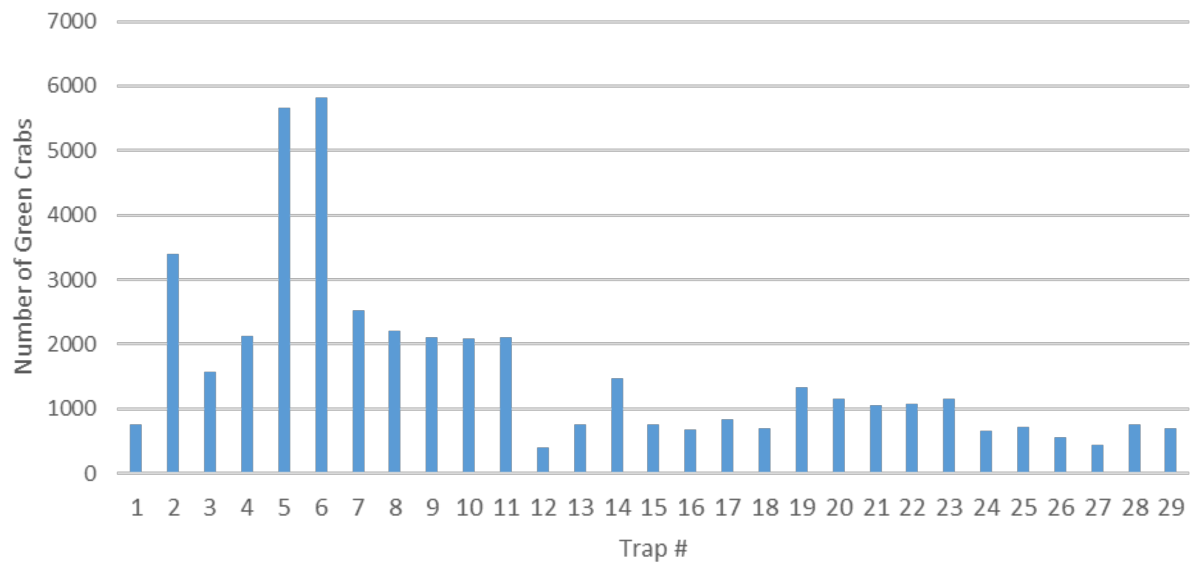


Figure 5.41. Number of Green Crab captured per trap or set at individual sites in 2018.

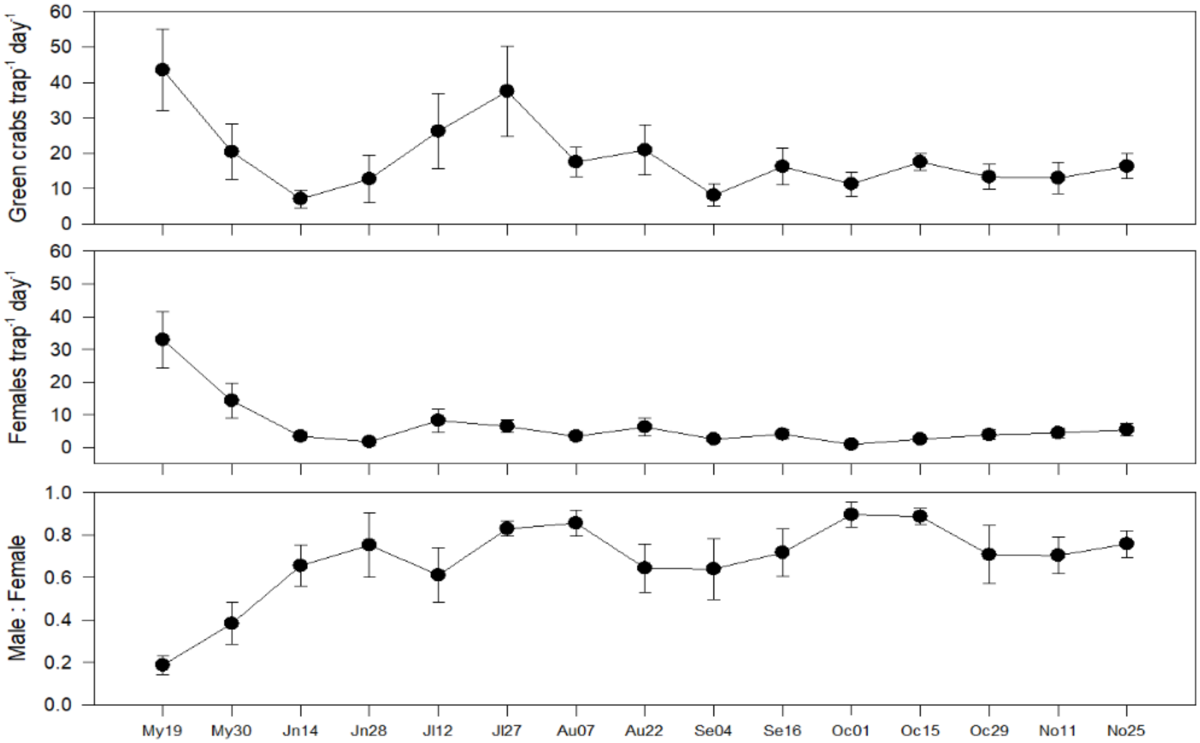


Figure 5.42. Mean densities of Green Crab (number of crabs per trap per day; mean with +/- 1 SE bars) in Basin Head, with sexes combined (upper panel), females only (middle panel), and male to female ratios (bottom panel) by time period in 2017. The data are from the combined catches of traps in the Main Basin and Northeast Arm.

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