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Gulf Region

REVIEW OF MONITORING ACTIVITIES IN THE BASIN HEAD MARINE PROTECTED AREA IN THE CONTEXT OF THEIR EFFECTIVENESS IN EVALUATING ATTAINMENT OF CONSERVATION OBJECTIVES

Irish moss (Photo: Bob Semple, DFO)

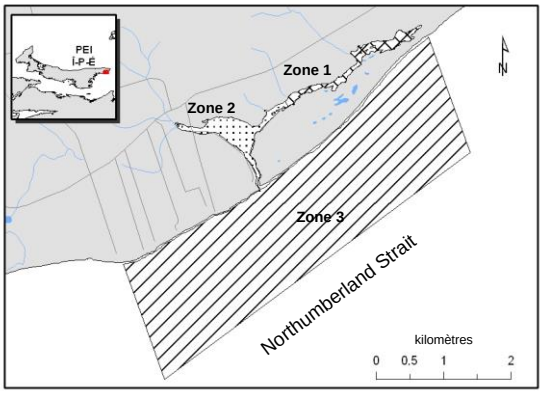

Figure 1. Basin Head Marine Protected Area.

Context:

The Basin Head Marine Protected Area (MPA), established in 2005, is a shallow marine lagoon that contains a unique strain of Irish moss (Chondrus crispus). The distinctive characteristics of Irish moss in this area include the complete dependence on fragmentation for dispersal and multiplication, the dependence on Blue Mussel for substrate attachment, the frond shape, and its sustained seasonal coloration. When assessed, the Irish moss biomass in Basin Head lagoon had declined by more than 99% over the period 1980 to 2008 (DFO 2009a). The Basin Head Marine Protected Area management plan identified four conservation objectives and monitoring programs were initiated for each conservation objective (DFO 2016). 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 restore Irish moss in Basin Head's Northeast Arm by outplanting artificially created moss-mussel clumps, and removing Green Crab. DFO Gulf Region Oceans Management Division 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. This Science Advisory Report is from the June 11-12, 2019 regional science peer review meeting of the monitoring activities in the Basin Head Marine Protected Area in the context of their effectiveness in evaluating attainment of conservation objectives. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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SUMMARY

- The Basin Head physical conditions, pre-dating the Irish moss collapse, are not fully described. Sedimentation and infilling have led to some of the most important structural changes in Basin Head, impacting the hydrodynamics of the lagoon that modify the suitability of the habitat for Irish moss.
- The monitoring program should be focused on indicators that are good integrators of ecosystem conditions and that have direct links to Irish moss itself or the ecosystem components associated with Irish moss persistence and recovery.
- A number of current monitoring activities are considered adequate for the purpose of assessing the attainment of conservation objectives. Modifications to some monitoring activities and several new monitoring initiatives are proposed.
- Point sampling of many variables (water chemistry, nutrients) as previously conducted is generally inefficient and not very informative of conditions that ultimately affect abundance and maintenance of Irish moss.
- Individual field sampling techniques can provide data for several indicators and conservation objectives simultaneously.
- Cost considerations override many monitoring choices as does the complexity of the many potential sampling and sample analysis techniques.
- The capacity and training of the local watershed group that has contributed to the field monitoring as well as field logistic constraints within Basin Head MPA must be taken into account when developing monitoring activities.

INTRODUCTION

The Basin Head Marine Protected Area (MPA) was established in 2005 under the *Oceans Act*. Basin Head is a shallow marine lagoon located near the eastern tip of Prince Edward Island (Figure 1). This area was chosen as an MPA because of the presence of a unique strain of Irish moss (*Chondrus crispus*). The distinctive characteristics of Irish moss in this area include the complete dependence on fragmentation for dispersal and multiplication, the dependence on Blue Mussel for substrate attachment, the frond shape, and its sustained seasonal coloration. It is also significantly larger and has a higher carrageenan yield than the outer coastal Irish moss. These characteristics seem to be defined by the specific environmental conditions in the lagoon (Sharp et al. 2003).

The purpose of the Basin Head MPA designation is to protect and conserve this unique strain of Irish moss and its habitat. The Basin Head Marine Protected Area management plan identified four conservation objectives (DFO 2009b):

- Maintain the quality of the marine environment supporting the Irish moss;
- Maintain the physical structures of the ecosystem supporting the Irish moss;
- Maintain the health (biomass and coverage) of the Basin Head Irish moss; and
- Maintain the overall ecological integrity of the Basin Head lagoon and inner channel including avoidance of excessive sea lettuce growth, maintenance of adequate oxygen levels, and maintenance of the diversity of indigenous flora and fauna.

Monitoring programs were identified and put in place in Basin Head for each of the conservation objectives (DFO 2016). Monitoring activities have included assessments of the abundance and

distribution of Irish moss, assessment of blooms of green macroalgae (including sea lettuce, *Ulva lactuca,* and associated algae), water quality indicators, and monitoring of fish and crustaceans (Sharp et al. 2003; Theriault and Courtenay 2010). In recent years, activities have been initiated to restore Irish moss in Basin Head including artificial propagation and enhancement, restoration / plantation of eelgrass, and removal of the invasive Green Crab (*Carcinus maenas*).

DFO Gulf Region Oceans Management Division requested a review and assessment of the monitoring activities undertaken in the Basin Head MPA over the last decade to determine their effectiveness in providing the information needed to evaluate whether the conservation objectives are being met. The information will also be used to update the Basin Head Operational Management Plan as well as to develop a long-term monitoring plan necessary to ensure that monitoring is strategic, efficient and effective for evaluating the achievement of the conservation objectives and the impact of restoration activities.

ASSESSMENT

A review of the monitoring activities is presented for each of the four conservation objectives.

Conservation Objective 1: Maintain the quality of the marine environment supporting the Irish moss

High summer water temperatures and low dissolved oxygen (a common symptom of eutrophication) are both threats to the sustainability of Irish moss in Basin Head. For Irish moss and Blue Mussel (*Mytilus edulis*), temperature stress can occur at approximatively 20ºC and mortality can occur from prolonged exposure to 28ºC. Low dissolved oxygen, i.e. hypoxia, can have deleterious effects on the biological community resulting in changes to animal assemblages and physiological effects on vital rates, including mass mortality of animals if anoxic (complete lack of oxygen) conditions are sustained. Hypoxic stress occurs at or below 4 mg per L oxygen for most fish and at or below 2 mg per L for most invertebrates (Vaquer-Sunyer and Duarte 2008). Since at least the 1970s, excess nitrates in the estuary have promoted proliferation of macroalgal (sea lettuce) blooms leading to hypoxic conditions when they die and decompose (McCurdy 1980).

Given that nitrogen is considered more limiting than phosphorous in marine environments (Howarth and Marino 2006), and that phosphorous is consistently high in surface waters of PEI regardless of land-use type (Coffin et al. 2018), nitrate concentration was investigated more thoroughly than other measured nutrients.

From 2001 to 2017 water sampling for nutrients (nitrate, nitrite, ammonium, phosphate, silicate) along with other biotic and abiotic water parameters (temperature, salinity, dissolved oxygen, chlorophyll *a*, and turbidity) was conducted weekly during the months of May to October at 11 sites in the Main Basin and Northeast Arm (Figure 2). Sampling was conducted during daylight hours in calm, dry weather but was not standardized with respect to tidal height, except for the avoidance of low tides that prevented access to sampling sites.

Data loggers for continuous measurements of temperature were deployed beginning in 2011 and for dissolved oxygen in 2014.

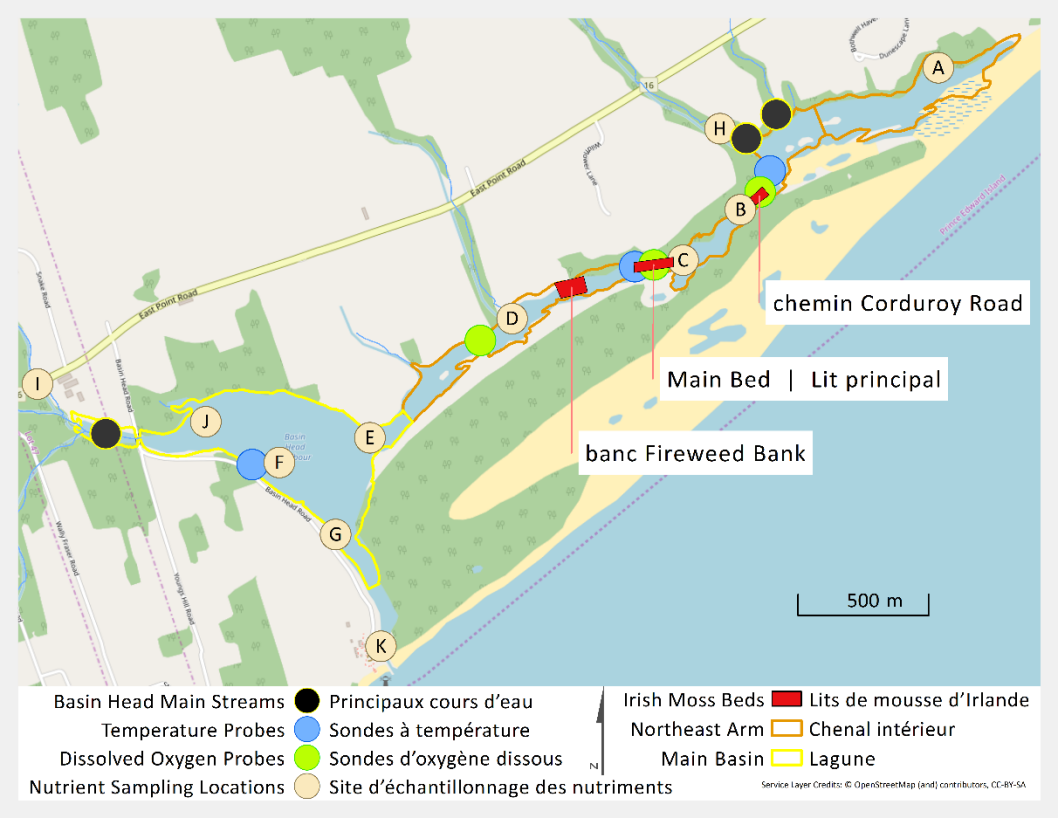

Figure 2. Water characteristics sampling sites in Basin Head during 2001 to 2017. The nine estuarine sites are lettered from A to K and the two freshwater sites are H and I. The names of the current three Irish moss beds in the Northeast Arm and the locations of the continuous data loggers are also shown.

Water Quality Characteristics

Sampling consisted of point measurements for temperature, salinity, dissolved oxygen, chlorophyll *a,* and turbidity (Table 1). Temperature, salinity, and dissolved oxygen were measured with a hand held multi-meter. Surface water was collected into a clean, rinsed cuvette and inserted into a handheld fluorometer to read in vivo chlorophyll *a* and turbidity. For chlorophyll *a* monitoring, two models of fluorometer were used; one model during 2011 to 2014 and a second from 2015 onward. The differences, namely on calibration protocols, between instruments preclude direct comparison of absolute values but are considered to reflect the relative chlorophyll a concentrations specific to each instrument.

In 2011, three continuous temperature loggers, set to record hourly, were deployed at two sites in the Northeast Arm and one site in the Main Basin (Figure 2).

Since August 2014, optical dissolved oxygen loggers have been set within the Northeast Arm; one unit in 2014 and three units since 2015 (Figure 2). The instrument recorded dissolved oxygen on an hourly basis. Although loggers were cleared of fouling periodically throughout their deployment, the loggers at the Corduroy Road and Main Bed stations were buried in anoxic silt and / or sea lettuce (*Ulva spp.)* in 2015 thus these data are deemed unreliable for that period and were subsequently excluded from the analyses.

A pH logger was deployed in the Northeast Arm but the data were not considered further because of the poor data quality due to instrument drift and fouling as well as the large natural variation associated with pH in freshwater-influenced tidal systems.

Water pressure (depth) loggers were also deployed starting in 2016 in each of the Irish moss beds in Northeast Arm and in the Northumberland Strait just outside the lagoon to provide data for hydrodynamic modelling. These data are not presented in this paper.

Water sample analyses for dissolved inorganic nutrients (nitrate, nitrite, phosphorus, ammonium, and silicate) were conducted at the DFO Bedford Institute of Oceanography (Dartmouth, Nova Scotia). On a number of occasions, samples were excluded due to anomalous results likely associated with contamination, mislabeling, over-filling of samples bottles, or thawing of samples during shipment to the laboratory.

Table 1. Monitoring activities for water characteristics in the Basin Head MPA.

Parameter (unit)	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	5	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 per L)	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 per L)	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
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 per L)	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

Adequacies

- Water temperature monitoring with data loggers recording hourly on the Irish moss beds in Northeast Arm provides sufficient data to assess the extent of temperatures which are sub-optimal and lethal for Irish moss. Average temperatures are used as metrics of stress (20°C) and maximum daily temperatures are used to quantify the extent to which temperatures exceed the potentially lethal limit (28°C). Data indicate that warming in the Northeast Arm may currently be detrimental for Irish moss and other ecosystem components such as Blue Mussel which is required by Irish moss for anchorage.

- Dissolved oxygen monitoring with data loggers, recording hourly, indicate that average dissolved oxygen concentrations from June to October ranged from 7 to 11 mg per L. The monitoring in Northeast Arm provides sufficient data with which to assess the extent of hypoxia and stressful conditions for Irish moss and Blue Mussel. Continuous data logger monitoring indicates that hypoxic conditions within the Northeast Arm are occurring and may lead to stress and loss of ecosystem components such as mussels required by Irish moss for persistence.
- Nitrate varied seasonally with the highest levels generally occurring in spring and fall. Nutrient concentrations in nine estuarine sites were generally below 10 µmol per L and elevated at sites closest to freshwater streams. Nitrate concentrations at the two freshwater nutrient sampling sites are highly variable ranging from 125 - 275 µmol per L, an order of magnitude higher than estuarine nutrient sampling sites. Generally, estuarine samples outside the influence of freshwater streams showed stable concentrations of nitrate over the 2001 to 2017 period, likely due to rapid uptake by fast growing macro algae such as sea lettuce (Burkholder et al. 2007).
- Phosphate levels in the estuarine and freshwater sites were similar and generally remained below 2 µmol per L. Phosphate loads are high and considered stable in PEI and its addition does not result in a stimulus of primary production.

Deficiencies

- Point sampling for temperature, salinity, and dissolved oxygen is deficient as there is no standardization for the state of tide at sampling nor any measure of the extent of stressful and / or lethal conditions to which Irish moss are exposed. Sampling at locations outside Northeast Arm does not provide any useful monitoring information on conditions for Irish moss.
- As opposed to temperature and dissolved oxygen, salinity was not measured continuously with loggers and only measured during point sampling.
- Dissolved oxygen (DO) concentrations measured punctually during daylight hours using a hand-held multi-meter ranged between 7 and 10 mg per L at all sites. All sites had high variability in DO concentrations and these do not reflect the stressful and anoxic conditions that can develop in the Northeast Arm.
- Chlorophyll *a* is generally used as a proxy for primary productivity in marine systems that are dominated by pelagic production. For shallow, well-mixed estuaries that are dominated by benthic production such as in Basin Head, pelagic chlorophyll *a* represents only a portion of total production and/or nutrient impacts in general (Coffin et al. 2018). The fluorometer data were extremely high relative to other eutrophic estuaries on PEI and these uncalibrated in vivo chlorophyll *a* data from the fluorometer are not considered reliable or useful for comparisons to other locations.
- Turbidity readings were occasionally negative, possibly owing to instrument error. Turbidity varied spatially in the lagoon, with the greatest values at sites closest to the inputs from freshwater streams and where sea lettuce accumulated and decomposed. Sampling was conducted from canoes under calm conditions, therefore, turbidity readings do not reflect the full range of conditions to which Irish moss are exposed, particularly after intense precipitation and storm events or outside the season of sampling.
- Turbidity measurements as currently collected may reflect in part the input and remobilization of sediments but may fail to reflect conditions detrimental to features such as

eelgrass beds which may support the Irish moss. The extinction of photosynthetically active radiation (light attenuation; PAR) would be a more relevant indicator to monitor.

- There are large variations in measured pH, whose values can vary with both tidal cycle and freshwater input related to precipitation. The consequence of these variations in pH levels on Irish moss and supporting components is not known.
- Concentrations of nutrients collected at sampling sites within the estuary were highly variable as expected from point sampling. Ultimately it is not possible to determine whether there are any trends in the nutrient inputs into Basin Head using these data as nutrient concentrations are affected by dry periods, rainfall events, and differences in concentration associated with surface water runoffs.
- Given that nitrate and ammonia are almost immediately assimilated by primary producers, specifically sea lettuce and phytoplankton, nitrogen concentrations measured at the estuarine sites do not reflect trends in nutrient loading.
- Phosphorus and silicate are not useful monitoring indicators. Phosphate is not limiting in the marine environment and silicate which can be limiting in systems dominated by pelagic production is not limiting in Basin Head.

Modifications to monitoring

- Continue, and enhance where required, the monitoring of temperature, dissolved oxygen, and salinity using continuous probes to gather temporal data series.
    - Ensure data reliability for dissolved oxygen by more frequent clearing of fouling from probes.
    - More extensive spatial sampling in Northeast Arm to assess conditions encountered by Irish moss.
    - Maintain one continuous monitoring logger in the Main Basin.
- The current point sampling design for temperature, salinity, dissolved oxygen, turbidity, and chlorophyll *a* does not provide reliable and useful information for monitoring water quality conditions for Irish moss. Any point sampling that does occur should target key input and exit points in Northeast Arm and the Main Basin. Sampling protocols should be standardized for state of tide and scheduled to monitor the full range of seasonal events in the watershed.
- Preliminary analyses indicate that air temperatures from the nearest meteorological station are correlated with Basin Head water temperatures. Such an association should be validated as it may serve as a basis for estimating temperature conditions for years prior to the use of data loggers.
- In place of extensive point sampling, it would be preferable to quantify nitrogen loading (product of base flow and average nitrate concentration) at fresh water inputs. Stream flow monitoring, in combination with water sampling for nutrients and sediments including monitoring at two outlet control points (at Northeast Arm into Main Basin, from Main Basin to the Gulf) is required to calculate loading of nutrients and sediments to Basin Head.
- In addition to surface streamwater, nutrient loading from ground water seeps and springs should be investigated to assess cumulative nutrient inputs.
- Consider incorporating alternate technologies (e.g. acoustic doppler current profilers) to monitor current velocities over the Irish moss beds in Northeast Arm. These units may also be used for monitoring turbidity (using backscatter strength data).

- The extinction of photosynthetically active light (i.e. light attenuation) in the water column would be a relevant monitoring indicator of conditions for growth and production of key macrophytes including Irish moss, sea lettuce, and eelgrass.

Conservation Objective 2: Maintain the physical structures of the ecosystem supporting the Irish moss

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. The indicator monitored for this conservation objective currently concerns only land use and related impacts on environmental processes. Other key physical features of the estuary that affect physical structure but that presently do not have explicit indicators include the salt marshes, natural oyster reefs and eelgrass beds.

Land use in the Basin Head watershed is reported to have been relatively stable since 2000, based on annual monitoring of satellite imagery. Lands abutting streams and Northeast Arm are highly vulnerable to erosion because of their slope and patterns of agricultural use.

The east end of Northeast Arm was reportedly navigable by fishing boats in the 1950s, but now there is not enough water depth for a canoe when the tide is low.

Measurements of water depth and penetrable sediment thickness beside Irish moss clumps and along defined transects in central Northeast Arm, as well as ice cover and bottom scouring by ice, were initiated in recent years. Land use information as well as studies on current speed were also completed for the entire Basin Head Lagoon (Table 2).

Adequacies

- Satellite imagery analysis of land use in the watershed is conducted annually by the province and is repeatable.

Deficiencies

- Many of the activities are exploratory studies designed to aid the planning and execution of restoration activities rather than for long-term monitoring.
- The reliability of land-use data, acquired from interpretation of satellite images, was variable; crops reported by farmers and by surveyors inspecting fields sometimes differed from the assessments provided by the province.
- There has not been any regular monitoring of the extent of land erosion into the Basin Head estuary.
- Seasonal sediment loads in streams entering Basin Head are largely unknown.
- There has not been any systematic monitoring of the dune structure or the opening of the Main Basin to the Northumberland Strait although the province does an annual verification of the water depth at the opening, for public safety purposes.

Table 2. 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	2017
	Ground truthing by surveyors	2014
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

Modifications to monitoring

- Annually acquire the land use data for Basin Head watershed from the Province of PEI and quantify the extent of land use in agricultural production that involves ploughing.
- Historical and contemporary aerial photographs could provide descriptions of changes in the dune structure.
- Use of LIDAR or remote sensing imagery to document dune structure and other physical features of the area, such as marsh edge dynamics, on a periodicity of 5 years for example, that would include 3-dimensional form of the dunes (elevation changes; sand loss or accumulation along ocean side; loss along saltmarsh side).
- Sediment core analyses from the the deepest portion of the Main Basin could be used to describe the sources and rate of sediment accumulation, either from marine and freshwater, and this information could be used to define the reference state in Basin Head.
- Monitor sediment loading in streams entering Basin Head Lagoon under various weather conditions.
- Explore options for drone-based image analysis or the use of depth profilers suitable for the estuarine environment to do 3-D modelling of the Northeast Arm to monitor changes in bathymetry profiles.

- Repeat selected 2016 transect surveys at 5 year intervals, or more often if there is a major storm surge, to document changes in water depth and sediment thickness in the Irish moss beds of Northeast Arm.
- Monitor inlet morphology (cross-sectional depth) and document if any dredging of the inlet has occurred or is occurring that would affect the hydrodynamics of the lagoon.
- Use hydrodynamic modelling to refine the calculation of the suitable area for Irish moss production, based on water depths and current speeds.
- Data from recent satellite deployments (Sentinel 2 operated by European Space Agency) with 5 day pass frequency and 10 m spatial resolution provides an opportunity to monitor a number of physical characteristics, such as variations in ice formation and departure, that can have consequences on persistence of Irish moss in Basin Head.
- Ground Penetrating Radar technology could be explored for sediment thickness modeling throughout the study area.

Other key physical structures supporting Irish moss

Short term studies of additional physical structures affecting Irish moss in Basin Head that were not considered in the management plan were conducted in recent years (Table 3). Salt marshes support the coastal dunes in protecting Basin Head from erosive wave action. Oysters and other filter feeding shellfish clear the water and their shells trap and stabilize loose sediments in soft substrate estuaries, improving conditions for Irish moss, eelgrass and mussels (including mussel spat) in the Basin Head system.

Table 3. 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, and 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

All the monitoring / studies of these components have been punctual and designed to answer specific questions. None were meant to be long term monitoring efforts, but some of the data could be used as baselines for future monitoring. The field work conducted to date is still exploratory and the appropriate indicators have yet to be defined.

Modifications to monitoring

- Georeferenced analyses of provincial aerial photos dating back to 1935 to quantify changes in the location of marsh edges and develop estimates of marsh erosion rates have been completed. Periodic analyses of contemporary images could be used to monitor ongoing changes in these characteristics.

- Monitoring the re-established presence of oysters and eelgrass (native species) should be added as these are important structural components of the lagoon supporting Irish moss (for eelgrass see CO 3).

Conservation Objective 3: Maintain the health of the Basin Head Irish moss

In 1980 an estimated 14,000 to 16,000 m^2 of bottom area was occupied by Irish moss-mussel clumps (Sharp et al. 2003). By the time the Basin Head MPA was established in 2005, the area of Irish moss presence had shrunk to an estimated 2,500 m^2. When last assessed, the Irish moss abundance and distribution in Basin Head lagoon had declined by more than 99%, over the period of 1980 to 2008 (DFO 2009a).

Ecological indicator 3a: Extent of Irish moss bed

The management plan for Basin Head calls for aerial photography to document the abundance of Irish moss in the estuary, or at minimum in the Northeast Arm, once every three years. Aerial surveys were conducted annually from 2001 to 2010 but were discontinued when the Irish moss distribution was too fragmented to be reliably quantified. As of 2012, the distribution and abundance has been monitored using a wading survey method (Table 4). Beginning in 2015, the use of drone-based photography has been explored to develop base maps for visualizing Irish moss clump distribution.

Table 4. 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 continuous, 2 m wide transects over the northern shallows of Main Bed	2012 – 2013
	Number and diameter of Irish moss fronds along continuous, 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 maps for the Northeast Arm.	2015 – 2018
	Aerial image mapping of Irish moss distribution and development of method for quantification of area and abundance	2017

Adequacies

- Aerial imagery provides a snapshot of the entire Basin Head lagoon at one point in time which can be replicated within season and years, with no impact on the ecosystem being monitored.
- Aerial surveys using drones can be completed in a relatively short window of opportunity but require appropriate conditions that include extremely low tides, calm dry weather, clear water, and sunshine for successful imaging. Aerial imagery collected at flyover heights of 6 m (maximum), at low speed to reduce motion blur and image processing with dehazing algorithms to improve the image quality, have provided a spatial resolution to 2 cm.
- Limited transect surveys may be sufficient to detect a large decline in Irish moss abundance and should be adequate for ground-truthing aerial imagery full bed surveys.

Deficiencies

- Without a full coverage survey, it is not possible to determine whether the clumps of Irish moss in a limited area have been lost, pushed into adjacent bottom, or overestimated because of the margin of error in geolocation of survey swath margins and clumps.

- Limited transect surveys alone may not provide enough information for determining the success or failure of Irish moss recovery in each bed.
- Wading surveys can have unintended consequences, by trampling, on Irish moss, oysters, and other biota, as well as re-suspension of sediments in the water column.
- The quantification of Irish moss coverage derived from aerial imagery has not been completed.

Modifications to monitoring

- Continue the analyses and validation of the aerial imagery from drone-based surveys as an alternative to wading surveys for total surface area estimation of Irish moss.
- Continue to monitor selected transects in each bed on an annual basis to detect major ecosystem changes that would indicate the need for a full-bed assessment using aerial imagery.
- Wading surveys should be conducted during daytime and full moon low tides, along the survey transects established in 2018 in each of the three Irish moss beds. The Irish moss clump positions should be georeferenced, the diameter of Irish moss clumps measured, and mussel-only clumps quantified.
- Minimally once every 5 years or more frequently if possible, conduct a slow, low-altitude drone-based photographic survey of all beds in order to locate and measure Irish moss clumps. The transect survey data would be used to ground truth the aerial imagery analyses.

Ecological indicator 3b: Extent of sea lettuce blooms

Sea lettuce blooms and their associated areas of anoxia were listed as one of the threats to Irish moss, particularly at the head of the Northeast Arm (DFO 2009a). The negative effects of macroalgal blooms can be more extensive and persistent in semi-enclosed water bodies such as Basin Head. There have been annual blooms of sea lettuce (predominantly *Ulva lactuca* and to a lesser extent *Ulva intestinalis* and various filamentous algae) in Basin Head lagoon since at least 1980 (DFO 2009a).

Beginning in 2011, pictures were taken at weekly intervals at various locations within Basin Head during the summer months as a way of monitoring sea lettuce bloom development and subsequent decay. A qualitative analysis of the Elliot's Marsh photo record was undertaken in 2017–2018, taking into consideration the possible influence of the timing of ice formation and melt, seawater temperatures, and rainfall-driven loading of nutrients into the estuary. Photographs taken by the time-lapse field camera attached to a tree at Main Bed were also reviewed, to detect patterns of sea lettuce development on the intertidal shore fringing Northeast Arm.

By monitoring and sampling Irish moss plantations on various bottom types in the Northeast Arm, it was confirmed that silt and sea lettuce mats accumulated on the bottom in areas of relatively slow current flow. Either one, or both in combination, eventually killed most of the Irish moss in the affected areas, while Irish moss cover was maintained in more current-swept portions of the plantation.

Adequacies

- Weekly imaging from individual locations could be used to describe the timing and extent of seasonal growth and die-off of sea lettuce.

Deficiencies

- Many photographic images were not useful because the high tide obscured the sea lettuce bloom.
- How the images were processed and the monitoring information collected has only been described in an unpublished field research report.
- No current speed ground-truthing data were obtained to confirm low and high energy areas but a hydrodynamic model indicates that the remnant Irish moss beds exist in those areas of the Northeast Arm that experience maximum current speeds.

Modifications to monitoring

- Introduce additional monitoring, for example documentation of sea lettuce cover within Irish moss survey transects, using quadrat sampling.
- Continue to monitor intertidal sea lettuce development at a key location in an Irish moss bed using the field camera and develop a metric of sea lettuce dynamics (e.g. number, timing, and duration of blooms) that would be relevant to the monitoring activities in Basin Head.
- Using an updated hydrodynamic model, reassess high and low energy areas in terms of current speeds to focus planting efforts on clean, hard, subtidal of bottom (> 10 cm depth at lowest tide) where Irish moss can be maintained.

Ecological indicator 3c: Extent of eelgrass

Basin Head lagoon was historically described as an “eelgrass dominated system” (McCurdy 1979) and local knowledge reports describe how in the 1950s fishing boat propellers would get tangled in and brought to a stop by dense eelgrass beds. Evidence from unpublished field reports and archived databases suggests that eelgrass declined dramatically over the period 2006 to 2008. Field surveys in 2014 indicated that eelgrass was practically absent from the Northeast Arm. Eelgrass presence was noted again in Basin Head in 2017 outside eelgrass restoration areas and continued to increase into June 2019.

Adequacies

- Punctual observations provided the first indication of changes in this component.

Deficiencies

- There is no systematic and temporal monitoring of eelgrass bed coverage (area) in Basin Head except for the random quadrat sampling done at the limited shore-based sites by the Community Aquatic Monitoring Program (CAMP).

Modifications to monitoring

- Measure the dimensions of all eelgrass patches within and adjacent to permanent survey transects used for annual ground-truthing of Irish moss cover.
- Analyze intermittently collected drone-based images to locate and measure the area of naturally occurring and planted eelgrass patches in Northeast Arm. Ground truth the results using the survey data.

Conservation Objective 4: Maintain the ecological integrity of the Basin Head Lagoon and Inner Channel

This conservation objective includes mainly the maintenance of diversity of indigenous flora and fauna.

Ecological Indicator 4a: Trends in Community Abundance and Diversity of Fish and Benthic Invertebrates Within the Basin Head Lagoon

The Community Aquatic Monitoring Program (CAMP) employs beach seine surveys in estuaries throughout the southern Gulf of St. Lawrence to assess variations and changes in coastal fish and invertebrate communities (Theriault and Courtenay 2010).

Sampling with a beach seine is conducted at six stations located in or near the main Basin. Nearshore fish communities which include fish, crabs and shrimps, are collected, identified and enumerated. Additional observations at each sampling station include quantifying the extent of submerged aquatic vegetation (SAV), sediments (mean grain size and organic matter), point estimates of water temperature, salinity, dissolved oxygen, and nutrient concentrations. CAMP data from 2004 to 2017, from June to August only, were reviewed.

Adequacies

- The CAMP program has used a standard sampling protocol at fixed sites within Basin Head which is essential for time series monitoring.
- The CAMP monitoring has signaled a strong change in relative abundance of the dominant species captured, from a mix of Sand shrimp, Mummichog and other species to catches currently dominated almost exclusively by Sand Shrimp. The change in species dominance is interpreted as a response to the loss of eelgrass from the system particularly since 2010.
- Additionally the CAMP index has captured an important temporal signal in Green Crab abundance, with peak abundances of Green Crab in 2012 and 2013 followed by a dramatic reduction in catch numbers in 2014. The declines in the index following the winters of 2013-2014 and 2014-2015 were also noted in other estuaries in PEI monitored by CAMP and were in part attributed to harsh winter conditions.

Deficiencies

- CAMP utilizes a beach seine to collect fish and this sampling method could harm the Irish moss by dislodging Irish moss from mussels clumps. It is also difficult to maneuver a beach seine in areas where sea lettuce is present in large amounts. As a result, there is only one CAMP sampling station within the Northeast Arm, close to the western end. Therefore, the biodiversity assessment is not conducted in the primary Irish moss habitat of the MPA.
- Species monitored by CAMP are predominantly mobile small-bodied species therefore, CAMP samples are not representative of the larger, more mobile species that are found in deeper part of Basin Head.

Modifications to monitoring

- To assess the fish and invertebrate communities, a non-invasive technique such as environmental DNA (eDNA) with meta-barcoding could be used at various locations in the Northeast Arm to supplement the CAMP data collected in the main Basin.

Ecological indicator 4b: Trends in Community Abundance and Diversity of Fish and Benthic Invertebrates (Other Surveys)

Biodiversity in the Northeast Arm of Basin Head was previously sampled by McCurdy (1979, 1980) using an Ekman grab sediment sampler and many species associated with the Irish moss-mussel clump population were explicitly documented. A limited species list was generated from sampling performed in 1999 by Sharp et al. (2003) that added two gastropods and three isopods to the total species reported previously.

Transect surveys of benthic organisms in Main Bed and Corduroy Road were conducted in 2015. Benthic core samples were collected at 5 m intervals along three cross-channel transects at Corduroy Road and four transects at Main Bed and species or groups of organisms were qualitatively enumerated. The percentage cover of macroalgae and eelgrass was estimated using a square meter quadrat, and 0.5 square meter areas of sediment surface were cleared by hand and all species enumerated. The numbers and sizes of oysters and mussels sampled were also enumerated. Benthic sediment cores and the surface of the bottom exhibited low densities of organisms and a limited number of taxa relative to those reported from the 1979 and 1980 surveys.

Trapping for Green Crab has been undertaken in Basin Head since 2014 using a variety of traps. Catches from these gears provide insight into the presence and abundance of larger mobile species. This said, bycatch data other than Rock Crab, was only recorded for the 2015 field season.

Sampling of Irish moss fronds growing suspended in the water column, on bottom lines, and within mussel clumps in 2017 indicated the presence of seven species of amphipods. On other occasions, Irish moss suspended on cultivation lines were covered in shellfish spat that included mussels, clams, oysters, and razor clams.

No single monitoring technique can provide comprehensive information on biodiversity in Basin Head. The Green Crab trapping time series is short and the gear used is focused on mobile species that are attracted to bait. These gears do not capture the entire range of species that are found or periodically use the Basin Head area. The catch data from traps specific to the Northeast Arm have not been analysed. The description of biodiversity is incomplete; for example there is no information on macroalgal species composition.

Modifications to monitoring

- Surface sampling and sediment cores could be performed within each Irish moss bed periodically (every five years) to document variations and changes in benthic diversity, abundance of mostly sessile communities, and demographics of mussels and oysters.
- Presence and relative abundance of shellfish (Blue Mussel, Eastern Oyster, Quahaug, clams and others) on intertidal flats (outside of Irish moss habitat) could be evaluated during wading surveys along transects.
- Continue to document and report on bycatches of other species in Green Crab traps as indicators of diversity in the main Irish moss beds in the Northeast Arm.

Monitoring relative to restoration efforts

Three restoration actions have been initiated in Basin Head to enhance Irish moss growth and sustainability: restoration of Irish moss / mussel clumps, Green Crab removal and assessment, and eelgrass restoration. Studies have been directed at planning and understanding the immediate impacts of restoration activities conducted on different types of bottom.

Restoration of Irish moss – mussel clumps

Much of the field work associated with this restoration activity is directed at evaluating the most appropriate technique for artificial construction and deployment of Irish moss-mussel clumps. The monitoring has consisted of geo-referencing the placement of the artificial clumps and conducting follow-up surveys to determine if the clumps are still present and to assess the condition of Irish moss on those clumps. These are short term directed studies.

- Monitoring activities for this restoration action could be included in the monitoring for CO-3: abundance and area of Irish moss by transect sampling, aerial photo monitoring, and interpretation.

Green Crab removal and assessment

A directed Green Crab removal program is a mitigation strategy implemented for Basin Head. The objectives are to remove as many Green Crab as possible and to reduce the abundance of larger / adult Green Crab in Basin Head (> 35 mm carapace width) in order to increase the survival and abundance of mussels that are integral to Irish moss survival. Rock Crab caught during the Green Crab trapping efforts were translocated from the Northeast Arm into the Main Basin.

- Specific indicators of success for the Green Crab trapping program need to be specified and monitored; these could include:
    - Increased relative abundance of the smaller size classes of Blue Mussel;
    - Reduction in catch per unit effort (CPUE) of Green Crab;
    - Changes in Green Crab size distribution (i.e. reduced abundance of larger individuals).
- Assess the effectiveness of Rock Crab translocation out of the Northeast Arm into the Main Basin (i.e. whether they are returning to the Northeast Arm).
- Monitor the relative abundance of small benthic invertebrate taxa (epifauna and infauna) that are favored in the Green Crab diet (i.e. molluscs, polychaetes), see CO-3.
- Standardize sampling protocol to correct for factors that can influence Green Crab catch (trap type, season, soak time, depth).

Eelgrass restoration

Eelgrass is a key physical structure of the estuary that improves environmental quality by stabilizing sediments and offering biogenic habitat, for example, nursery areas for many species. An eelgrass planting program was initiated in 2017. Three 100 m² plots were planted with eelgrass in the Basin Head lagoon and Northeast Arm in 2017 and 2018. Specific indicators of success for the eelgrass could include:

- Monitor eelgrass in the planted plots for coverage and changes over time.
- Monitor eelgrass in and around the permanent survey transects used for Irish moss monitoring.
- Investigate the possibility of tracking eelgrass bed development (expansion and contraction) using drone imagery.
- Monitor Green Crab in eelgrass patches to detect destructive activities such as burrowing.

Sources of Uncertainty

The dissolved oxygen loggers were not consistently calibrated. This likely has limited effect on interpretation of low dissolved oxygen values, as zero oxygen is the reference condition for these loggers and thus they are always accurate with respect to low dissolved oxygen values. Higher dissolved oxygen values should be treated with caution though, as absolute errors in dissolved oxygen concentration of 1-2 mg L^{-1} can occur without calibration. Ultimately, this source of error could lead to erroneous average dissolved oxygen conditions though more confidence applies to the low dissolved oxygen data.

The fluorometer data were extremely high relative to other eutrophic estuaries on PEI and these uncalibrated in vivo chlorophyll *a* data from the fluorometer are not considered reliable or useful for comparisons to other locations. If in-situ data (no extractions) are taken during day time hours when the sun is out (without being properly dark-adapted), there is an artifact called "quenching'', meaning that the chloroplasts are already "open'' and the fluorescence reading may be less than or different from anticipated. The fluorometer data may only be reliable for turbidity purposes.

It is not clear to what baseline the monitoring is expected to describe the status relative to conservation objectives. Recovery of Irish moss seems to be the understood objective, at least no further deterioration of conditions.

Basin Head lagoon is shallowing. The longer term consequences of this on Irish moss are not positive but there remains a large amount of uncertainty related to this directional change in basin morphology.

Monitoring inputs to the lagoon from overland water sources does not address all the input sources. Some of the nutrient inputs may occur through groundwater seeps in the lagoon itself. Some of these seeps are visible in the winter but the cumulative contribution of groundwater relative to overland streams is currently unknown.

CONCLUSIONS AND ADVICE

The conservation objectives in the management plan speak of maintenance of the various components in Basin Head that are required for persistence of Irish moss but the conditions to be maintained are not indicated. In particular, given the changes that have occurred in Irish moss abundance and distribution in Basin Head since the first assessment dating to 1979, the desired condition (end point) of Irish moss needs to be more clearly defined.

The Basin Head physical conditions, pre-dating the Irish moss collapse, have not been described. Many aspects of physical conditions (e.g. sediment redistribution, sediment chemistry, marsh edge erosion) have only been monitored in recent years. Establishing reference conditions for physical characteristics is a particular challenge given the highly dynamic nature of soft-sediment estuaries and the biological communities inhabiting these areas. Sedimentation and infilling of Basin Head have led to some of the most important structural changes in Basin Head because of the impacts on hydrodynamics of the lagoon that modify the suitability of the habitat for Irish moss.

- Sediment core analyses from the deepest portion of the Main Basin could be used to describe the sources of sediment deposition, and the quantity and timing of sediment deposition and infilling that has occurred over previous decades. This information could potentially be used to define the reference state in Basin Head.
- Analyses of historical and contemporary aerial photographs could also be used to characterize a reference state for the dune structure and salt marshes.

The monitoring program in the Basin Head MPA must be sensitive enough or have sufficient resolution to determine with relative certainty whether a management action has been effective. The main objective should be to develop and monitor indicators that are good integrators of ecosystem conditions.

Although there are many questions that could be considered, the monitoring program should be focused on indicators that have direct links to Irish moss itself or to the ecosystem components that are associated with Irish moss persistence or improvement. Point sampling of many variables (water chemistry, nutrients) is inefficient and not very informative of conditions that

ultimately can affect abundance and maintenance of Irish moss and the supporting components because it does not capture the short period variations in many of the physical and chemical characteristics in tidally affected estuaries.

The priority monitoring activities suggested for the current conservation objectives and restoration actions, as defined in the 2014 management plan, are described below:

- Conduct continuous recording of temperature, salinity, and dissolved oxygen within the historical and current Irish moss area in the Northeast Arm and maintain one station within the Main Basin. As conditions can be quite variable within the Northeast Arm on hourly, daily and seasonal cycles, the positioning of these loggers should include at least an exit, middle and upper station in the Northeast Arm.
- Loading assessment for nitrogen and sediments should be considered, as nitrogen loading affects the extent of macroalgal blooms, and sediment inputs contribute to changes in the physical characteristics of the Northeast Arm. This monitoring would be directly related to the extent of macroalgal blooms and their subsequent decay that can lead to hypoxic and anoxic conditions in the basin and the Northeast Arm that are detrimental to Irish moss and supporting biota. Loading calculations would require the monitoring of freshwater inputs (concentrations of nutrients, sediments, and discharge profiles). The quantification of total nutrient loading in the basin and the Northeast Arm could be used to assess the effectiveness of management actions related to land use activities and inputs into the watershed.
- Bathymetric profiling and characterization of current velocities during tidal cycles and relative to variations in freshwater inputs to the Northeast Arm streams where the Irish moss beds are located should be conducted periodically (e.g. every 5 years). This should involve an update to the hydrodynamic model to assess the changes in the extent of habitat available for Irish moss.
- Aerial imagery could be collected and analyzed periodically (e.g. every 5 years) to assess changes in dune structure and salt marsh configuration.
- Irish moss beds aerial imagery every three years (or less if variations in Irish moss distribution and abundance are important at shorter periods) at a constant date to fully quantify Irish moss density and coverage. This survey can also potentially be used to characterize eelgrass distribution and surface area, and other features (e.g. sea lettuce, oyster reefs, clam beds).
- Monitor the extent and timing of sea lettuce growth and deterioration using fixed images at a key index site (for ex., Elliott's marsh) as an indicator of variations in nutrient inputs associated with management actions.
- Characterize ecosystem components using a suite of sampling methods including seining (i.e, CAMP protocol), fyke nets, baited traps, and benthic sampling to characterize fish and invertebrate diversity within Basin Head and particularly within the Northeast Arm.
- Monitoring of restoration efforts for Irish moss and eelgrass can be incorporated in the monitoring activities described above.
- Monitor indicators of effectiveness of the Green Crab removal program, including population dynamics of Blue Mussel and Green Crab (e.g., abundance, size classes). This will require the use of a standardized sampling protocol to correct for factors that can influence Green Crab catch (e.g. trap design, soak time, depth, season).

Individual field sampling techniques can provide data for several indicators and conservation objectives simultaneously (Table 5).

Table 5. Data collection techniques and indicators monitored for the corresponding conservation objectives (CO 1-4, restoration) of the Basin Head MPA.

Sampling technique	Method / metric	CO-1 Water quality	CO-2 Physical environment	CO-3 Irish moss abundance	CO-4 Biodiversity	Restoration actions
Point sampling	Handheld meters, water samples, stream flow	Nutrient loading, sediment loading	Hydrodynamic modelling	na	na	na
Continuous data loggers	Temperature, pressure, DO, light flux density, current profilers	quantify stress, light flux density, water quality	Hydrodynamic modelling	na	na	na
Wading transect surveys	Visual, rulers, sampling quadrats, geolocation, transect lines, flagged survey swath perimeters	na	sediment penetration, water depth profiles	Irish moss-mussel clump number and area, eelgrass presence and area, sea lettuce presence and area	epifauna and infauna	Irish moss restoration, eelgrass restoration, Green Crab indices
Remote sensing	Satellite, aerial (drone-based)	na	Dune structure and dynamics, salt marsh erosion, bathymetry, hydrodynamic modelling	Irish moss clump number and area, eelgrass presence and area, sea lettuce presence and area	na	Irish moss presence and area, eelgrass presence and area
Fixed imagery	Mast camera	na	Ice dynamics, sediment plumes, sea lettuce cover	Sea lettuce seasonal dynamics	na	na
Beach seining	CAMP faunal diversity, quadrats	na	na	na	Bycatch, submerged aquatic vegetation, faunal and flora biodiversity	Green Crab CPUE and size distributions, eelgrass, sea lettuce presence
Green Crab trapping	Traps catches and bycatch	na	na	na	Bycatch, faunal biodiversity	Green Crab CPUE and size distributions,
Bottom coring	Sediment cores, dating of layers	na	Sedimentation history, baseline conditions	na	Benthic communities survey (infaunal biodiversity)	na

Statistical analyses of long term monitoring data are so far minimal with the exception of CAMP data analysis, thus a lot of discussion evolved around field observations. To provide some degree of statistical reliability on the monitoring indicators in future work, consideration must be given to the effect size to be detected (statistical power) which will be dependent on the sampling design, the variability of the measurements, and the applied statistical treatment. Cost considerations override many monitoring choices as does the complexity of the many potential sampling and sample analysis techniques.

Finally, it must be borne in mind that important components of the field monitoring have been and continue to be conducted by the local watershed group. As such, the monitoring activities must be developed in coordination with the local watershed group, taking into account the capacity, training, and field logistic constraints at play in the Basin Head MPA (for example, prohibition of the use of motorized crafts in zone 1).

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SOURCES OF INFORMATION

This Science Advisory Report is from the June 11-12, 2019 regional science peer review meeting of the review of monitoring activities in the Basin Head Marine Protected Area in the context of their effectiveness in evaluating attainment of conservation objectives. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Burkholder, J.M., Tomasko, D.A., and Touchette, B.W. 2007. Seagrass and Eutrophication. Journal of Experimental Marine Biology and Ecology 350: 46–72.

Coffin, M., Courtenay, S., Pater, C., and van den Heuvel, M. 2018. An empirical model using dissolved oxygen as an indicator for eutrophication at a regional scale. Marine Pollution Bulletin. 133. 10.1016/j.marpolbul.2018.05.041.

DFO. 2009a. Ecological Assessment of Irish Moss (*Chondrus Crispus*) in Basin Head Marine Protected Area. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/059.

DFO. 2009b. Operational Management Plan, Basin Head Marine Protected Area. Oceans and Habitat Branch, Gulf Region. Cat. No. Fs 119/2009E. 34p. incl. annexes.

DFO. 2016. Basin Head Marine Protected Area: 2014 Operational Management Plan. Basin Head Management Series. 2016/01: viii + 40p.

Howarth, R.W., and Marino, R. 2006 Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: Evolving views over three decades Limnol. Oceanogr. 51(1, part 2): 364–376.

McCurdy, P. 1979. A preliminary study of the ecology of Basin Head harbour and South Lake P.E.I. Final report, Canada Summer Job. Corps Project 16-01-009S. 57 p.

McCurdy, P. 1980. Investigation of a unique population of Chondrus crispus in Basin Head Harbour, Prince Edward Island. Internal report to National Research Council of Canada under Contract CS155-0-6302, 080-005, 34 pp.

Sharp, G.R., Connolly, K., Blok, R., Audet, D., Cairns, D., and Courtenay, S. 2003. Ecological assessment of the Basin Head lagoon: A proposed Marine Protected Area. Can. Manuscr. Rep. Fish. Aquat. Sci. 2641, 69 p.

Thériault, M.H., and Courtenay, S.C. 2010. Overview analyses of the Community Aquatic Monitoring Program (CAMP) in the Basin Head Lagoon from 2002 to 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/001.

Vaquer-Sunyer, R., and Duarte, C.M. 2008. Thresholds of hypoxia for marine biodiversity. Proc. Natl. Acad. Sci. USA 105: 15452-15457.

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