An adaptive ecological monitoring approach for the Basin Head Marine Protected Area: indicators and strategies

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ABSTRACT

Bringloe, T., Joseph, V., Dinn, C., Bourque, D., Arseneault, T. 2026. An adaptive ecological monitoring approach for the Basin Head Marine Protected Area: indicators and strategies. Can. Manuscr. Rep. Fish. Aquat. Sci. 3345: viii + 46 p. https://doi.org/10.60825/98tk-6a56

The Basin Head Marine Protected Area (MPA) was established in 2005 to protect a unique population of the red alga Irish Moss (*Chondrus crispus*). This document details the first streamlined ecological monitoring approach for the Basin Head MPA and proposes indicators and strategies for the eventual implementation of an effective monitoring plan. Conservation objectives are operationalized, and key scientific surveys and sources of data are categorized into core monitoring, complementary data, and targeted research. Several proposed indicators have long term monitoring data such as temperature, dissolved oxygen, abundance of Irish Moss and Blue Mussel (*Mytilus edulis*), nearshore community composition, and invasive species. Other indicators require targeted research to update or reconceptualize, including a hydrodynamic model of the basin and the density of biofouling green algae (*Ulva* spp.). By streamlining monitoring efforts to indicators directly impacting the Irish Moss, our monitoring approach provides clarity and direction for reporting on the status and health of the Basin Head MPA.

RÉSUMÉ

Bringloe, T., Joseph, V., Dinn, C., Bourque, D., Arseneault, T. 2026. An adaptive ecological monitoring approach for the Basin Head Marine Protected Area: indicators and strategies. Can. Manuscr. Rep. Fish. Aquat. Sci. 3345: viii + 46 p. https://doi.org/10.60825/98tk-6a56

La zone de protection marine (ZPM) de Basin Head a été créée en 2005 afin de protéger une population unique de mousse d'Irlande (*Chondrus crispus*), une algue rouge. Ce document détaille la première approche simplifiée de suivi écologique pour la ZPM de Basin Head et propose des indicateurs et des stratégies pour l'implémentation éventuelle d'un plan de suivi efficace. Les objectifs de conservation sont opérationnalisés, et les principaux relevés scientifiques et sources de données sont classés en surveillance principale, données complémentaires et recherche ciblée. Plusieurs indicateurs proposés intègrent des données de suivi à long terme, telles que la température, l'oxygène dissous, l'abondance de mousse d'Irlande et de moule bleue (*Mytilus edulis*), la composition des communautés littorales et les espèces envahissantes. D'autres indicateurs nécessitent des recherches ciblées pour leur mise en œuvre ou leur reconceptualisation, notamment le modèle hydrodynamique pour le bassin, et la densité des algues vertes constituant des biosalissures (*Ulva* spp.). En rationalisant les efforts de suivi pour les indicateurs impactant directement la mousse d'Irlande, notre approche de suivi apporte clarté et orientation pour l'établissement de rapports sur l'état et la santé de la ZPM de Basin Head.

LIST OF ABBREVIATIONS

AIS	Aquatic Invasive Species
BCB	Biodiversity Conservation Benefit
BHIM	Basin Head Irish Moss
CAMP	Community Aquatic Monitoring Program
CO	Conservation Objective
CPUE	Catch Per Unit Effort
CSAS	Canadian Science Advisory Secretariat
DFO	Department of Fisheries and Oceans
DO	Dissolved Oxygen
eDNA	Environmental DNA
GBD	Gas Bubble Disease
MCT	Marine Conservation Target(s)
MPA	Marine Protected Area
MR	Marine Refuge
NMDS	Non-Metric Multidimensional Scaling
OECM	Other Effective Area-Based Conservation Measures
PEI	Prince Edward Island
PERMANOVA	Permutational Multivariate Analysis of Variance

GLOSSARY

The definitions provided here are intended to clarify the terminology and abbreviations used within the current document, and do not necessarily represent broad definitions upheld by DFO.

Biodiversity Conservation Benefit (BCB): the net positive change in, or preventing the loss of, biodiversity resulting from the implementation of an area-based management measure (DFO 2016). BCBs may either be a direct result of an other effective area-based conservation measure (OECM), or an indirect benefit provided by an area-based measure established for another purpose.

Conserved area: Lands and waters that are managed in ways that achieve positive long-term outcomes for the conservation of biodiversity. These include protected areas as well as OECMs (Government of Canada 2025a)

(Strategic) Conservation Objective (CO): Reflects the species, habitat, or features that the area has been put in place to conserve. Every conserved area has a conservation objective. Certain activities may be allowed to take place within a conserved area provided they do not interfere with the conservation objective (CCFAM 2018).

Canadian Science Advisory Secretariat (CSAS): Coordinates scientific peer-review and science advice for the Department of Fisheries and Oceans (DFO 2020).

Department of Fisheries and Oceans (DFO): A federal institution of the Canadian Government responsible or safeguarding the nation's waters and managing fisheries and ocean resources (DFO 2026).

Indicator: Measurable variables used to evaluate the state of a particular species/ecological system with respect to achieving a particular objective (ECCC 2025; DFO 2013).

Marine Conservation Targets (MCT): A percentage of Canada's marine and coastal waters that must be recognized as conserved. This target is 30 % by 2030 for marine and coastal regions (Government of Canada 2025b). Federal MCT funding aims to establish new protected sites and develop monitoring and management plans in existing sites.

Marine Protected Area (MPA): A clearly defined geographical space recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Government of Canada 2011).

Marine Refuge (MR): A marine refuge is a fisheries-area closure established under the *Fisheries Act* that meets specific criteria in Canada's OECM guidance and is recognized as an OECM by the Minister of DFO (Government of Canada 2022).

Operational Objective: An objective that is more specific and measurable as compared to the (strategic) conservation objective. Specifies a parameter or indicator used for ecological monitoring, including reference points where available (DFO 2013).

Other Effective Area-Based Conservation Measures (OECM): A geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity (either directly or indirectly through BCBs) with associated ecosystem functions and services and, where applicable, cultural, spiritual, socio-economic, and other locally relevant values (Government of Canada 2022). Among the criteria for OECMS, sites must provide a benefit for an important species, an important habitat, and an additional benefit.

1. INTRODUCTION

The Government of Canada has committed to meeting international biodiversity protection goals, as outlined in the Kunming-Montréal Global Biodiversity Framework (Government of Canada 2025a). In support of these global objectives, Canada has set national targets to protect 30% of its marine environment by 2030 (Government of Canada 2025b) and has, as of 2026, conserved 15.54% of its marine territory. The Department of Fisheries and Oceans (DFO) is working towards Marine Conservation Targets (MCT) through Marine Protected Areas (MPAs) created under the *Oceans Act* (S.C. 2024, c. 30) and other effective area-based conservation measures (OECMs), also known as marine refuges (MRs). These MRs safeguard critical species and habitats from fishing activities through closures enacted under the *Fisheries Act* (S.C. 2024, c. 30), and they contribute to Canada's national MCT program by providing Biodiversity Conservation Benefits (BCB; Government of Canada 2022).

The purpose of this document is to detail an adaptive ecological monitoring approach for the Basin Head MPA (Figure 1; Government of Canada 2024) for 2026–2031. To achieve this goal, we first provide a general overview of the proposed monitoring approach in the context of the Guidance on the Formulation of Conservation Objectives and Identification of Indicators, Monitoring Protocols and Strategies for Bioregional Marine Protected Area Networks (DFO 2013). We then provide a general overview of the Basin Head MPA and its Conservation Objectives (COs), propose indicators for monitoring those COs, identify ongoing surveys/existing datasets that can be used to measure those indicators, outline the proposed strategies for reporting and managing data, and identify gaps in knowledge. This document will help to operationalize ecological monitoring of the Basin Head MPA over the next five years, establishing a foundation for refining and expanding the approach into a long-term monitoring plan after 2030.

2. MONITORING APPROACH

2.1. Unpacking conservation objectives

The ecological monitoring framework detailed in this document, to be applied across all of Gulf Region's conservation areas, follows the advice produced via a formal scientific peer-review process coordinated by the Canadian Science Advisory Secretariat (CSAS), namely the Guidance on the Formulation of Conservation Objectives and Identification of Indicators, Monitoring Protocols and Strategies for Bioregional Marine Protected Area Networks (DFO 2013). According to the National Framework for Canada's Network of Marine Protected Areas (Government of Canada 2011), the overarching conservation goals of Canada's MPAs are to: (1) Provide long-term protection for marine biodiversity, ecosystem function and special features; (2) support conservation and management of marine resources, including socio-economic and ecosystem services; and (3) enhance public awareness and appreciation for marine environments and associated history and culture. For each conserved area, these goals are developed into strategic COs that detail the desired state of the conserved area and contribute to the conservation goals (Figure 2A). For the ecological monitoring framework described here, these COs are unpacked into operational objectives (Figure 2A), which are more specific and tied to measurable indicators.

The ecological monitoring is meant to assess, as simply and as accurately as possible, the status, trends, and health of various biological and ecological components of interest in each conservation area. This information can then be integrated with other sources, including socio-economic and non-ecological factors, to inform management plans and decision-making. Any thresholds included in the ecological monitoring plan are based solely on the biology and ecology of the conservation area, such as limits related to stress, mortality, or the collapse of ecological functions. These thresholds should, where feasible, be linked to management actions.

2.2. Developing indicators

DFO (2013) provided further guidance on suitability of indicators. An indicator is defined as a variable or index that reflects changes in a system, and the position or trend of an indicator relative to reference data points indicates the present state of a given system. DFO (2013) provides guidance on selection criteria for indicators, which include:

- sound theoretical basis
- ease and accuracy of measurement
- availability of historical data (10–20 years)
- suitable sensitivity (correspondence between change in indicator and pressure)
- suitable responsiveness (signal to noise ratio)
- suitable specificity (ability to disentangle multiple pressures)
- suitable public awareness (ease of comprehension to non-specialists)
- reasonable cost-effectiveness.

When specifically considering indicators for the monitoring of marine conservation areas, other guiding principles can be used to aid in selection. When possible, minimally invasive methods (e.g., environmental DNA [eDNA], imagery, etc.) should be preferred for monitoring, quantitative thresholds should be prioritized over qualitative ones, and indicators that can be used to assess similar objectives across many conservation areas should be standardized.

The approach to identifying and testing indicators for ecological monitoring of conservation areas is staged and iterative. First, potential indicators are identified by reviewing literature relevant to COs (Stage 1; Figure 2B). Once a potential indicator is identified, data are gathered and analyzed to establish its baseline status (Stage 2; Figure 2B). At Stage 2, relevant gaps in knowledge may be identified and iteratively addressed with new research and data. Once the baseline status for an indicator is sufficiently established, new data building off the baseline are collected by leveraging existing surveys, where possible, or by developing new monitoring protocols. At Stage 3, the validity and feasibility of the indicator is tested, specifically whether the indicator can reflect changes in operational objectives (Stage 3; Figure 2B). Once an indicator passes implementation testing, it can be fully integrated into a scientifically peer-reviewed (i.e., through a CSAS process) monitoring plan to inform on health and status updates in a given conservation area (Stage 4; Figure 2B) through various reporting channels (e.g., scientific, management, and public facing documents). The indicator should also be periodically re-evaluated to ensure it remains valid and feasible to inform on the status of priority species and overall ecosystem health. This will be done through updates to the ecological monitoring approaches specific to each Gulf Region conservation area, optimally on a 5-year basis and in line with overall management plans. Any scientific evidence suggesting that a better indicator or

metric exists (e.g., a new technology or method is developed), or that a current indicator is not adequate, should result in an update to a given ecological monitoring approach and published as soon as feasible, even when falling outside the regular update cycle.

2.3. Data types

Ecological monitoring indicators and activities will be organized and prioritized by assigning them to one of three categories (modified from DFO 2024a): core monitoring, complementary data, and targeted research (Figure 2C). Core monitoring includes priority indicators that are assessed frequently (i.e., yearly when feasible) and are considered essential for building long-term datasets directly addressing conservation objectives for each conservation area. In marine conservation areas within the Gulf Region, core monitoring is carried out (or contracted out with validated protocols) by DFO Science. Since core monitoring is critical to informing on the status and trends related to the COs, DFO Science must maintain scientific oversight of these monitoring activities. In order to optimize feasibility and cost effectiveness, monitoring will often leverage existing DFO surveys that can provide adequate data. Complementary data includes surveys or datasets that provide additional information that can help with interpretations of the status, health, and trends of marine conservation areas and associated operational objectives. Targeted research represents short-term projects that could help inform and fill knowledge gaps related to core monitoring, address observed changes in the operational objectives, test new methods, or refine existing protocols.

3. BASIN HEAD MARINE PROTECTED AREA

3.1. Monitoring approach context

3.1.1. History of Basin Head Marine Protected Area

The Basin Head Marine Protected Area (MPA), established in 2005 under the *Oceans Act* (S.C. 2024, c. 30), is a shallow marine lagoon located on the eastern shore of Prince Edward Island (PEI) (Figures 1 and 3) designated to conserve a unique population of the red alga Irish Moss (*Chondrus crispus*). Irish Moss within the Basin Head MPA, hereafter referred to as Basin Head Irish Moss (BHIM), exhibits several distinct characteristics that differentiate it from coastal populations (Figure 3). BHIM is asexual, reproducing through fragmentation of gametophytes, the haploid phase of the sexual life history typical of the species. BHIM does not possess a holdfast to anchor it to substrate, but rather is held in place by Blue Mussel (*Mytilus edulis*) byssal threads. Morphologically, BHIM is characterized by broader and thicker fronds and persistent seasonal coloration, features that have contributed to its colloquial designation as “Giant Irish Moss” (Figure 3). Furthermore, this population yields a higher concentration of carrageenan compared to its coastal counterparts, which attracted commercial interests in the 1970s and 80s (Chopin et al. 1999). These characteristics are presumed to be influenced by the specific environmental conditions in the Northeast Arm where the Irish moss is found (Sharp et al. 2003). A genetic basis of the differences between the larger BHIM and other populations of *C. crispus* is currently being investigated. The BHIM in conjunction with Blue Mussel also provides dynamic habitat that promotes biodiversity as compared to bare bottom substrate (Gibbons 2024) and appears to protect native fauna from non-native predators (Tummon Flynn et al. 2020).

BHIM biomass has declined substantially in recent decades and struggles to persist today. In 1980, the total estimated area of BHIM coverage was 15,000 m^2. By the time the MPA was

established in 2005 the bed had already declined to an estimated 2,500 m^2, after which it continued shrinking due to a combination of pressures (see *3.1.2 Threats*), approaching extirpation (1.88 m^2) by 2013 (Joseph et al. 2021). Restoration efforts to maintain the BHIM population were undertaken each year since 2015. Restoration is achieved though the out-planting of algal-mussel clumps that are created from BHIM kept in culture at a National Research Council facility in Ketch Harbour, Nova Scotia. As of the most recent census in 2025, only 145 m^2 of the beds exist today.

The Basin Head MPA is managed according to zones that progressively restrict activities that are potentially harmful to the Irish Moss and ecosystem. Zone 3 (outer coastal) extends from the mouth of the Basin one nautical mile seaward and three nautical miles from east to west (Figure 3) and prohibits all activities that disturb, damage, destroy, or remove from the area living marine organisms or any part of their habitat. Zone 2 consists of the lagoon and the west end of the inner channel, and motorized vehicles are additionally prohibited. Zone 1 comprises the majority of the inner channel where BHIM resides; in addition to above mentioned activities, swimming and fishing are also prohibited.

3.1.2. Threats

The persistence of BHIM depends on specific environmental conditions and is subject to several pressures (Figure 4), as reviewed in the CSAS Research Document by Joseph et al. 2021. Thermal regimes are especially important to both BHIM and Blue Mussel, as Basin Head exhibits consistent stressful (>20 °C) and acute lethal temperatures (> 28 °C) during the summer (see *3.2.1.a. Water Temperature*). Another consideration are flushing rates, which refer to the rate at which water is replaced, affecting the system in several ways. For example, at the historical Oyster Cross bed (experimental plantation of Blue Mussel/BHIM clumps) in Basin Head (est. 2016), spatial variation in hydrodynamics resulted in areas of firm, current-swept substrates and other areas of reduced flow and deposition. Monitoring of these areas revealed that in low-flow zones, silt accumulated beneath *Ulva* mats, a green macroalga benefiting from eutrophication, and led to mortality of BHIM. In contrast, areas with stronger currents retained their Irish Moss cover. These findings suggest that *Ulva* overgrowth, combined with sediment accumulation, can smother and reduce light availability, ultimately threatening the persistence of BHIM in areas of reduced water flow. Water renewal times in Basin Head have been estimated in multiple studies, ranging from 0.25 to 6.82 days. Hydrodynamic models developed to characterize circulation patterns revealed spatial variability in renewal times. The most recent model, incorporating 2017 lidar-derived bathymetry, confirmed rapid flushing (<1 day) near the inlet, intermediate times (1–1.5 days) in the main basin, and slower flushing (>3 days) at the head of the Northeast Arm. The hydrodynamic model was used to preliminarily assess current flow in areas where BHIM clumps were observed.

The sustainability of BHIM is also closely linked to the survival of Blue Mussels in the face of these environmental pressures (Figure 4), which serve as essential anchoring substrates due to the lack of a holdfast. Nutrient runoff from surrounding agricultural land promotes blooms of the green macroalga *Ulva*, which can raise oxygen demand and potentially lead to anoxic conditions during decomposition—a critical concern for Blue Mussel survival. Hypoxic stress generally occurs at dissolved oxygen (DO) levels below 4 mg/L for most fish and below 2 mg/L for most invertebrates (Vaquer-Sunyer and Duarte 2008; Riedel et al. 2014). Prolonged oxygen depletion promotes anaerobic bacterial activity, which may ultimately lead to Blue Mussel mortality, despite their general tolerance for short-term low-oxygen exposure (Babarro and De Zwaan 2002, 2008). Herbivory does not appear to significantly affect Irish Moss (Vandermeulen 2009), but predation by invasive European Green Crab on Blue Mussels reduces the availability of substrate, indirectly threatening Irish Moss persistence (Tummon Flynn et al. 2019; Figure 4).

3.1.3. Conservation objectives

The Basin Head MPA Operational Management Plan (DFO 2022) lists four strategic conservation objectives (CO) to protect the unique BHIM and its environment (Table 1). These are:

1. Maintain the quality of the marine environment supporting the BHIM.
2. Maintain the physical structures of the ecosystem supporting the BHIM.
3. Maintain the health (biomass and coverage) of the BHIM.
4. Maintain the overall ecological integrity of the Basin Head lagoon and inner channel.

Monitoring activities in Basin Head MPA have previously been submitted for scientific peer review, in the context of their effectiveness in evaluating attainment of COs. The Science Advisory Report for that process made several recommendations for the development of the ecological monitoring plan going forward (DFO 2020). In particular:

“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.” (DFO 2020).

Given the recommendation, this monitoring approach aims to streamline indicators to those directly related to the health and status of the BHIM, and therefore informing directly on the conservation objectives. The purpose of this document is to summarize available indicators for core ecological monitoring of the Basin Head MPA, as well as highlighting important gaps. This was achieved by first reviewing the most recent operational management plan (DFO 2022) and CSAS document (DFO 2020; Joseph et al. 2021) summarizing monitoring for Basin Head. Indicators were identified and qualitatively assessed for whether they met suitable criteria (Table S1). Indicators with 6/8 criteria were developed into the monitoring approach in order to balance feasibility (1-3 indicators per CO) with rigor of the indicator (majority of criteria apply). The draft monitoring approach was then reviewed by Subject Matter Experts (Table S2) and discussions were held during a workshop (held November 18th, 2025). Notes were taken and feedback was implemented prior to peer review. While some indicators and/or data collected in the MPA to date were considered redundant or not suitable for the core monitoring detailed here, these can still be leveraged as complementary data. We also note that this document represents a conceptual exercise to identify the most adequate indicators for ecological monitoring based on currently available data, that this approach will be adapted as novel indicators are developed, and that implementation and operationalization towards a formal monitoring work plan depends on further review (i.e., CSAS) and additional factors such as funding, human resources and regional priorities.

3.2. CO1. Maintaining the environmental quality supporting Basin Head Irish Moss

3.2.1. Core monitoring and opportunities for targeted research

3.2.1.a. Water temperature

Rising water temperature is a well-established stressor for Irish Moss and Blue Mussels. Irish Moss growth and survival are optimal at 10–15 °C (Fortes and Lüning, 1980) with declining performance at higher temperatures and mortality recorded at 28 °C (Lüning et al. 1987). For Blue Mussels, thermal stress begins at 16 °C (Lauzon-Guay et al. 2006; van der Veer et al. 2006), with pronounced stress at temperatures above 20 °C and lethality at 25–30 °C (Clarke et al. 2025). Temperatures within Basin Head have been monitored for several decades, but routine monitoring at three sites (Main Arm: T1 and T2; Lagoon: T3; Figure 3) began in 2012

using continuously recording probes. Given the importance and direct relevance to BHIM, several indicators are proposed for temperature (Table 1). First, water temperature should be monitored for increasing yearly trends of time spent at various temperature categories, with special attention to the 20 °C and 28 °C thresholds for stress and mortality in Blue Mussel and BHIM (Figure 5). Second, the cumulative hours and longest time span spent above the 20°C and 28°C thresholds should be monitored for increasing trends year over year (Figure 6).

Targeted research efforts are currently underway to confirm temperature thresholds for stress and mortality in BHIM. In collaboration with National Research Council in Ketch Harbour (Nova Scotia, Canada), temperature control experiments are being conducted on three strains of Irish Moss initially isolated from Basin Head in different years, which are also used in current restoration efforts. Temperatures at 3-degree intervals from 18 °C to 30 °C are being trialed to determine growth and mortality effects on BHIM. Follow-up experiments are being planned that will incorporate diurnal cycling of temperature regimes, which will more accurately determine the length of time BHIM can tolerate elevated temperatures before stress or mortality sets in. Of particular relevance is determining the maximum length of time that BHIM can survive at sustained 28+ °C temperatures. These results will help refine thresholds for monitoring, both for temperature and length of time spent at elevated temperatures, and provide insight on the direct vulnerability of BHIM to increasing temperature trends. Targeted research should also be considered for Blue Mussel; specifically, the impacts of temperature on spat (settled larvae) and mussel beds (aggregations) versus individuals (current state of Basin Head Blue Mussel) would provide important context for adapting future monitoring and restoration efforts.

3.2.1.b. Dissolved oxygen

DO is a well-established stressor in marine fish and invertebrates, both at high and low levels. Moreover, it is a suitable proxy for eutrophication (Coffin et al. 2018a), meaning DO can stand in for other indicators of historical interest such as nutrient loading and *Ulva* biomass, which are less straightforward to monitor and interpret. The lower threshold for hypoxia stress is 4 mg/L in fish and 2 mg/L in invertebrates (thresholds used here for monitoring), though this threshold is often species dependent (Vaquer-Sunyer and Duarte 2008; Riedel et al. 2014). Blue Mussels, which are vital to the anchoring of BHIM, tolerate periods of low DO, with survivability decreasing after 4–5 days at DO levels <1.0 mg/L (Li et al. 2022). Moreover, survival rates were notably higher when levels were allowed to fluctuate between 0.5 and 1.5 mg/L on a 24-hour cycle, a fluctuation pattern also observed in Basin Head (Figure S1). Opposite to hypoxia, supersaturation can similarly impact marine fauna by causing Gas Bubble Disease (GBD), wherein excessive DO comes out of solution in an organism as gas bubbles, causing significant health problems if the bubbles remain. Xue et al. (2019) demonstrated lethal effects of supersaturation in various fish species within a few hours at 135+% DO, though survivability persisted beyond 24 hours in some species at lower supersaturation levels (125 and 130%). Huang et al. (2010) also show the mortality threshold for supersaturation in juvenile rock carp is 120%. GBD can also lead to blisters in soft tissues and even buoyancy in bivalves, with impacts reported in experimental procedures of Surf Clam (*Spisula solidissima*), Little Surf Clam (*Mulinia lateralis*), Bay Scallop (*Argopecten irradians*), Eastern Oyster/Soft-Shelled Clam (*Crassostrea virginica*), and Hard Clam (*Mercenaria mercenaria*) (Malouf et al. 1972; Goldberg 1978; Bisker and Castagna, 1985), and reported in wild populations of New Zealand Surf Clam (*Paphies ventricosa;* Ross et al. 2018). Impacts scaled with the level of supersaturation and were species dependent; for instance, Bisker and Castagna (1985) demonstrated mortality in *M. lateralis* at 114% supersaturation, whereas *Mya arenaria* mortality and floating was notable at 120%.

Unfortunately it is not known whether Blue Mussel is impacted by supersaturation. Experimental work has shown Blue Mussel will scale metabolic activity with oxygen supersaturation at 160% (Booth et al. 2021), and experiments in diel fluctuations also suggest Blue Mussel are more resilient to shifts between hypo- and hyperoxia compared to other bivalves (Kraemer and Gobler 2026). Note, Basin Head spends considerable time in a supersaturated state, consistent with *Ulva* in the presence of nitrogen loading (Hirayama et al. 2024), and also swings between high and low DO values daily (Figure S1), creating more stressful conditions for bivalves. Finally, it should be noted that the renewal time for water in Basin Head is more than 72 hours in the furthest reaches of the main arm (Joseph et al. 2021), which may help to prevent hypoxic or supersaturation conditions from extending beyond a few days.

Two indicators are proposed for DO (Table 1). The proportion of time spent at various conditional categories (<2 mg/L, 2–4 mg/L, >120% DO) should be monitored across years. Normal readings are considered neither low nor supersaturated as defined here and in Figure 7. DO saturation is dependent on temperature, salinity, and pressure, meaning high values of DO in mg/L are not comparable across time and locations; supersaturation is therefore evaluated as a percentage to account for these differences. Data should also be quality controlled for instances where probes may become buried, which may result in continuous low DO readings; recording values in 15-minute intervals is recommended to improve data quality. DO should be monitored across months and sites to account for spatial and inter-annual variability in readings. It is recommended a probe be deployed in zone 2, consistent with the temperature monitoring. In addition, the longest continuous recordings at <2 mg/L, 2–4 mg/L, and >120% DO should be monitored across sites and years for any increasing trends (Figure 8).

Important knowledge gaps persist for using DO as an indicator for Basin Head. While the lower threshold for Blue Mussel survival is well established, the impact of supersaturation has not yet been investigated. Health indicators for Blue Mussel indicating hypo- and hyperoxia could serve as more direct indicators of stress in tandem with the DO readings (e.g., toxic byproducts of DO stress, lesions, floating). The benthic environment, in contrast to the water column, could be more relevant for DO monitoring given BHIM occupies the benthos; sediment core sampling for indicators of hypoxic conditions, such as hydrogen sulfides, could be considered. Moreover, the threshold for DO impacts (both hypoxia and supersaturation) will be species, size, and life stage dependent, meaning the threshold is dynamic across species of conservation interest. Finally, the criteria for identifying data linked to a buried probe, a common occurrence due to excessive *Ulva*, must also be established for data quality control.

3.2.2. Complementary data

Nutrients were identified as a stressor to the Basin Head MPA ecosystem before its official designation in 2005 (Sharp et al. 2003). Early research focused on nitrate concentrations within the estuary (McCurdy 1979) and the contribution of nitrate from streams (Connolly 2002). In Prince Edward Island, potato farming commonly relies on nitrate-based fertilizers. Excess nitrogen not taken up by crops (residual soil nitrogen) can runoff or leach into groundwater, eventually entering estuaries via streams, rivers, or direct freshwater inputs such as springs (Bugden 2014; Grizard 2013). Agriculture and Agri-Food Canada updates and publishes an Indicator of the Risk of Water Contamination by Nitrogen (among other Agri-environmental indicators), using the Residual Soil Nitrogen Indicator, every few years (AAFC 2025).

When estuarine flushing is limited, the influx of high levels of nitrogen can lead to eutrophication (Bugden et al. 2014). The susceptibility of estuaries to eutrophication depends on both nutrient

input and flushing capacity (Bugden et al. 2014; DFO 2020). Well-documented symptoms of eutrophication in coastal systems include harmful algal blooms, overgrowth of macroalgae (e.g., *Ulva* spp.), hypoxic or anoxic conditions leading to fish death (Schein et al. 2012), declines in invertebrate populations (Coffin et al. 2018a, 2018b), elevated sediment organic matter, and broader shifts in aquatic community composition (Valiela et al. 1997; Gilbert et al. 2010; Bugden et al. 2014; Coffin et al. 2018a).

Excess nutrients have an indirect effect on the BHIM. The proliferation of fast growing macroalgae such as *Ulva* can smother BHIM. The decomposition of excess *Ulva* can also leave debris on the fronds of BHIM. As highlighted in the CSAS advice for Basin Head monitoring (DFO 2020), macroalgal blooms and their subsequent decay can lead to hypoxic and anoxic conditions that are detrimental to BHIM and supporting biota, which can be directly captured using continuous DO monitoring. Indicators for nutrients are not proposed for routine monitoring at this time, but complementary data are available (Table 2) and suitable indicators may be developed for future monitoring.

3.3. CO2. Maintaining the physical structure of the ecosystem

Maintaining the physical structure supporting the BHIM comes from the stability of the entrance channel, the dune structure, and the bathymetry of the basin, as they contribute to the flushing of the lagoon. There are many short-term goals in the Basin Head management plan (DFO 2022) including monitoring dune structure (particularly the opening and the relatively low and narrow dune at the top of the main arm), salt marsh erosion, water circulation, depth, flushing rates, and land use changes. In order for the geomorphology of Basin Head to be directly linked to the health and status of BHIM, however, a novel Basin wide ecological indicator was needed.

3.3.1. Core monitoring and opportunities for targeted research

3.3.1.a. Suitable habitat based on hydrodynamic modelling

As noted above, BHIM is primarily found in areas with a firm benthos. Presumably, less stable substrates are less conducive to the establishment of Blue Mussel, which threatens the anchoring mechanism for BHIM. Increasing sedimentation would also threaten to bury the BHIM itself, or otherwise leave deposits on the fronds, impacting access to light for photosynthesis. Hydrodynamic modelling supported by flow observations collected in 2017 suggest BHIM occurs in areas with mean current speeds between 10 and 15 cm/s (Guyondet, unpublished). In Basin Head, current speeds must be slow enough to not pull BHIM from the mussel or displace the clumps themselves, but fast enough to clear debris and sediments from accumulating, particularly *Ulva*. Observations made in 2014 further refine characteristics of BHIM habitat, indicating that remnant Irish Moss clumps were primarily restricted to firm, shallow subtidal habitats (10–60 cm depth at low tide) with sediment penetrable to less than 20 cm (Joseph et al. 2021; for some historical data, see Figure S2).

In order to link physical aspects of the environment (e.g., bathymetry, sedimentation, current speeds) to the health and status of BHIM, two indicators are proposed for monitoring the status of CO2: the amount and locations of habitat (m^2) suitable for BHIM as estimated using a basin scale hydrodynamic model (Guyondet, unpublished). The model, initially created in 2017, should be updated every 5 years (or earlier following large disturbances such as storms) to

track changes in suitable habitat, with ground truthing using flow observations and bed transect surveys (see CO3).

Several opportunities for targeted research exist for CO2. Experimental procedures comparing BHIM to coastal populations and evaluating preferences for current speed would help refine thresholds to determine suitable habitat using the hydrodynamic model. The impacts of sedimentation could also be investigated to determine whether BHIM is able to persist in areas of sediment deposition, or areas of varying sediment stability. Novel methods to measure changes in sedimentation should be considered (Mathews et al. 2026). Core samples within the BHIM beds could also provide insights on grain size and percent organic matter, further helping to ground truth the hydrodynamic model. The impact(s), if any, of ice scour during the winter months is also unknown.

3.3.2. Complementary data

Additional monitoring has been outlined by the Basin Head management plan (DFO 2022) that could be used as complementary data (Table 2), including monitoring the dune structure, salt marsh erosion, water circulation, flushing rates, and land use changes. Increased storm frequency due to climate change is a concern for this system. Storms have previously damaged the entrance channel to the basin and work has been done to stabilize the infilling of sediment affecting channel depth for public safety (CBCL Ltd. 2021). The proposed updating of the hydrodynamic model (Guyondet unpublished) would also provide complementary data and insights on water renewal times, depth profiles, and depth averaged flow speed throughout the Basin. As part of this modelling, pressure and water level loggers have been routinely deployed since 2016 to provide a proxy for water levels. Salt marsh erosion using rods in fixed locations have also been used to track movement of marsh delineations since at least 2020.

Several recommendations were provided during the Basin Head 2019 CSAS peer review meeting (DFO 2020). Among them is the consideration of alternative technologies for monitoring current velocities such as acoustic doppler current profilers, and the use of historical data such as provincial aerial photos dating back to 1935 to document changes in the marsh edges. Drone surveys could be developed with targeted research to determine whether this type of imagery can successfully document changes to the dune structure or marsh edges. These datasets have yet to be formally developed, but could serve as complementary data in the future.

3.4. CO3. Maintaining the health (biomass and coverage) of Basin Head Irish Moss

3.4.1. Core monitoring and opportunities for targeted research

3.4.1.a. Abundance, size, and coverage of Irish Moss

While estimates of BHIM coverage date back to the 1980s, tools and survey types have shifted with the declining coverage of the beds. While ground-based surveys were used in the 1980s, aerial surveys were prominent from 2000–2010 until these surveys could no longer detect the BHIM (Appendix 1, Table S1; Figure 9). A combination of drone, snorkeling, underwater camera tows, and wading were used post 2010. Several limitations have been encountered, including difficulties distinguishing beds using drone imagery, and visibility with underwater methods (i.e. snorkel and camera tows). Wading data (i.e. DFO Science Swath Surveys, hereafter swath surveys) have thus far provided the most reliable method to quantify the coverage of BHIM. Coverage (m^2), including the historical data described here, is the first proposed indicator for

CO3 (Table 1; Figure 9). Routine monitoring continues with swath surveys, which count the number of BHIM mussel clumps and size by wading along predetermined transects each year. The number and size of BHIM clumps are the second proposed indicator for this CO (Table 1, Figure 10).

Several challenges persist for monitoring BHIM that can be the subject of targeted research. Unfortunately, the beds have further declined to the point that there are limitations on wading surveys to detect the remaining BHIM coverage in known beds. This could be remedied with a combination of hydrodynamic modelling (CO2) to inform on locations to monitor for BHIM, and less invasive and more spatially comprehensive underwater footage taken in October when the water is most clear according to on-the-ground observations. Other methods to quantify the biomass of BHIM such as drones, sonar, multispectral cameras, and GPS led mini boat transects could be explored for feasibility. Also, there is no threshold for ecological monitoring; presumably the BHIM will be self-sustaining (that is, restoration efforts will no longer be needed; Figure 10) once the beds reach a critical size and are able to recruit new biomass each year, however, no efforts have been made to quantify that number, tease apart natural recruitment from restoration efforts, or determine if recovery of the BHIM is a realistic expectation with or without human interventions.

Whether BHIM is a genetically unique population has been a persistent research gap throughout the history of the MPA. Chopin et al. (1996) included Basin Head in a genotyping survey of *Chondrus* species using nuclear ITS and plastid restriction digestion but did not detect any differences when compared to other coastal specimens of *Chondrus crispus*. An unpublished report by Provan and Maggs did directly test for genetic differences in BHIM using microsatellites, and did detect some degree of differentiation, though the resolution of their dataset left them with inconclusive results. To address this research gap, targeted research to genotype BHIM using whole genome data is currently underway (Table 2). Transcriptomic analyses of BHIM in natural beds or lab settings could also profile gene expression in presumably stressed versus non-stressed individuals (Table 2). This approach could facilitate more direct molecular indicators for stress and will potentially provide context for some of the unique features of the BHIM, such as larger size and lack of reproductive cycling.

3.4.1.b. Blue Mussel abundance

In addition to recording BHIM mussel clumps, the swath surveys also record the number of Blue Mussel clumps without BHIM. Blue Mussel abundance is relevant to the conservation objective of maintaining the health of BHIM given it is the substrate holding the BHIM in place. The swath survey counts are the proposed indicator for the abundance of Blue Mussel (Table 1; Figure 10). Similar to BHIM, novel methods to quantify Blue Mussel would be needed (see discussion above). Also similar to BHIM, the monitoring of Blue Mussel abundances lacks a monitoring threshold for a population size that is self-sustaining, or any context for teasing apart restoration from natural recruitment. Unfortunately, given the temperature stress (Figure 5), potential impacts of DO (Figure 7), the presence of invasive Green Crab, and declining Blue Mussel counts (Figure 10), Basin Head mussels do not appear to be self-sustaining. Targeted research to quantify natural recruitment (mussel spat) may lead to novel protocols to monitor Blue Mussel in the future. Targeted research could also characterize the size distribution of the population in order to provide direct insights on the pressures impacting the persistence of Blue Mussel in Basin Head. For instance, the absence of smaller individuals could confirm ongoing predation by Green Crab (Tummon Flynn 2019), while the lack of larvae or spat could point to limited recruitment.

There have been observations recently of Irish Moss growing attached to oyster shells within the main arm of Basin Head (Bringloe pers. obs). While this does not technically correspond to the known ecology of the BHIM, it is possible this population is shifting its behavior to more readily available substrate. Preliminary genotyping results suggest these attached individuals are derived from the zone 2 beds (Figure 3). Monitoring for oyster shell abundance could be considered moving forward as a potential substrate for recruitment of Irish Moss in the main arm.

3.4.2. Complementary data

Two sources of complementary data have been identified relevant to CO3. First restoration numbers provide important context/complementary data for interpreting the biomass of BHIM and Blue Mussel year over year (Figure 10). Second, Green Crab Catch Per Unit Effort (CPUE) provides a proxy for the abundance of a non-native species to PEI that is a known predator of Blue Mussel. Experimental work done directly on BHIM and Green Crab interactions has shown that Green Crab specifically targets smaller mussels for predation, which would impact recruitment and the mechanism for anchoring BHIM (Tummon Flynn 2019). While there is routine monitoring for Green Crab through removal programs, recent work has shown that removal programs may attain short-term local benefits but seem unable to ultimately reduce Green Crab populations (Tummon Flynn et al. 2024). CPUE through removal programs in Basin Head can nonetheless inform on monitoring for Blue Mussel abundance.

3.5. CO4. Maintaining overall ecological integrity of Basin Head lagoon and inner channel

3.5.1. Core monitoring and opportunities for targeted research

3.5.1.a. Abundance and diversity of fish and benthic invertebrates

Monitoring of other species is proposed given the MPA also protects the ecological integrity of the BH lagoon and inner channel. This remains relevant to BHIM, in that the BHIM in conjunction with Blue Mussel also provides dynamic habitat that promotes biodiversity (Gibbons 2024). The Community Aquatic Monitoring Program (CAMP) provides monitoring of watersheds throughout the Gulf Region. Fish, crab, and shrimp are collected using a 30 x 2 m beach seine at six sites in Basin Head monthly from May to September. All fauna are counted and released, while accompanying water quality, vegetation cover, and sediment composition data are recorded. These data can be used to monitor for changes in species richness and community composition, with baseline data extending back to 2012, though it should be noted stations are limited to the lagoon and the mouth of the main arm (Figure 3). Two indicators are proposed, specifically leveraging the faunal counts data (Table 1).

First, overall species richness and Shannon's diversity index should be monitored for year over year increases or decreases, separately for the months of June, July, and August (the months with the most consistent sampling since 2012; Figure 11). We recognize these indices are simple metrics that may not be sensitive enough to detect changes, particularly in species composition. An important gap to address moving forward will be to explore other indices, particularly ones that can be directly linked to the abundances of BHIM and Blue Mussel.

Second, community composition should be monitored for changes in presence-absence data year over year while maintaining the number of stations (n=6) and timing (June to August; Figure 12). This can be done using Non-Metric Multidimensional Scaling (NMDS) and testing for

an effect of year using Permutational Multivariate Analysis of Variance (PERMANOVA), while ensuring the assumption of homogeneity of dispersion remains valid. Pairwise PERMONOVAs can also be used (correcting for multiple tests) to pinpoint when community shifts are occurring, facilitating the threshold for this indicator (Table 1). CAMP also records environmental variables at the time of sampling, including temperature, salinity, dissolved oxygen, vegetation cover, and substrate composition. These can be fitted to the NMDS results to determine whether shifts in community structure are linked to environmental variables (Figure 12).

In terms of targeted research, DNA technology has emerged as a promising biodiversity monitoring technique that differs from traditional approaches requiring physical specimen collection (e.g., CAMP). eDNA is genetic material left in the environment (water, soil, air) by organisms, which can be used to sequence taxonomically informative DNA markers that identify and delineate taxa (Çevik and Çevik 2025). eDNA is fast and cost efficient on a per sample, per ID basis, given it offers simultaneous information on a wide array of taxa (e.g., bacteria to fungi to fish) without the inherent need for taxonomic expertise (Beng and Corlett 2020). The simple and minimally invasive sampling protocols are also especially amendable to MRs or MPAs that prohibit activities destructive to protected flora, fauna, and habitat. Moreover, eDNA is being widely adopted at DFO (e.g., Aquatic Invasive Species [AIS] detections: Abbott et al. 2021; targeted species detection: Wringe et al. 2023; inferring community structure: Trask et al. 2025), providing a link between efforts regionally and nationally (DFO 2024b). eDNA collection was initially attempted at Basin Head in 2024. First year results were promising, with eDNA detections for fish and invertebrates from both the mouth, lagoon, and main arm of the Basin. It should be noted that the CAMP is no longer conducted by DFO Science, but is now completed annually by a local watershed group. It is therefore expected that eDNA will eventually complement the CAMP based datasets, providing a better overall picture of biodiversity (eDNA) and relative abundances of species (CAMP surveys). eDNA can also provide opportunities to develop new community level indicators, such as phylogenetic diversity, and standardize species detection methods across geographic scales (for instance, comparing results at regional to national levels). Moving forward, the main priorities to onboarding eDNA for core ecological monitoring at Basin Head are 1) ensuring methods for sampling are consistent and comparable across years, 2) building up the dataset to establish a baseline for monitoring, and 3) populating reference libraries to enable DNA based identifications.

3.5.1.b. Aquatic Invasive Species

The distribution and abundance of AIS are monitored by the DFO Gulf Region by deploying PVC collector plates at predetermined sites during spring of each year. Physico-chemical data are recorded during deployment and retrieval of the plates, the latter occurring in the fall of the same year. Upon retrieval, all biofouling organisms are identified and percent cover is estimated. AIS monitoring in Basin Head has been occurring since 2018, with some data published via the Open Government data portal. The plates are deployed in the lagoon, close to the channel that connects to the mouth of the Basin, and two sites in the Northeast Arm. AIS occurrences will be used as an indicator for the ecological integrity of the lagoon (Table 1).

3.5.1.c. Ulva *biomass*

Ulva spp. are a substantial biofouler along PEI coastlines. In Basin Head, *Ulva* spp. create dense mats that cover the BHIM, leading to perceived negative impacts. The smothering by *Ulva* could lead to benthic hypoxia that might impact the Blue Mussel, while releasing oxygen and creating hyperoxic conditions (supersaturation) of the water column (Figure 7). The smothering by *Ulva* would reduce accessibility to light, decrease flow over the BHIM, and might

even result in physical dislodging of BHIM if the *Ulva* is eventually swept away. The impact of *Ulva* on BHIM warrants targeted research to determine the exact mechanisms of the pressure.

Ulva density has been monitored along the same transects used to monitor Blue Mussel and BHIM, with standardized measurements dating back to 2019. These data are proposed as a placeholder indicator (Table 1; Figure 13). *Ulva*, despite its biological relevance to the health and status of BHIM, is difficult to monitor accurately and consistently (low measurability and responsiveness). This is due mainly to tidal flushing, which moves the *Ulva* around in the main arm, quickly changing the circumstances of this pressure. Targeted research could aim to reconceptualize how *Ulva* is monitored across the entire basin moving forward.

3.5.2. Complementary data

Some species were considered for core monitoring but ultimately not incorporated due to sparse data. Other species are potential emerging threats. For instance, a red macroalga abundant within Basin Head and identified as a species of *Melanothamnus* has the capacity to smother suitable habitat for BHIM, much like *Ulva* (Bringloe pers. obs.). These data and observations serve as complementary data at this time, but could be developed into core monitoring should their importance become evident over time.

4. KNOWLEDGE GAPS AND OPPORTUNITIES

This section describes priority gaps in terms of the scientific knowledge generated and how this can better inform core monitoring. Operationally, the next steps in implementing and further developing this ecological monitoring approach depend on several factors, including funding, regional priorities and human resources required to carry out the work.

Basin Head is among Canada's earliest established MPAs. It has a long history of research, monitoring, and accumulated datasets. The main challenge for Basin Head is to streamline efforts to ensure ecological monitoring is realistic and efficient, while remaining accurate and informative. Here, we have narrowed our core monitoring into indicators where the link to conservation objectives, and ultimately the status and health of the BHIM is most direct. For instance, monitoring for nutrients has been routine for Basin Head, with presumed negative impacts to the BHIM through *Ulva* blooms that lead to DO extremes and physical smothering. Because nutrients indirectly impact BHIM through *Ulva*, it is not a direct indicator, meaning it should not appear in core monitoring. The CO of maintaining the physical structure of the ecosystem was similarly filled with redundancies that are remedied with basin scale and direct measures on pressures relevant to BHIM (suitable habitat as determined by bathymetry, current speeds, temperature, ect.). Future efforts should similarly ensure that onboarding of new indicators remains as efficient as possible.

Several biological thresholds remain unknown at this time. Arguably the most critical thresholds to determine are the population sizes needed to ensure BHIM and Blue Mussel are self-sustaining within Basin Head. Thresholds for *Ulva,* current speeds, and sedimentation (the latter two to inform the hydrodynamic model) also do not exist, something that can be investigated as the indicators are developed or reinvented. Adding further complexity, threshold for stress and

mortality are likely determined by the interactions of pressures (e.g. temperature and DO), which remain unknown at this time. Monitoring should therefore consider the pliability of thresholds as different pressures ebb and flow over time.

Some indicators require reinventing or updating moving forward. Specifically, the indicator for *Ulva* is a placeholder leveraging existing surveys and historical data, while the hydrodynamic model for CO2 was constructed in 2017. These indicators require stepping back to step 2 of the developmental flow for indicators (Figure 2), with a thorough review of options for monitoring and ground truthing, and targeted research to assess implementation in Basin Head.

Multiple knowledge gaps were identified that are not currently being addressed. These include: 1) the impact, if any, of DO supersaturation on Blue Mussel, 2) the mechanism of impacts of sedimentation on BHIM, 3) alternative substrate opportunities for BHIM in the main arm, 4) the mechanism of impacts of *Ulva* smothering on BHIM, and 5) other species of concern to BHIM (e.g. red algal blooms of *Melanothamnus*). These knowledge gaps could be addressed with targeted research moving forward.

Power analyses, the determination of sample sizes required to detect specified degrees of change, should be incorporated as soon as possible because the ability to detect statistically supported changes in the proposed monitoring of indicators remains unknown at this time. These should ideally be applied to each indicator and accompanying dataset. A critical step in these power analyses is to determine what constitutes biologically meaningful change within the context of the proposed indicators. Once completed, these power analyses may help to determine if the current surveys have sufficient power to measure relevant change in the proposed indicators (Morris et al. 2024). This in turn can inform routine monitoring, either by increasing or decreasing sampling effort accordingly, or shifting an indicator to something more feasible if sampling effort cannot be scaled to address detection limitations.

Core monitoring includes some data collection performed by stakeholders and agencies external to DFO. For monitoring to be successful long-term, DFO should maintain oversight of monitoring not conducted by DFO Science with carefully documented protocols. The reliance on programs external to the DFO MCT program also leaves vulnerabilities in the core monitoring proposed here. While proposed monitoring relies on the continuance of non-MCT led monitoring programs, enhancing efficiencies by leveraging existing datasets bolsters the justification for these monitoring programs to continue moving forward.

5. DATA MANAGEMENT AND REPORTING

Currently, all data collected in Basin Head are stored on a DFO server with restricted access. The next step is to develop a database for long-term storage of data series, including all the indicators outlined here. The ultimate goal is to systematically capture and organize data for multiple parameters collected at various GPS-referenced locations throughout Basin Head. The database can be queried by location, parameter, and date and be made available through open data portals. It will be designed to support automatic updates and generate annual reports as new data become available.

Informal reporting to management and other stakeholders should be performed on a yearly basis to prevent data backlog, ensure timely analysis, and provide up to date insights on emerging trends to be used in decision making. Automation must be considered to promote efficiency. Currently, the proposed indicators can be reanalyzed with established R code; assuming a reasonable timeframe to access data, the user would update the master datasheets for the proposed indicators and rerun the code. This can be further automated to produce a single workflow of all indicator datasets and publication into a standardized “report card” on the status and health of the conservation area. Interactive web applications are also being considered as data/result portals for internal and external stakeholders and to ensure DFO’s open data standards are being met.

Formal reporting should follow a regular publication cycle targeting a wider scientific audience. This can be achieved using DFO manuscript reports providing status and health updates on the conservation area, acting as checkpoints on a 3 year cycle, or earlier depending on whether notable and prescient trends emerge. Published status updates should be clear on the status of the monitoring approach and whether it has passed into a long term monitoring plan. In order to achieve and maintain a monitoring plan, a CSAS should be conducted as soon as feasible and then following a regular cycle (i.e. every 5 years) in order to review, validate, and update indicators. Note, the proposed reporting cycles are dependent on funding, human resources, and regional priorities.

6. CONCLUSIONS

Establishing long-term monitoring of validated core indicators is needed for the Basin Head MPA in order to achieve its COs. This document represents a revised conceptual framework streamlining indicators and accompanying sources of data for monitoring of the Basin Head MPA. The proposed indicators for monitoring the Basin Head MPA are primarily in stage 3 (validity and feasibility assessment through further data collection and analysis) or stage 4 (ready for integration into long term monitoring; Figure 2). Some indicators require entirely new datasets or approaches (stage 2) and require targeted research for further development, with a priority given to the core monitoring indicators. Ongoing targeted research seeks to identify thresholds for monitoring, with a focus on the core indicators of temperature and complementary genomic structure of the BHIM. Several sources of complementary data have been identified such as nutrient loading, continuous monitoring of some environmental parameters (e.g. salinity, water levels), and survey data (e.g. sediment characteristics). Several years of data collection and analysis are required to pass all proposed indicators into stage 4 where they can be subjected to scientific peer-review (i.e., CSAS) and form the basis for a long-term monitoring plan. This monitoring approach is not meant to be prescriptive, but is intended to be adaptive as new data and better indicators become available dependent on funding, human resources, and regional priorities. Nonetheless, the monitoring approach presented here represents a significant checkpoint for the Basin Head MPA, providing renewed direction for monitoring moving forward.

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Table 1. Core ecological monitoring indicators for Basin Head Marine Protected Area. See Figure 2 for status stage definitions.

Conservation objective	**Operational objective**	**Indicator(s)**	**Starting reference point**	**Threshold**	**Survey(s)**	**Frequency**	**Stage**
1. Maintain the environmental quality supporting Basin Head Irish Moss	*a. Monitor for increases in the proportion of time spent at stress **temperature** thresholds, and the frequency and duration of heatwave events*	Proportion of time spent at 20–24 °C, 24–28 °C, and >28 °C; cumulative hours and longest time span spent at 20 °C and 28 °C	2012 with sporadic earlier time points and some gaps in data	20°C (stress) and 28°C (mortality) for BHIM and Blue Mussel	DFO Science	Annual	4
	*b. Monitor for increases in the proportion of time spent and longest continuous time spent at **dissolved oxygen** stress thresholds*	Proportion of time spent and longest continuous time spent at DO readings < 4 mg/L, <2 mg/L, and >120% supersaturation	2016	4 mg/L for fish; 2 mg/L for invertebrates; 120% for supersaturation	DFO Science	Annual	4
2. Maintain the physical structure of the ecosystem	*a. Monitor for changes in the amount and locations of **suitable habitat** (based on hydrodynamic modelling)*	Suitable habitat (m^2); location(s) of suitable habitat	2017	Suitable habitat (m^2) TBD; any significant changes in the location of suitable habitat	DFO Science	Every 5 years or earlier as needed	2
3. Maintain health (abundance, size, and coverage) of Basin Head Irish Moss	*a. Monitor for declines in **Irish moss** abundance, size, and coverage*	Irish Moss abundance, size, coverage (m^2)	2015 (sporadic earlier time points)	TBD	Currently DFO MPC swath surveys	Annual	4
	*b. Monitor for decreases in **Blue Mussel** abundance*	Blue Mussel abundance	2018	TBD	Currently DFO MPC swath surveys	Annual	4

Conservation objective	Operational objective	Indicator(s)	Starting reference point	Threshold	Survey(s)	Frequency	Stage
4. Maintain overall ecological integrity of the Basin Head lagoon and inner channel	*a. Monitor for changes to abundance and **diversity** of fish and benthic invertebrates year over year*	Richness, Shannon's Diversity Index, Non-metric Multidimensional Scaling	2012	Any significant year on year shift in community composition (PERMANOVA)	DFO Community Aquatic Monitoring Program Benthic sampling	Annual	3
	*b. Monitor for new and known **AIS***	Novel AIS detections	2018	Any new AIS	DFO Aquatic Invasive Species (AIS) Biofouling Monitoring Dataset	Annual	3
	*c. Monitor for changes in **Ulva** density or biomass*	Mean coverage (m^2)	2019	TBD	Currently DFO MPC swath surveys	Annual	2

Table 2. Ongoing targeted research and complementary surveys relevant for ecological monitoring of the Basin Head Marine Protected Area.

Organization	Survey/dataset	Monitoring type	Reference point	Potential indicator(s)	Frequency
Maintain the environmental quality supporting BH Irish Moss					
National Research Council	Irish Moss temperature threshold(s)	Targeted research	None	Lethal temperature limit	NA
DFO Science	BHIM restoration	Complementary	2015	BHIM restoration numbers	Annual
Souris and Area Branch of the PEI Wildlife Federation (SAB)	Swath surveys	Complementary	2018	Eelgrass coverage	Annual
DFO Science	Nutrient data	Complementary	2019	Nitrate loading	Annual
Agriculture and Agri-Food Canada	Nutrient data	Complementary	1981	Residual Soil Nitrogen Indicator	Every 3 years
DFO Science	Probes data	Complementary	2016	Salinity, Water Level	Annual
Maintain the physical structure of the ecosystem					
DFO Management	Salt marsh erosion	Complementary	2020	Erosion rates	Annual
Maintain health (biomass and coverage) of BH Irish Moss					
DFO Science	Irish Moss genomic structure	Targeted research	TBD	Irish moss genomic uniqueness	TBD
Maintain overall ecological integrity of the BH lagoon and inner channel					
DFO Science	eDNA surveys	Targeted research	2024	Community composition (fish and invertebrates)	Annual
DFO Science	CAMP vegetation surveys	Complementary	2012	*Ulva* coverage; eelgrass coverage; sediment classification	Annual

Organization	Survey/dataset	Monitoring type	Reference point	Potential indicator(s)	Frequency
Souris and Area Branch of the PEI Wildlife Federation	Green Crab Removal Program	Complementary	2019	Catch Per Unit Effort (CPUE)	Annual

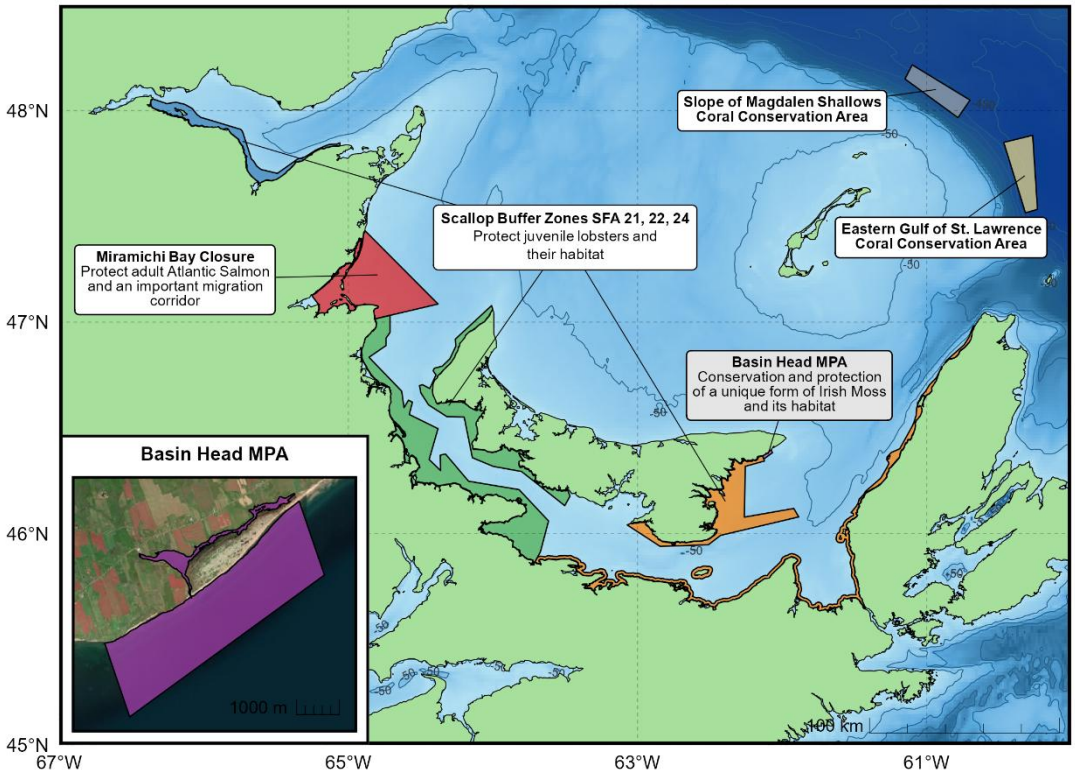


Figure 1. Conservation areas in the southern Gulf of St. Lawrence managed by DFO Gulf Region. Area-based conservation measures are denoted by coloured polygons.

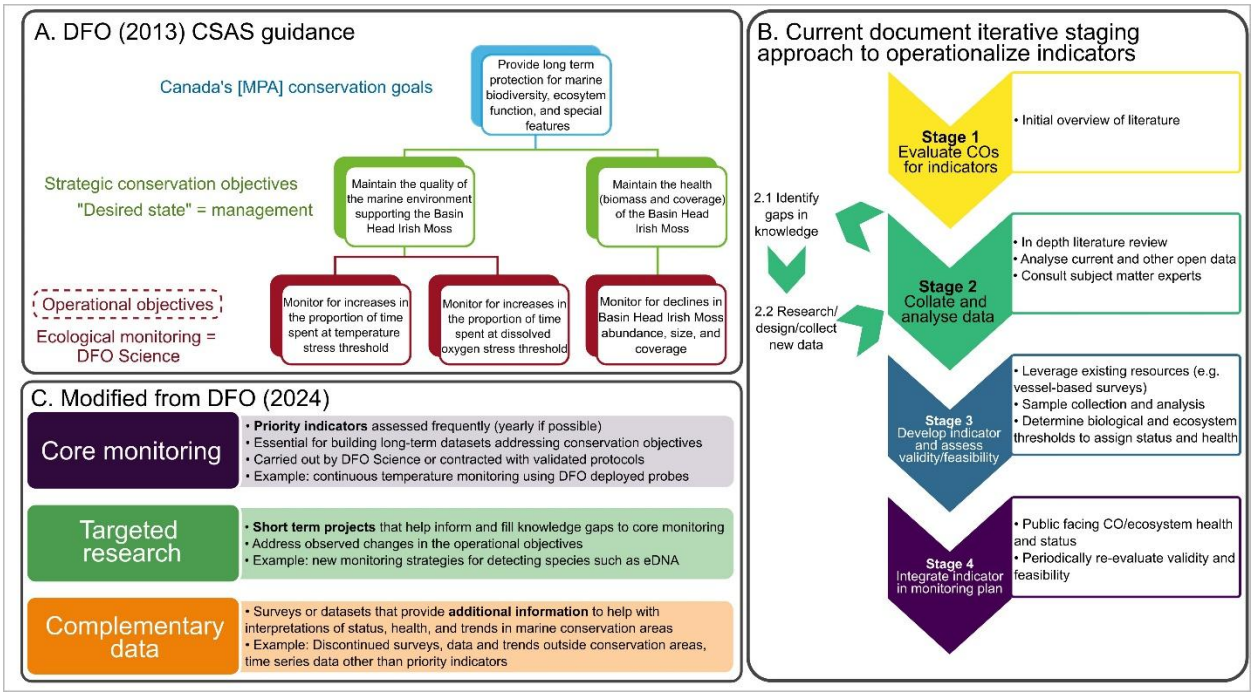


Figure 2. Conceptual approach to ecological monitoring, including A) how conservation objectives are unpacked from national to site level objectives, B) categories for data types used in monitoring, and 3) stages to developing indicators for ecological monitoring.

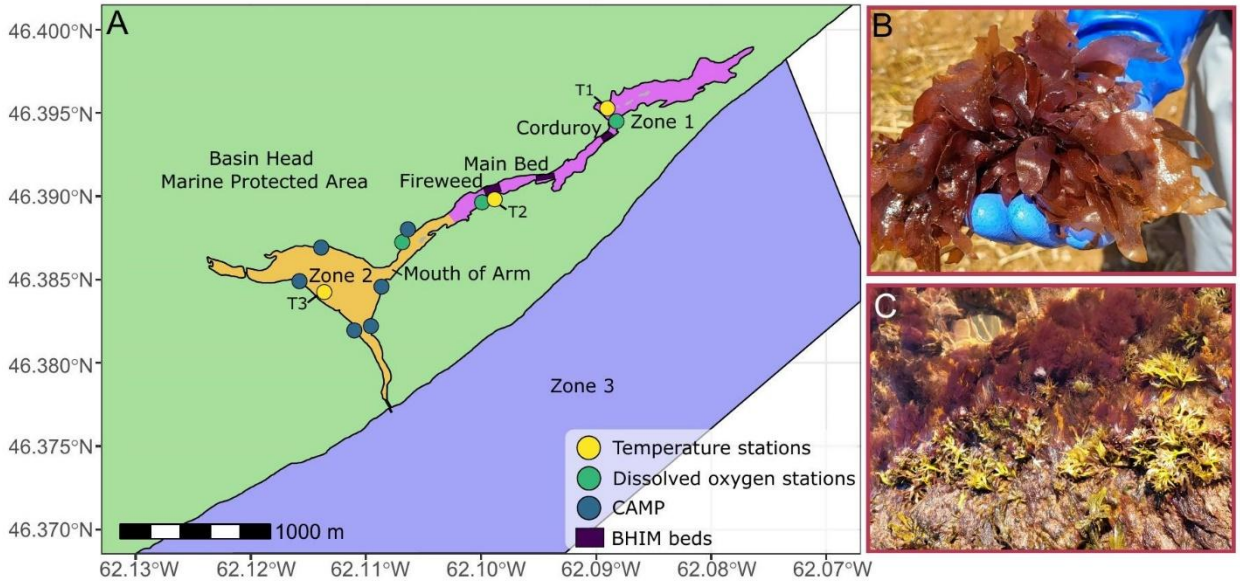


Figure 3. (A) Map of Basin Head site locations and pictures of (B) "Basin Head" and (C) "Coastal" (green coloration) morphotypes of Irish Moss. CAMP=Community Aquatic Monitoring Program, BHIM=Basin Head Irish Moss. T1–T3=temperature logger locations.

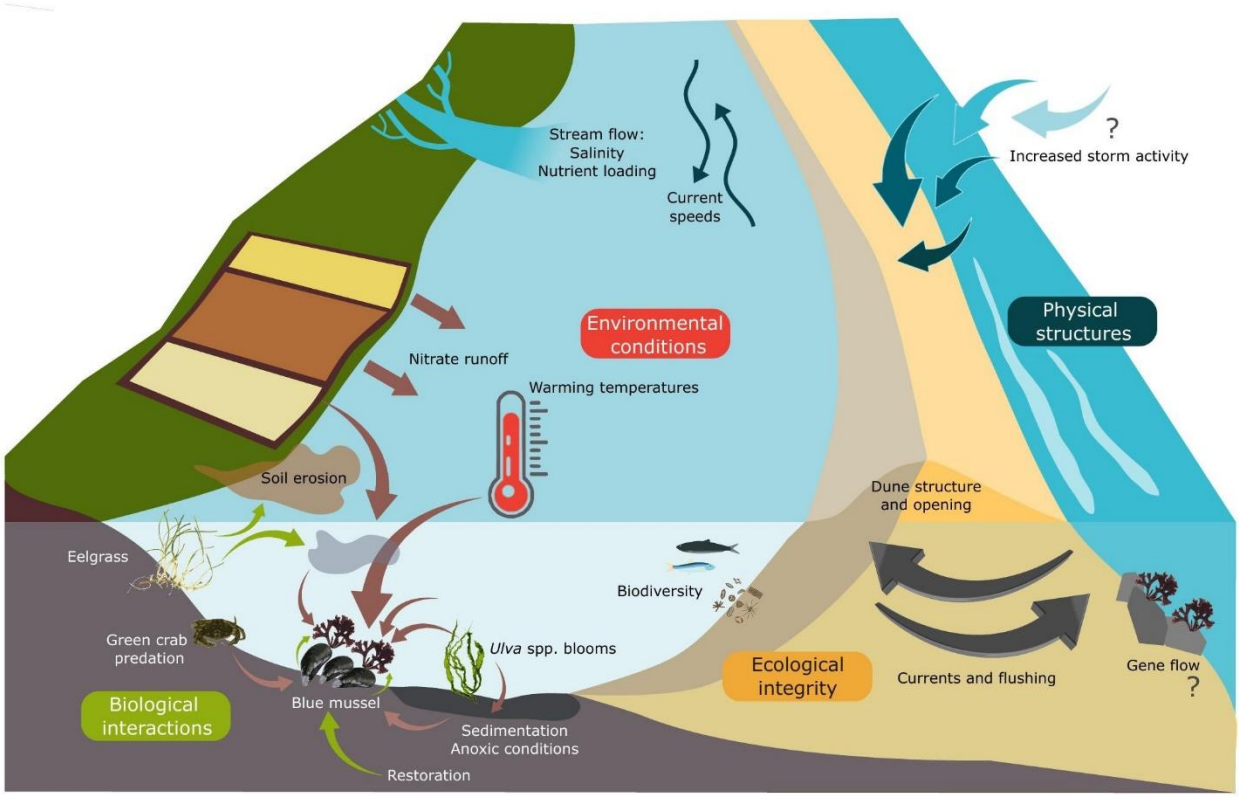


Figure 4. Conceptual diagram of pressures impacting Basin Head Marine Protected Area Irish Moss and ecosystem.

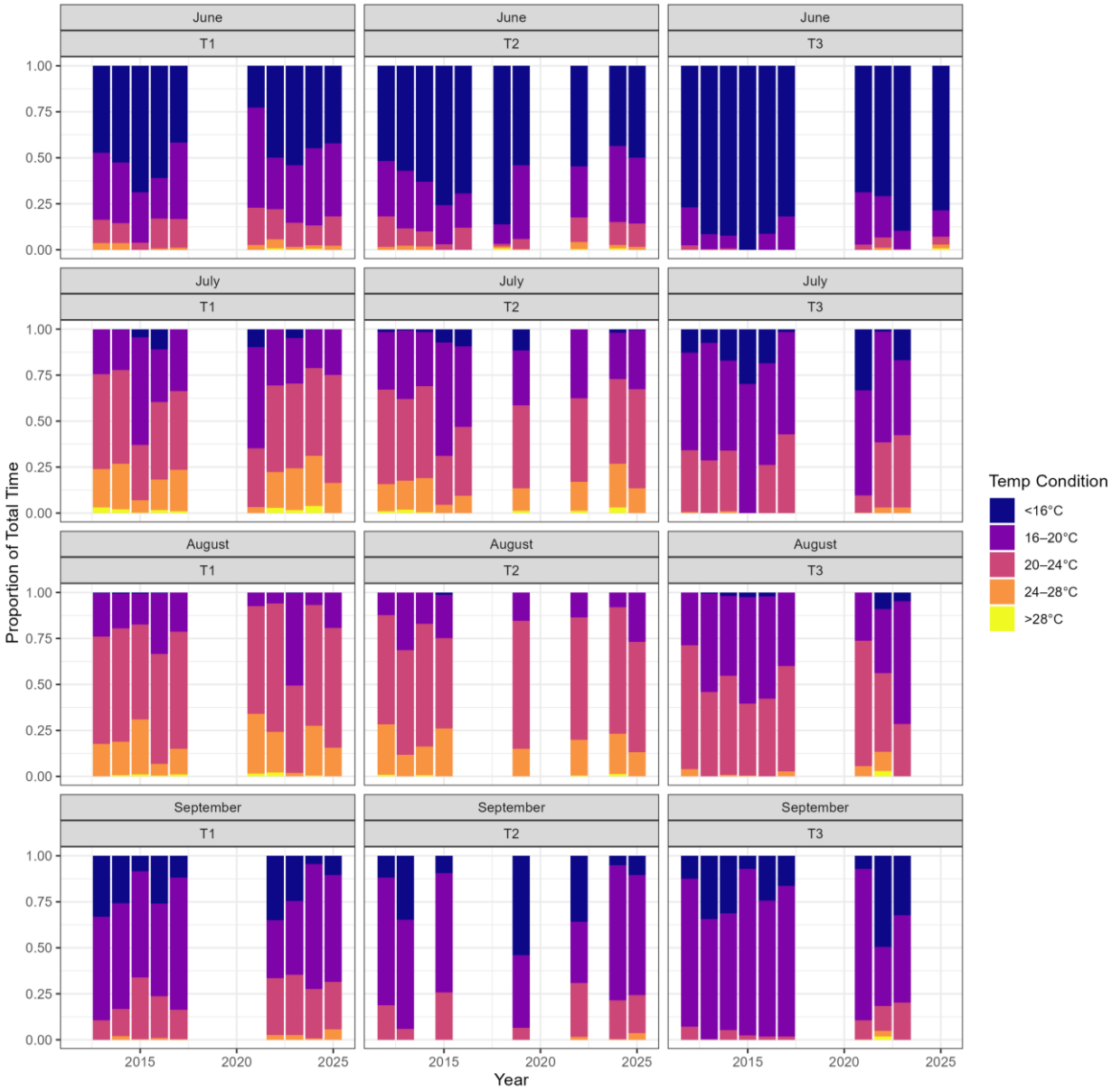


Figure 5. Proportion of time spent at various temperature thresholds throughout summer months in Basin Head Marine Protected Area from 2012–2025. Note, missing bars are due to missing data. T1=Corduroy, T2=Main Bed, and T3= Zone 2 Lagoon (Figure 3).

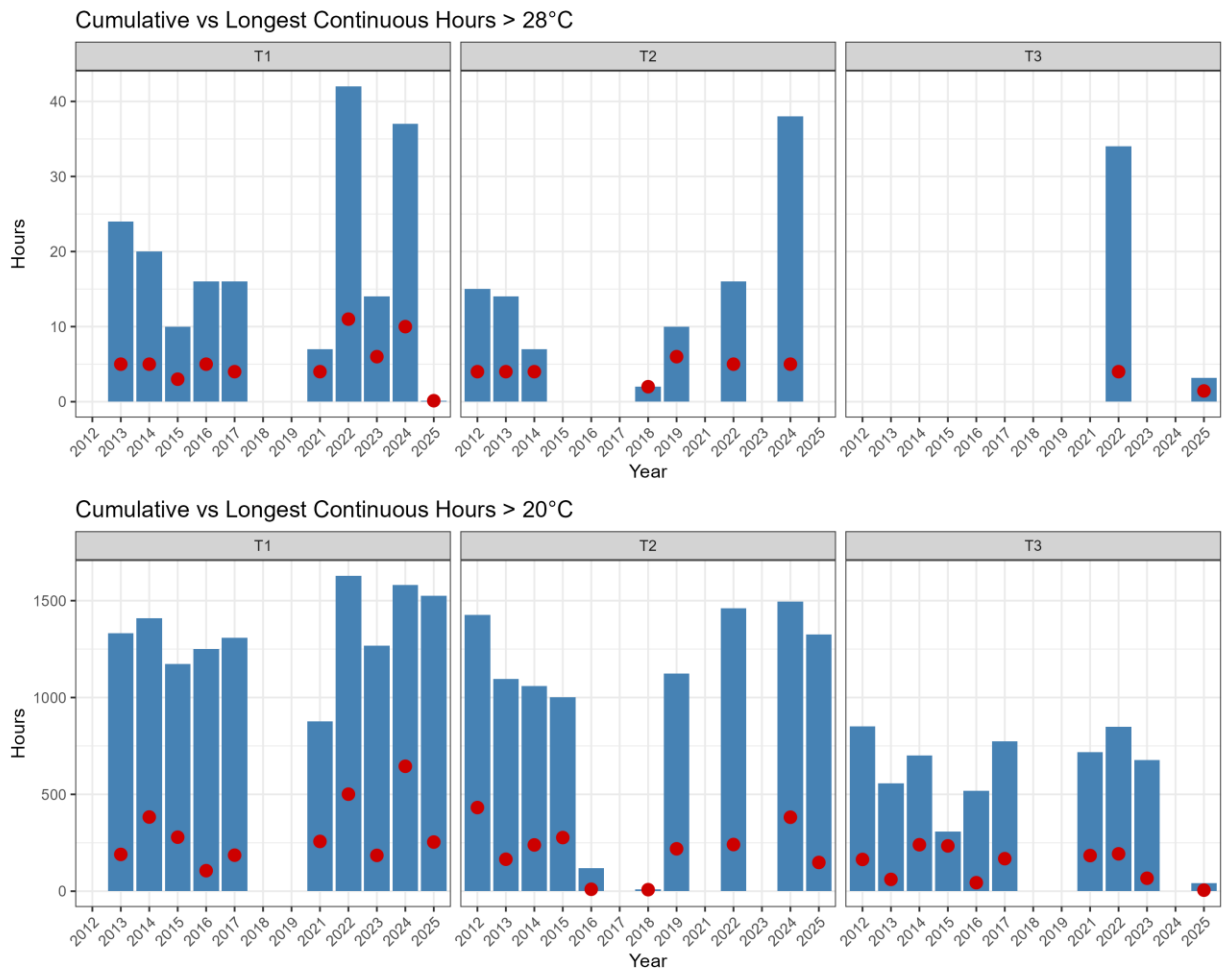


Figure 6. Cumulative (bars) and longest time span (indicated by red dots) spent above 20°C and 28°C by year and site in Basin Head Marine Protected Area from 2012–2025. T1=Corduroy, T2=Main Bed, and T3= Zone 2 Lagoon (Figure 3).

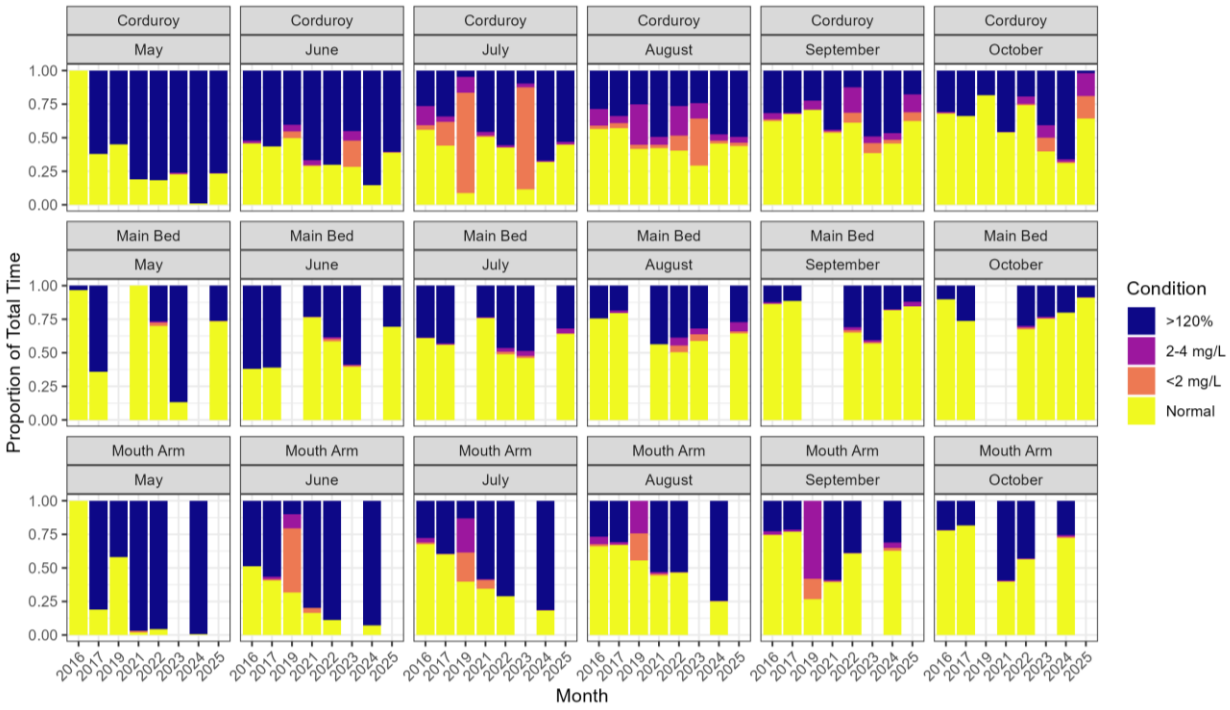


Figure 7. Time spent at various dissolved oxygen categories, per site-month combination, in Basin Head Marine Protected Area from 2016–2025.

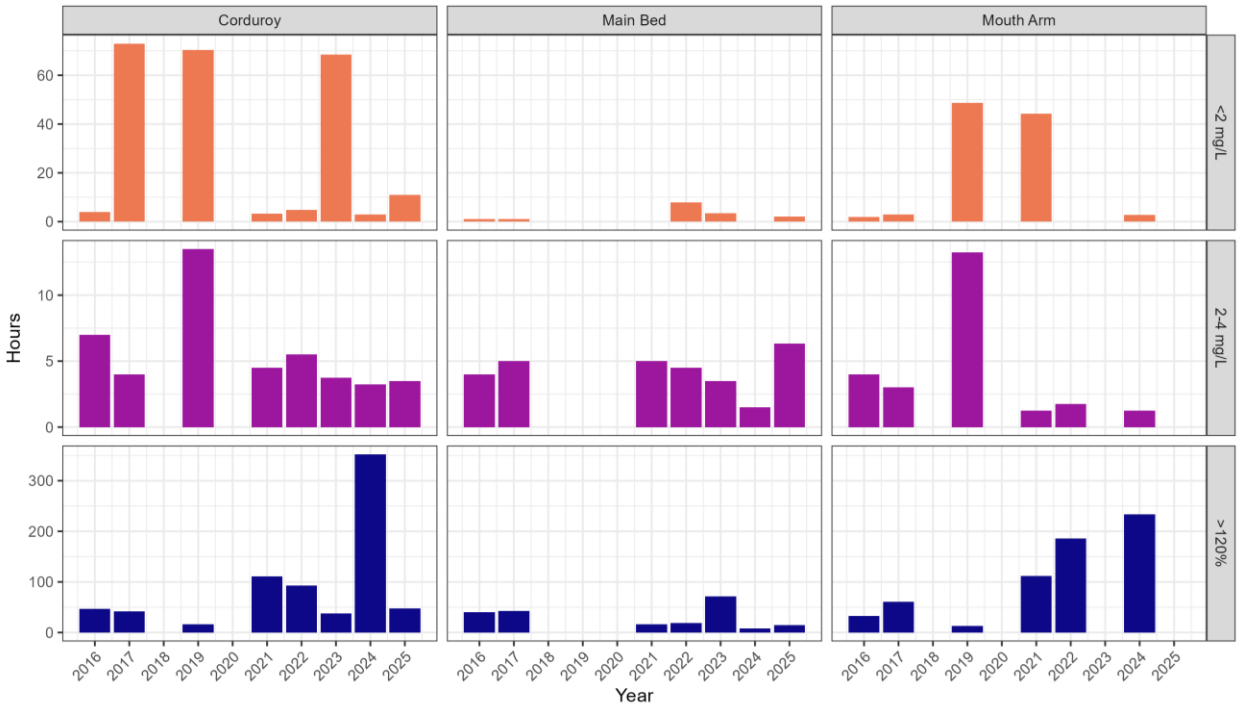


Figure 8. Longest recorded runs of Dissolved Oxygen conditions from Basin Head Marine Protected Area from 2016–2025.

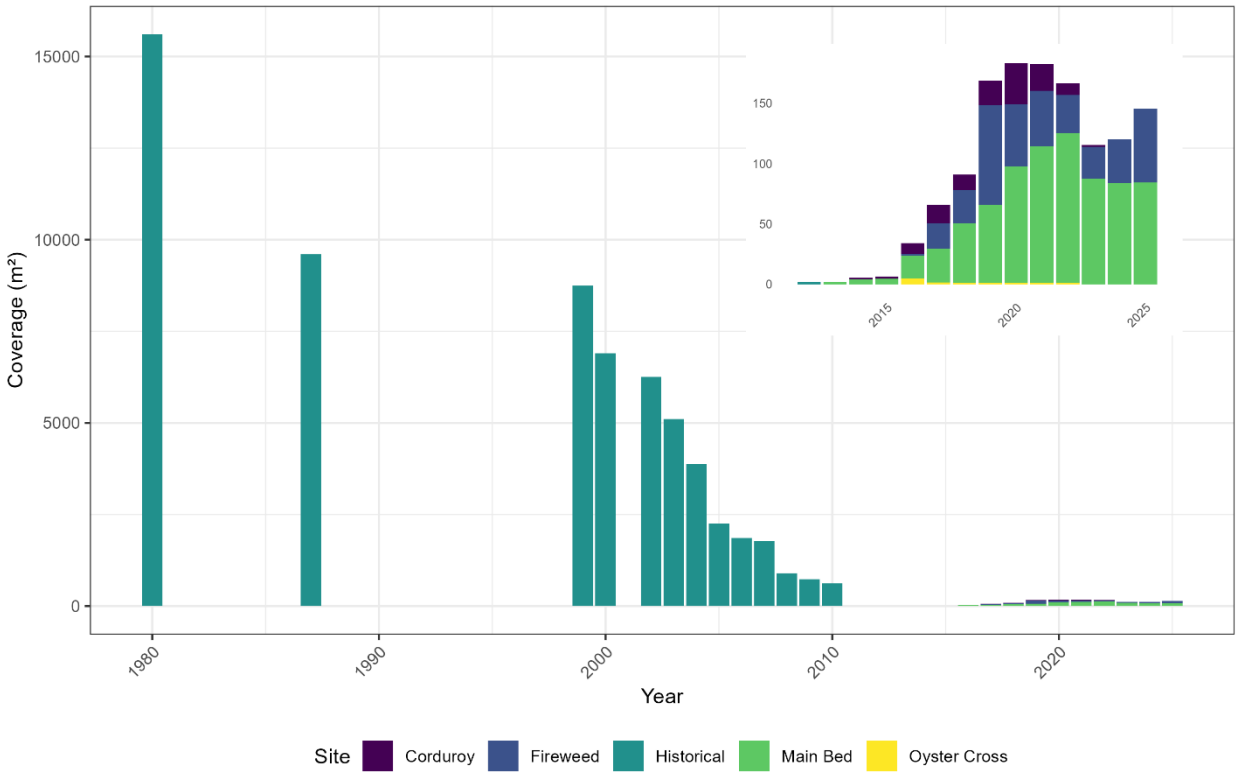


Figure 9. Historical coverage of Basin Head Irish Moss within the Basin Head Marine Protected Area from 1980–2025. Note, the Oyster Cross bed no longer exists, and is not depicted in Figure 3. The inset (top right) depicts coverage from 2012-2025.

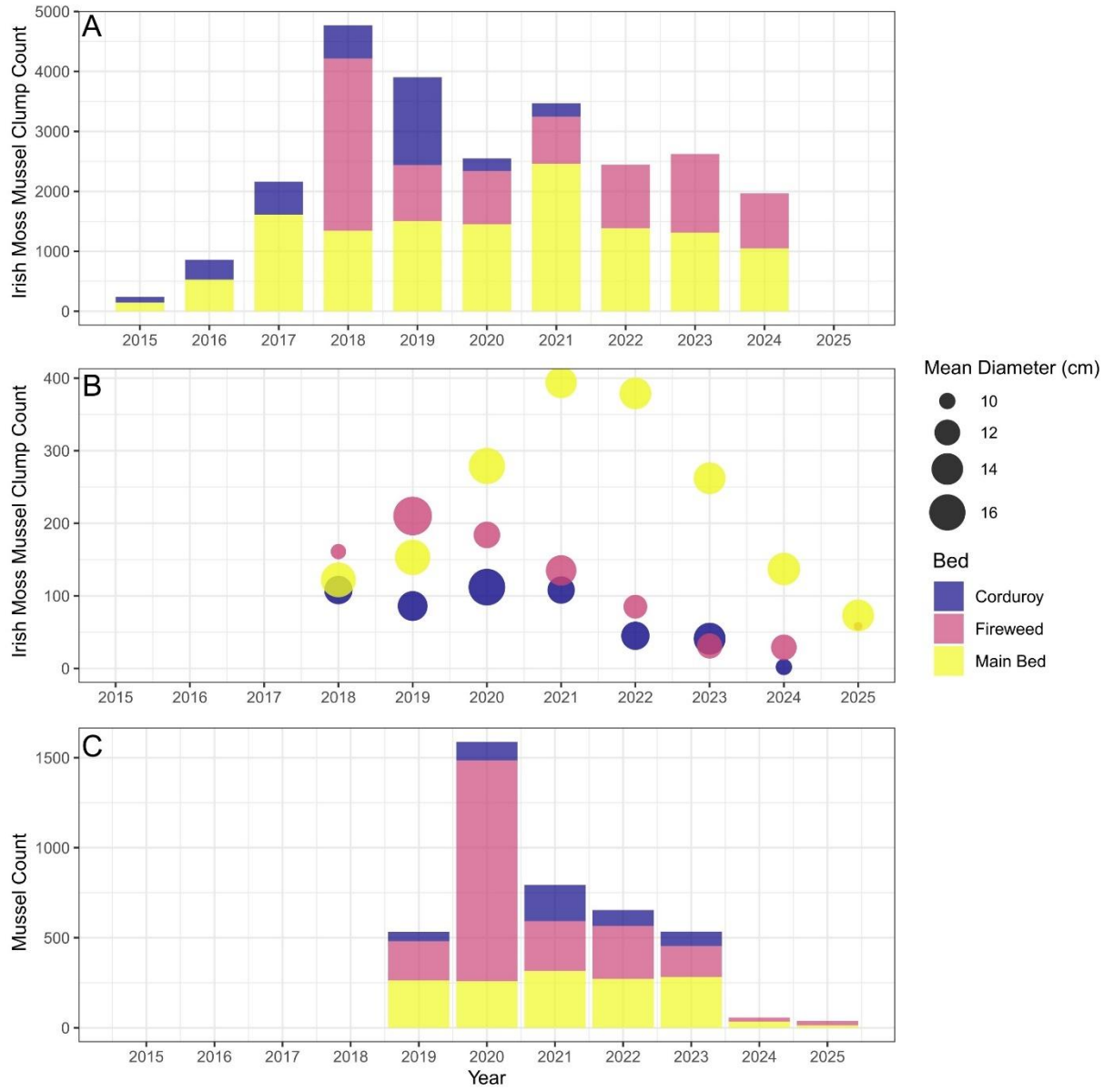


Figure 10. (A) Restoration clump counts, (B) abundance and size distribution of Basin Head Irish Moss, and (C) counts of Blue Mussel in Basin Head Marine Protected Area from 2015–2025.

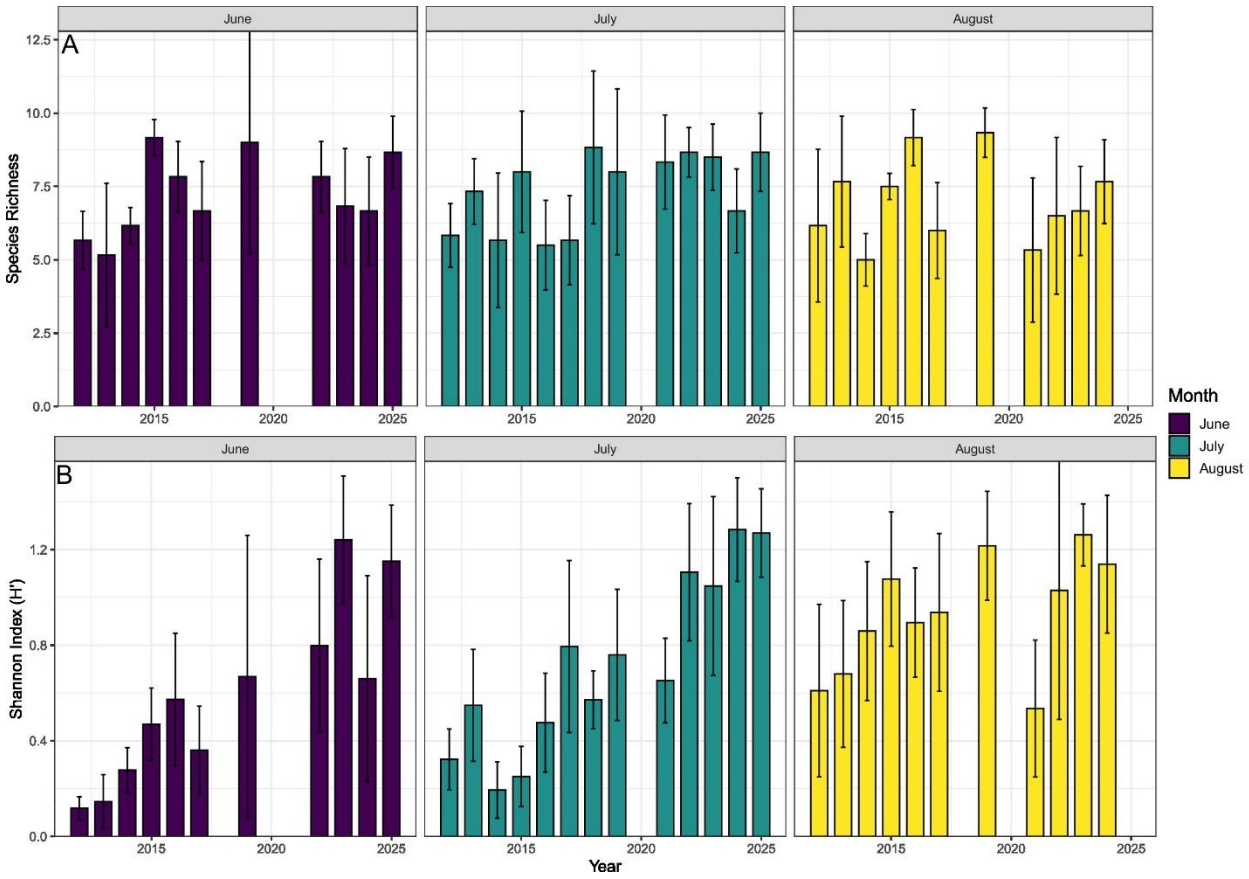


Figure 11. (A) Species richness and (B) Shannon's index based on Community Aquatic Monitoring Program data from Basin Head Marine Protected Area from 2012–2024.

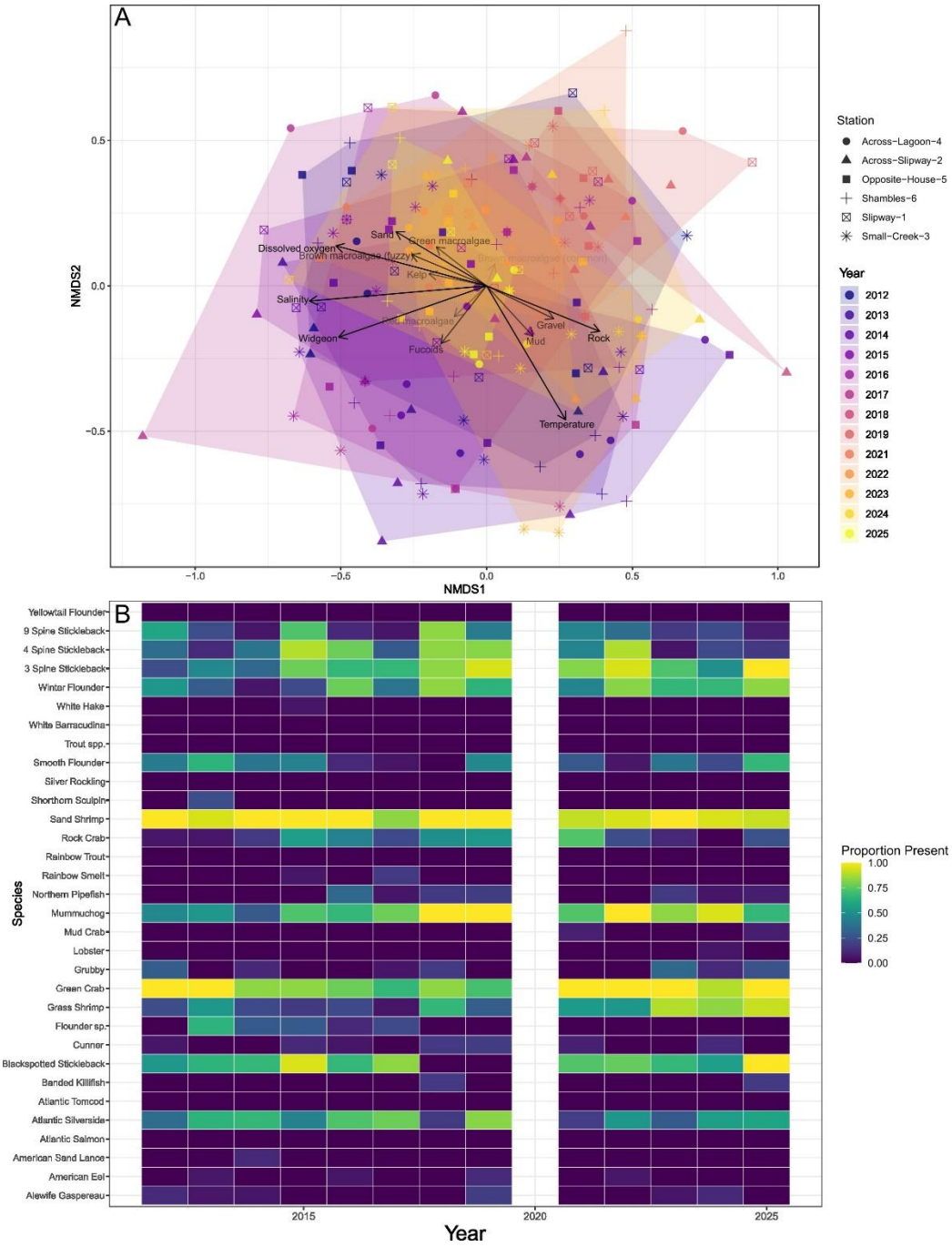


Figure 12. (A) Non-metric multidimensional scaling and (B) heatmap of Community Aquatic Monitoring Program data from Basin Head Marine Protected Area, 2012-2025. Data are analysed as presence-absence data from 5 lagoon stations and 1 main arm station for the months of June-August. Each point represents a sample taken at a given station, month, and year combination. The arrows represent the contribution of environmental vectors fit to the non-metric multidimensional scaling results; faded (non-significant) to solid (significant) text represent significance of contributions. Permutational multivariate analysis of variance indicates a significant effect of year, though tests for homogeneity of dispersion indicate this assumption is not met. See figure 3 for site locations. The heatmap of proportion present refers to the proportion of stations a given species was recorded at in a given year. Note 2020 is missing due to covid circumstances.

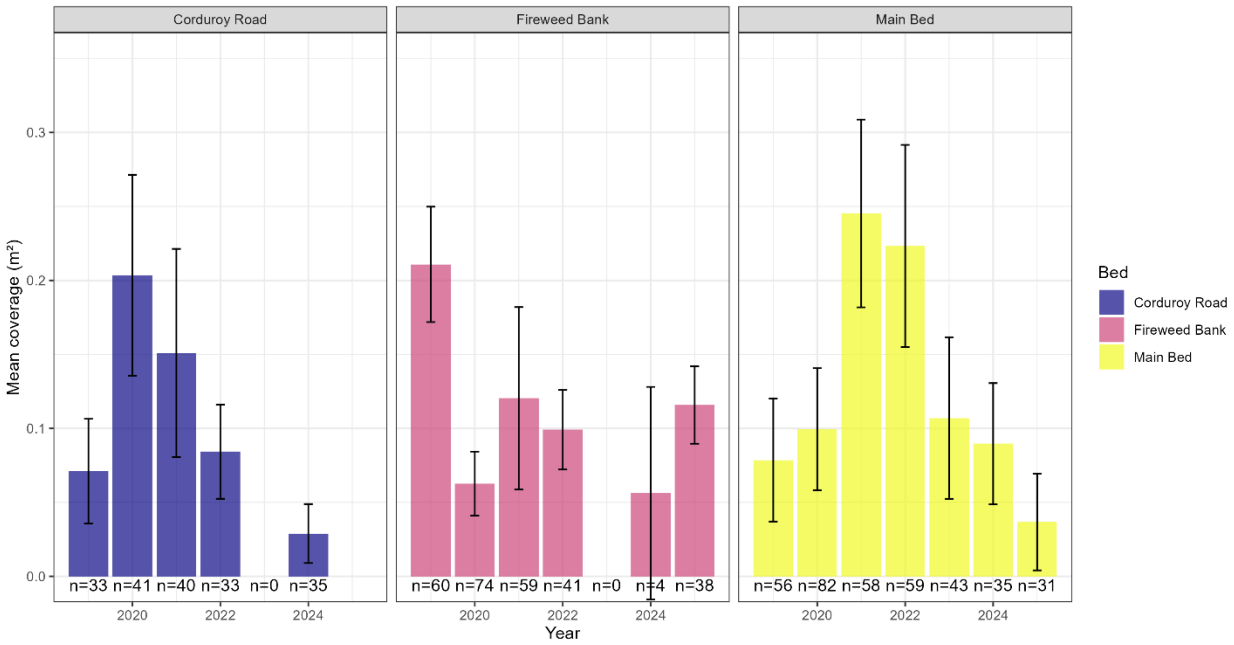


Figure 13. Prince Edward Island Wildlife swath survey data for Ulva coverage from Basin Head Marine Protected Area from 2019–2025. Error bars represent ±2 standard errors. Sample sizes refer to the number of observations.

9. APPENDIX I

Table S1. List of potential indicators qualitatively evaluated. DFO (2013) provides guidance on selection criteria for indicators, which include sound theoretical basis, ease and accuracy of measurement (measurable), availability of historical data (10-20 years), suitable sensitivity (correspondence between change in indicator and pressure), suitable responsiveness (signal to noise ratio), suitable specificity (ability to disentangle multiple pressures), suitable public awareness (ease of comprehension to non-specialists), and reasonable cost-effectiveness. Each criteria was assessed using currently available information and methods for evaluating each indicator; this can change as research and new technologies evolve. Indicators with the highest scores for each CO (usually of 6 or greater) were selected for monitoring (in green); indicators below this threshold (in yellow) may still be explored for suitable future applications. na=not evaluated (at the time of this report).

	Criteria								Score
Indicator	Theoretical basis	Measura-ble	Historical data	Sensitivity	Responsive-ness	Specificity	Public awareness	Cost-benefit ratio	
CO1. Maintain the environmental quality supporting BH Irish Moss									
Temperature (°C)	•	•	•	•	•	•	•	•	8
Dissolved oxygen (mg/L; %)	•	•	•	•	•	•	•	•	8
Salinity (PSU)		•	•		•		•	•	5
Nutrients (concentration, loading)		•	•				•		3
pH		•	•				•	•	4
Turbidity		•	•						2
Chlorophyll a		•	•						2
CO2. Maintain the physical structure of the ecosystem									
Suitable habitat (m^2)	•		•	•	•		•	•	6
Current speed (m/s)	•			NA	•	•	•	•	5
Sediment depth of penetration (cm)		•	•	NA	•	NA	•	•	5

	Criteria								Score
Indicator	Theoretical basis	Measura-ble	Historical data	Sensitivity	Responsive-ness	Specificity	Public awareness	Cost-benefit ratio	
Water depth (cm)	•						•	•	3
Marsh erosion rates			•				•		2
CO3. Maintain health (biomass and coverage) of BH Irish Moss									
Irish Moss abundance/size/coverage (m^2)	•		•	•		•	•	•	6
Blue Mussel abundance	•		•	•		•	•	•	6
Green Crab abundance	•	•	•	•			•		5
CO4. Maintain overall ecological integrity of the BH lagoon and inner channel									
Species richness/Shannon's diversity Index (CAMP)	•	•	•	•	•		•		6
Community composition (CAMP)	•	•	•	•	•		•		6
Presence of aquatic invasive species	•	•	•			•	•	•	6
Ulva coverage (m^2)	•		•	•		•	•	•	6
eDNA fish and invertebrates	•			•	na		•	•	4
Eelgrass bed coverage (m^2)			•				•		2

Table S2. List of workshop participants (DFO-Gulf Region), held at the Gulf Fisheries Centre in Moncton, New Brunswick, November 18th, 2025.

Name	Section	Area of expertise
Trevor Bringloe	Marine Conservation Science	Genomics, Phycology
Daniel Bourque	Marine Conservation Science	Ecosystem monitoring, conservation
Venitia Joseph	Marine Conservation Science	Ecosystem monitoring, conservation
Tanya Arseneault	Marine Conservation Science	Ecosystem monitoring, conservation
Curtis Dinn	Marine Conservation Science	Ecosystem monitoring, conservation
Alain Mallet	Marine Planning and Conservation	Management, conservation
Madelyn Stewart	Marine Planning and Conservation	Management, conservation
Thomas Guyondet	Aquaculture and Coastal Ecosystems	Hydrodynamic modelling
Jeffrey Barrell	Aquaculture and Coastal Ecosystems	Estuarine environmental biology
Luc Comeau	Aquaculture and Coastal Ecosystems	Molluscan biology, aquaculture

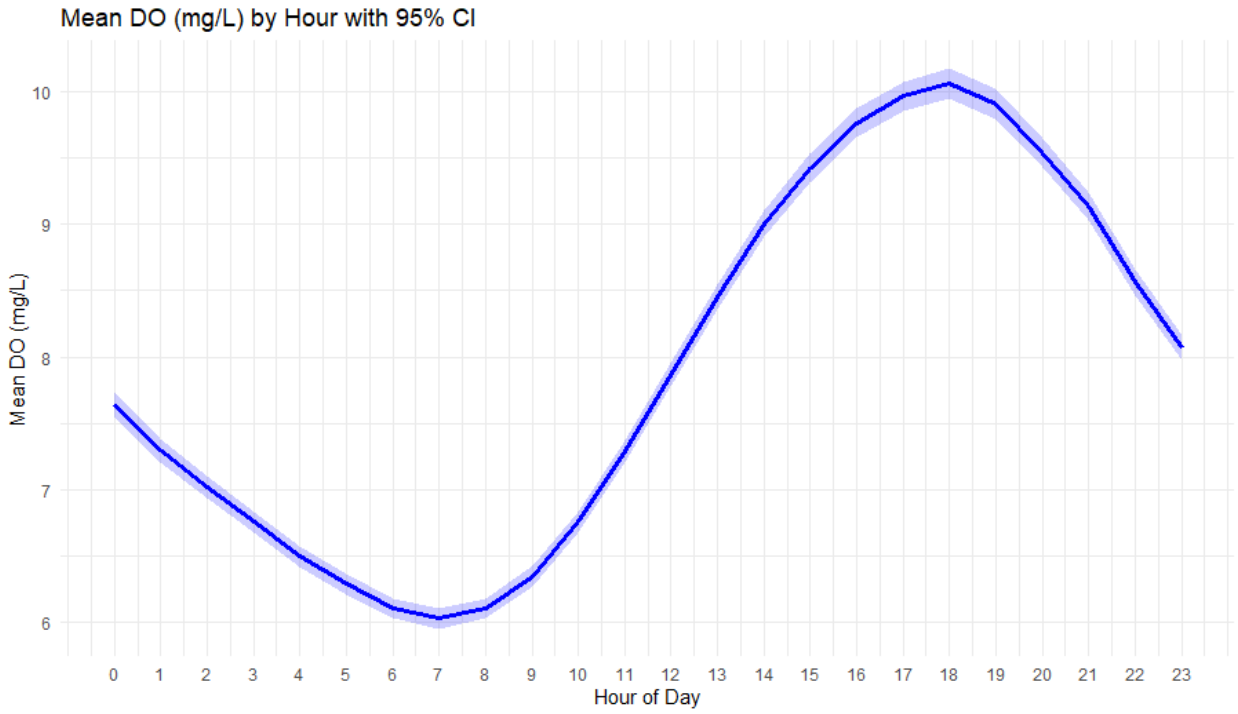


Figure S1. Fluctuations in dissolved oxygen readings in Basin Head Marine Protected Area over a 24-hour time period. Recordings are from 2016–2023.

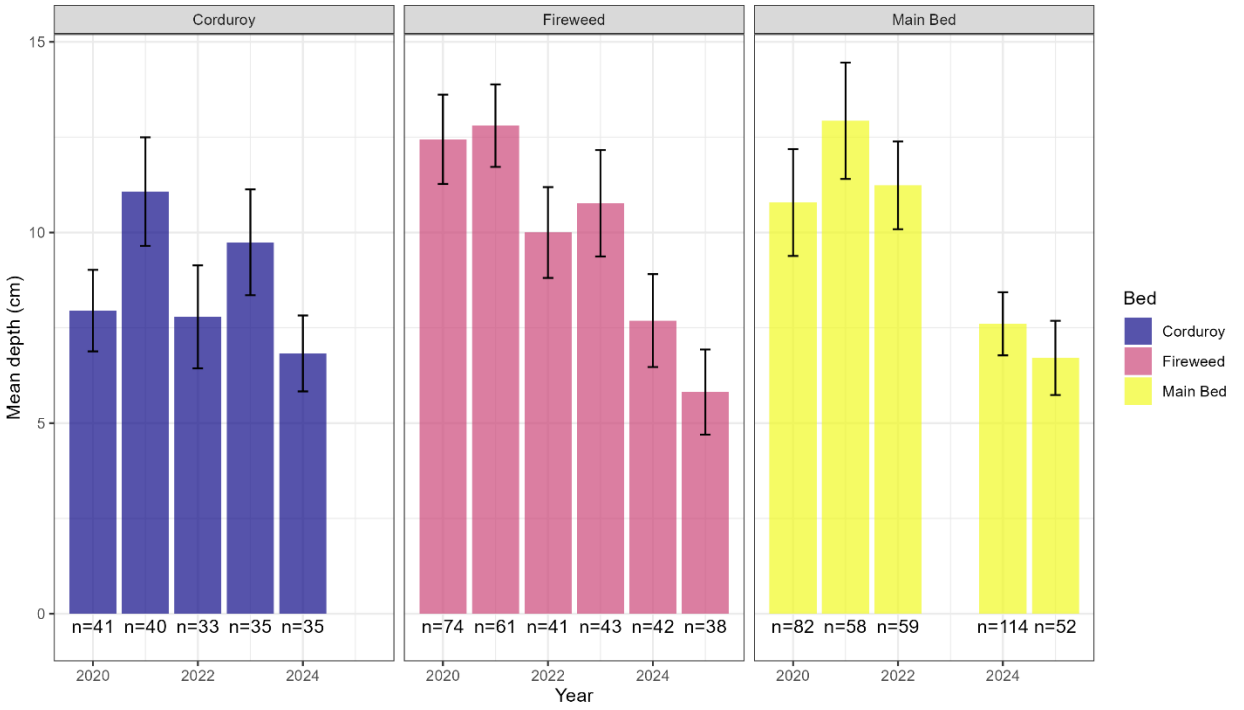


Figure S2. Sediment depth of penetration (cm) at various beds within Basin Head Marine Protected Area, 2010-2024. Error bars represent ±2 standard errors.