A semi-quantitative analysis of spatial-temporal distributions of soft corals (*Alcyonium sp., Gersemia sp.)* and Basket Stars (*Gorgonocephalus sp.)* in the Passamaquoddy Bay region creating baseline data for informing management strategies.

By

Aidan Joshua Vincent McDiarmid
HBASc Environmental Sustainability

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

of

Master of Marine Management

At

Dalhousie University

Halifax, Nova Scotia

December 2024

ACKNOWLEDGEMENTS

This project would not have been possible without the help and mentorship of many amazing people who have contributed, inspired, and encouraged me throughout its development. These amazing individuals have deeply reinforced my passion for the ocean, inspiring me to pursue a career in marine science.

First and foremost, I would like to thank my incredible research supervisor, Dr. Claire Goodwin, for her endless patience, enthusiasm, and extraordinary expertise in her field. This project was only possible with your guidance. Working with you has been a tremendous privilege, and you have inspired me to take on challenges bigger than I could have ever imagined, encouraging me to continue exploring the oceans as a scientific diver.

I would like to thank Dave Davison, who trained me from my first breath underwater to the beginning of my career as a dive professional. SCUBA has taken me to some of the most amazing places I have ever seen. This project would not have been possible without your dedication as a dive instructor, ensuring my skills and training were sufficient to undertake the challenges of conducting science underwater, giving me the confidence to keep myself and my team safe.

I would like to thank Dr. Brandon Barton for his expertise in ecology and willingness to be the second reader for this project. Your enthusiasm as an educator has encouraged me to continue asking questions and learning about the world around us.

To soon-to-be “Dr.” Margaret Cassidy. Your unwavering support and positivity were exactly what I needed to finish this project. Thank you for being the best dive buddy ever.

My sincerest gratitude to Connie and Claire. This project would not have been possible without your incredible dive records, knowledge and dedication as divers and scientists.

I would also like to thank Dr. Hannah Harrison, Dr. Ramon Filguiera, Dr. Nanda Kanvilli, Dr. Victoria Tebrugge, and Dr. Richard Mocchia for their support and guidance.

As Jacques Yves Cousteau once said, “What is a scientist after all? It is a curious man looking through a keyhole, the keyhole of nature, trying to know what’s going on.”

McDiarmid. A. J.V. (2024). A semi-quantitative analysis of spatial-temporal distributions of soft corals (*Alcyonium* sp*., Gersemia* sp.) and Basket Stars (*Gorgonocephalus* sp.) in the Passamaquoddy Bay region creating baseline data for informing management strategies. Huntsman Marine Science Center (HMSC).

Abstract:

Understanding the habitat range shifts of benthic species is crucial for determining the health of marine ecosystems, planning and resource management. Monitoring as part of ecosystem-based management can be accomplished with the use of bioindicator organisms. This case-study focuses on recording the changes in spatial-temporal ranges of benthic invertebrates in Passamaquoddy Bay and the Western Isles using *Gorgonocephalus* sp., *Alcyonium* sp., and *Gersemia* sp. which are historically under-studied organisms. This study aims to create more comprehensive spatial-temporal records of these benthic invertebrates in Passamaquoddy Bay and the Western Isles by compiling historical records from multiple data sources. Having a more comprehensive perspective on how these species' ranges have shifted and tracking their presence in Passamaquoddy Bay over time will help inform planning and management strategies. Data sources used included; collaborative knowledge observations from Huntsman affiliates, DFO drop camera surveys, records from GBIF and dive surveys. Based on the records collected from secondary source data and most of the recent benthic habitat surveys conducted in this study, it is likely that *Gorgonocephalus* sp. and *Gersemia* sp. are extirpated from Passamaquoddy Bay and the Western Isles as well as a decrease in the abundance of *Alcyonium* sp.

Introduction:

Passamaquoddy Bay is a contender for one of the most challenging marine ecosystems in the world to conduct scientific diving, with extreme tidal ranges, very low visibility, down currents and cold water temperatures. While difficult to study, these benthic habitats are home to many benthic invertebrates which thrive in these conditions, including *Gorgonocephalus* sp., are part of the order Ophiuroidea (Neves et al., 2020), and belong to the family Gorgonocephalidae, which are found globally (Stöhr, 2024). *Gorgonocephalus* sp. are found in the cold waters of the northern hemisphere including Canada's east and west coasts, relying on highly specialized branching arms evolved to filter plankton and krill from the water column while allowing for clinging and crawling but (Rosenberg et al., 2005). Populations of *Gorgonocephalus* sp. in Labrador, Canada, were found to be associated with soft coral habitats including varieties of *Gersemia* sp. and *Alyconium* sp.; Evidence suggests a relationship between the juvenile stage of *Gorgonocephalu*s sp. and soft corals early in its lifecycle, with the larval *Gorgonocephalus* sp. residing within the *Gersemia* sp. polyps for a portion of their development (Neves et al, 2020). Anecdotal evidence found mature *Gorgonocephalus* sp. and *Gersemia* sp. occupying the same habitats during surveys of Saguenay Fjord conducted in 2024 by the Huntsman Marine Science Center's scientific dive team (A. McDiarmid, unpublished fieldnotes, 2024). Based on the relationships of these species, all are being included in this study investigating the historical ranges of *Gorgonocephalus* sp., *Gersemia sp.* and *Alcyonium* sp. in Passamaquoddy Bay.

Marine Management Problem:

Ecosystems, especially marine ones, are inherently complex and ever-changing, making them difficult to accurately model and study. This inherent complexity slows the creation of scientific knowledge and therefore advice for decision-makers (Harvey et al., 2020). Within a Canadian context, fisheries management has historically focused on quantitative measuring of fishery productivity only for commercially valuable species, leading to the collapse and decline of many fish stocks within Canadian territorial waters and abroad (Stacey et al., 2020). The absence of background knowledge of habitat health and benthic community compositions has led to what is commonly described as shifting baselines, where successive generations gradually accept degraded ecosystems without full awareness of the cumulative losses of biodiversity that have occurred over time (Pauly, 1995). Shifting baselines are particularly concerning for scientists and marine managers responsible for maintaining ecosystem sustainability, often equipped with datasets reaching back only a few decades prior. Historic data is also limited as many underwater surveying techniques like SCUBA diving and remotely operated vehicles (ROVs) becoming more accessible in recent decades, well after human impacts have already occurred (Thurstan et al., 2015; Parsons et al., 2015). Gaps in long-term knowledge of changes occurring in the ecosystems over time could severely restrict the ability of scientists and marine managers to understand the historical structure and health of the ecosystem which could potentially influence management and recovery strategies (Thurstan et al., 2015). Undertaking management and recovery actions with shifted baselines could lead to overconfidence in an ecosystem's health or resilience to anthropogenic pressures in addition to underestimating what is needed to achieve sustainability or meet recovery targets as only species resilient to the pressures their habitat is experiencing persist (Holt et al., 2011; Klein et al., 2016; Thurstan et al., 2015). Assessing the true condition or robustness of ecosystems is dependent on determining the cumulative impacts of chronic disturbances and pollutants over time (Hiscock et al., 2005; Holt et al., 2011).

Studies focused on singular disturbance events or singular ecosystem pressures in isolation are limited in scope as studies like these do not incorporate the impacts of compounding and chronic real-world pressures that push environmental conditions beyond the tolerance range of the organisms inhabiting the ecosystems of interest (Holt et al., 2011) Simulated studies, while providing valuable insights, often have limited scope. For example, a study on bottom trawling using *Gersemia* sp. colonies from the Bay of Fundy found no significant impact from simulated trawling treatments (Henry et al., 2003). However, such studies like these fail to account for the combined effects of multiple stressors caused by activities like bottom trawling to an environment beyond physical contact with the benthic substrate, which include sediment resuspension, sediment compaction and changes to benthic biodiversity which can disproportionately affect sensitive indicator organisms (Morys et al.; 2021; Hiscock et al., 2003). As a result, only highly tolerant species may survive, leading to lasting changes in the ecosystem's species composition that when not considered could have major concerns for conservation (Hiscock et al., 2005; Thurstan et al., 2015).

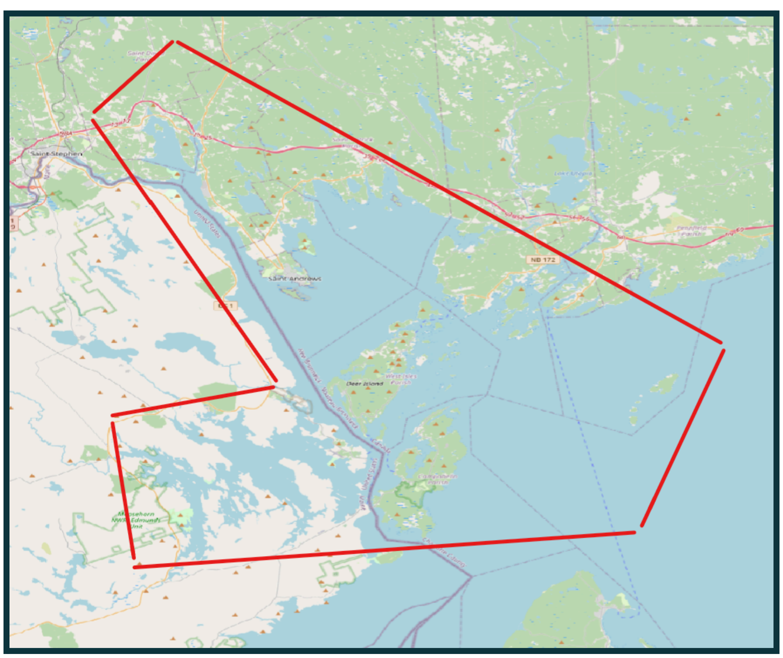
This is especially pressing for conservation efforts of species like *Gorgonocephalus* sp. as one of the major concerns surrounding the status of *Gorgonocephalus* sp. is a lack of data on the biology, lifecycle, role in benthic ecosystems, habitat preferences and large gaps in knowledge surrounding the spatial-temporal distribution of *Gorgonocephalus* sp. populations (Rosenberg et al., 2005; Neves et al.., 2020; Maine Government, 2016). Historically, *Gorgonocephalus* sp. populations have been found distributed abundantly throughout the lower Bay of Fundy but have experienced drastic decreases in population size, potentially leading to localized extirpation of *Gorgonocephalus* sp. in Passamaquoddy Bay for unknown reasons (Maine Government, 2016). Without extensive historical spatial-temporal data on the presence of *Gorgonocephalus* sp. in the region, it is hard to determine what pressures may have impacted *Gorgonocephalus* sp., causing its disappearance. This has potentially been the demise of many benthic invertebrate species in Passamaquoddy Bay as continuous anthropogenic impacts have been ongoing in marine ecosystems long before recorded scientific observation, including areas like the Bay of Fundy, where human activities have caused serious impacts to biodiversity over time (Buzeta, 2014). Marine ecosystems may be slow to respond to ecological pressures, potentially showing signs of disturbance in the present to events that may have occurred decades or even centuries ago (Buzeta, 2014, Jackson et al., 2001). Coupled with marine conservation methods generally employed in the past may unintentionally overlook damaged and deteriorated ecosystems, focusing on managing individual species populations, and potentially missing other indicators of ecosystem health (Buzeta, 2008; Jackson et al., 2001). Some of this uncertainty can be minimized with well thought out, long-term studies across the entirety of an ecosystems' trophic levels and biotic and abiotic factors helping create a more informed picture of dynamic ecosystem processes and the statuses of individual species (Harvey et al., 2020).

The data collected in this project contributes to the Department of Fisheries and Oceans (DFO) baseline monitoring project under the DFO public mandate of establishing a historical database of species compositions and documenting the current state of benthic habitats in Canada’s territorial waters including Passamaquoddy Bay (Fisheries and Oceans Canada, 2024). DFO acknowledges that geospatial and temporal data for vulnerable benthic species could be greatly improved. In a 2012 report, the DFO identified Passamaquoddy Bay’s ecosystems as environmentally and biologically significant areas (EBSA's), noted for their high species abundance and productivity but lacking the accurate habitat and geospatial data needed for further conservation efforts (Buzeta, 2008, 2013; McKay, 1978, 1979). These considerations have brought Passamaquoddy Bay forward as a candidate for the development of an MPA program within the Bay of Fundy (Fisheries and Oceans Canada, 2022). However, a better understanding of the composition of benthic habitats and how they have changed over time is crucial when planning conservation initiatives and undertaking ecosystem-based fisheries management (Harvey et al., 2020). Benthic habitats and species living in them are vital to marine ecosystems providing nutrient cycling, processes within the water column and heterotropic productivity, playing a consequential role in supporting ecosystem services and coastal fishing activities (Beisiegel et al., 2017, Fortune et al., 2023, Kritzer et al. 2016).

The importance of identifying species of interest to represent ecosystem health can be seen in documents like the European Union Water Framework Directive which serves as a key foundational document for the protection and restoration of aquatic ecosystems in addition to the sustainable use of water in Europe (European Commission, 2003). One of the most important aspects of the EU Water Framework Directive is its broad applicability, encompassing all bodies of water within the EU including both fresh and marine, demonstrating the benefits of integrated management for water resources and monitoring plans that rely on benthic invertebrates as a monitoring tool (European Commission, 2003).

Study Area

Passamaquoddy Bay is located along the southern shore of New Brunswick in the Bay of Fundy, bordering Maine. Separated from the greater Bay of Fundy is a complex archipelago of islands sheltering Pamaquoddy from the broader Bay of Fundy, creating significant eddies and currents as tides are funnelled through the narrow passages between islands. This unique environment is characterized by high nutrient mixing, including the largest tidal whirlpool in the western hemisphere near Deer Island, and historically high biodiversity of marine organisms (Bailey, 1957; Buzeta, 2014). Additionally, Passamaquoddy Bay is an estuary for the St. Croix River which is the dividing border between Canada and the United States and a large source of fresh water creating a brackish environment deeper within the Bay towards the river outlet into the Bay (FB Environmental, 2008). The Passamaquoddy Bay region of the Bay of Fundy has extensive historical records from biological surveys conducted by the Huntsman Marine Science Center and the Department of Fisheries and Oceans being home to Canada's first marine biological monitoring station founded in 1908, followed by the establishment of the Huntsman Marine Science Center in 1969 (Department of Fisheries and Oceans, 2021a; Huntsman Marine Science Center, 2024). Based on these considerations, Passamaquoddy Bay and the Wolves Archipelago were selected as the study area as seen below in *Figure 1*.



(Figure 1: Study boundaries surrounding Passamaquoddy Bay and the Wolves Archipelago.)

The foundational surveys conducted by Art Mackay in 1978 did not include observations of *Gorgonocephalus* sp. around Grand Manan, excluding it from the study.

Research Questions:

The first goal of this study was to assess the practicality and potential of creating a more complete historical presence dataset of understudied benthic invertebrate species using historical observations from multiple sources, including both formal surveys and informal anecdotal reports. These historical species presence data support current ongoing baseline surveying work in the Passamaquoddy Bay and Western Isles region.

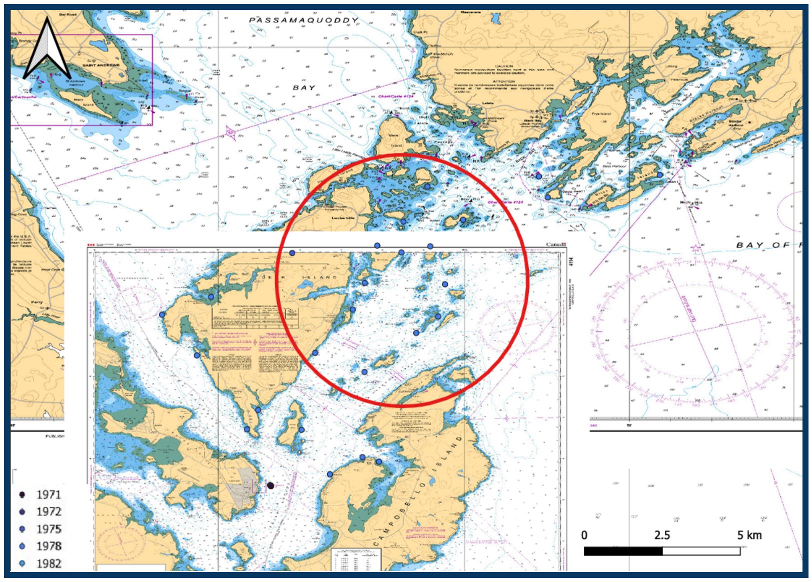
The second goal of this study was to conduct formal surveys to confirm anecdotal reports of a population decline for these understudied invertebrates and use these historical data to approximate when this decline occurred. That timeline allows us to identify potential environmental pressures and/or anthropogenic causes, better informing future monitoring and conservation efforts of these species.

Materials and Methods:

To address this research question of when and where *Alcyonium* sp., *Gersemia* sp. and *Gorgonocephalus* sp. have disappeared in Passamaquoddy Bay, a semi-qualitative analysis was conducted to collect spatial-temporal data for the three species of interest. Species observation criteria included a requirement for geospatial data and a year of observation. Based on these criteria, observations were compiled from multiple data sources including; The 1978-1979 Bay of Fundy Resource Inventory survey, GBIF database, DFO drop camera surveys, Huntsman Marine Science Center (HMSC) Scientific Trawl Data archives, collection records of *Gorgonocephalus* sp. from a study of their feeding mechanisms, with specimens collected from

Cobscook Bay (Emson et al., 1991), collaborative knowledge gathering observations and habitat survey dives conducted in summer 2024 by the HMSC scientific dive team.

The primary data used in this study came from the HMSC's archived digitized version of Art Mackay's 1978-1979 baseline habitat survey series around Passamaquoddy Bay called the *Bay of Fundy Resource Inventory Series*. HMSC historical archives included hard copies of bottom drag surveys conducted by HMSC in Passamaquoddy with records from the 1950s through to the 1990s reviewed as part of this study. This dataset was condensed down to the three species of interest in this survey and input into a master dataset in QGIS, which is a free Geographic Information Systems software used to analyze and visualize spatial data.
Using a CSV layer of drop camera transect locations provided by the St. Andrews Biological Station (SABS), a proximity analysis was done in QGIS to find the most recent historical observations of *Gorgonocephalus* sp. and survey data from Mackay that were close to the drop camera transects. This analysis was intended to reduce the size of the data request sent to SABS and maximize the probability of finding *Gorgonocephalus* sp. by focusing on transects near habitats known to be suitable to them. Based on the point distance analysis done in QGIS, SABS provided a series of drop camera video surveys conducted in 2007, which was concentrated in an area south of Mac's Island in the Western Isles as seen in *Figure 2* below.



(Figure 2: Focus area south of Mac's Island for a data request to the Department of Fisheries and Oceans.)

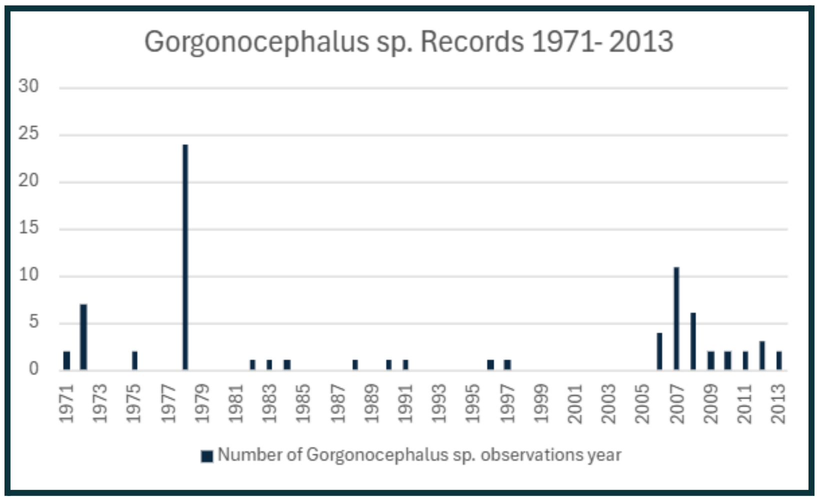
Collaborative knowledge observations were a key source of data in this project and were integrated in two forms including a request for data to Huntsman Marine Science Center affiliates and through the open-access online database GBIF. HMSC affiliates were sent a research engagement letter requesting data for presence-absence observations with spatial-temporal data for *Gorgonocephalus* sp., *Gersemia* sp. and *Alcyonium* sp.

All collected secondary knowledge source data was into a comprehensive master dataset organized by date, data source, and location within the study area for each species of interest. This dataset was used to enhance the original QGIS map created to support the video transect data request to SABS. Observations from outside the study area were included in the master dataset to provide more comprehensive data for future studies. However, observations outside the study area were not incorporated into the QGIS map, or used in the criteria for site suitability when selecting locations to conduct dive surveys. Site suitability criteria were established to determine where benthic habitat dive surveys would be conducted based on the most recent observations of *Gorgonocephalus* sp., sites with multiple of the species of interest present, sites with historically high abundance for the species of interest and sites that are accessible to diving.

The Huntsman scientific dive team utilizes open circuit scuba equipment to conduct dive surveys, following the Canadian Association of Underwater Science guidelines for scientific diving which includes the use of DCIEM decompression tables. Dive surveys were conducted to a maximum depth of thirty meters within no decompression limits. A roving survey technique for benthic habitats was used, with multiple types of data collected including video, macro-photography and specimen collection. A post-dive review of video, photographic records and diver memory were compiled into habitat forms including a description of substrate composition and species presence and abundance. Species abundance was measured using the SACFOR abundance scale which provides a semi-quantitative measurement for species abundance and diversity (Hiscock, 1996). The SACFOR scale is divided into categories from greatest to least presence in the ecosystem including; Super-abundant, abundant, common, frequent, occasional, rare and present with standardized percentage breakdowns for substrate coverage of individual colonies, crusts and turfs (Hiscock, 1996.). Using this standardized surveying scale in conjunction with a review of video footage and still images taken during the dive aids in limiting the bias of divers when filling out habitat survey forms.

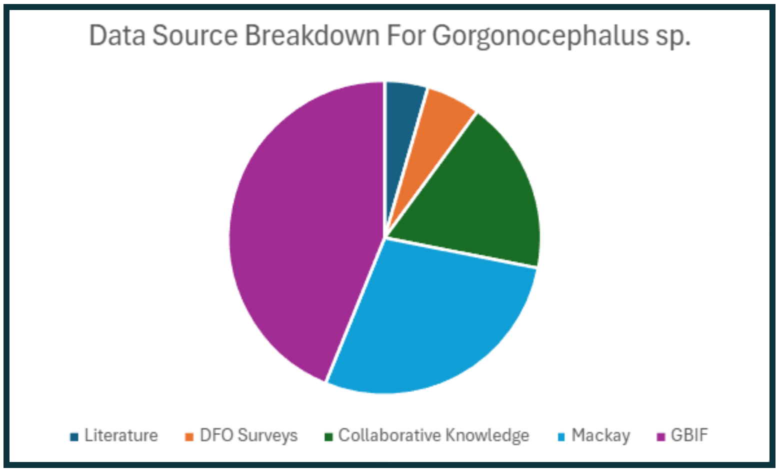
Results

The results of this study support anecdotal accounts suggesting that *Gorgonocephalus* sp. were no longer present in the Passamaquoddy Bay area from around 2013–2015, with the last recorded observation of *Gorgonocephalus* sp. in 2013. Despite the success of this project in compiling seventy-six observations of *Gorgonocephalus* sp., there are still significant gaps in the timeline of recorded observations of *Gorgonocephalus* sp. in Passamaquoddy Bay. Noteworthy of consideration, years with the highest numbers of recorded observations of *Gorgonocephalus* sp. coincided with years where formal scientific biodiversity studies took place, including initial baseline habitat surveys conducted by Art Mackay and SABS's series of drop camera surveys in Passamaquoddy Bay. In total seventy-six individual records of *Gorgonocephalus* sp. were made in Passamaquoddy Bay spanning from 1971-2013 as shown in *Figure 3* below.



(Figure 3: Temporal distribution of *Gorgonocephalus* sp. records in Passamaquoddy Bay from 1971-2013.)

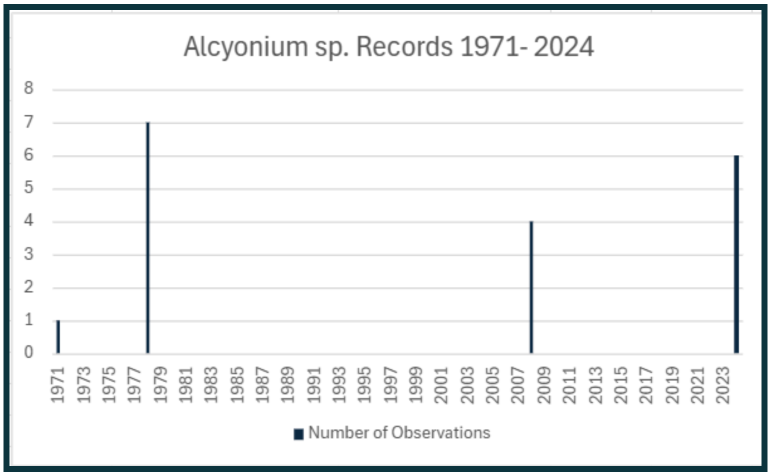
The breakdown in data sources for *Gorgonocephalus* sp. can be seen with GBIF and Mackay's surveys being the primary sources of data making up a combined seventy-two percent of recorded observations. However collaborative knowledge sources from HMSC affiliates and GBIF accounted for a combined forty-eight percent of observations for *Gorgonocephalus* sp. and covered a much broader temporal range spanning from 1971-2013, as can be seen in *Figure 4* below.



(Figure 4: Data source breakdown for *Gorgonocephalus* sp. records in Passamaquoddy Bay from 1971-2013.)

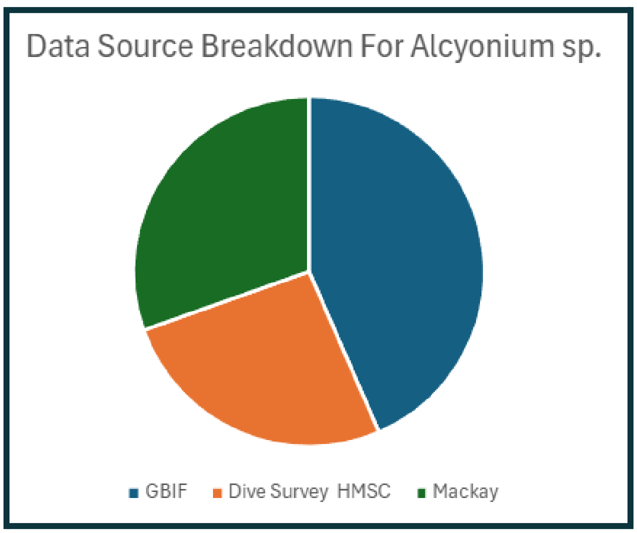
There were very few observations of *Alcyonium* sp. temporally, following the initial biodiversity surveys conducted by Art Mackay in 1978. The historical dataset created in this project obtained a total of twenty-two recorded sightings of *Alcyonium* sp. Observations of *Alcyonium* sp. compiled from all secondary knowledge sources spanned from 1971 to 2016.

Dive surveys conducted in 2024 by the Huntsman Marine Science Center's scientific dive team found several sites with *Alcyonium* sp. still present, leaving it as the only one of the three species in this study remaining in Passamaquoddy Bay. Observations for *Alcyonium* sp. from GBIF like *Gorgonocephalus* sp. had the broadest temporal range of recorded sightings spanning from 1971-2016 as seen in *Figure 5*.



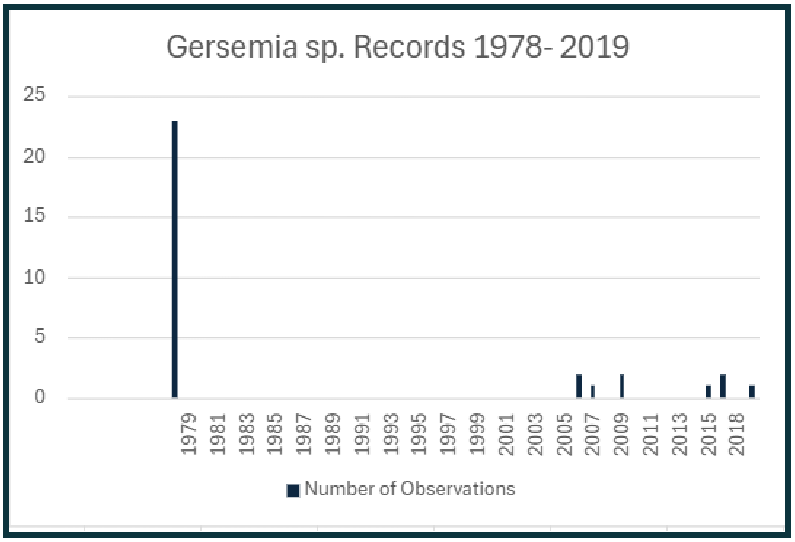
(Figure 5: Temporal distribution of *Alcyonium* sp. in Passamaquoddy Bay from 1971-2024.)

The initial surveys by Mackay accounted for forty-three percent of the data for *Alcyonium* sp., thirty percent was sourced from GBIF and twenty-six percent of observations from dive surveys conducted by the HMSC scientific dive team as seen in *Figure 5* below.



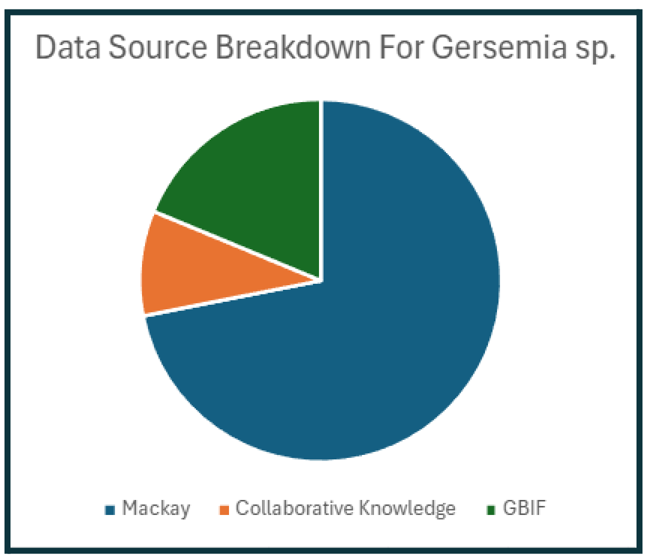
(Figure 5: Datasource breakdown for *Alcyonium* sp. records in Passamaquoddy Bay from 1971-2013.)

Secondary knowledge source records for *Gersemia* sp. provide thirty-two documented sightings. However, there are significant gaps in the temporal record of this species' presence in Passamaquoddy Bay, including an almost thirty-year gap between the initial baseline surveys conducted by Mackay in 1978 and the next recorded observation from GBIF in 2006. The most recent observations of *Gersemia* sp. come from collaborative knowledge sources, as shown in *Figure 6* below.



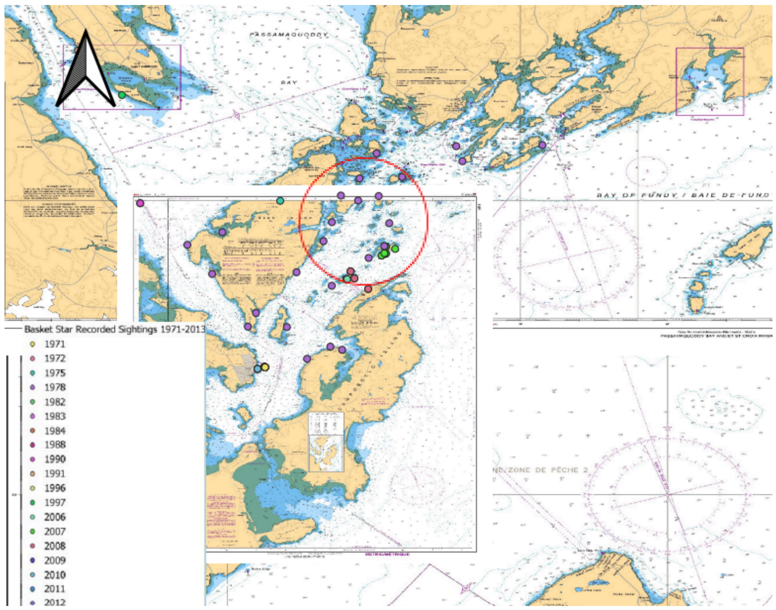
(Figure 6: Temporal distribution of *Gersemia* sp. in Passamaquoddy Bay from 1971-2019.)

Sources of records for *Gersemia* sp. were limited in sources. Seventy-two percent of observations were made by Mackay during the 1978 baseline surveys, followed by nineteen percent from GBIF and nine percent from collaborative knowledge as seen below in *Figure 7*.

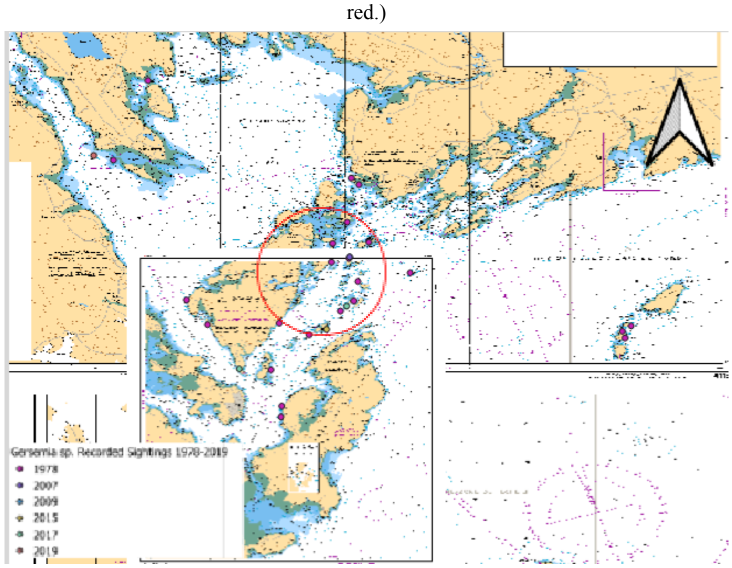


(Figure 7: Data source breakdown for *Gersemia* sp. records in Passamaquoddy Bay from 1971-2019.)

The findings outlined in the Results section reveal some notable trends and gaps in the spatial-temporal distributions of the three studied species. One of the key areas of interest identified in the study was the concentrations of observations of *Gorgonocephalus* sp. and *Gersemia* sp. within the island archipelago of the Western Passages as seen below in *Figures 7 and 8*.



(Figure 7: Distribution of *Gorgonocephalus* sp. from 1971-2012 in Passamaquoddy Bay with population concentrations in the Passages circled in red.)



(Figure 8: Distribution of *Gersemia* sp. from 1978-2019 in Passamaquoddy Bay with population concentrations in the Passages circled in red.)

These findings warrant further exploration with more complete data sets to understand their implications for ecosystem health and management strategies in Passamaquoddy Bay using statistical methods. The following discussion interprets these patterns, contextualizing them within existing ecological frameworks and identifying potential drivers behind the observed changes.

Discussion

This project met its objectives of creating more comprehensive spatial-temporal records of *Gorgonocephalus* sp., *Gersemia* sp., and *Alcyonium* sp. in Passamaquoddy Bay, using data from a variety of sources. It also identified some of the strengths and weaknesses of different data sources and how they can potentially be integrated to identify areas of interest within an ecosystem and species presence over time.

One of the implicit challenges in this study was finding quality datasets that spanned extensive durations of time, satisfying both inclusion criteria for accurate locations and dates of observation. Many observations further back in Passamaquoddy Bay's history lacked either accurate locations or dates in the observations, leading to their exclusion from the study.

Secondary knowledge sources including GBIF proved to be a good source of supplementary data to this study. However, many years of GBIF data only provided one observation for *Alcyonium* sp. and *Gersemia* sp. per year, restricting the ability to track overall species distribution changes within Passamaquoddy Bay over time using GBIF data alone.

Collaborative knowledge from Huntsman affiliates were a valuable source of data, providing some of the most recent observations of the three species of interest. In this study, the data provided was research-grade observations and included spatial-temporal data with accompanying photographic records for the species of interest. One of the limiting factors of this type of data is accessibility as the majority of data used in this study was from unpublished fieldnotes. With these two factors to consider, data from these sources and quality may not be replicable in studies of other species or locations. Despite the success of this study in accumulating enough observations from secondary data sources to document records of *Gorgonocephalus* sp. and *Gersemia* sp. in support of the independent anecdotal accounts from many users of Passamaquoddy Bay and identifying a decrease in the abundance of *Alcyonium* sp., gaps still remain in the spatial-temporal data for these species. The largest gap for *Gorgonocephalus* sp. is between 1998 and 2006 with no recorded observations during this period. *Gersemia* sp. also had a large gap between 1978 and 2006 with no recorded observations. *Alcyonium* sp. had some of the largest gaps in its dataset with observations only made in 1971,1978, 2008 and 2023.

Another study successfully addressed gaps in historical timelines of commercially harvested species by supplementing their data with several unconventional sources including but not limited to restaurant menus, museum archives, artwork, cookbooks and benthic sediments (Thurstan et al. 2015). They identified historical fisheries collapses through documented changes in seafood dishes served by restaurants over time (Thurstan et al., 2015). However, these methods are not as useful for species like *Gorgonocephalus* sp. *Gersemia* sp. and *Alcyonium* sp. as these species were never historically harvested for commercial purposes and have few geographically accurate historical observations before the 1900s.

Due to fluctuations in the number of recorded observations of the three species over time, there is insufficient data to conduct meaningful statistical analyses to determine whether species distribution within the bay has significantly changed. However, the absence of recent historical records for *Gorgonocephalus* sp. and *Gersemia* sp. from secondary knowledge sources, combined with the absence of observations during dive surveys conducted by the Huntsman scientific dive team in the 2024 field season, suggests that large-scale ecosystem changes are occurring in Passamaquoddy Bay, rendering it inhospitable for these species with the last recorded sightings of *Gorgonocephalus* sp. in 2013 and *Gersemia* sp. in 2019. These findings are particularly significant for habitats that have experienced or are currently undergoing disturbances, indicating that many other species are no longer present in Passamaquoddy Bay. This situation necessitates a need for historical ecology to better understand changes that have occurred in the past (Thurstan et al. 2015).

Based on the most recent and last records of *Gorgonocephalus* sp. and *Gersemia* sp. several potential factors occurred around the period, which could have contributed to the decline of these species in Passamaquoddy Bay. In 2012, around the same time, *Gorgonocephalus* sp. was last reported in Passamaquoddy Bay. A new disease affecting over 20 species of echinoderms was detected in the North Atlantic, corroborated by anecdotal reports from commercial fishers, marine education institutions, and others (Bucci et al., 2017). In 2013, the infection was named Sea Star Wasting Disease and was found to be spreading up the East Coast including areas off the shores of Maine, causing symptoms including limp or curled limbs, slimy undersides, and eventual death due to the breakdown of the central body disk (Bucci et al., 2017). Sea Star Wasting Disease likely impacted *Gorgonocephalus sp.*, with anecdotal accounts from Huntsman taxonomic staff confirming the presence of Sea Star Wasting Disease in Passamaquoddy Bay during this time, along with the disappearance of most echinoderm species from the bay.

It is suspected that climate change was a driving factor in the decline of these two species from Passamaquoddy Bay as *Gorgonocephalus* sp. and *Gersemia* sp. are both cold water species found distributed across the cold waters of the northern hemisphere (Rosenberg et al., 2005; Williams et al., 1988). Sea surface temperatures during the period of *Gorgonocephalus* sp. disappeared were warming rapidly, with a recorded surface temperature increase in 2012 of 1–3°C on average in the western North Atlantic, compared to average temperatures recorded from 1982 to 2011 (Mills et al., 2013). One paper of interest studied water temperature increase in benthic habitats, using diving Basking Sharks to collect temperature at depth. This paper found a significant increase of 8°C in water temperatures below 100m between 2008-2012 in the Bay of Fundy (Koopman et al., 2014). Using *Gorgonocephalus* sp., *Gersemia* sp., and *Alcyonium* sp. as case-study organisms, demonstrated the potential for developing more comprehensive datasets and the benefits of compiling historical observations for other benthic marine species. Future studies of *Gorgonocephalus* sp. may potentially benefit from the use of Environmental DNA (eDNA) sampling to determine if the species are still present in the Bay of Fundy but have been pushed to deeper colder waters where direct observation would be difficult (Fisheries and Oceans Canada, 2024). As well, the use of semi-quantitative data collection from a variety of secondary knowledge sources demonstrated the ability to narrow in on specific periods and events that could potentially impact populations of benthic invertebrates.

Management Recommendations:

Based on the findings of this study, it is apparent that there is an urgent need to better understand what is happening and what has historically happened within Canada's coastal marine ecosystems through the collection of more data from all available sources on benthic invertebrates and benthic habitats. Incorporating historical data to fill gaps in current knowledge can help spur conservation and management, emphasizing the value in addressing existing data gaps in existing knowledge to encourage future conservation efforts (Thurstan et al., 2015). A historical perspective can be a useful tool for stakeholders and marine managers to highlight the ecological capacity to recover depleted fish stocks and guide more informed decisions about the future of ecosystem management and restoration (Thurstan et al., 2015). Using an adaptive approach to marine resource management is necessary, through the implementation of ecosystem-based management (EBM), which manages anthropogenic activities in consideration of their impacts on the relationships between organisms, habitats and the broader ecosystem, based on scientific knowledge (Government of Canada, 2005). Integrating the EBM framework would help to better address the anthropogenic activities occurring within Canada's coastal waters in light of the numerous pressures these ecosystems like Passamaquoddy Bay face, including climate change, invasive species, and ecosystem degradation as well as helping to make predictions on predicting what the future of marine ecosystems will look like (Koopman et al., 2015; Teed et al., 2024; Buzeta, 2014; Thurstan et al., 2015). While EBM is being considered within the Department of Fisheries and Oceans, DFO acknowledges that there is still more work needed to complete before it is fully integrated into the DFO management strategy (Daly et al., 2020).

Areas for improvement identified in this study are recommended for implementation in a future EBM framework. These improvements include supporting management and planning activities with more data on benthic invertebrate species populations. This could be accomplished through the use and identification of suitable indicator organisms within Canada's coastal marine ecosystems, similar to the EU water framework which sets out guidelines for the identification and usage of benthic invertebrates in environmental monitoring (European

Commission, 2003). In a Canadian context, there are many tools for protecting species threatened with extinction, including the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the Species at Risk Act (SARA) (COSEWIC, 2024; Department of Justice, 2002). COSEWIC was established in 1977 to provide a unified, science-based system for categorizing all terrestrial and aquatic wildlife species that are at risk of extinction (COSEWIC, 2024).

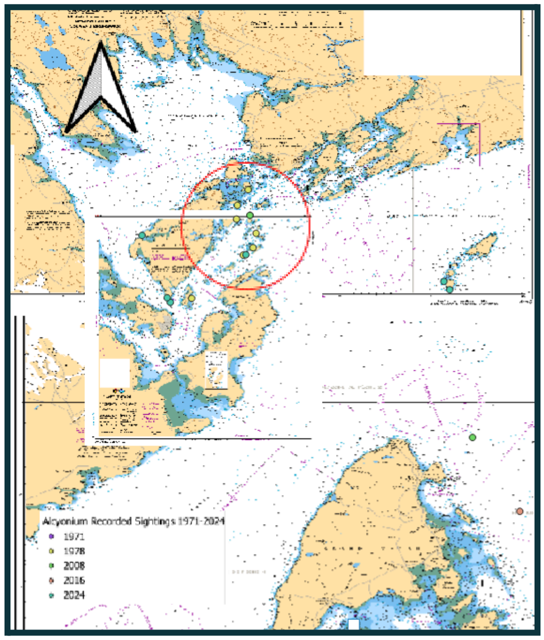
Some of the COSEWIC indicators of species decline include section A1 for endangered status which includes the requirements of a species to have undergone a greater than a fifty percent decrease in the number of detected, estimated, assumed and presumed decreases in the total population of mature individuals over three generations or ten years, due to a cause that is not fully understood or may be irreversible (COSEWIC, 2024). COSEWIC indicator B1 includes criteria for the area of a threatened species occupancy to be less than 500 square kilometres with the species of concern being observed at 5 or fewer survey locations where it was known to inhabit historically (COSEWIC, 2024).

The criteria from COSWEIC indicators A1 and B1 describe the status of the three species of interest in Passamaquoddy Bay as there have been no observations of *Gorgonocephalus* sp. or *Gersemia* sp. were made in five of the survey locations in this study where they were historically present. Passamaquoddy Bay fits within the habitat size classification as it is approximately 160 square kilometres in surface area (Bailey, 1957). However, despite *Gorgonocephalus* sp., *Gersemia* sp. and *Alcyonium* sp. meeting the quantitative criteria, quantitative metrics are not included in the legal framework for species designation with COSEWIC status only being the first step to designation at the discretion of the Minister of Environment and Climate Change (Dorey et al. 2017).

Tools like COSEWIC come with several benefits to threatened species including helping threatened species gain legal protection under the *Species at Risk Act* conservation as SARA status includes considerations for protecting not only the threatened species but also the habitats where they are found (COSEWIC, 2024). However, these benefits of COSEWIC status come at the price of requiring the species of interest to have significant historical records of presence in the region and show evidence of decline. Results from a study on the *Limitations Of Threatened Species Lists In Canada: A Federal And Provincial Perspective* found that many species that are globally threatened lack sufficient conservation status and protection under national and provincial law in Canada. Findings also included evidence of different taxa receiving favouritism with mammals having the highest likelihood of obtaining status, whereas fish were not as likely (Dorey et al. 2017). These requirements are large demands for understudied species like *Gorgonocephalus* sp., *Gersemia* sp. and *Alcyonium* sp. Dive surveys that were conducted by the Huntsman scientific dive team during the 2020-2022 and 2024 field seasons did not find either *Gorgonocephalus* sp. or *Gersemia* sp. at sites where they were recorded as historically abundant, however data for intervening period was not available. During the 2024 dive season, there was an observed decrease in the abundance of *Alcyonium* sp. in Passamaquoddy Bay compared to previous studies. These findings will likely require further surveying to support these species' eligibility for COSEWIC threatened status.

The benefits of more robust scientific data could be used for other applications within the EBM framework including conservation planning. Based on the findings in this research project, it is recommended that Passamaquoddy Bay have a Marine Protected Area developed within the Western Isles and the Wolves Archipelago to protect vulnerable benthic species including the remaining *Alcyonium* sp. still found in the bay during this study. Marine Protected Areas are an increasingly common tool being implemented worldwide to protect biodiversity in the face of rapidly changing ocean environments (Bryce et al., 2024). Parks Canada identifies the Bay of Fundy as not being represented in Canada's National Marine Conservation Areas System Plan. This is severely detrimental to the extremely rich biodiversity found in Passamaquoddy Bay, which holds status as an area of interest and evidence of species decline found in this study (Parks Canada Agency, 2024; Buzeta, 2008). An MPA or an MPA network would be very beneficial to Passamaquoddy Bay as they contribute to the conservation and protection of marine species populations and the biodiversity of the ecosystems that they inhabit (Fisheries and Oceans, 2021).

Within the proposed MPA program for Passamaquoddy Bay, protecting stationary benthic invertebrates like *Alcyonium* sp. cannot stop at a species conservation level and must extend to the surrounding ecosystem to effectively protect them. Within the proposed implementation of an MPA program, there should be established no-take zones which would provide several benefits to the benthic fauna including protection from drag fisheries for sea cucumbers which are a large industry in Passamaquoddy Bay. A study of drag fisheries in Passamaquoddy Bay emphasized the damages caused to benthic habitats with findings of a complete displacement of crabs, lobsters, sculpins and whelks and damage to kelps shortly after drag-fishing events as well as decreases in urchin populations and longer-term impacts remaining unknown (Robinson, 2015). A DFO trawl survey study from 2009-2014 in Passamaquoddy Bay found both The Wolves and The Passages to be trawl-able with an observed 37-75 species observed each year (Cooper et al., 2016) This study recognized The Passages to be an area with large numbers of historic observations of *Alcyonium* sp. indicating it is likely an area of valuable habitat that should be conserved to help to bolster the health of benthic ecosystems in the area as seen in *Figure 10* below.



(Figure 10: Distribution of *Alcyonium* sp. from 1971-2024 in Passamaquoddy Bay with population concentrations in the Passages circled in red)

Passamaquoddy Bay has an active sea cucumber drag fishery throughout biologically significant areas identified in this study overlapping with Zone 1 located at the mouth of Passamaquoddy Bay and Zone 2 located outside the bay near Campobello Island (Fisheries and Oceans Canada, 2020). The majority of sea cucumber stocks that are commercially fished worldwide have collapsed without significant signs of recovery, with the overexploitation of sea cucumber fisheries considered to be a tragedy of the commons (Fisheries and Oceans Canada, 2021b; Ferguson et al. 2022). As of 2019, twenty-five countries have banned the export of sea cucumbers or established a moratorium on sea cucumber fisheries. These findings indicate that sea cucumbers are very sensitive to intense fishing pressure (Baker-Medard et al., 2019). Further considerations should be made for the continuation of this fishery due to the absence of data on the resilience of sea cucumbers at these latitudes compared to fisheries in more temperate regions (Fisheries and Oceans Canada, 2021b). Reducing ecosystem pressures on benthic habitats through the establishment of no-take zones can help protect ecosystems from anthropogenic activities like bottom trawling, allowing them to maintain high species abundance and diversity (Lester et al., 2009). Both of these ecosystem traits are associated with ecosystem resilience to disturbances (Cleland, 2011).

Having historical datasets is extremely important for tracking the impacts of threats and disturbances over time (Thurstan et al., 2015). One of the current greatest threats to Passamaquoddy Bay and the Maritimes besides climate change is the introduction of an invasive species. Invasive species are a major threat to biodiversity only getting more severe with time (Bax et al., 2003). One of the most prominent invasive species currently being studied in Passamaquoddy Bay is the colonial tunicate called *Didemnum vexillum* (Teed et al., 2024). One of the major concerns of *D. vexillum* spreading is the transportation of colonies to new areas as a result of fishing activity with special concern for drag fisheries including scallops (Fisheries and Oceans Canada, 2010).

The establishment of a no-take MPA in the Western Isles, would further promote ecosystem resilience to disturbances as surveys of Georges Bank found *Didemnum vexillum* to be more prevalent in areas where drag fishing is allowed in comparison to benthic habitats within the MPA (Kaplan et al. 2016). *Didemnum vexillum* is extremely detrimental to sensitive benthic habitats, growing in thick mats that smother marine life including scallops, which are an extremely valuable fishery in the region (Kaplan et al. 2016; Kaplan et al. 2017). Increasing the monitoring of benthic habitats and invertebrates through frequent surveys would help track the spread of invasive species like *D. vexillum* and allow for the development of monitoring and mitigation strategies as environmental-based management plans for Passamaquoddy Bay (Teed et al. 2024).

The most important use of historical marine data is studying the impacts of climate change on marine benthic ecosystems, as marine species are particularly susceptible to increases in water temperatures (Thurstan et al., 2015; Pinsky et al., 2019). However, it demands a thorough understanding of community structure and how these communities react to various environmental pressures (Saeedi, 2022). This might be accomplished by looking further south to habitats like Passamaquoddy Bay, which are currently experiencing increased water temperatures due to climate change, pushing species out of the southernmost extents of their ranges (Koopman et al, 2015; Reuben et al, 2020). Compiling historical records from these benthic habitats would help fill in gaps in current knowledge and should allow researchers to extrapolate and predict the impacts that warming water temperatures will have on marine ecosystems and benthic invertebrates at more northern latitudes (Saeedi, 2022, Thurstan et al., 2015). Having detailed historical data on benthic invertebrates can reveal the rate and pattern of changes over time. Additionally, long-term datasets can help uncover the underlying mechanisms behind these changes and determine whether the primary drivers have shifted over time (Thurstan et al., 2015). Historical ecology could offer significant benefits to ecosystem-based management in this context, as the disappearance of *Gorgonocephalus* sp and *Gersemia* sp. were found to coincide with environmental changes that took place in the same period as their disappearances from Passamaquoddy Bay as mentioned in the discussion.

To minimize gaps in historical spatial-temporal knowledge of benthic invertebrates, the final recommendation for EBM-based planning framework is Traditional Ecological Knowledge (TEK). Some of the central values of TEK involve Indigenous knowledge systems that are deeply rooted in cultural traditions which shape understandings of ecosystems and guide behavior as well as the importance of studying how cultural traditions inform values and perceptions of ecosystems (Lertzman, 2010). Integrating Indigenous traditional knowledge with Western science can be used in conjunction to inform EBM. Integrating Indigenous knowledge into existing spatial-temporal data could allow researchers to go back even further in history and can help reveal historical events and trends that began before the formal recording of scientific knowledge through surveys and other means of data collection (Lertzman, 2010; Sauyaq Jean Gordon, 2023). The Passamaquoddy, Mi'kmaq, and Maliseet Peoples have a long history of fishing in the region for species including salmon, alewives (gaspereaux), herring, sturgeon, cod, mackerel, and eels (Government of Canada, 2010). Indigenous perspective and knowledge would allow for historical records to potentially extend farther back in history and provide a more holistic approach to management decisions asa part of TEK.

Based on the findings in this study, including these recommendations within the EBM framework will allow for a more holistic approach to management of benthic habitats in the Passamaquoddy Bay region, as well as expanding knowledge on the status of benthic invertebrates in Canada's Maritime waters.

Conclusion:

This study demonstrates the benefits and difficulties of integrating multiple sources of observations for *Gorgonocephalus* sp., *Alcyonium* sp. and *Gersemia* sp. from historical datasets of formal and informal sources for benthic habitats in Passamaquoddy Bay. Through more complete datasets, a better understanding of historical spatial-temporal distributions of benthic species in Passamaquoddy Bay can help play a pivotal role in understanding the dynamics of marine ecosystems and developing realistic conservation goals (Thurstan et al., 2017; Jackson et al., 2001). Comprehensive historical records enable researchers to identify cause-and-effect relationships, trace rates of change, and establish meaningful benchmarks for ecosystem management (Jackson et al., 2001). Ultimately, this project highlights the importance of integrating multiple sources of historical data, anecdotal reports, and modern scientific methodologies to support informed marine management. By building a comprehensive picture of species' ecological roles and their responses to environmental pressures, this work contributes to the sustainable conservation of Canada's marine biodiversity, underscoring its cultural, economic, and ecological significance.

References:

Bailey, W. B. (1957, September 19). Some features of the oceanography of the Passamaquoddy region. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40708330.pdf

Ballantyne, L. (2018). An examination of the distribution, abundance, and habitat preferences of soft corals (Octocorallia: Alcyonacea) in offshore Nova Scotian waters (thesis). Dalhousie University, Halifax.

Bax, N., Williamson, A., & Aguero, M. (2003). Marine invasive alien species: a threat to global biodiversity. https://www.sciencedirect.com/science/article/pii/S0308597X03000411

Beisiegel, K., Darr, A., Gogina, M., & Zettler, M. (2017, August 15). Marine Pollution Bulliten. https://www.sciencedirect.com/science/article/abs/pii/S0025326X1730303X

Bucci, C., Francoeur, M., McGreal, J., Smolowitz, R., Zazueta-Novoa, V., Wessel, G., & Gomez-Chiarri, M. (2017, December). *Sea Star Wasting Disease in Asterias forbesi along the Atlantic Coast of North America*. PubMed Central.

Buzeta, M. (2014, August). Identification and Review of Ecologically and Biologically Significant Areas in the Bay of Fundy. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/359756.pdf

Buzeta, M. I. (2013). Identification and Review of Ecologically and Biologically Significant Areas in the Bay of Fundy. Canadian Science Advisory Secretariat (CSAS). https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/359756.pdf

Buzeta, M. I. (2008). *Relationship between shallow nearshore species richness and environmental factors in the lower Bay of Fundy and implications for identifying sites of high biodiversity.* (thesis). Government of Canada, Saint John.

Bryce, K., & Hunter, K. (2024). Enhancing climate change planning and adaptive management in marine protected areas through targets, thresholds, and social-ecological objectives. https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2024.1339871/full

Cooper, J. A., & Blanchard, M. J. (2016). *Coastal Biodiversity Trawl of the Passamaquoddy Bay Area; 2009 to 2014*. Coastal Biodiversity Trawl of the Passamaquoddy Bay Area. https://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs97-6-3176-eng.pdf

Cleland, E. E. (2011). Biodiversity and Ecosystem Stability. https://www.nature.com/scitable/knowledge/library/biodiversity-and-ecosystem-stability-17059965/

Daly, J., Bundy, A., & Stephenson, R. (2020). Maritimes Region Workshop to Develop a Consensus EBM Framework to Assess the Cumulative Impacts of Fishing. https://publications.gc.ca/collections/collection_2020/mpo-dfo/Fs97-6-3368-eng.pdf

Department of Fisheries and Oceans. (2021a, August 9). *Services and Information*. St. Andrews Biological Station. https://www.mar.dfo-mpo.gc.ca/en/st-andrews-biological-station

Department of Justice. (2002, December 12). Species at Risk Act. https://laws.justice.gc.ca/eng/acts/s-15.3/page-1.html

Dorey, K., & Walker, T. (2017). Limitations of threatened species lists in Canada: A federal and provincial perspective. https://www.sciencedirect.com/science/article/abs/pii/S0006320717312545

Eckert, L. E., Ban, N. C., Frid, A., & McGreer, M. (2018). Diving back in time: Extending historical baselines for yelloweye rockfish with Indigenous knowledge. Aquatic Conservation, 28(1), 158–166. https://doi.org/10.1002/aqc.2834

Emson, R. H., Mladenov, P. V., & Barrow, K. (1991). The feeding mechanism of the basket star Gorgonocephalus arcticus. *Canadian Journal of Zoology*, *69*(2), 449–455. https://doi.org/10.1139/z91-070

Environment and Climate Change Canada. (2024, January 17). *Government of Canada*. Milestone document. https://www.canada.ca/en/environment-climate-change/services/biodiversity/national-biodiversity-strategy/milestone-document.html#toc3

European Commission. (2003). *Water Framework Directive*. Environment. https://environment.ec.europa.eu/topics/water/water-framework-directive_en

Fisheries and Oceans Canada. (2024). Environmental DNA (eDNA). https://www.dfo-mpo.gc.ca/science/biotech-genom/dna-adn/index-eng.html

Fisheries and Oceans Canada. (2022, November 23). *Coastal Environmental Baseline Program*. Coastal Environmental Baseline Program. https://www.dfo-mpo.gc.ca/science/partnerships-partenariats/research-recherche/cebp-pdecr/index-eng.html

Fisheries and Oceans Canada. (2021b). ASSESSMENT OF THE SEA CUCUMBER FISHERY IN QUEBEC'S INSHORE WATERS IN 2020. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/41017560.pdf

Fisheries and Oceans Canada. (2020). 2020 sea cucumber (southwest New Brunswick). https://www.dfo-mpo.gc.ca/fisheries-peches/decisions/fm-2020-gp/atl-03-eng.html

Fisheries and Oceans Canada. (2010). *Prevent non-authorized introduction of invasive species within the PBGB LOMA*. Prevent non-authorized introduction of invasive species within the PBGB LOMA . https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/342998rank25.pdf

Fortune, J., Butler, E., & Gibb , K. (2023, September). *Estuarine benthic habitats provide an important ecosystem service regulating the nitrogen cycle*. Marine Environmental Research. https://www.sciencedirect.com/science/article/pii/S0141113623002490#:~:text=Benthic%20environments%20play%20a%20pivotal,et%20al.%2C%202019).

FB Environmental. (2008). ST. CROIX RIVER: STATE OF THE WATERSHED REPORT. https://legacyfiles.ijc.org/publications/watershed_report.pdf

Government of Canada. (2005). Canada's Oceans Action Plan For Present and Future Generations. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/315255e.pdf

Harvey, C. J., Fisher, J. L., Samhouri, J. F., Williams, G. D., Francis, T. B., Jacobson, K. C., deReynier, Y. L., Hunsicker, M. E., & Garfield, N. (2020). The importance of long-term ecological time series for integrated ecosystem assessment and ecosystem-based management. *Progress in Oceanography*, *188*, 102418-. https://doi.org/10.1016/j.pocean.2020.102418

Henry, L.-A., Kenchington, E. L., & Silvaggio, A. (2003, October). *Effects of mechanical experimental disturbance on aspects of colony responses, reproduction, and regeneration in the cold-water octocoral Gersemia rubiformis*. Canadian Science Publishing. https://cdnsciencepub.com/doi/10.1139/z03-161

Hiscock, K., Langmead, O., Warwick, R., & Smith, A. (2005, July). Identification of seabed indicator species to support implementation of the EU habitats and water framework directives. MarLIN. https://www.marlin.ac.uk/assets/pdf/MBA_Indicators_Final.pdf

Hiscock, K. (1996). *Marine Nature Conservation Review: Rationale and Methods*. Joint Nature Conservation Committee. https://data.jncc.gov.uk/data/3c5bc4ca-2f0a-4fc9-a188-2ea755ee7203/mncr-rationale-methods-part-1-c1-c10.pdf

Huntsman Marine Science Center. (2024). *Press Room*. https://www.huntsmanmarine.ca/press-room#:~:text=The%20Huntsman%20Marine%20Science%20Centre,ocean%20education%2C%20conservation%20and%20research.

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., & al, e. (2001). Historical overfishing and the recent collapse of coastal ecosystems. Science, 293(5530), 629-37. https://ezproxy.library.dal.ca/login?url=https://www.proquest.com/scholarly-journals/historical-overfishing-recent-collapse-coastal/docview/213578194/se-2

Jenkins, T. L., & Stevens, J. R. (2022). Predicting habitat suitability and range shifts under projected climate change for two octocorals in the north-east Atlantic. *PeerJ*, *10*, e13509-. https://doi.org/10.7717/peerj.13509

Kaplan, K., Hart, D., Hopkins, K., Gallager, scott, York, A., Taylor, R., & Sullivan, P. (2017). *Evaluating the interaction of the invasive tunicate Didemnum vexillum with the Atlantic sea scallop Placopecten magellanicus on open and closed fishing grounds of Georges Bank*. Academic.oup.com. https://academic.oup.com/icesjms/article/74/9/2470/3831747

Koopman, H., Westgate, A., & siders, z. (2015, October 2). Rapid Subsurface Ocean Warming in the Bay of Fundy as Measured by Free-Swimming Basking Sharks. https://tos.org/oceanography/article/rapid-subsurface-ocean-warming-in-the-bay-of-fundy-as-measured-by-free-swim

Klein, E. S., & Thurstan, R. H. (2016, May). Acknowledging long-term ecological change: The problem of Shifting Baselines. https://www.researchgate.net/publication/303514701_Acknowledging_Long-Term_Ecological_Change_The_Problem_of_Shifting_Baselines

Lester S. E., Halpern B. S., Grorud-Colvert K., Lubchenco J., Ruttenberg B. I., Gaines S. D., Airame S. (2009). Biological effects within no-take marine reserves: a global synthesis. *Marine Ecology Progress Series*, 384: 33–46.

Lertzman, D. A. (2010). *Best of two worlds: Traditional ecological knowledge and Western science in ecosystem-based management*. Journal of Ecosystems and Management. https://jem-online.org/index.php/jem/article/view/40

Maine Government. (2016, January 13). *Gorgonocephalus Arcticus (northern basket ... - maine.gov*. Gorgonocephalus Arcticus. https://www.maine.gov/ifw/wildlife/reports/pdfs/SGCN_Reports/SGCN/Northern%20Basket%20Starfish__Gorgonocephalus%20arcticus.pdf

MacKay, A.A.., Bosien, R., & Wells, B. (1978). *Bay of Fundy Inventory*. Marine Research Associates LTD.

MacKay A.A., Bosien, R.K., and Wells, B. (1978a). Bay of Fundy Resource Inventory, Volume 1: St. Croix - Passamaquoddy Bay. Marine Research Associates Ltd. Lord's Cove, Deer Island,123pp N.B.

MacKay A A., Bosien, R.K., and Wells, B. (1978b). Bay of Fundy Resource Inventory, Volume 2: Back Bay - Letang Inlet. Marine Research Associates Ltd. Lord's Cove, Deer Island, N.B. 134pp.

MacKay A.A., Bosien, R.K., and Wells, B. (1978c). Bay of Fundy Resource Inventory, Volume 3: Deer Island - Campobello Island. Marine Research Associates Ltd. Lord's Cove, Deer Island, N.B.

MacKay, A.A., & Bosien, R.K., and Leslie, P. (1979b). Bay of Fundy Resource Inventory, Volume 4: Grand Manan Archipelago. Marine Research Associates Ltd. Lord's Cove, Deer Island, N.B. 141pp. MacKay, A.A., Bosien, R.K., and Leslie P. 1979b. Bay of Fundy Resource Inventory, Volume 6: Pea Point to Point Lepreau.

MacKay A.A., & Bosien, R.K. (1979a). Bay of Fundy Resource Inventory, Volume 5: Wolves Islands. Marine Research Associates Ltd. Lord's Cove, Deer Island, N.B.

Mills, K.E., A.J. Pershing, C.J. Brown, Y. Chen, F.-S. Chiang, D.S. Holland, S. Lehuta, J.A. Nye, J.C. Sun, A.C. Thomas, and R.A. Wahle. 2013. Fisheries management in a changing climate: Lessons from the 2012 ocean heat wave in the Northwest Atlantic. Oceanography 26(2):191–195, http://dx.doi.org/10.5670/oceanog.2013.27.

Morys, C., Bruchert, V., & Bradshaw, C. (2021). *Impacts of bottom trawling on benthic biogeochemistry in muddy sediments: Removal of surface sediment using an experimental field study*. Marine Environmental Research. https://www.sciencedirect.com/science/article/pii/S0141113621001409

Pauly, D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution*, *10*(10), 430. https://doi.org/10.1016/s0169-5347(00)89171-5

Parsons, E. C. M., Favaro, B., Aguirre, A., Bauer, A. L., Blight, L., Cigliano, J., Coleman, M., Cote, I., Draheim, M., Fletcher, S., Foley, M., Jefferson, R., Jones, M., Kelaher, B., Lundquist, C., McCarthy, J. B., Nelson, A. Patterson, K., Walsh, L., … Sutherland, W. (2014). Seventy-One Important Questions for the Conservation of Marine Biodiversity, 28(5), 1206–1214. https://doi.org/10.1111/cobi.12303

Pinsky, M., Selden, R., & Kitchel, Z. (2019). *Climate-Driven Shifts in Marine Species Ranges: Scaling from Organisms to Communities*. Annual Reviews. https://www.annualreviews.org/content/journals/10.1146/annurev-marine-010419-010916

Reuben, H., Rutterford, L., Freer, J., Collins, R., Simpson, S., & Genner, M. (2020). *Climate Change Drives Poleward Increases and Equatorward Declines in Marine Species*. Current Biology. https://www.cell.com/current-biology/fulltext/S0960-9822(20)30250-5

Robinson, S. M. C., Bernier, S., & MacIntyre, A. (2015, February 13). *The impact of scallop drags on sea urchin populations and benthos in the Bay of Fundy, Canada - hydrobiologia*. SpringerLink. https://link.springer.com/article/10.1023/A:1014561429791

Rosenberg, R., Dupont, S., Lundälv, T., Sköld, H. N., Norkko, A., Roth, J., Stach, T., & Thorndyke, M. (2005). Biology of the basket star gorgonocephalus caputmedusae (L.). *Marine Biology*, *148*(1), 43–50. https://doi.org/10.1007/s00227-005-0032-3

Saeedi, H., Warren, D., & Brandt, A. (2022). *The Environmental Drivers of Benthic Fauna Diversity and Community Composition*. Frontiers. https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2022.804019/full

Sauyaq Jean Gordon, H., Ashleigh Ross, J., Bauer-Armstrong, C., Moreno, M., Byington, R., & Bowman, N. (2023). Integrating Indigenous Traditional Ecological Knowledge of land into land management through Indigenous-academic partnerships Author links open overlay panel. https://www.sciencedirect.com/science/article/pii/S0264837722004963

Stöhr, S., O'Hara, T., & Thuy, B. (2024). World Ophiuroidea Database. Gorgonocephalus Leach, 1815. https://www.marinespecies.org/aphia.php?p=taxdetails&id=123586

Teed, L., Goodwin, C., Lawton, P., Lacoursiere-Roussel, A., & Dinning, K. (2024). *Multiple perspectives on the emergence of the invasive colonial tunicate Didemnum vexillum Kott, 2002 in the western Bay of Fundy, Atlantic Canada*. InvasivesNet. https://www.reabic.net/journals/bir/2024/3/BIR_2024_Teed_etal.pdf

Thurstan, R. H., McClenachan, L., Crowder, L. B., Drew, J. A., Kittinger, J. N., Levin, P. S., Roberts, C. M., & Pandolfi, J. M. (2015). Filling historical data gaps to foster solutions in marine conservation. *Ocean & Coastal Management*, *115*, 31–40. https://doi.org/10.1016/j.ocecoaman.2015.04.019

GBIF.org (21 May 2024) GBIF Occurrence Download https://doi.org/10.15468/dl.wby3gm

Williams, D., Andersen, R., Kingston, J., & Fallis, A. (1988). *Minor metabolites of the cold water soft coral Gersemia rubiformis* . Minor metabolites of the cold water soft coral Gersemia rubiformis. https://cdnsciencepub.com/doi/pdf/10.1139/v88-452