A tale of two fishes: Evaluating the benthic habitat and habitat use of culturally important fish species in nearshore Nunatsiavut waters

by © Zachary MacMillan-Kenny

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Abstract

Amidst the rapid environmental change occurring in northern marine environments, baseline ecological knowledge is essential for implementing effective management measures. Through the development of an adaptive marine management initiative, called *Imappivut*, the Nunatsiavut government has prioritized various marine species and habitats of cultural, ecological, and economic importance for dedicated research. Among these priorities are two iconic fish species, iKaluk / Arctic charr (*Salvelinus alpinus*) and ogak / Greenland cod (*Gadus ogac*), valued highly throughout communities in Nunatsiavut for supporting Inuit subsistence and economic opportunities. Despite rich local ecological insights, regional data on these species and their habitat associations in the changing marine environment are limited. Recognizing the importance of further understanding these species, this study describes and maps the seafloor habitats occupied by these fish and investigates the ecological and environmental relationships within these habitats. Using local harvester fishing locations, acoustic telemetry and video surveys, chapter 2 assesses the habitat use of tagged iKaluk during their marine residency period, while gathering baseline ecological knowledge on the available seafloor habitats throughout Nain, Nunatsiavut. Chapter 3 employs a habitat mapping approach within and around local ogak fishing locations to produce a full-coverage habitat map of species assemblages across Nain's nearshore marine environment. The research integrated traditional ecological knowledge with Western scientific methods, offering insights into critical habitats and aiding conservation efforts amid climate change challenges in Nunatsiavut. Together, the findings of this research established a baseline understanding of the seafloor habitats in Nain's marine waters and their association with two culturally important fish species.

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List of Abbreviations

ANOSIM	Analysis of Similarity
BPI	Bathymetric Position Index
CTD	Conductivity, Temperature, and Depth
DEM	Digital Elevation Model
DFO	Department of Fisheries and Oceans Canada
DS	Diatomaceous Sediments
EBK	Empirical Bayesian Kriging
EBM	Ecosystem-Based Management
FS	Fine Sediments
FSP	Fine sediments with Pebbles
GEBCO	General Bathymetric Chart of the Oceans
GLATOS	Great Lakes Acoustic Telemetry Observation System
GMA	Gravel Mix with Algal Turf
GRTS	Generalize Random Tessellation Stratified
HSI	Habitat Suitability Index
IEK	Indigenous Ecological Knowledge
LED	Light Emitting Diode
LILCA	Labrador Inuit Land Claims Agreement
LOOCV	Leave-One-Out Cross Validation
MBARI	Monterey Bay Aquarium Research Institute
MBES	Multi-Beam Echosounder Sonar
MPA	Marine Protected Area
NG	Nunatsiavut Government

NL	Newfoundland and Labrador
NONNA	Non-Navigational Bathymetry
RDA	Redundancy Analysis
RF	Random Forest
RMDV	Relative Difference to Mean Value
SD	Standard Deviation
SLR	Single-Lens Reflex Camera
TEK	Traditional Ecological Knowledge
UPGMA	Unweighted Pair Group Method using Arithmetic Averages
VARS	Video Annotation and Reference System
VIF	Variance Inflation Factor
VME	Vulnerable Marine Ecosystem
VRM	Vector Ruggedness Measure

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Co-authorship Statement

The student's contributions to this research project are as follows:

- Conducted data processing and analysis used for all chapters
- Led ground-truthing video surveys aboard the M/V *Inuttatik* in Nain's nearshore marine environment
- Secured funding for community outreach and conference presentations
- Led community outreach and engagement activities, including a hands-on benthic video workshop in Nain
- Drafted all thesis chapters and lead author on the resulting two manuscripts (Chapters 2 & 3)

Co-supervisor Dr. Katleen Robert (Fisheries and Marine Institute, Memorial University of Newfoundland and Labrador) co-authored Chapters 2 and 3, contributed to project design and data collection, secured funding, provided guidance on data analysis and helped edit and write manuscript drafts. Co-supervisor Dr. Evan Edinger (Geography Department, Memorial University of Newfoundland and Labrador) co-authored Chapters 2 and 3, secured funding, and helped improve manuscript drafts. Committee member Dr. David Cote (DFO) co-authored Chapter 2 and 3, provided feedback and revisions to manuscript drafts, and provided the telemetry data used in the study. Committee member Mary Denniston (Nunatsiavut Government) co-authored Chapter 2 and 3, provided revisions to manuscript drafts and helped conceptualize local community engagement activities. Adam Templeton helped with data collection and is a co-author for both manuscripts. Dr. Audrey Limoges (University of New Brunswick) helped collect video data for chapter 2, while Myrah Graham helped collect video data for chapter 3 and both are acknowledged as co-authors of their respective manuscripts.

This thesis is based on the following manuscripts:

Chapter 2:

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Chapter 3:

MacMillan-Kenny Z, Denniston M, Edinger E, Templeton A, Côté D, Graham M, Robert K. (in prep for submission to Arctic Science). Association of Ogak/Greenland cod (*Gadus ogac*) with complex habitats: Insights from traditional fishing locations in nearshore Nunatsiavut waters.

1 Introduction

1.1 Coastal & benthic habitats

Coastal and benthic ecosystems are vital in providing and protecting a variety of services that hold economic, ecological, cultural, and social value (Woollett 2010; Wynja et al. 2015). These services may vary from access to resources (i.e., subsistence), to cultural or spiritual traditions, employment opportunities, shipping routes, and recreation (Barbier et al. 2011; Bell et al. 2015; Swiderska et al. 2018). The coast harbors a rich diversity of flora and fauna that contribute significantly to the health of the ecosystem and its services (Barbier et al. 2011). These areas are highly productive and have pivotal roles in activities like feeding, functioning as nurseries, supporting spawning, and facilitating migration for species of both commercial and ecological significance (Seitz et al. 2014; Jokinen et al. 2015; Henseler et al. 2019). Benthic organisms, which live on or in the seabed, are paramount in maintaining the functionality and health of coastal ecosystems. Their activities (i.e., bioturbation, feeding, defecation) significantly contribute to organic matter remineralization, nutrient recycling, and energy cycling between benthic and pelagic zones (Levin et al. 2001; Henseler et al. 2019; Lam-Gordillo et al. 2021). Moreover, many benthic invertebrates (e.g., sponges, mussels) act as effective biofilters, filtering the water of pollutants and excess nutrients (Barbier et al. 2011; Snelgrove et al. 2014; Lam-Gordillo et al. 2021; Wyness et al. 2021). Several species comprising the coastal seafloor are deemed 'ecosystem engineers' which alter the physical structure of the environment (Jones et al. 1994; Jones et al. 1997; Bagur et al. 2016). For example, tube-dwelling organisms (e.g., polychaete worms, cerianthid anemones) form burrows of varying depth and complexity, re-working and stabilizing the sediment (Volkenborn et al. 2009; De Backer et al. 2011; Hale et al. 2015). Organisms that build three-dimensional (3D) structures in dense aggregations, such as mussels, oysters, and corals offer shoreline protection, help control coastal erosion, and positively influence species richness (Borthagaray & Carranza 2007; Joy & Gopinath 2021). By modifying and stabilizing substrates, these species encourage habitat heterogeneity, boosting biodiversity (Gutiérrez et al. 2003).

Benthic habitats represent the combination of "physical and environmental conditions that support a biological community, together with the community itself" (MESH 2008; Brown et al. 2011). These habitats include a variety of bottom types (e.g., sediment attributes), as well as diverse geomorphological features, hydrodynamic patterns, and varying levels of structural and biological complexity (McArthur et al. 2010). The varying environmental features manifest themselves in an uneven distribution over space (Robert et al. 2014) thereby affecting the distribution of species across the seabed (Törnroos et al. 2013; Henseler et al. 2019; Loke & Ryan 2022). As such, an increase in habitat structural complexity and heterogeneity generally leads to an increase in biodiversity compared to homogeneous habitats on the seafloor (Buhl-Mortensen et al. 2010; Robert et al. 2014; Zeppilli et al. 2016; Henseler et al. 2019). The faunae living within these seafloor habitats are typically long-lived, immobile, or sessile, and sensitive to disturbances (Bilyard 1987), and as a result, can act as effective indicators for the health of the ecosystem (Lennon & Sullivan Sealey 2023). Characterized by their diversity, structural complexity and fragility, the benthos can contribute to the classification of Vulnerable Marine Ecosystems (VMEs). Generally, VMEs are distinguished by the presence of certain indicator taxa that are sensitive, physically fragile, and slow to recover from anthropogenic disturbances (FAO 2009). These organisms enhance the complexity and heterogeneity of the seafloor, ultimately boosting diversity. For instance, fields composed of large, structurally complex sponges can provide shelter and substrate for a variety of organisms, including commercially important fish, as seen in the Northwest Atlantic (Beazley et al. 2013; Kenchington et al. 2013).

However, the ongoing pressures of climate change pose significant threats to the coast and its benthic habitats, potentially disrupting their unique structure and function, ultimately affecting their ability to support unique benthic assemblages and ecosystem services.

1.2 Northern environmental change

In Canada, northern coasts are undergoing significant environmental change along with their services. As a result of anthropogenically-induced warming, sea-ice development is occurring later in the season, and the extent and thickness of this ice is diminishing at a rapid rate (Furgal et al. 2002; Ford et al. 2018; Bird 2021; Jenkins & Dai 2021). This reduction in sea-ice cover has presented great concerns, particularly for coastal Arctic regions since warming is occurring up to four times faster than the rest of the planet (Rantanen et al. 2022) – a phenomenon known as Arctic amplification (Holland & Bitz 2003; Serreze & Barry 2011; Previdi et al. 2021). This phenomenon has various direct consequences in the Arctic, including glacier melting, rising sea levels, heightened coastal erosion, increased storm surges, and more frequent and intense coastal storms (Hoegh-Guldberg & Bruno 2010; Wassmann et al. 2011; Duarte et al. 2012; Previdi et al. 2021). Some recent models suggest that Arctic benthic invertebrates may not exhibit higher vulnerability compared to taxa with southerly distributions in response to habitat changes resulting from the broader impacts of climate change (Renaud et al. 2019). However, the combination of warming conditions, shifts in ocean circulation, and ecological alterations, including changes in migration patterns, prey availability, and reproduction, continue to cause profound transformations to northern fish (Christiansen et al. 2014; Côté et al. 2021), benthic ecosystems (Kortsch et al. 2012), and the services they provide (Bianchi et al. 2023).

Warming conditions make it easier for southern species, like Atlantic cod (*Gadus morhua*), to move into Arctic waters where they may outcompete and prey on Arctic species or offer a less nutritious food source (Secretariat 2017). For example, warmer conditions led to the northward expansion of capelin (*Mallotus villosus*) in the Canadian Arctic, with unknown consequences for biological interactions (e.g., competition, predation) (Secretariat 2017). Due to the loss of certain northern habitats (e.g., sea-ice) from warming, food resources are becoming increasingly scarce in northern marine environments, forcing northern species to travel farther and expend more energy to feed (Orlova et al. 2009; McNicholl et al. 2016; Secretariat 2017; Panikkar & Lemmond 2020). Overall, these changes collectively pose a significant threat to the well-being of coastal ecosystems, individual organisms, and their associated populations.

Inuit Nunangat (Inuit homeland in Canada), which encompasses communities throughout four northern regions (Inuvialuit Settlement Region, Nunavut, Nunavik, and Nunatsiavut) has garnered national and global concern with respect to climate change (ITK 2019). The livelihoods of communities throughout Inuit Nunangat are deeply connected to the coastal marine environment for sustenance, cultural identity, and overall well-being (Kirmayer et al. 2000; Cunsolo Willox et al. 2013), yet climate change continues to pose a significant threat. Nunatsiavut is one region at the forefront of rapid environmental change by way of rising temperatures and shifting weather patterns, sea ice thickness and seasonality, and species distributions (Bush & Lemmen 2019; Bishop et al. 2022).

Covering approximately 72,000 km² of land and 48,690 km² of coastal and marine areas, Nunatsiavut is the Inuit settlement region in the northern part of the Labrador Peninsula, established by the Labrador Inuit Land Claims Agreement (LILCA). This agreement, voted by Labrador Inuit, led to self-governance and the establishment of the Nunatsiavut Government (NG) in 2005. Communities throughout Nunatsiavut continue to voice a spectrum of concerns (e.g., sea-ice, harvesting, mental health) regarding their local marine waters, all in the context of confronting the challenges of a changing climate (Durkalec et al. 2015; MacDonald et al. 2015;

Bishop et al. 2022). While the communities of Nunatsiavut are well-aware of the challenges posed by climate change in their homeland, it is crucial to highlight the existing knowledge gaps for effective management of the coastal marine ecosystems of northern Canada.

1.3 Coastal knowledge gap

Coupled with environmental change is a coastal knowledge gap, particularly significant in the North. Although Canada is home to the longest coastline in the world, much of its coastline has yet to be fully explored through high resolution mapping. As of 2023, nearly 25% of the global ocean was mapped at a resolution of around 1 km according to the *Seabed 2030* project (GEBCO compilation group 2023). The 'white ribbon,' referring to the empty space nearshore on many nautical charts (Mason et al. 2006), poses a challenge for conventional bathymetric surveys. This challenge arises from potential hazards such as rocks, reefs, and waves, coupled with limitations on survey time (Carvalho et al. 2017). This specific difficulty in mapping the coastal zone exacerbates the prevailing knowledge gap, as these regions are not adequately represented in current mapping initiatives. Therefore, information on depth, terrain (i.e., geomorphic features), and biological community composition (i.e., species assemblages) is notably deficient in many coastal areas, especially in the North. Due to high operating costs and seasonal or perennial ice cover, the sampling seasons are short, causing surveys to be highly constrained, compounding the already spatially limited and time-consuming biological and/or sediment sampling process (Wynja et al. 2015; Coad and Reist 2017). As such, there is a limited understanding of the spatial distributions, abundances and functional roles of many species and habitats in northern waters.

1.4 Management & Inuit research priorities

To address the environmental changes in Nunatsiavut, the northern coastal knowledge gap, and the concerns voiced by community members, the NG launched the Imappivut – ‘Our

Oceans' Marine Planning Initiative in September 2017. Given the commitments made by NG and the Canadian government to establish a marine management plan encompassing the northern Labrador coastline, this initiative's objective revolves around managing and safeguarding the interests and rights of Labrador Inuit in the coastal and marine areas of Labrador (ITK 2019). Imappivut is guided by the principles, wisdom, and priorities of Labrador Inuit, as well as the current understanding of the marine environment. The marine plan aims to represent the full diversity of species, habitats, and community interests while implementing marine protected areas (MPAs) to safeguard their marine waters. Two species designated as top priorities for the Imappivut initiative include iKaluk, Inuktitut for Arctic charr (*Salvelinus alpinus*) (Linnaeus 1758) and ogak, Inuktitut for Greenland cod (*Gadus ogac*) (Richardson 1836).

1.5 Study species

iKaluk - Arctic charr and ogak – Greenland cod (locally called rock cod) are two fish species that are valued highly within Nunatsiavut communities, as they have traditionally been a large part of Inuit subsistence, cultural identity, and economic opportunities.

1.5.1 Study species: iKaluk / Arctic charr

Arctic charr are cold-water salmonid fish that inhabit a broad latitudinal range (Johnson 1980), spanning from Arctic to north temperate regions (Reist et al. 2013). These fish exhibit remarkable phenotypic diversity across various life histories, encompassing both freshwater resident and anadromous forms (Klemetsen et al. 2003). Undergoing a summer sea residency of 1-4 months (Dempson & Kristofferson 1987; Klemetsen et al. 2003; Spares et al. 2015), anadromous charr migrate to the sea in early spring when the rivers are ice-free until they must return to fresh water in the fall to overwinter (Klemetsen et al. 2003). Arctic charr typically remain in estuarine waters for extended periods during a transition phase to and from the marine environment to capitalize on optimal temperatures, salinities, and high productivity for foraging

(Dempson & Kristofferson 1987; Klemetsen et al. 2003; Spares et al. 2015; Harris et al. 2020). While the preference for estuarine habitats during the marine phase of charr migration is well-documented (Harwood & Babaluk 2014; Moore et al. 2016; Harris et al. 2020; Cote et al. 2021), it is worth noting that these fish have been observed in other habitats (e.g., fjords, coastal headlands) during transit to estuarine systems (Moore et al. 2016) or for enhanced feeding opportunities (Cote et al. 2021; Nordli et al. 2023). These fish consume a variety of marine prey, including pelagic fish, plankton, and benthic organisms (Davidsen et al. 2020; Cote et al. 2021). Overall, the migration period serves to increase or restore somatic growth, fecundity, and lipid reserves as charr spend the summer feeding (Dempson & Kristofferson 1987; Spares et al. 2015; Moore et al. 2016). The baseline knowledge surrounding marine charr habitat associations in Nunatsiavut is lacking, particularly with respect to their ecological makeup and trophic levels, which ultimately hinders the conservation of this data-poor fishery (Kourantidou et al. 2022).

The anadromous form stands as one of the most crucial subsistence fisheries for Inuit communities in Arctic Canada, due to its wide distribution and relative abundance in northern regions (Murdoch 2012; Kourantidou et al. 2022). In fact, the charr fishery out of Nain Bay is seen by community members as one of the most important marine resource from a social and cultural standpoint across Nunatsiavut (Kourantidou et al. 2022) despite its small contribution to fishery revenues, employment, and the broader economic landscape of the region (Kourantidou et al. 2020; Kourantidou et al. 2021). This fishery dates to the 1860s (Dempson et al. 2008), has a deep cultural connection to Inuit communities in the region, and is still utilized for both commercial and subsistence purposes (Kourantidou et al. 2022). Despite the recognized adaptability of Arctic charr, as highlighted in previous studies (Dempson et al. 2002; Klemetsen et al. 2003; Cote et al. 2021), recent research has indicated that declines in southern Labrador charr populations are anticipated to persist for many decades due to the pressures of climate change (Layton et al. 2021). The reduced genetic diversity observed in southern Labrador charr populations limits their ability to respond to rapid environmental change. Currently, numerous populations of anadromous charr are declining in subarctic and Arctic regions of Norway (Svenning et al. 2021; Nordli et al. 2023). These findings are also anticipated in northern Labrador as drastic environmental shifts continue (Layton et al. 2021). Furthermore, local harvesters in Nain, Nunatsiavut, have reported observing smaller and less abundant charr (Dempson et al. 2008; Cote et al. 2021) which may be indicative of a less sustainable fishery due to the deteriorating environmental conditions in the region.

1.5.2 Study species: Ogak / Greenland cod

Ogak, also known as rock cod or Greenland cod (*Gadus ogac*), holds significant importance as a demersal fish species in the subsistence practices of Inuit communities throughout Nunatsiavut. Initially believed to be distributed from Alaska to Greenland and down to Cape Breton, Nova Scotia (Scott & Scott 1988), recent evidence suggests that ogak is, in fact, a subspecies of Pacific cod (*Gadus macrocephalus*) (Stroganov 2015; Mecklenburg & Steinke 2015) as once proposed (Carr et al. 1999). This discovery implies an expansion of their range from the western and eastern Pacific through the Bering, Chukchi, and Beaufort Seas across the Arctic to eastern Canada and Greenland (Mecklenburg & Steinke 2015). Ogak is primarily a coastal species and is seldom encountered in deep or offshore waters (Nielsen & Andersen 2001; Knickle 2013). This fish does not engage in extensive migrations and in coastal Newfoundland and Labrador, ogak maintains a benthic opportunistic lifestyle, feeding primarily on crustaceans, annelids, mollusks, echinoderms, and various fish species such as capelin and Arctic cod (*Boreogadus saida*) (Nielsen & Andersen 2001; Knickle 2013; Knickle & Rose 2014). Due to the limited ecological knowledge on ogak in Nunatsiavut, their resiliency to environmental change is largely unknown. A decrease in the abundance of rock cod has been reported by NG in recent years, with some communities reporting smaller fish sizes, and rock cod with empty stomachs (NG 2018; ASLP 2021). However, to determine the sustainability of this fishery, more baseline ecological knowledge of this species is required. While they tend to remain in proximity to the coast throughout their lifespan (Mikhail & Welch 1989), research on the habitat associations of ogak is limited. In Nain, fishers actively seek out ogak in the vicinity of eroded cobbles and boulders lining cliffsides. Despite the importance of these habitats, detailed descriptions of ogak associated habitats have yet to be described in the region (but see Knickle & Rose 2014; Schornagel 2015; Dalley et al. 2017 for habitat associations in coastal Newfoundland and Labrador).

1.6 Benthic habitat mapping

The development of detailed maps of seabed habitats has become a useful tool for managing and protecting marine ecosystems. Using a multitude of various technological equipment, benthic habitat mapping characterizes distinct areas of the seabed based on physical (e.g., depth, bottom-type) and biological variables (e.g., species composition) (Brown et al. 2011). The process involves linking spatially limited biological samples, obtained through methods like sediment grabs and visual recordings (e.g., videos, underwater imagery), with environmental datasets gathered through remote sensing tools (Brown et al. 2011). The linkage is facilitated through a variety of modeling techniques, enabling the creation of versatile maps with applications across a wide range of research domains, including biology, geology, conservation, marine management, marine spatial planning, navigation, and geography (Cogan et al. 2009; Brown et al. 2011; Baker & Harris 2020). Furthermore, it has proven highly valuable in establishing foundational information for various purposes, like conservation initiatives (Buhl-Mortensen et al. 2015), and marine spatial planning (Schill et al. 2011).

The goal of habitat mapping is to uncover biophysical patterns and processes that allow simplified representations of the seafloor. These simplified depictions help us better comprehend the functioning of benthic ecosystems, and these representations are continuously being improved (Brown et al. 2011). Advancements in acoustic survey technologies, including the use of multibeam echosounders (MBES), have allowed marine scientists to achieve similar mapping quality and resolution as terrestrial efforts, resulting in highly accurate seafloor images (Mayer 2006; Brown et al. 2011). The use of these sonar instruments provides essential physical information such as bathymetry, describing seabed depth and topography, and backscatter, which acts as an indicator of seabed texture and sediment composition. To further describe and characterize the seabed, secondary terrain features (e.g., slope, roughness, curvature) can be derived from these sonar data (Wilson et al. 2007; Lecours et al. 2017). Although these features may not be direct drivers of biological spatial patterns, they offer a measurable proxy for other influential variables which are harder to measure directly (e.g., seabed hydrodynamics, food supply) (Wilson et al. 2007; Lecours et al. 2017; Mackin-McLaughlin et al. 2022; Nemani et al. 2022).

The spatial scale, or spatial resolution and geographic extent, of explanatory features mentioned above are important to consider due to the complex dynamics and ecological processes within a benthic ecosystem. Most habitat mapping studies apply either single or multiscale approaches for the derivation of the attributes mentioned above (Lecours et al. 2015; Misiuk et al. 2018; Misiuk et al. 2021; Shang et al. 2021). Single scale approaches use a constant analysis scale (e.g., 3 X 3 window) across all features; however, studies have shown that this method often fails to consider the scale at which the species-environment relationship is most pronounced, and ultimately overlooks important relationships (MacMillan & Shary 2009; Shang et al. 2021). Multiscale approaches are more desirable to help ensure that the most important scale-dependent patterns and processes are captured (Porskamp et al. 2018; Shang et al. 2021; Nemani et al. 2022; Mackin-McLaughlin et al. 2022). Overall, considering terrain characteristics at both finer and broader spatial scales provides a more complete understanding of the benthic ecosystem (Dolan 2012; Lecours et al. 2015), especially when considering the underlying biological composition of these physical seabed features.

To visually examine and characterize seafloor biology, underwater imagery and videos are commonly used. A variety of underwater video techniques (e.g., towed cameras, baited cameras, drop cameras) can be used to observe megafauna (>2 cm) and habitats in marine ecosystems (Mallet & Pelletier 2014). These visualizations of the seabed are called ground-truthing, and on their own have proven highly useful in identifying and monitoring ecologically important habitats and species (Rangeley et al. 2022; Boulard et al. 2023; Zhao et al. 2023). This information holds substantial value, particularly in regions where comprehensive acoustic mapping is lacking (see Devine et al. 2019; Rangeley et al. 2022). Analysis of video data involves meticulous annotations and identifications of species' presence and abundance. These observations can then be correlated with features derived from acoustic sonar data through a range of statistical modeling techniques (Ferrier & Guisan 2006; Brown et al. 2011; Misiuk et al. 2019B). Relationships between physical seafloor characteristics (e.g., depth, topography) and their influence on the spatial distribution of benthic communities can then be explored and used to derive full-coverage habitat maps.

Numerous demersal fish species, including those of commercial significance, exhibit strong associations with various benthic habitat parameters. These parameters encompass factors such as the type of substratum, the relief or topography of the seabed, and the presence and density of habitat-forming species (Stephens et al. 2006; Anderson et al. 2009). Our knowledge surrounding the distribution of benthic habitats in Nain and their critical role in supporting two highly valued species within Nunatsiavut communities is severely lacking. This deficiency in information puts local fisheries and the conservation of these fish and their habitats at risk, especially in the face of rapid environmental changes. Therefore, there is an urgent need to provide more detailed descriptions of these vital benthic habitats, along with their connections to the focal fish species. Such information is essential for informing resource management strategies and making decisions regarding protected areas in the region.

1.7 Mapping for marine management

Benthic habitat mapping plays a crucial role in ecological conservation, pinpointing areas with high biological or conservation significance. Notably, it contributes to the establishment of baseline information, supporting ongoing monitoring and assessment of temporal changes (Buhl-Mortensen et al. 2015; Novaczek et al. 2017B; Lacharite & Brown 2019; Proudfoot et al. 2020). These maps have also been used to support MPA planning (Lacharite & Brown 2019; Proudfoot et al. 2020), promote sustainable fisheries management (Lacharite & Brown 2019) and locate commercial fish habitat (Le Pape et al. 2014). Benthic habitat mapping aligns well with ecosystem-based management (EBM) strategies, focusing on conserving ecosystem function, services, and biodiversity by recognizing intricate ecological linkages across different scales (O’Higgins et al. 2020). The maps produced are valuable for understanding the overall dispersion of ecosystems, which holds significant importance for both resource managers and scientists. Mapping techniques can also be enhanced using local and traditional knowledge systems, where knowledge of marine habitat and/or individual species’ distributional patterns are passed down for generations (Lauer & Aswani 2008; Teixeira et al. 2013; Misiuk et al. 2019A).

Indigenous and Traditional Ecological Knowledge (IEK/TEK) represents the empirically accumulated knowledge held by local communities whose livelihoods are closely intertwined with natural resources (Berkes 1993). These knowledge systems can serve a comparable function to ground-truthing techniques in the context of marine habitat mapping, where it offers firsthand observations of marine ecology (Lauer & Aswani 2008; Misiuk et al. 2019A). In Nunatsiavut, IEK and TEK have been used extensively to guide Imappivut research goals. Fishing locations for Arctic charr and rock cod, passed down through generations, hold immense importance for community members in Nain, Nunatsiavut and were the focal points of this research. These locations, where community members have historically found great success in fishing for these species, were generously shared to deepen our understanding of their habitats. Mapping the benthic habitats of these fishing sites will unveil the biological communities that underpin the benthic ecosystem, supplying vital ecological baseline information about the habitat preferences and associations of these fish species. By integrating IEK/TEK and habitat mapping, important knowledge gaps relative to seafloor habitats and the ecology of important species can be filled (Misiuk et al. 2019A). Furthermore, this holistic approach has been shown to bolster credibility and reduce criticism from diverse stakeholder groups (Silver & Campbell 2005).

1.8 Rationale

Understanding the benthic habitat use and associations of charr and ogak through the insights from both Inuit and Western scientific perspectives, is crucial for developing co-management recommendations. These recommendations are essential for the sustainable management of these species and their ecosystems in a rapidly changing environment. Indeed, this approach fosters stronger community engagement in initiatives such as the planning of MPAs and other coastal management interventions (Aswani & Lauer 2006; Lauer & Aswani 2008; Teixeira et al. 2013). The knowledge derived from this research will help bridge existing gaps in our shared understanding of charr and ogak habitats, contributing to the identification of potential threats to these fish and their associated habitats in the region. Moreover, the collection of baseline ecological knowledge of Nain's nearshore benthic environment will contribute to the identification of vulnerable and critical habitats for future conservation efforts. Ultimately, this collaborative approach, blending traditional knowledge systems with scientific insights, will help inform effective co-management strategies and ensure the long-term health and resilience of valuable species and their associated habitats.

1.9 Thesis overview

The research questions and objectives in this thesis were shaped in collaboration with project partners from Imappivut and NG, reflecting the questions and concerns of the local community of Nain, Nunatsiavut. The primary objective is to enhance our comprehension of the benthic habitats that charr and ogak inhabit, thereby advancing our understanding of the ecology of these crucial fish species.

1.9.1 Associations between iKaluk/Arctic charr (*Salvelinus alpinus*) and estuarine benthic diatom habitats in nearshore Nunatsiavut waters

Chapter 2 identified the biological makeup of Arctic charr associated habitats, ecological relationships within these habitats, and assessed the use of habitat by charr using previously collected acoustic telemetry data, harvester-identified fishing locations, and benthic video surveys. The main question of this research was which marine benthic habitats do charr associate with in Nain, Nunatsiavut? The objectives of the study were to interpret the habitat-use of charr by:

1) Representing benthic biological patterns within charr acoustic receiver locations.
2) Exploring benthic species-environment relationships.
3) Calculating charr habitat suitability and habitat availability indices.

1.9.2 Association of Ogak/Greenland cod (*Gadus ogac*) with complex habitats: Insights from traditional fishing locations in nearshore Nunatsiavut waters

Chapter 3 used ogak fishing locations identified by local harvesters to describe and map the ecological composition and distribution of benthic habitats in nearshore Nain, Nunatsiavut. The study aims to establish a baseline understanding of the benthic habitats in Nain's nearshore waters and their relationship with ogak habitat use through habitat mapping. The question lying at the foundation of this research was which marine benthic habitats do ogak associate with in Nain? The objectives of the study were to interpret the habitat-use of ogak by:

1) Describing & mapping the distribution of benthic habitats within Nain’s nearshore marine environment.
2) Inferring benthic relationships within rock cod habitats.
3) Establishing a baseline for future conservation efforts relative to ogak and other important benthic species.

1.9.3 Conclusions

Chapter 4 of this thesis delves into the conclusions drawn from the study and outlines potential avenues for future research. This chapter highlights important findings from this research and recommendations for management. This section is targeted towards the Nunatsiavut Government and residents of Nain. Its purpose is to support resource users in identifying critical habitats for conservation, tackling the difficulties presented by changing environmental conditions, and determining the subsequent actions required to safeguard the region's valuable marine resources.

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2 Associations between iKaluk/Arctic charr (*Salvelinus alpinus*) and estuarine benthic diatom habitats in nearshore Nunatsiavut waters

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Abstract

iKaluk, Inuktitut for Arctic charr (*Salvelinus alpinus*), holds significant commercial and cultural value for Inuit communities throughout Nunatsiavut. Studies evaluating charr habitat associations in freshwater are plentiful; however, there is limited information on the ecological makeup and sediment characteristics of anadromous charr habitats in marine environments. This study investigated the available habitat and habitat use of Arctic charr during their marine residency period in Nain, Nunatsiavut using underwater videos, harvester-identified fishing locations, and acoustic telemetry. Drop-camera surveys were deployed on previously placed hydrophone acoustic receivers and within harvester-identified fishing locations to describe and quantify available benthic habitats in the study area. Telemetry information was used to identify charr presence hotspots, track movements between receivers and calculate habitat suitability indices. A total of 248,056 organisms belonging to 63 morphotaxa were identified within the 125 video drops used for benthic community analyses and these represented five faunal assemblages. The assemblage prevalent in the majority of charr hotspots, characterized by homogeneity and extensive brittle star (Ophiuroidea spp.) coverage, was frequently observed in Nain estuaries with fine sediments covered by benthic diatom mats. These habitats likely offer abundant foraging opportunities. The highest habitat suitability values for tagged charr were observed on these diatomaceous sediments, where they were detected the most and spent the most time cumulatively. The results of this study serve to fill gaps in ecological knowledge relative to the benthic habitats present in Nain, as well as the habitat associations of the iconic Arctic charr, a species of paramount importance to Inuit communities. Moreover, these findings aim to support management strategies for the charr fishery in Nain, which faces increasing threats from the accelerated environmental perturbations taking place in the North.

2.1 Introduction

In the context of widespread global concerns about climate change, Arctic and subarctic regions serve as critical indicators of profound environmental transformations. This is evident in the case of northern fish populations, where trophic dynamics are being disrupted, geographic ranges are in flux, and critical life history traits are being lost due to warming temperatures (Falardeau et al. 2017; Layton et al. 2021; Wight et al. 2023). Nunatsiavut, situated in Inuit Nunangat (Inuit homeland in Canada), stands at the forefront of these rapid environmental changes. Nunatsiavut is an Inuit self-governed area located in the northern part of Labrador, Canada where heightened Arctic warming, and climate-driven environmental changes have caused shifts in the distribution of marine species and a loss of habitat (Cunsolo Willox et al. 2013; Ford et al. 2012). Since 1993, consistent annual warming has led to reduced ice coverage on both land and sea, accompanied by a notable alteration in fjord salinity in the region (Allard & Lemay 2012). These impacts are poised to intensify in the near future due to the current rate of climate change (Post et al. 2019), and important species for Inuit communities, like iKaluk - Arctic charr (*Salvelinus alpinus*) (Linnaeus 1758), are becoming increasingly vulnerable (Layton et al. 2021).

Arctic charr exhibit high variability in habitat selection with a circumpolar distribution, ranging from the Arctic to north temperate regions (Johnson 1980; Reist et al. 2013). Across their range, anadromous charr play a significant role in the economies and livelihoods of northern communities by supporting commercial fisheries (Day & Harris 2013; Roux et al. 2019), and holding profound cultural, and food security significance (Friesen 2002; Dubos et al. 2023). The Arctic charr fishery out of the Nain region in Nunatsiavut, Labrador, Canada, is perceived as the most significant marine resource, holding critical social and cultural importance, throughout Nunatsiavut (Kourantidou et al. 2022). In the sea, charr inhabit a range of habitats stretching from protected estuaries to coastal headlands, but a clear preference for estuarine environments is reported in the literature (Spares et al. 2015a; Moore et al. 2016; Cote et al. 2021). These estuaries host a diverse range of prey for charr, including benthic invertebrates and fish, which are integral components of the Arctic charr diet (Dempson et al. 2002; Spares et al. 2012). Supporting the preference for estuaries, community members and harvesters in Nain have traditionally been successful in catching charr within local estuaries during the summer (Mary Denniston, personal communication). These fishing locations are vital for community members and have been passed down for generations for subsistence and economic gain. The combination of intermediate salinities (Thorpe 1994), optimal temperatures (Harris et al. 2020), and high productivity, leading to rich foraging opportunities (Miller & Sadro 2003), allows for a gradual transition into the marine environment after spawning, and makes estuaries highly attractive for anadromous salmonids. The timing and duration of estuarine residency can vary (Dempson & Kristofferson 1987; Klemetsen et al. 2003; Spares et al. 2015a; Harris et al. 2020), but anadromous charr typically reside within and near estuarine systems, and may venture along the coastline to other habitats (e.g., fjords, coastal headlands) while in transit to estuarine systems (Moore et al. 2016) and/or for increased feeding opportunities (Cote et al. 2021; Nordli et al. 2023). The motivation to journey beyond these estuarine systems has been linked to variations in sex, size, maturation, local environmental conditions, the availability of food resources, and the proximity to other river systems (Dempson & Kristofferson 1987; Spares et al. 2012; Spares et al. 2015a; Cote et al. 2021).

The preferences and use of habitat by charr have been extensively studied in freshwater environments (Sandlund et al. 2010; Sinnatamby et al. 2012; Murdoch & Power 2013), and studies on their movements are also plentiful (Spares et al. 2015a; Moore et al. 2016; Harris et al.

2020); however, there is limited information about the ecology of anadromous charr habitats in marine environments. Refuges for charr, like estuaries, along with other critical habitat used for foraging, are threatened by changing environmental conditions, particularly in northern regions which are experiencing more accelerated and pronounced impacts of climate change relative to the rest of the world (Bush & Lemmen 2019). Understanding charr-associated marine habitats can help us assess changes in charr habitat associations and the ecosystems that are key to their survival (Harris et al. 2020).

A lack of comprehensive biological knowledge about a species can severely hinder its sustainable management, potentially resulting in collapse (Hutchings 1996; Walters & Maguire 1996; Foley et al. 2011). The significance of this challenge is especially pronounced in the context of studying Arctic charr habitats. The lack of sufficient data and a solid grasp of both the biotic and abiotic characteristics of these habitats limits our ability to fully comprehend the consequences of environmental changes. It also hinders the establishment of a clear link between habitat health and the productivity of the fishery, and makes it difficult to assess the impacts of present harvesting levels on future harvesting opportunities (Kourantidou et al. 2021; Kourantidou et al. 2022). Due to high operating costs and seasonal or perennial ice cover in the North, sampling seasons are short, causing scientific surveys to be highly constrained (Coad and Reist 2017; Wynja et al. 2015). As such, there is a limited understanding of the spatial distributions, abundances and functional roles of many species and habitats in northern waters. In addition, knowledge on baseline coastal information such as bathymetry, and biological community composition is sparse within the habitats occupied by valuable species, like charr. Investigating the biological makeup of these marine ecosystems (e.g., estuaries, fjords) will enable the understanding of habitat associations of commercially and culturally important species in the region.

The lack of ecological knowledge on charr stocks, combined with coastal knowledge gaps and the threat of climate change in the region have sparked the development of the Imappivut – ‘Our Oceans’ Marine Planning Initiative. This initiative was developed by the Nunatsiavut Government through consultation and collaboration with communities in order to manage and protect Labrador Inuit interests in the coastal and marine areas of Labrador. Further understanding habitat associations for fish like charr can inform management strategies, assess the quantity and health of fish habitat, and aid in forecasting and observing the effects of habitat changes on fish populations (Rudolfsen et al. 2021). The primary objective is to fill ecological knowledge gaps within the marine habitats of Arctic charr, a species of social, commercial, and cultural importance to northern communities. In this study, 1) epifaunal-habitat associations were investigated using drop-camera surveys within charr acoustic receiver locations and local harvester-identified fishing locations; 2) benthic species-environment relationships were explored; and 3) benthic habitat availability and suitability was assessed using habitat suitability indices for Arctic charr in Nain, Nunatsiavut.

2.2 Methods

2.2.1 Study Area

This study focuses on the marine charr habitats in Nain, Labrador, Canada. Nain is a remote coastal community nestled within Nunatsiavut (56◦N, 61◦W; Fig 2.1), a region at the transition between subarctic and polar climates. Its coast is open to the Labrador Sea and is characterized by rocky islets and deep fjords, forming an expansive archipelago teeming with marine biodiversity (Rangeley et al. 2022). Nain stands as the largest Inuit community in Nunatsiavut and holds the distinction of being one of the oldest permanent Inuit settlements in

Canada. The marine environment is a cultural cornerstone and plays a crucial role for Inuit communities, providing subsistence and economic opportunities through species like Arctic charr. Despite the rich baseline ecological data derived by local knowledge holders throughout the community, Nain's coastline remains largely unmapped, lacking comprehensive bathymetric and Western scientific data. Consequently, there exists a limited understanding of the spatial distributions and roles of various habitats on its seafloor.

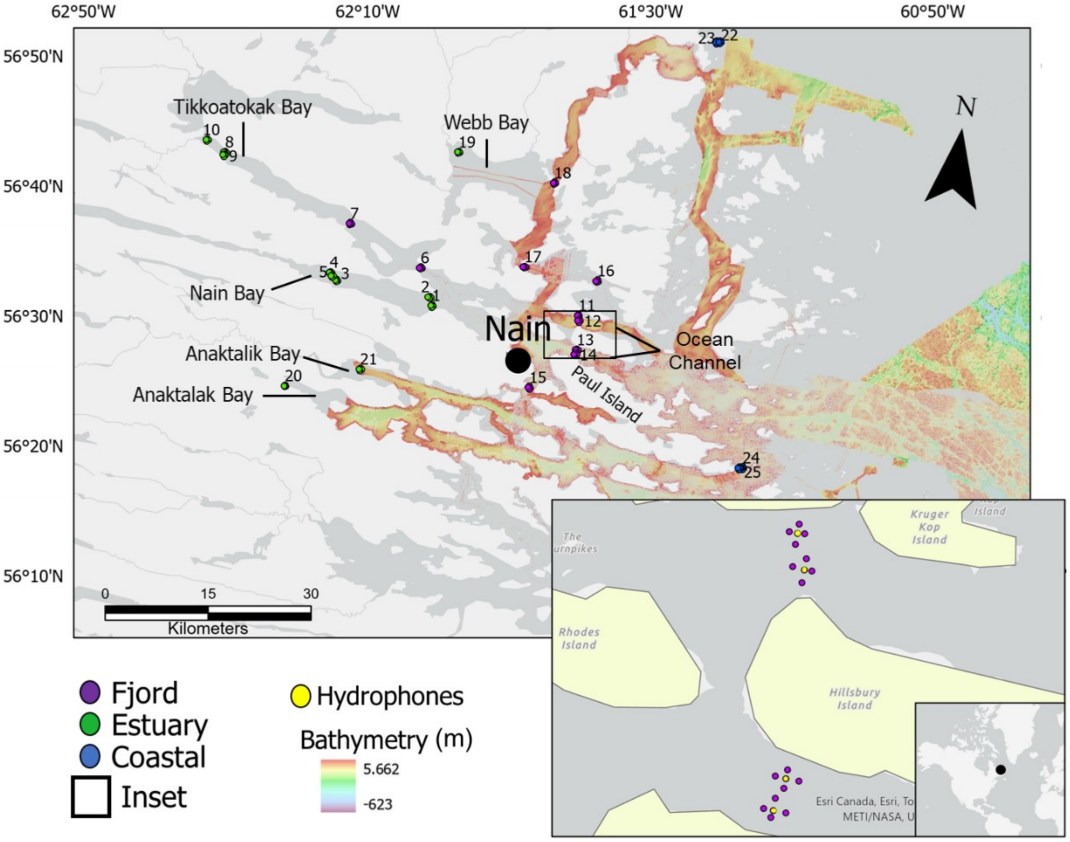


Figure 2.1 Drop-camera (n=125) and hydrophones (n=25) sites in the Nain region of Newfoundland and Labrador, Canada. Hydrophones are positioned in Nain Bay (Estuary: n=5), Tikkoatokak Bay (Estuary: n=3, Fjord: n=2), Ocean Channel (Fjord: n=4), Anaktalak Bay (Estuary: n=1), Webb Bay (Estuary: n=1, Fjord: n=3), and coastal headlands (Coastal: n=4). Hydrophones are located in the center of each cluster of 4 drop camera stations. Canadian Hydrographic Service Non-Navigational (NONNA) bathymetric coverage with a spatial resolution of 100 metres is shown in the background. The sites in Anaktalik Bay did not contain a hydrophone, but were community-identified as important fishing locations for Arctic charr.

2.2.2 Site selection

Drop-camera deployments were placed surrounding the sites of previously deployed hydrophones. Hydrophone acoustic receivers (n=24) deployed by Fisheries and Oceans Canada (DFO) were positioned in river estuaries, fjords, and coastal headlands to record movements of tagged Arctic charr in the summer of 2018 and 2019, using a method designed to replicate charr migratory pathways (i.e., anadromy) (Klemetsen et al. 2003; Cote et al. 2021). Video drift surveys were conducted at every hydrophone location. Within these locations, we observed an overlap with traditionally important Arctic charr fishing areas. These fishing spots, identified by local community members and provided by the NG for our study, were among the hydrophone estuary locations (Fig 2.1). We also conducted surveys at an additional fishing location in Anaktalik Bay, despite the absence of a hydrophone. This site was treated as if a hydrophone were present for the survey.

2.2.3 Video surveys

Most sites were surveyed in September 2021; however, coastal hydrophones, and sites in Anaktalak and Anaktalik Bays were surveyed in October 2022. Video surveys were performed using five replicate video camera drops positioned north, south, east, west, and within the center of each charr hydrophone site from September 9 - 15, 2021, on the local M/V *Safe Passage*, for a total of 95 video samples (5 videos X 19 sites). Video surveys were employed using the DTPod drop camera system manufactured by Deeptrekker inc. DTPod specifications include an LED light (1000 Lumens), two red-light scaling lasers 2.5 cm apart, and high-definition video (1920 x 1080, 30 fps) recording capabilities. From October 3 – 12, 2022, thirty additional drop-camera surveys were conducted (5 videos X 6 sites) on the local M/V *Inuttatik* with the same camera system. These surveys were conducted around the four coastal hydrophone locations, a community identified location in Anaktalik Bay, and an additional hydrophone location in

Anaktalak Bay. Videos spanned a total of five minutes while drifting at each drop site. Overall, 125 videos were collected within 24 hydrophone locations and one community identified fishing location.

In addition to these video surveys, photographic transects were performed on the 2022 R/V *William Kennedy* to collect additional benthic community data on the two coastal sites near Paul Island (sites 24 & 25). The custom drop-camera, built by Natural Resources Canada, was triggered to take a photograph every time the attached hanging weight touched the seafloor (Normandeau et al. 2018; Campbell & Normandeau 2019). A Canon Rebel Digital SLR and Canon flashes were used, powered by a 12 volt/80 Amphr Deep Sea Power & Light pressure-compensated sea battery. Transects were performed taking approximately 20 photos with a 12 kHz OIS pinger mounted on the camera sled being monitored for bottom trigger closure using the Knudsen 12 kHz in Pinger mode.

2.2.4 Video analysis

Using the Monterey Bay Aquarium Research Institute's (MBARI) Video Annotation and Reference System (VARS) (Schlining & Stout 2006), videos were annotated based on a randomized order to reduce human annotation biases (Durden et al. 2016). Every organism greater than 2 cm was counted and identified to the lowest taxonomic level. Due to poor video quality, suspended sediment, or camera drift speed, species-level identification was not always possible; therefore, identification was done using morphotypes (Howell et al. 2019) based on the production of an image catalogue for the Nain region (Supplementary material). Taxa identification was performed with aid from experts and published species identification guides (Nozères et al. 2014A; Nozères et al. 2014B; Salvo et al. 2018; Lacasse et al. 2020). Similarly, photographic transects were annotated using the same method in ImageJ, an open source image processing program.

All substrates (Fig 2.2) observed in the survey were identified and classified with guidance from the Coastal and Marine Ecological Classification Standard (Federal Geographic Data Committee 2012). The substrate classes documented in this survey included: a) fine sediments, b) fine sediments with pebbles, c) gravel mix with algal turf, d) diatomaceous sediment, e) gravel, f1) scallop shell hash, and f2) mussel shell hash. The majority of sites were dominated by substrate classes A – E and only had patches of shell hash (F1, F2) (Fig 2.2); therefore, sites were categorized within the dominant substrate classes only. However, reliance on video for substrate identification meant that differentiating between mud and sand could not be reliably achieved (combined into fine sediments) while hard substrate under a veneer of soft substrate was unidentifiable. Using the software *Blender*, 1 frame for every 10 second intervals was extracted from each video and overlayed with 30 randomly placed points in *ImageJ*. Each of the randomly placed points were then assigned to a substrate category and the percentage cover of sediment in each image was calculated. The distance between the two reference lasers was measured and used to estimate sediment grain size.

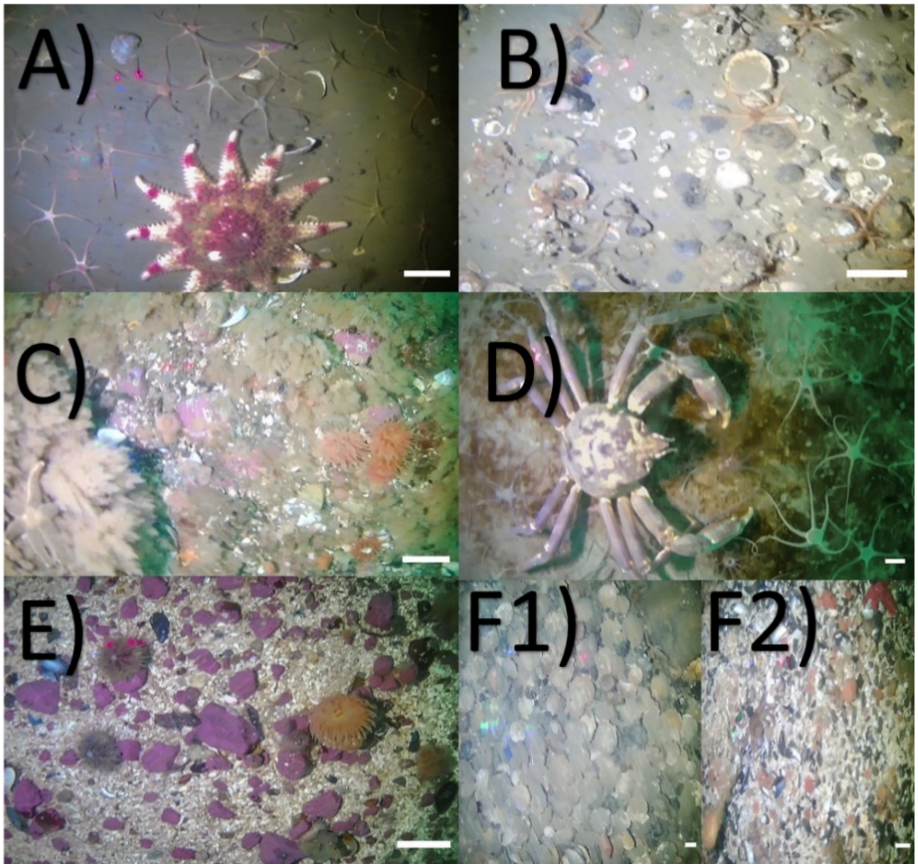


Figure 2.2 Images of the different substrate classes identified during video annotation: A) fine sediments, B) fine sediments with pebbles, C) gravel mix with algal turf, D) diatomaceous sediment, E) gravel, F1) scallop shell hash, and F2) mussel shell hash. White bar for scale is 2.5 cm.

2.2.5 Epibenthic community analyses

All epibenthos abundance data obtained from the 125 video surveys were aggregated per hydrophone site. Taxa with three or fewer observations in all 25 sites were removed from the data set prior to analysis to reduce the variability caused by these low abundances (Brown et al. 2012). The visual footprint (area m^2) of each image extracted for the substrate classification was computed using *Biigle's* laser point detection tool (Schoening et al. 2015; Langenkämper et al. 2017). The summed visual footprint was used to estimate the approximate area (m^2) of each transect and the total number of organisms per morphotype per transect was converted into densities. Using Bray-Curtis (Bray & Curtis 1957) similarities, the distance for the species matrix was calculated. The species matrix was Hellinger transformed to reduce the effect of higher abundances (e.g., Ophiuroidea spp.) (Legendre & Gallagher 2001).

Cluster analyses (i.e., Hierarchical Clustering Analysis) were performed in *R* using the hclust function in the 'cluster' package. These clustering techniques were used to identify discontinuities and groupings of organisms within the data (Legendre & Legendre 2012; Brown et al. 2012; Van Der Reijden et al. 2021). An average hierarchical clustering method ('Unweighted Pair-Group Method using arithmetic Averages' – UPGMA) was selected to derive faunal assemblages from the Hellinger-transformed species density data (Sokal & Michener 1958; Borcard et al. 2018). To determine the size and cutoff of each cluster, fusion level values, silhouette widths and matrix correlations were optimized (Borcard et al. 2018). Analysis of similarity (ANOSIM), is a non-parametric statistical test, and was used to identify significant differences between and within clusters. To investigate the number of observed species relative to the sampling effort, species accumulation curves were derived (Gotelli & Colwell 2001). Species accumulation curves were created for each hydrophone site and cluster.

To describe the biological composition of each assemblage the dominant taxa were derived. Dominant taxa consist of the most abundant species within a community that may influence the occurrence and distribution of other species and overall community structure (Smee 2010; Nemani 2022). These organisms have abundances that are greater than the individual group assemblage mean (Borcard et al. 2018). Additionally, an Indicator Value approach was used to determine indicator taxa of each assemblage (Dufrêne and Legendre 1997). These values were derived using the indval function from the 'labdsv' package in *R* and are used to measure the association between a species and assemblage by assessing the relative abundance and frequency of each species per grouping. The function aims to identify an ideal indicator species found exclusively for each assemblage (Mouillot et al. 2002; Dufrene and Legendre 1997). Because the indicator species are determined based on their specificity to one grouping, they are useful for monitoring changes to the sites associated with those specific groupings (McGeoch & Chown 1998; Kubosova et al. 2010).

2.2.6 Modelling of benthic species-environment relationships

Prior to modelling the influence of environmental variables (Appendix: Table 2.2) on assemblages, a data exploration protocol was performed using methods from Zuur et al. (2010). This exploration method consisted of (1) identifying any outliers in the response and explanatory variables; (2) assessing the homogeneity of variance in the response variables; (3) assessing normality in the response variables; (4) checking for zero inflation in the response variables; (5) assessing collinearity between all explanatory variables; (6) visualizing the relationship between response and explanatory variables; (7) checking for interactions; (8) checking for independence in the response variables. In addition to the substrate percentage cover described previously, from the 5 video drops at each hydrophone, depth was measured using the vessel's depth sounder and the mean value was calculated. Each drop location was measured to the nearest river mouth on ArcGIS Pro using the Geodesic measurement tool which is calculated in a 3D spherical space as the distance across the curved surface of the world (Appendix: Table 2.2). A mean distance to freshwater variable was then calculated per hydrophone site.

Using the Hellinger-transformed species matrix, a redundancy analysis (RDA) was performed using the Vegan package in *R* to summarize the variation in faunal density and to explain this variation using a set of explanatory variables. RDA is a canonical ordination approach that can be used to statistically test the relationships between environmental variables and species data (Legendre & Legendre 2012). To select the explanatory variables tested in the

RDA, linear dependencies were explored by computing the X variables' variance inflation factors (VIF) and a forward variable selection procedure was performed (Borcard et al. 2018). The number of explanatory variables were reduced to achieve model parsimony and avoid strong correlations among the explanatory variables. Only taxa with a goodness-of-fit of at least 0.65 in the ordination plane formed by axes 1 and 2 were represented in the RDA. To test the significance of the RDA, along with the explanatory variables and canonical axes, permutation tests were performed (n=999).

2.2.7 Telemetry

The DFO hydrophone acoustic data on Arctic charr from 2018 to 2019 (see Cote et al. 2021 for collection and tagging methodology) contained detection information for 18 receivers and 47 unique animal IDs. Of the 24 deployed acoustic receivers, two were lost (one in Nain Bay and one in Webb Bay) and unable to provide telemetry data, and the four coastal receivers did not have any detections throughout the duration of their deployment. Detection data was imported into *R* and the GLATOS package was used to identify and remove potential false detections from the dataset (Holbrook et al. 2019). A false positive detection (i.e., false detections) occurs when two or more transmitter signals collide and cause a different unique tag ID code by receiver (Simpfendorfer et al. 2015). The 'false_detections' function in GLATOS was used to identify false detections where the time between that detection and the next closest detection of any one transmitter on the same receiver ('min_lag') exceeds the threshold time (tf) (Binder et al. 2017), set as 45 minutes for the current study. Individual animals that were not detected at least twice by the same receiver at different times or were not detected by more than one receiver were removed (Binder et al. 2017; Murray 2022).

To examine residency time, the 'detection_events' function was then used to distill 20,332 detections down to 87 distinct detection events (i.e. a period of a series of sequential detections that occurred on the same receiver before being detected on a different receiver (Binder et al. 2017). The threshold time to distinguish an event was set to 5 days (432000 seconds) to preserve the limited data available. Fish residency time at each receiver was derived to create a rasterized movement map of local hotspots. A comparison of residency time in estuaries, fjords and coastal headlands was made, and by extracting the substrate type and community information present at each assemblage, interpretations on the habitat associations of the focal fish species were made (Murray 2022).

Fish movement was classified as either sedentary, where there are no movements between receivers, but are repeatedly detected at one location, or vagrant, where individuals were detected by at least two more distantly spaced receivers (Béguer-Pon et al. 2015; Murray 2022). A two-sample t-test was then used to determine whether the total length and weights of sedentary charr were significantly different from vagrant charr, as larger charr are more likely to travel further from their natal river mouths (Dempson & Kristofferson 1987; Nordli et al. 2023). Movement between receivers was calculated using the ‘shortestPath’ function from the gDistance package in R, which calculates the least-cost distance between points in the water while using a land polygon as a boundary. The total estimated distance travelled, and the minimum distance dispersed from the release site was calculated for each individual fish and their movements were compiled to represent their pathways throughout the study sites in a heat map (see Hamoutene et al. 2018 for full methodology). The generated summary grid was smoothed for visual clarity by averaging each cell value with those in the surrounding two adjacent cells. Specifically, this involved considering values from a 5 × 5 grid centered on the point of interest, achieved through the ‘focal’ function in the Raster package. The density calculations were determined by the frequency of overlap between an estimated track and each grid cell (Hamoutene et al. 2018).

Habitat availability and suitability was calculated using a habitat suitability index (HSI) method outlined in Rudolfsen et al. (2021). The obtained value (0-1) estimates the suitability of habitat types for populations based on the species observed presence or absences within a dataset (Murray et al. 2022; Rudolfsen et al. 2021). HSI was calculated based on the number of individual detections that occurred on a given substrate. An average HSI was determined for each substrate class (Rudolfsen et al. 2021) throughout the duration of the telemetry data (2018-2019). A chi-square goodness of fit test was used to determine if there was a significant difference in habitat use (observed) and available habitat (expected) based on the prediction that charr use all the habitat available to them. The mean proportions of availability and use of habitat, which are metrics within the HSI calculation (see Rudolfsen et al. 2021), were used to estimate the number of charr that were expected and observed to use a particular habitat, respectively.

2.3 Results

2.3.1 Charr hotspots & substrate types

Of the 47 fish in the raw dataset, 3 were not detected by the same receiver at different times and were filtered out of the analysis leaving a total of 44 animals. Charr hotspots (i.e., high level of charr movement) around Nain showed that for the majority of this study's duration, charr frequented estuarine habitats during their period of marine residency (Fig 2.3). Three movement hotspots were identified in Tikkoatokak Bay, Nain Bay, and Webb Bay; however, a charr movement hotspot was also observed in Anaktalak Bay where they remained sedentary. It should be noted that migration route coverage for Anaktalak Bay was limited to one receiver; therefore, charr may have used other habitats in proximity. The estuarine habitats were mostly dominated by fine sediment overlain with diatom mats (Fig 2.3). Charr spent 61 % of their time near hydrophones positioned in diatomaceous substrates. Hydrophones located on fine sediment seafloors were used the second most at 16%. Sites with fine sediments covered in pebbles as well as gravel mix with algal turfs were not as frequently occupied by charr, at only 11% and 12%, respectively.

Table 2.1 Cumulative residency time (days) spent at receivers positioned in four substrate classes.

	Fine sediments	**Diatomaceous sediments**	**Fine sediments with pebbles**	**Gravel mix with algal turf**
Cumulative time (days)	70	265	49	52
Proportion (%)	16.0	60.8	11.3	11.9

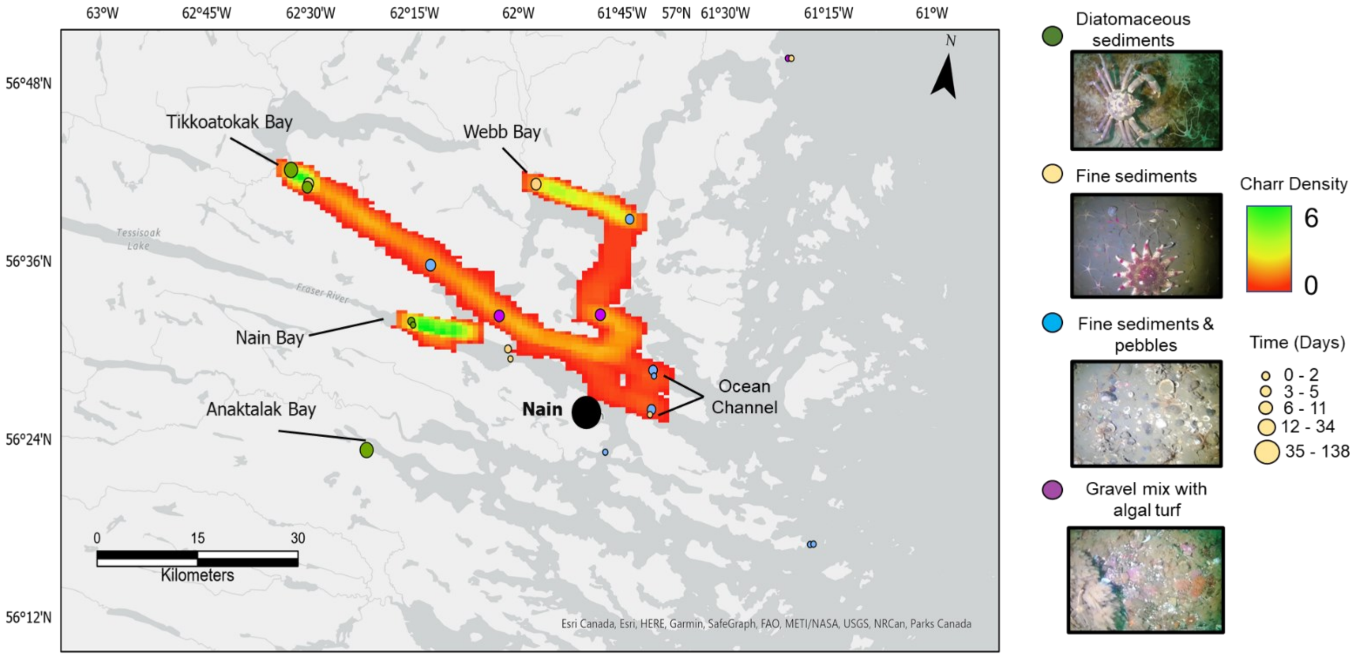


Figure 2.3 Arctic charr rasterized movement paths (5 x 5 grid) between acoustic receivers and substrate classes. Charr hotspots around Nain are highlighted in green and yellow. Density calculations are based on the number of times an estimated track overlaps with each grid cell (815 m × 387 m). Receivers are coloured by dominant substrate class identified during video annotation.

2.3.2 Community analyses

A total of 248,056 organisms belonging to 63 morphotaxa were identified within the 125 video drops used for community analyses and these were clustered into five faunal assemblages (Fig 2.4). The ANOSIM statistic ($R = 0.976$) indicated a significant difference in species composition between the clusters ($p < 0.001$), suggesting distinct taxonomic profiles. Species accumulation curves for each assemblage revealed that assemblages 2, 4 and 5 were not sufficiently sampled because of their limited spatial coverage (Fig 2.5). Assemblage 1 had the largest spatial extent, representing 56% of all video drops and occurring mainly in estuaries with fine sediments, diatom mats and evidence of bioturbation. This assemblage contained 223,700 individuals across 60 morphotaxa; however, the most commonly observed organism, and also this assemblage's indicator taxa (Appendix: Figure 2.10), was the brittle star (Ophiuroidea spp.) ($n = 194,889$) which created extensive agglomerations. The assemblage also contained 11 dominant taxa (Fig 2.6) that included two potential local prey species (sculpin, *Cottidae* spp. and snake blennies, *Lumpenus lampretaeformis*) for Arctic charr. Assemblage 2 represented 8% of all video drops and occurred within fjords dominated by a mixed gravel substrate sparsely populated by large boulders, pebbles, and algal turf. This assemblage was characterized by epibenthic fauna that attached to the underlying hard substrate, like northern red anemones (*Urticina felina*) ($n = 5,278$) and sea stars (*Leptasterias polaris* & Asteroidea spp.). In addition to those indicator taxa, the assemblage contained 13 total dominant taxa. This assemblage contained 10,758 individual organisms across 48 taxa. Assemblage 3 had the second largest spatial extent, representing 28% of all video drops, occurring only in fjord and coastal habitats with fine sediments, pebbles, cobbles, boulders, and patches of algal turf. Characterized by scarlet sea cucumbers (*Psolus fabricii*) and bryozoans (Bryozoa spp.) as the indicator taxa, this assemblage held 27 dominant morphotaxa and 10,055 individual organisms across 57 taxa.

Assemblages 4 and 5 were represented by only one site each. Assemblage 4 was located in an estuarine habitat and was comprised of fine sediments that were mostly barren, but had small patches of epibenthic fauna. This assemblage contained 690 individual organisms across 26 taxa and was characterized by bivalves (*Portlandia arctica*), ascidians (Ascidiacea spp.) and bryozoans (Bryozoa spp.) as the indicator species. There were 16 dominant taxa within this assemblage, and the majority of these had low occurrences. Located near the estuarine habitat in Anaktalak Bay, Assemblage 5 was comprised of fine sediments with a diatomaceous cover and was characterized by tube-dwelling anemones (Ceriantharia spp.) as the indicator taxon. This assemblage contained 2,853 individuals across 18 taxa and showed similarities to Assemblage 1; however, it mostly lacked the presence of Ophiuroids (n = 1). There were 12 dominant taxa in this assemblage which included patches of sponges (Porifera spp.) and potential local prey species (sculpin & snake blennies) for Arctic charr. These prey items were dominant taxa in all other assemblages as well.

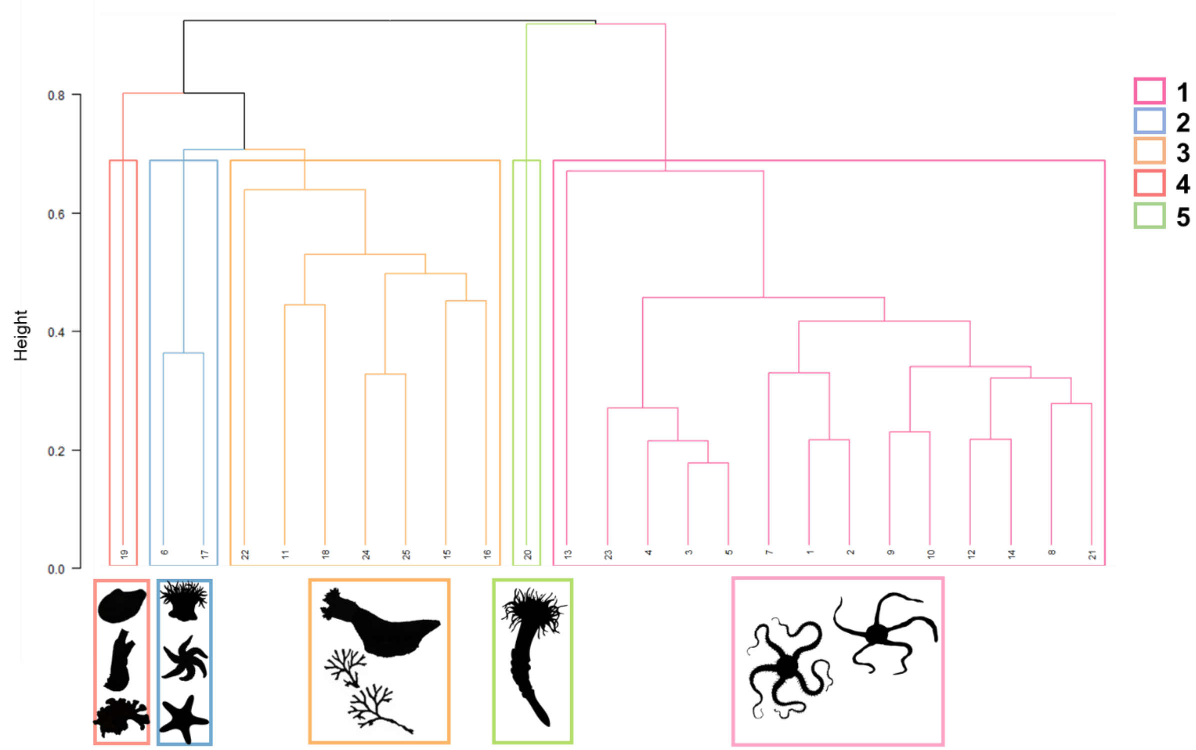


Figure 2.4 Unique assemblages of epifauna found in surveyed habitats based on hierarchical clustering (UPGMA). Indicator taxa silhouettes represent each assemblage.

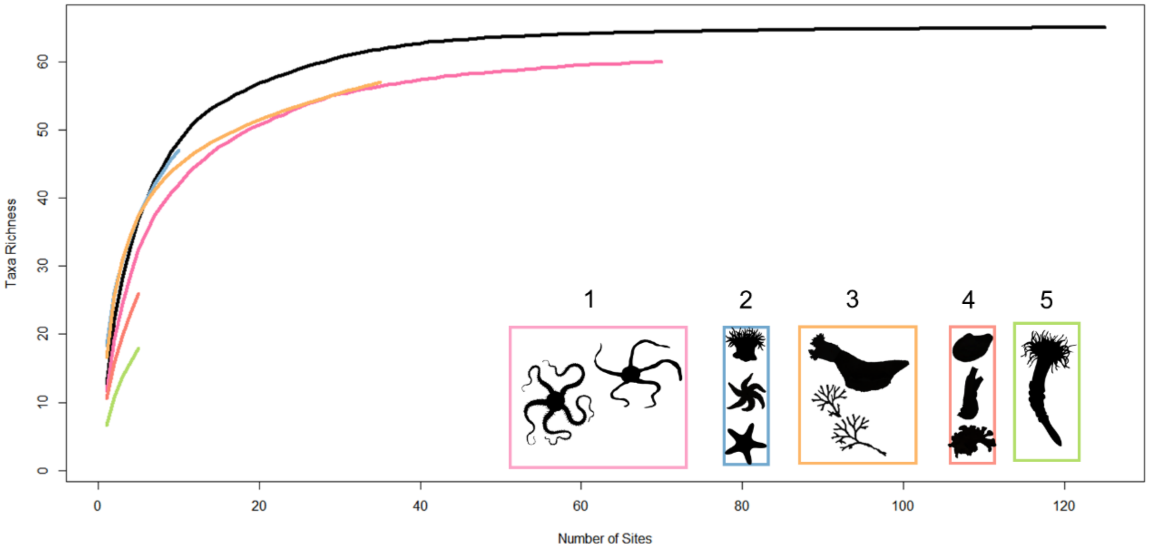


Figure 2.5 Species accumulation curves for each epifaunal assemblage derived from clustering. Figure includes the summation of species observed across all sites included in analysis (in black).Y axes represent the number of morphotaxa observed; X axes are the total number of sites sampled.

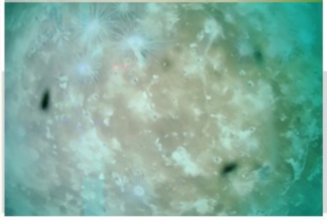
Assemblage	Name	Image	Dominant Taxa	Sample Size
1	Brittle star dominated 		Ophiuroidea.sp.1, *Psolus phantapus*, Ceriantharia spp., *Stronglyocentrotus droebachiensis*, Ophiuroidea sp.2, *Myxicola infundibulum*, Ascidiacea sp.1, *Pandalus* spp., *Cottidae* spp., Bryozoa sp.1, *Lumpenus lampretaeformis*	70
2	Northern red anemones and sea star mix 		*Urticina felina*, *Stronglyocentrotus droebachiensis*, *Leptasterias polaris*, Ophiuroidea sp.2, *Cucumaria frodosa*, *Nephtheidae* sp.3, *Psolus* sp.1, *Boltenia ovifera*, *Crossaster papposus*, Porifera sp.3, *Psolus phantapus*, *Henricia sanguinolenta*, *Hyas araneus*, *Halocynthia pyriformis*, *Hyas coarctatus*	10
3	Scarlett sea cucumbers and bryozoans 		*Stronglyocentrotus droebachiensis*, *Psolus fabricii*, *Myxicola infundibulum*, *Psolus phantapus*, Bryozoa.sp.1, *Cottidae* spp., Porifera sp.13, Bryozoa.sp.6, *Boltenia ovifera*, *Chlamys islandica*, *Lumpenus lampretaeformis*, *Pandalus* spp., Poriferasp.3, Bryozoa sp.004, *Urticina felina*, Ophiuroidea.sp.1, *Stomphia coccinea*, *Halocynthia pyriformis*, *Crossaster papposus*, *Hyas araneus*, Bryozoa.sp.2	35
4	Bivalves, tunicates and bryozoans 		Ascidiacea sp.1, *Myxicola infundibulum*, Bryozoa.sp.4 *Lumpenus lampretaeformis*, *Polinices heros*, *Psolus fabricii*, *Zoarcidae* sp.2, Bryozoa.sp.6, *Halocynthia.pyriformis*, Ophiuroidea.sp.1, *Pandalus* spp., *Sagittidae* spp., Bryozoa.sp.2, Ascidiacea sp.2, *Hyas coarctatus*	5
5	Tube-dwelling anemones 		Ceriantharia spp., Porifera sp.3, *Psolus phantapus* *Sagittidae* sp.1, *Polinices heros*, *Henricia sanguinolenta*, *Pagurus* spp., *Hyas coarctatus*, *Psolus fabricii*, *Buccinum* spp., *Myoxocephalus* spp., *Lumpenus lampretaeformis*	5

Figure 2.6 Images of epifaunal assemblages and dominant taxa observed for each species assemblages observed around Nain. Sample size refers to the number of drop-camera stations.

A redundancy analysis (RDA) was performed to investigate species-environment relationships. Six explanatory variables were retained after forward selection: depth, mean latitude (meanlat), and the four substrate classes (subclass). The selected environmental variables significantly explain 44% (R^2adj) (p = 0.001) of the variation in benthic taxa abundances and the parsimonious model yielded two significant axes (RDA1: p = 0.001, df=1, *F*=18.230, RDA2: p = 0.039, df=1, *F*= 3.243) (Fig 2.7). The proportions of accumulated constrained eigenvalues (i.e., proportions relative to the explained variance) showed that the first axis alone explains 24.4% variance, while both axes together explain 28.7%. Of the explanatory variables, a permutation test determined that substrate class (p = 0.001, df=3, *F*= 6.712) significantly influenced the variation in epifaunal density.

Morphotaxa with a goodness of fit greater than 0.65 included green sea urchins (*Strongylocentrotus droebachiensis*), slime tube worms (*Myxicola infundibulum*), as well as two indicator taxa including scarlet sea cucumbers, and brittle stars (Ophiuroidea spp.) (Fig 2.7). Urchins were positively correlated with heterogeneous habitats, such as Gravel Mix with Algal Turf. In contrast, brittle stars were positively correlated with homogeneous habitats dominated by Fine Sediments at higher latitudes as well as Diatomaceous Sediments. Sites associated with the brittle star-dominated assemblage were mostly found to be correlated with depth, with shallower sites found mostly in Diatomaceous Sediments. Sites that were positively correlated with Fine Sediments with Pebbles were associated with a high abundance of scarlet sea cucumbers found attached to the larger pebbles and rocks. Slime tube worms, which were exposed above the fine sediments, were also associated with these sites (Fig 2.7).

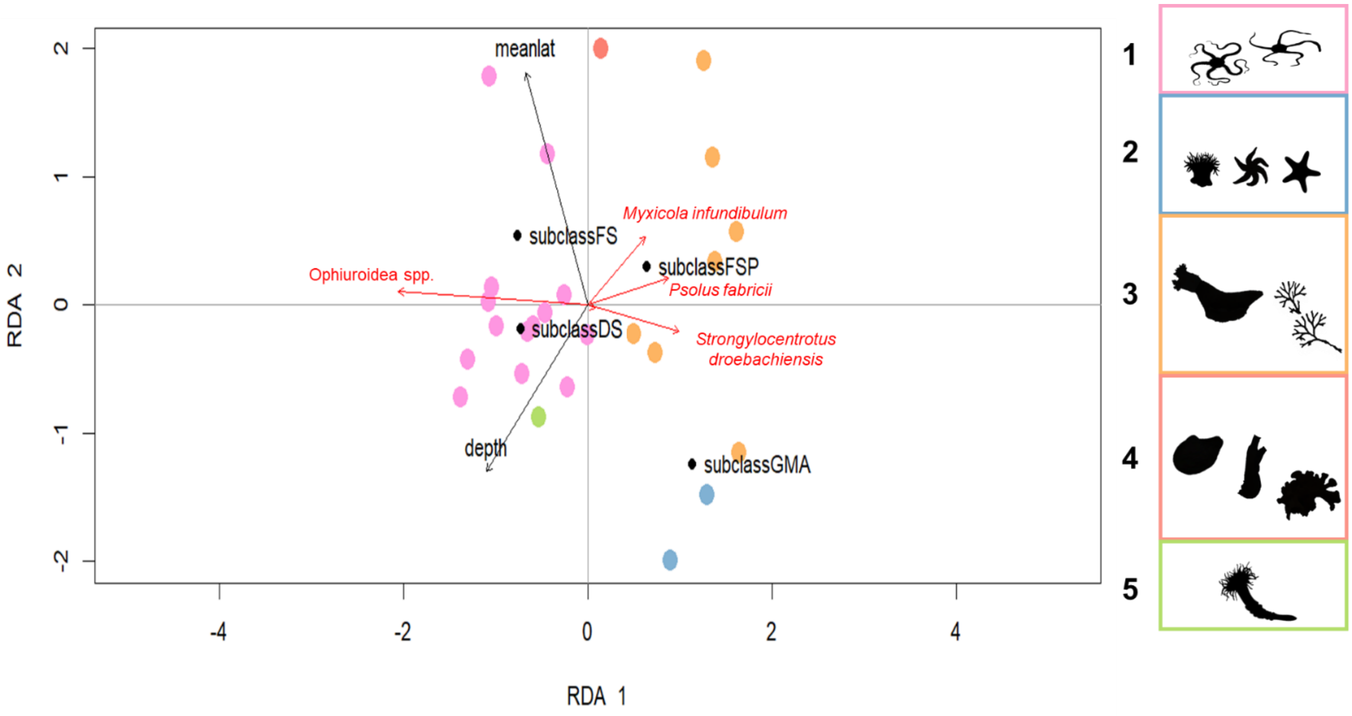


Figure 2.7 Taxa (<0.65 goodness of fit) and environmental variable associations with assemblage types, based on parsimonious RDA. Points are coloured according to assemblage. Scaling shows the strength and effect of explanatory variables.

2.3.3 Habitat associations & movement

Habitat associations were assessed for all charr detected in the study (n=44). Some charr were detected within all substrate classes identified; however, individual variability in substrate use was observed (Appendix: Table 2.3; Table 2.4). Sedentary charr represented 59% of the individuals in the study and predominantly remained within estuarine habitats, with the exception of one individual (ID: 2459) who remained in a fjord in proximity to an estuary for the duration of its receiver detections. Of the sedentary individuals, 23 were detected only on Diatomaceous Sediments while the other 2 were detected on Fine Sediments and Fine Sediments with Pebbles, respectively (Appendix: Table 2.4). Vagrant charr tended to frequent harder substrates, like Fine Sediments with Pebbles and Gravel Mix with Algal Turfs more often; however, on average vagrant charr were found to frequent Diatomaceous Sediments and Fine

Sediments the most (Fig 2.8). Overall, tagged charr in this study were detected 71% of the time in Diatomaceous Sediments found in estuaries. The mean weights and lengths of sedentary charr were not significantly different from the vagrant charr according to the two-sample t-test.

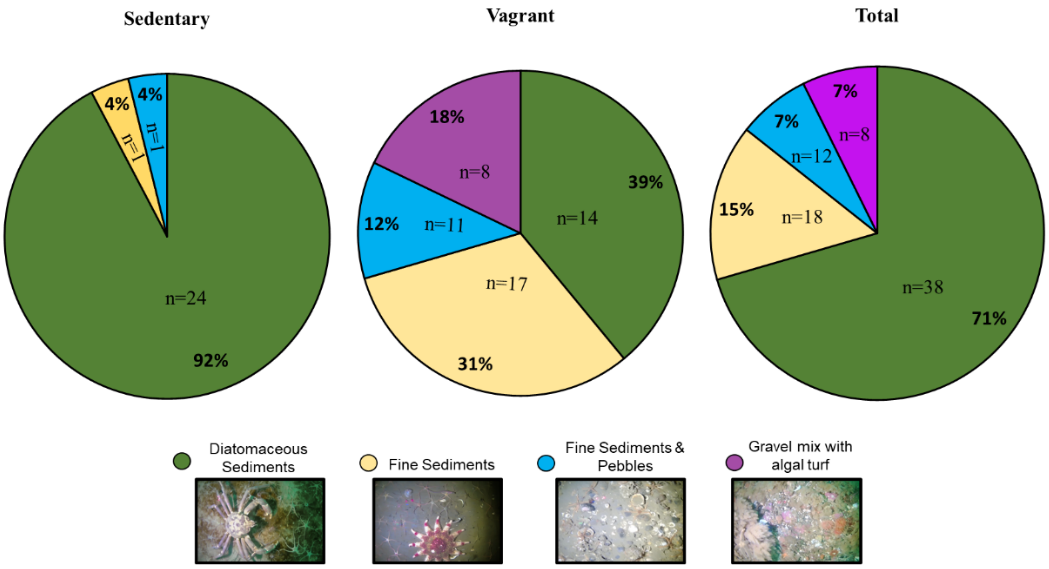


Figure 2.8 Mean sedentary, vagrant, and total charr variability per substrate classification (% use) based on number of detections. Number of individuals (n) per substrate class is also indicated.

2.3.4 Habitat availability & habitat use

On average, the most used substrate class by charr was Diatomaceous Sediments followed by Fine Sediments, Gravel Mix with Algal Turfs, and Fine Sediments with Pebbles. The mean HSI values exhibited the same pattern (Fig 2.9). The substrate class with the most availability in the survey area was Fine Sediments with Pebbles, followed by Fine Sediments, Diatomaceous Sediments, and Gravel Mix with Algal Turfs. There was a statistically significant difference in the mean habitat used (observed) and habitat available (expected) in the chi squared test ($p<0.001$, $df=3$, $\chi^2 = 58.270$).

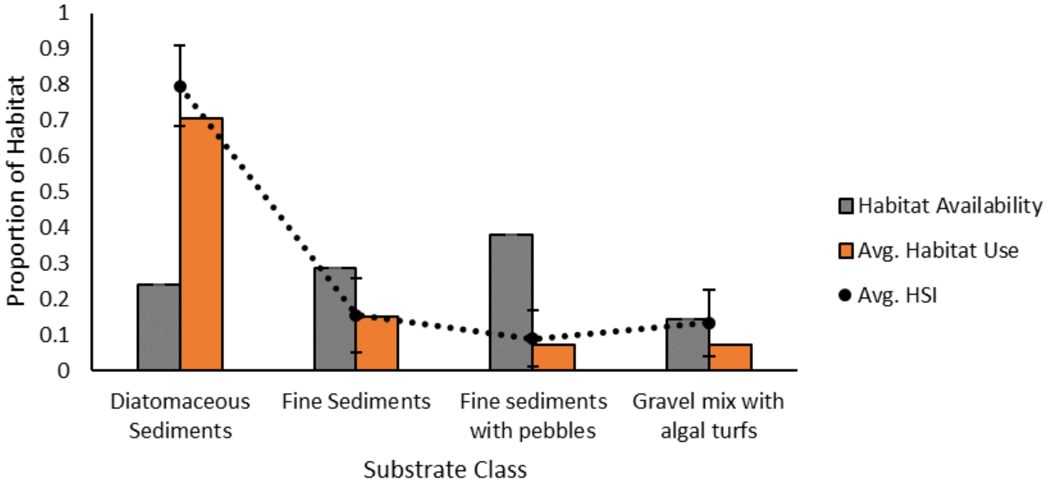


Figure 2.9 Habitat suitability indices (HSI) for Arctic charr (n=44) by substrate class based on telemetry detections from August 03, 2018 to September 10, 2019. Points indicate the average HSI value for each substrate for all charr. Error bars represent the 95% confidence intervals of the HSI values. Habitat availability was calculated using the number of receivers in each substrate class. Habitat use proportions were based on the telemetry detections of individual char.

2.4 Discussion

The spatial representation of epifaunal assemblages in community-identified charr fishing locations and telemetry information from the summer of 2018 and 2019 provides valuable information on charr habitat associations in the marine environment. The findings elaborate on the significance of estuarine habitats, identifying those dominated by fine sediment covered with diatom mats, as charr hotspots during their period of marine residency. Habitat associations of charr are important to establish in order to address critical knowledge gaps in the ecology of this iconic fish, and aid in the development of targeted conservation and management strategies. While the primary objective was to unveil Artic charr habitat associations, the video surveys concurrently addressed the scarcity of baseline ecological data in the region. Despite ongoing efforts to expand the protection of northern habitats, potential gaps in critical habitat information persist.

2.4.1 Charr habitat associations

The utilization of non-estuarine habitats by charr in Nain exhibits variability year to year (Cote et al. 2021) and has been linked to biological characteristics (e.g., size, sex), local environmental conditions, foraging opportunities, and the proximity to other river systems (Dempson & Kristofferson 1987). However, the preference for estuarine habitats during charr marine residency has been well-documented in the literature (Spares et al. 2015a; Moore et al. 2016; Cote et al. 2021). Several hypotheses have been proposed to explain this preference, including the presence of intermediate salinities in estuaries, optimal temperatures (Harris et al. 2020), and rich foraging opportunities (Miller & Sadro 2003; Moore et al. 2016). While these factors have been studied, limited attention has been given to understanding the productivity patterns of coastal habitats within Nunatsiavut (McCarney et al. in press) or the intricacies of the food-web dynamics.

Diet analyses conducted in Nain have revealed a preference for Arctic charr piscivory on capelin (*Mallotus villosus*) and sand lance (*Ammodytes* spp.) (Dempson et al. 2008; Cote et al. 2021), with higher levels of piscivory in nearshore areas relative to offshore areas. It has been suggested that estuaries in Nain may attract a higher abundance of charr and limit their exploration of non-estuarine habitats in years when capelin and sand lance are more plentiful (Cote et al. 2021). Like 71 % of detections in this study, Harris et al. (2020) found that 72.6 % of charr detections in the Cambridge Bay region of Nunavut occurred in estuaries. The study also suggested a link between charr prey preferences and their estuarine habitat use, as capelin, which spawn in shallow-water, seem to be highly important in the diet of Cambridge Bay charr (Harris et al. 2020). Although substrate was not assessed in the study, their findings mirrored the importance of estuarine habitats for charr in Nain, where sedentary and vagrant charr predominantly occupied shallow estuarine habitats with diatomaceous sediments throughout the entire summer of 2018 and 2019. Through commercial fisheries in Nain, associations between captured charr near coastal headlands (far from natal estuaries) and a diet shift away from capelin has been observed (Cote et al. 2021). It is possible that capelin abundance was high in Nain estuaries throughout the duration of this study (2018-2019), as they continue to recover from their low abundance in the 1990s (Cote et al. 2021). Diatom mats covering the sediments of these estuaries may support the abundance of this prey, although they were not observed in video footage from this survey. Despite this, the use of other prey taxa like sculpin and blennies in Arctic charr diets (Dempson et al. 2002; Spares et al. 2012) may also contribute to their common use of estuarine habitats covered in diatom mats.

The role of benthic diatoms in estuarine ecosystems is crucial, influencing the carbon cycle in coastal environments and acting as a primary food source in estuarine food webs (Glud et al. 2002; Virta et al. 2020; Liu et al. 2022). These phytoplankton have been documented as an important component of the juvenile capelin and sand lance diet (Vesin et al. 1982; Robards 1999). The significance of diatoms is further enhanced by the fact that copepods, which form a primary component of capelin and sand lance diet (Fortier et al. 1992; Dalpadado & Mowbray et al. 2013; Danielsen et al. 2016; McNicholl et al. 2016), rely heavily on diatoms for food (Irigoien et al. 2000; Michels & Gorb 2015; Hong & Tew 2023) and reproduction (Fortier et al. 1992; Irigoien et al. 2002). Consequently, the diatoms observed throughout the estuaries in Nain likely contribute to increased productivity. This, in turn, may lead to higher populations of calanoid and cyclopoid copepods that are most abundant in the region (Brown et al. 2012), followed by capelin and sand lance, and finally completing the short food web by sustaining Arctic charr. While acknowledging that the extensive coverage of diatom mats in estuarine habitats may indicate potential habitat suitability for charr, it is important to note that this hypothesis does not imply a direct one-to-one correlation. The presence of diatom mats could suggest favorable conditions for charr habitat but does not guarantee their exclusive presence or all the necessary elements for char habitat suitability. Despite these complexities, chlorophyll a concentrations (Chl *a*), strongly linked to phytoplankton biomass, have been correlated with charr distributions and are proposed as a proxy for charr food availability (Finstad et al. 2012; Harris et al. 2020). It is hypothesized that the Chl *a* within Nain's estuaries are high due to the extensive coverage of benthic diatom mats that may be contributing to the charr hotspots in the region.

2.4.2 Epibenthic community & charr relationships

The benthic community analysis revealed the presence of five distinct faunal assemblages among different substrate classes. Located within a majority of charr hotspots identified in this study, Assemblage 1, characterized by extensive agglomerations of brittle stars, showed a strong association with fine sediments and diatomaceous sediments. A similar ophiuroid-dominated biotope was noted on fine sediments in Nain and regions farther north in Labrador, including Hebron and Okak (Rangeley et al. 2022). Similar occurrences and coverage of extensive benthic diatom mats over fine sediments were observed during drop camera surveys in fjords in Young Sound, Greenland (Glud et al. 2002) with brittle stars also listed as dominant. The high abundance of these taxa is crucial for the cycling of energy between benthic and pelagic habitats and for stabilizing soft substrates, yet their sole dominance in some sites may lead to low functional diversity, making these areas more vulnerable to food web disruptions (Cadotte et al. 2011; Kędra et al. 2015; Rangeley et al. 2022). Of the 11 dominant species in this assemblage, two potential charr prey taxa were identified, including small sculpin and blennies (*Lumpenus* spp.) which have been observed in charr diet analyses (Magnan et al. 2002; Spares et al. 2015b; Cote et al. 2021). The association of charr with brittle star-dominated habitats is noteworthy, but likely coincidental, since brittle stars are not an important component of charr diet according to the literature.

Assemblages 2 and 3 were similar relative to their coverage of mixed, hard substrates (i.e., pebbles, cobbles, boulders) and shared a high abundance of various sea cucumber morphotaxa, such as *Cucumaria frodosa* and *Psolus* spp. as well as anemone (*Actiniaria* spp.) morphotaxa. The association of these holothuroids and anemones with hard substrates has been documented previously on the south coast of Newfoundland, Nain archipelago, and southeast part of the Hudson Bay (Salvo et al. 2018; Rangeley et al. 2022; Hamel et al. 2023). Vagrant charr tended to occupy sites in these assemblages more than sedentary charr; however, there was still a clear preference for sites with increased homogeneity. While these habitats farther from their natal estuaries could have been used to feed (Rikardsen & Amundsen 2005; Cote et al. 2021), vagrant charr may have also been transiting through these heterogeneous habitats to other estuarine habitats in the region, as suggested by Moore et al. (2016).

Located in a less dense charr hotspot in the northwest corner of Webb Bay, Assemblage 4 was comprised entirely of fine sediments with small patches of epibenthic fauna. Evidence of subsea permafrost was recently discovered in this area (Limoges et al. 2023), which may be significantly limiting the distribution of fauna within the bay. These frozen sediments can act as a barrier, restricting the availability of oxygen and nutrients in the bay (Vonk et al. 2015). The thawing of this permafrost may increase the mobility of metals to nearby waters (Vonk et al. 2015; Costis et al. 2020; Marginson et al. 2023) and may impact the trophic structure and food web processes; however, the effect of the presence of subsea permafrost as well as its thawing on benthic epifauna remains poorly studied. It should be noted that the sampling effort for this assemblage was poor as indicated by the species accumulation curve; however, further drop-camera images were collected from this area in 2022 and 2023 where the same patterns were identified (Limoges et al. 2023; Normandeau et al. in press.). These photographic transects conducted in locations near the acoustic receiver and charr hotspot in Webb Bay were not included in this analysis; however, they revealed a high coverage of diatomaceous sediments, which further supported the charr habitat use findings in this study.

The final assemblage, located in a charr hotspot in Anaktalak Bay was characterized by tube-dwelling anemones (Ceriantharia spp.), scattered along a seafloor covered by diatoms. This area is home to a nickel-copper-cobalt mine and concentrator operated by Vale NL (formerly Voisey's Bay Nickel Company) since 2005. Labrador Inuit have expressed concerns about potential environmental impacts arising from mining operations which include the effects of winter shipping activities from the dock facility at Edward's Cove along Anaktalak Bay to the Labrador Sea, and the discharge of treated effluent from the mine into the bay (Brown et al. 2012). These concerns are particularly relevant due to the sensitive and complex nature of the characterizing taxon (i.e., cerianthids) for this assemblage (Fuller et al. 2008; Murillo et al. 2011) and the presence of a charr hotspot where local community members fish. The scarcity of brittle stars in this assemblage is also notable, as brittle star distribution patterns have been correlated with effluent sediment contamination (de Moura Barboza et al. 2015), where contaminated areas were found to have less ophiuroids than non-contaminated areas. The presence of diatom mats may also be correlated to higher sedimentation rates, effluent, and the influx of terrestrial erosive material into Anaktalak Bay (Kahlmeyer 2009; Richerol et al. 2014; Back et al. 2021).

2.4.3 Environmental change & associated impacts

As warming continues across Nunatsiavut, it is hypothesized that an earlier spring bloom will influence the dynamics of sympagic (ice-associated), benthic, and pelagic productivity which may have implications for the diet and habitat use of Arctic charr (Falardeau et al. 2022).

If the sea ice breaks up earlier and the onset of melting occurs sooner (Markus et al. 2009), it would lead to an earlier progression of the spring bloom. This progression begins with an algal bloom within the ice, where a significant portion of algal-derived biomass settles on the seafloor after the ice melts, becoming a critical food source for benthic organisms (Boetius et al. 2013; AMAP 2017). Subsequently, a phytoplankton bloom is initiated beneath the melting ice cover (Ardyna et al. 2020; Back et al. 2021; Falardeau et al. 2022), providing nourishment for the development of pelagic prey, including copepods. The diatom mats observed throughout charr hotspots in this study likely serve as a critical food source for benthic organisms, including copepods and other zooplankton, which are highly important in the marine food web. An earlier spring bloom, driven by rapid warming, could impact the timing and abundance of these prey (Daase et al. 2013) and cause breaks in the charr trophic web, as suggested for other high-latitude fish like Polar cod (*Boreogadus saida*) (McNicholl et al. 2016). Understanding the potential impact of an earlier spring bloom, becomes crucial, not only for the timing and abundance of prey but also for the marine residency periods of Arctic charr. Seasonal patterns in the use of marine habitats by Arctic charr, as highlighted in studies like Cote et al. (2021), further underscore the importance of considering the timing of environmental events. Even vagrant charr exhibit a notable preference for estuaries during a transition phase to and from the marine environment, aligning with specific phases of the spring bloom (Harris et al. 2020; Cote et al. 2021). Climate change-induced disruptions in the timing of blooms and marine residency periods could have cascading effects, potentially forcing charr populations to adapt by altering their migration patterns, feeding behavior, and energy expenditure for optimal growth and survival (McNicholl et al. 2016; Secretariat 2017).

As environmental conditions change, there is a potential for Arctic charr in Nain to modify their behavior, possibly discontinuing their marine residency altogether. The loss of anadromy in fish populations is expected to occur in southern Labrador due to climate-driven range contractions (Layton et al. 2021), a trend also observed in other subarctic regions like Norway (Finstad et al. 2012; Nordli et al. 2023). This shift could serve as an indicator of broader changes throughout Inuit Nunangat. Longer ice-free seasons and increases in precipitation under future climate change scenarios could lead to increased productivity in freshwater systems, supporting an abundance of prey, and reducing the importance of anadromous behavior during the summer (Reist et al. 2006; Layton et al. 2021; Anderson 2022). The high fidelity of one individual to an estuarine habitat (34 days of continuous presence) was suggested to be indicative of a low degree of charr anadromy, as observed in the Bay of Two Rivers, Nunavut (Dempson & Kristofferson 1987). The reduction in the diversity of Arctic charr life histories may pose a long-term threat to Arctic charr as a species (Nordli et al. 2023), as well as the availability of this resource for commercial and subsistence fisheries throughout Inuit Nunangat. Further research and monitoring efforts are needed to verify whether the limited movements of charr throughout the duration of this study are due to a behavioural shift away from anadromy as well as the associated implications. Such a behavioral shift could pose a threat to the sustainability and stability of the fishery that is valued highly in communities of Nunatsiavut.

2.4.4 Management & monitoring

Management and monitoring efforts are crucial to address the potential impacts of changing environmental conditions on Arctic charr populations in Nain and to ensure the conservation and sustainability of this critical fishery. The following recommendations are proposed to better understand and protect the habitats and populations of Arctic charr:

1. *Long-term monitoring*

Establishing a comprehensive, long-term monitoring program for Arctic charr populations in Nain is essential. This program should include regular surveys of abundance, size, distribution, diet, and habitat use, as well as monitoring of environmental variables such as water temperature, ice cover duration, and prey availability. Trends and potential changes in charr behavior and habitat use can then be identified, providing valuable insights for management decisions.

Understanding the intricate food-web dynamics discussed earlier is crucial for comprehending the factors influencing charr habitat associations and ensuring the conservation and management of their critical habitats in the Nain region. To assess the significance of benthic diatoms in Nain's charr food web, stable isotopes and fatty acids should be used as dietary tracers (Kelly & Scheibling 2012; Falardeau et al. 2022). Diatoms have rapid responses to environmental change due to their short life cycle; therefore, these microalgal communities have been regarded as an effective bio-indicator tool (Clark et al., 2020; Liu et al. 2022). Examining the long-term patterns of benthic diatom biomass in Nain estuaries and its potential implications for charr populations could provide valuable insights into the resilience of the species in the face of climate change.

2. *Engaging local harvesters*

Involve local community members and harvesters in monitoring efforts, research, and decision-making processes, considering their traditional and Indigenous knowledge systems and experiences with charr. By involving local community members and harvesters in monitoring efforts, research, and decision-making processes, we can integrate their traditional and Indigenous knowledge systems to enrich scientific understanding and ensure that management strategies for iKaluk are aligned with community needs and perspectives.

3. *Habitat protection*

Safeguard critical habitats, particularly estuaries dominated by benthic diatom mats which may be essential foraging grounds for Arctic charr. Due to the importance of these habitats, they should be protected from potential threats such as pollution, habitat degradation, and coastal development.

4. *Impacts of climate change*

Continue modeling the impacts of climate-driven changes on charr populations as well as their prey. These model predictions can aid in developing adaptive management and adaptation strategies (Layton et al. 2021).

5. Investigate non-estuarine habitats

While estuarine habitats have been shown to be critical for charr during their marine residency period, non-estuarine habitats should not be overlooked. Additional research should collect further baseline benthic information surrounding Nain's coastal and offshore environment. Moreover, the importance of these non-estuarine habitats, especially under changing environmental conditions, must be investigated to further understand their potential role as alternative or supplemental feeding areas for charr. Future research should develop additional habitat suitability indices (Rudolfsen et al. 2021), like this study, to describe changes in charr habitat associations over time and explore the availability of other habitats not covered in this survey.

2.5 Conclusion

With the use of community-identified fishing locations and acoustic telemetry, this study offers important insights on Arctic charr habitat associations in the marine environment. This study highlights the significance of estuarine habitats dominated by diatom mats as charr hotspots during their marine residency period which likely provide rich foraging grounds for these fish. The insights provided by this study aim to assist resource users in prioritizing critical charr habitats to ensure the conservation and sustainability of Arctic charr populations in the face of climate change. This study’s findings and recommendations are geared towards supporting *Imappivut* and effectively managing Nain’s charr fishery, thus safeguarding the valuable marine ecosystem for the well-being of Nunatsiavut's Inuit communities.

2.6 Appendix

Table 2.2 Full set of environmental variables per site. List includes cluster, visual footprint area (m^2), depth (m), distance to freshwater (m), substrate classification (subclass), habitat type, mean latitude (Lat), mean longitude (Lon), and percentage (%) of substrates: fine sediments, gravel, pebbles, cobbles, boulders, diatoms, coralline algae, red seaweeds (Porphyra spp.) and brown seaweeds (Laminaria spp.) (Algae), and shellhash.

Site	**Cluster**	**Area**	**Depth**	**Dist2fresh**	**Habitat**	**Lat**	**Lon**	**Subclass**	**Fine sediments**	**Gravel**	**Pebbles**	**Cobbles**	**Boulders**	**Bedrock**	**Diatoms**	**Coralline algae**	**Algae**	**Shellhash**	**Unidentified**
1	1	19	226	20337	Estuary	56.592	-61.906	FS	94	0	0	0	0	0	0	0	0	0	6
2	1	16	260	19696	Estuary	56.603	-61.915	FS	97	0	0	0	0	0	0	0	0	0	3
3	1	10	33	6012	Estuary	56.605	-62.138	DS	22	0	0	0	0	0	75	0	3	0	0
4	1	10	53	4937	Estuary	56.614	-62.155	DS	20	0	0	0	0	0	79	0	1	0	0
5	1	7	47	5281	Estuary	56.610	-62.150	DS	13	0	0	0	0	0	85	0	1	0	1
6	2	16	169	26678	Fjord	56.639	-61.947	GMA	0	53	20	1	3	10	0	5	7	0	1
7	1	20	340	24942	Fjord	56.681	-62.128	FSP	87	0	7	0	0	0	0	0	0	0	5
8	1	14	131	3878	Estuary	56.746	-62.448	FS	99	0	0	0	0	0	0	0	0	0	1
9	1	12	76	4042	Estuary	56.742	-62.449	DS	32	0	0	0	0	0	67	0	0	0	1
10	1	21	69	713	Estuary	56.758	-62.495	DS	44	0	0	0	0	0	55	0	1	0	0
11	3	11	118	40111	Fjord	56.609	-61.561	FSP	86	0	2	1	0	0	2	0	1	0	8
12	1	13	275	40490	Fjord	56.603	-61.557	FSP	92	0	5	1	0	0	0	0	1	0	1
13	1	14	307	38397	Fjord	56.565	-61.552	FSP	64	0	15	2	1	0	0	0	0	17	1
14	1	11	277	38950	Fjord	56.559	-61.555	FS	99	0	0	0	0	0	0	0	1	0	0
15	3	27	236	28843	Fjord	56.507	-61.649	FSP	41	6	17	1	3	0	0	0	1	29	2
16	3	25	80	36500	Fjord	56.658	-61.530	GMA	23	32	3	1	0	0	0	8	24	0	9
17	2	17	119	25433	Fjord	56.661	-61.705	GMA	0	51	9	1	3	1	0	1	20	11	3
18	3	10	95	15946	Fjord	56.775	-61.666	FSP	84	0	2	1	1	0	0	1	6	2	2
19	4	10	56	1221	Estuary	56.795	-61.902	FS	97	0	0	0	0	0	1	0	1	0	0
20	5	23	70	301	Estuary	56.459	-62.218	DS	52	0	0	0	0	0	41	0	5	0	1
21	1	33	161	3679	Estuary	56.496	-62.049	FS	99	0	0	0	0	0	0	0	0	0	0
22	3	48	118	41487	Estuary	56.989	-61.336	GMA	77	11	5	0	0	0	0	5	0	0	0
23	1	34	155	41949	Estuary	56.990	-61.328	FS	100	0	0	0	0	0	0	0	0	0	0
24	3	72	148	58971	Coastal	56.445	-61.125	FSP	70	0	29	0	1	0	0	0	0	0	0
25	3	66	121	58460	Coastal	56.444	-61.132	FSP	66	1	22	1	1	0	0	9	0	0	0

Table 2.3 Metadata associated with telemetered charr. Includes length (cm), weight (g), release date, date and time of first and last detection, number of days detected, number of days passed since their release, number of receivers, and hydrophone IDs.

Fish	**Length.cm**	**Weight.g**	**Release date**	**Date & time (UTC) of first detection**	**Date & time (UTC) of last detection**	**# Days detected**	**# Days since release**	**# Unique receiver**	**Status**	**Hydrophone**	**Substrate**	**Site**	**Habitat**
2438	60.5	3855.54	2-Aug-18	8/3/2018 12:10	8/3/2018 14:13	0	1	1	Sedentary	124358	FS	19	Estuary
2441	48.7	1587.57	2-Aug-18	8/3/2018 2:33	8/11/2018 11:09	8	9	1	Sedentary	124408	DS	10	Estuary
2443	51	1814.37	2-Aug-18	8/3/2018 1:54	8/3/2018 11:40	0	1	1	Sedentary	124408	DS	10	Estuary
2445	50.8	1814.37	2-Aug-18	8/3/2018 2:08	8/19/2018 9:14	16	17	1	Sedentary	124408	DS	10	Estuary
2447	48	1814.37	2-Aug-18	8/3/2018 10:10	8/4/2018 9:35	1	2	1	Sedentary	124408	DS	10	Estuary
2449	53	2041.17	2-Aug-18	8/3/2018 1:17	8/22/2018 8:16	19	20	1	Sedentary	124408	DS	10	Estuary
2459	38.2	635.03	31-Jul-19	8/10/2019 11:51	8/13/2019 16:26	3	13	1	Sedentary	547227	FSP	18	Fjord
2465	45.5	1133.98	4-Aug-18	8/6/2018 19:21	7/18/2019 17:27	346	348	1	Sedentary	547211	DS	20	Estuary
2466	49	1587.57	4-Aug-18	8/4/2018 16:02	7/14/2019 8:59	344	344	1	Sedentary	547211	DS	20	Estuary
2467	45	1360.78	4-Aug-18	8/4/2018 18:54	7/21/2019 20:56	351	351	1	Sedentary	547211	DS	20	Estuary
2469	48	1587.57	4-Aug-18	8/5/2018 20:24	8/13/2018 18:39	8	9	1	Sedentary	547211	DS	20	Estuary
4364	53	2041.17	4-Aug-18	8/4/2018 15:05	8/8/2018 20:18	4	4	1	Sedentary	547211	DS	20	Estuary
4365	50	1360.78	4-Aug-18	8/11/2018 5:21	8/11/2018 5:29	0	7	1	Sedentary	547211	DS	20	Estuary

4366	47.1	1360.78	4-Aug-18	8/5/2018 7:07	7/16/2019 6:58	345	346	1	Sedentary	547211	DS	20	Estuary
4367	49.5	1587.57	4-Aug-18	6/2/2019 15:37	7/23/2019 8:06	51	353	1	Sedentary	547211	DS	20	Estuary
4368	47.5	1814.37	4-Aug-18	6/3/2019 5:24	7/10/2019 6:35	37	340	1	Sedentary	547211	DS	20	Estuary
4369	41.5	1814.37	4-Aug-18	8/4/2018 14:08	8/9/2018 0:27	5	5	1	Sedentary	547211	DS	20	Estuary
4371	48.2	1133.98	4-Aug-18	8/5/2018 12:35	6/25/2019 14:53	324	325	1	Sedentary	547211	DS	20	Estuary
4372	45	1587.57	4-Aug-18	8/4/2018 20:09	7/24/2019 15:25	354	354	1	Sedentary	547211	DS	20	Estuary
4373	46	1360.78	4-Aug-18	8/11/2018 18:21	8/11/2018 18:32	0	7	1	Sedentary	547211	DS	20	Estuary
4375	48.3	1587.57	4-Aug-18	8/4/2018 18:13	7/7/2019 2:09	337	337	1	Sedentary	547211	DS	20	Estuary
4378	51.5	1814.37	3-Aug-18	8/3/2018 15:33	8/3/2018 15:39	0	0	1	Sedentary	122386	DS	4	Estuary
4383	58.5	2721.55	2-Aug-18	8/3/2018 4:26	9/3/2018 6:31	31	32	1	Sedentary	124408	DS	10	Estuary
4386	52	1814.37	2-Aug-18	8/3/2018 12:32	8/3/2018 12:52	0	1	1	Sedentary	124408	DS	10	Estuary
4388	63.5	3401.94	2-Aug-18	8/3/2018 7:00	8/3/2018 13:03	0	1	1	Sedentary	124408	DS	10	Estuary
2436	47	1814.37	31-Jul-18	8/3/2018 9:15	7/24/2019 21:27	355	358	2	Vagrant	547227, 124358	FS, FSP	18, 19	Fjord, Estuary
2437	58	3175.15	2-Aug-18	8/3/2018 9:11	7/21/2019 0:13	352	353	2	Vagrant	547227, 124358	FS, FSP	18, 19	Fjord, Estuary

2439	52	1814.37	2-Aug-18	8/3/2018 11:09	9/3/2019 10:24	396	397	8	Vagrant	547207, 547209, 547210, 547215, 547216, 547225, 547228, 124408	FSP, FS, FS, FSP, DS, GMA, FSP, DS	12, 14, 8, 11, 9, 6, 13, 10	Fjord, Fjord, Estuary, Fjord, Estuary, Fjord, Fjord, Estuary
2440	53	1814.37	2-Aug-18	8/3/2018 0:00	7/31/2019 18:03	362	363	6	Vagrant	547210, 547213, 547216, 547225, 547229, 124408	FS, FSP, DS, GMA, FSP, DS	8, 17, 9, 6, 7, 10	Estuary, Fjord, Estuary, Fjord, Fjord, Estuary
2444	46.5	1360.78	2-Aug-18	8/3/2018 3:30	8/7/2019 21:09	369	370	8	Vagrant	547201, 547210, 547216, 547221, 547225, 547229, 122386, 124408	FS, FS, DS, FS, GMA, FSP, DS, DS	2, 8, 9, 1, 6, 7, 4, 10	Estuary, Estuary, Estuary, Estuary, Fjord, Fjord, Estuary, Estuary
2446	49.5	1587.57	2-Aug-18	8/3/2018 1:12	8/4/2018 15:04	1	2	3	Vagrant	547210, 547216, 124408	FS, DS, DS	8, 9, 10	Estuary, Estuary, Estuary
2455	34.5	NA	1-Aug-19	8/4/2019 15:23	8/23/2019 23:30	19	22	4	Vagrant	547210, 547216, 547229, 124408	FS, DS, FSP, DS	8, 9, 7, 10	Estuary, Estuary, Fjord, Estuary
2456	41.7	NA	1-Aug-19	8/2/2019 17:20	8/3/2019 19:26	1	2	4	Vagrant	547210, 547216, 547229, 124408	FS, DS, FSP, DS	8, 9, 7, 10	Estuary, Estuary, Fjord, Estuary

2460	42.7	512.56	31-Jul-19	8/1/2019 11:25	8/8/2019 9:36	7	8	6	Vagrant	547210, 547213, 547216, 547225, 547229, 124408	FS, GMA, DS, GMA, FSP, DS	8, 17, 9, 6, 7, 10	Estuary, Fjord, Estuary, Fjord, Fjord, Estuary
2461	49.5	952.54	31-Jul-19	8/8/2019 18:18	8/9/2019 18:34	1	9	2	Vagrant	547213, 547221	GMA, FS	17, 1	Fjord, Estuary
2462	43.5	952.54	31-Jul-19	8/5/2019 21:25	8/24/2019 8:49	19	24	5	Vagrant	547201, 547213, 547225, 122386, 124881	FS, GMA, GMA, DS, DS	2, 17, 6, 4, 5	Estuary, Fjord, Fjord, Estuary, Estuary
2463	47	961.62	31-Jul-19	8/9/2019 15:45	8/18/2019 14:43	9	18	2	Vagrant	547213, 547227	GMA, FSP	17, 18	Fjord, Fjord
2468	NA	680.39	31-Jul-19	8/1/2019 5:32	8/12/2019 22:18	11	12	6	Vagrant	547210, 547213, 547216, 547225, 547229, 124408	FS, GMA, DS, GMA, FSP, DS	8, 17, 9, 6, 7, 10	Estuary, Fjord, Estuary, Fjord, Fjord, Estuary
4376	50	1133.98	2-Aug-18	8/3/2018 5:46	8/4/2018 11:20	1	2	3	Vagrant	547210, 547216, 124408	FS, DS, DS	8, 9, 10	Estuary, Estuary, Estuary
4377	58.5	2041.17	2-Aug-18	8/3/2018 2:17	8/4/2018 12:53	1	2	3	Vagrant	547210, 547216, 124408	FS, DS, DS	8, 9, 10	Estuary, Estuary, Estuary
4380	49.5	1360.78	3-Aug-18	6/6/2019 14:41	6/12/2019 12:37	6	313	4	Vagrant	547212, 547221, 124881, 122386	FSP, FS, DS, DS	15, 1, 5, 4	Estuary, Estuary, Estuary, Estuary
4381	44.5	453.59	3-Aug-18	8/4/2018 15:28	8/4/2018 15:49	0	1	2	Vagrant	122386, 124881	DS, DS	4, 5	Estuary, Estuary

4382	43	2041.17	2-Aug-18	8/3/2018 2:33	8/4/2018 14:24	1	2	3	Vagrant	547210, 547216, 124408	FS, DS, DS	8, 9, 10	Estuary, Estuary, Estuary
4384	57.5	2267.96	2-Aug-18	8/3/2018 9:09	9/10/2018 10:08	38	39	3	Vagrant	547210, 547216, 124408	FS, DS, DS	8, 9, 10	Estuary, Estuary, Estuary

Table 2.4 Individual charr variability per substrate classification (% use) based on number of detections.

Fish ID	Diatomaceous Sediments	Fine Sediments	Fine sediments with pebbles	Gravel mix with algal turfs
2436	0.0	60.2	39.8	0.0
2437	0.0	92.3	7.7	0.0
2438	0.0	100.0	0.0	0.0
2439	26.6	12.7	54.5	6.3
2440	61.4	12.7	2.5	23.4
2441	100.0	0.0	0.0	0.0
2443	100.0	0.0	0.0	0.0
2444	55.0	35.2	0.7	9.1
2445	100.0	0.0	0.0	0.0
2446	81.8	18.2	0.0	0.0
2447	100.0	0.0	0.0	0.0
2449	100.0	0.0	0.0	0.0
2455	17.8	29.5	52.7	0.0
2456	55.1	38.5	6.4	0.0
2459	0.0	0.0	100.0	0.0
2460	34.8	18.6	1.4	45.2
2461	0.0	76.5	0.0	23.5
2462	9.3	10.7	0.0	80.0
2463	0.0	0.0	26.5	73.5
2465	100.0	0.0	0.0	0.0
2466	100.0	0.0	0.0	0.0
2467	100.0	0.0	0.0	0.0
2468	20.2	8.8	10.5	60.5
2469	100.0	0.0	0.0	0.0
4364	100.0	0.0	0.0	0.0
4365	100.0	0.0	0.0	0.0
4366	100.0	0.0	0.0	0.0
4367	100.0	0.0	0.0	0.0
4368	100.0	0.0	0.0	0.0

Fish ID	**Diatomaceous Sediments**	**Fine Sediments**	**Fine sediments with pebbles**	**Gravel mix with algal turfs**
4369	100.0	0.0	0.0	0.0
4371	100.0	0.0	0.0	0.0
4372	100.0	0.0	0.0	0.0
4373	100.0	0.0	0.0	0.0
4375	100.0	0.0	0.0	0.0
4376	52.2	47.8	0.0	0.0
4377	63.3	36.7	0.0	0.0
4378	100.0	0.0	0.0	0.0
4380	82.9	10.5	6.6	0.0
4381	100.0	0.0	0.0	0.0
4382	44.1	55.9	0.0	0.0
4383	100.0	0.0	0.0	0.0
4384	97.7	2.3	0.0	0.0
4386	100.0	0.0	0.0	0.0
4388	100.0	0.0	0.0	0.0
avg	70.5	15.2	7.0	7.3

	Brittle stars	Northern red anemone	Polar six-rayed star	Sea star (Asteroidea spp.)	Scarlet sea cucumbers	Bryozoa	Arctic yoldia	Sea squirt	Bryozoa	Tube-dwelling anemone
Assemblage	**1**	**2**	**2**	**2**	**3**	**3**	**4**	**4**	**4**	**5**
Indicator Value	**0.843**	**0.891**	**0.840**	**0.746**	**0.717**	**0.681**	**0.930**	**0.924**	**0.894**	**0.888**
Probability Value	**0.001**	**0.007**	**0.039**	**0.026**	**0.008**	**0.012**	**0.045**	**0.006**	**0.007**	**0.003**

Figure 2.10 Indicator taxa with associated indicator and probability values for 5 epifaunal assemblages.

Table 2.5 Total abundance of morphotaxa throughout survey in the Nain region of NL. Status denotes dominant (x) and indicator taxa (*).

Status	Morphotaxa	Total abundance
	Actiniaria spp.	17
	Amphipoda spp.	16
x *	Ascidiacea sp.1	1044
x	Ascidiacea sp.2	129
	Asterias forbesi	26
x	Asteroidea sp.11	22
	Asteroidea spp.003	20
x	*Boltenia ovifera*	626
	Bryozoa.sp.003	30
x	Bryozoa.sp.004	126
x *	Bryozoa.sp.1	678
x	Bryozoa.sp.2	98
x *	Bryozoa.sp.4	74
x	Bryozoa.sp.6	384
	Buccinum spp.	19
x *	Ceriantharia spp.	11874
	Chionoecetes opilio	78
x	*Chlamys islandica*	264
x	*Cottidae* spp.	376
x	*Crossaster papposus*	367
	Ctenodiscus crispatus	10
x	*Cucumaria frodosa*	473
	Halcampa arctica	56
	Haliclona sp.2	50
x	*Halocynthia pyriformis*	109
	Heliometra glacialis	242
x	*Henricia sanguinolenta*	172
x	*Hyas araneus*	146
x	*Hyas coarctatus*	77
x *	*Leptasterias polaris*	514

Status	Morphotaxa	Total abundance
x	*Lumpenus lampretaeformis*	360
	Lycodes vahlii	88
	Mya truncata	32
	Myoxocephalus scorpius	58
	Myoxocephalus spp.	30
x	*Myxicola infundibulum*	1845
x	*Nephtheidae* sp. 3	535
	Nephtheidae sp.1	54
x *	Ophiuroidea sp.1	194993
x	Ophiuroidea sp.2	5633
	Pagurus spp.	31
x	*Pandalus* spp.	540
x	*Polinices heros*	34
	Polychaeta spp.	11
	Porifera sp.11	72
x	Porifera sp.13	515
	Porifera sp.21	38
x	Porifera sp.3	690
	Porifera sp.5	14
	Poriferasp 22	42
*	*Portlandia arctica*	22
x *	*Psolus fabricii*	2725
x	*Psolus phantapus*	9380
x	*Psolus* sp.1	394
	Ptychogena lactea	19
	Sabellida spp.	16
x	*Sagittidae* spp.	91
	Scypha spp.	12
x	*Stomphia coccinea*	121
x	*Stronglyocentrotus droebachiensis*	6106
x *	*Urticina felina*	5412
	Zoarcidae sp.1	5
x	*Zoarcidae* sp.2	21

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3 Association of Ogak/Greenland cod (*Gadus ogac*) with complex habitats: Insights from traditional fishing locations in nearshore Nunatsiavut waters

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Abstract

In the face of rapid climate change impacting Canada's northern coastlines, northern fish, benthic ecosystems, and ecosystem services are being heavily impacted. The ongoing environmental pressures heavily influence the social, cultural, and physiological well-being of Labrador Inuit who are intrinsically linked with the marine environment. This research employs community-identified fishing locations to map benthic habitats in Nain, Nunatsiavut, and gain insights on the habitat associations of ogak, Inuktitut for Greenland cod (*Gadus ogac*), a demersal fish relied upon heavily for subsistence in the region. Collaborating closely with community members and the Nunatsiavut Government, 75 drop-camera transects were performed, unveiling a total of 44,809 organisms belonging to 50 morphotaxa which were clustered into three distinct faunal assemblages. Fishing locations were represented in two of three assemblages which were heterogeneous and composed mainly of pebbles, boulders, and rhodolith beds. The only assemblage not represented by a community fishing location was highly homogeneous and composed entirely of fine sediments. These results suggested an association of ogak to habitats with increased complexity, including rhodolith-dominated habitats which may serve as important foraging grounds and/or nurseries for juveniles. A variety of vulnerable marine ecosystem (VME) indicators were abundant throughout the survey, including fields of tube-dwelling anemones, large sea squirts, erect bryozoans and extensive rhodolith beds. These indicators aid in boosting biodiversity by providing structures and areas of suitable colonization to increase the heterogeneity of the seafloor. By pairing traditional ecological knowledge systems with habitat mapping, this research provides a baseline on the distribution and structure of benthic habitats in Nain, as well as habitat associations of a culturally iconic species. The identification of critical habitats and taxa aim to aid in conservation and management strategies under the pressures of climate change throughout Nunatsiavut.

3.1 Introduction

Benthic habitats, comprising the ecological communities and physical structures on the seafloor, are vital for supporting marine ecosystems and organisms with high economic, cultural, and/or ecological importance (Kritzer et al. 2016; Griffiths et al. 2017; Flávio et al. 2023). Yet, the collection of data across vast stretches of the seabed remains highly constrained globally (Mayer et al. 2018), particularly in northern regions characterized by challenging environments, high operating costs, and seasonal ice cover (Coad & Reist 2017; Wynja et al. 2015). As such, benthic data collection has been disproportionately focused on southern regions, posing a lower priority in northern Indigenous areas, despite their crucial reliance on country foods for subsistence and economic benefit. These limitations hamper our understanding of the spatial distributions, abundances, and functional roles of many species and habitats in northern waters, posing challenges for successful self-governance efforts.

As regions within the Circumpolar North continue to experience more accelerated and pronounced impacts of climate change relative to the rest of the world (Bush & Lemmen 2019), the concerns of local communities continue to grow. Located in a subarctic and polar climate region, Nunatsiavut is the settlement region in Labrador for Labrador Inuit, established by the Labrador Inuit Land Claims Agreement. The well-being of Labrador Inuit is intricately linked with the coastal marine environment encompassing Nunatsiavut. Communities throughout the region have voiced a spectrum of priorities and concerns regarding their local marine waters (e.g., navigation, over-harvesting), all in the context of confronting the challenges of a changing climate (Felt et al. 2012; Durkalec et al. 2015; MacDonald et al. 2015; Rangeley et al. 2022). The ongoing effects of climate change continue to influence subsistence activities, food security, and physical and mental health of northern communities (Cunsolo Willox et al. 2013; Ford et al. 2012; Middleton 2020; Bishop et al. 2022). While traditional and local knowledge has resulted in sustainable harvesting practices for generations, a changing environment is pushing the Nunatsiavut Government (NG) to seek multiple knowledge systems to improve their ability to manage their resources. Assessments on the spatial distribution and ecological roles of important marine habitats and species is hindered as the region faces limitations in specialized surveying equipment and advanced data collection tools, resulting in a scarcity of available data. Without this essential knowledge, protecting the resources and ecosystem services provided by the local marine environment becomes challenging. Given that Inuit rely on these marine resources, they must understand it well to sustainably harvest in a changing environment. To address the knowledge gap, the Imappivut – 'Our Oceans' Marine Planning Initiative was established by the NG. The initiative is guided by the values, knowledge, and interests of Labrador Inuit and the available knowledge of the marine environment.

Benthic mapping, where ecological communities and physical structures present on the seafloor are characterized, is an important step in understanding and managing species, habitat, and harvesting interactions (Brown et al. 2012; Buhl-Mortensen et al. 2015; Baker & Harris 2020). This process involves the utilization of full-coverage acoustic data (e.g., bathymetry – depth, backscatter – reflectivity) acquired through sonar systems, along with biological samples obtained through ground-truthing techniques (e.g., underwater videos, sediment grabs, dive surveys) (Brown et al. 2011). To characterize the physical morphology and seafloor composition of the seabed, additional features (e.g., slope, roughness) can be derived from the acoustic sources (Wilson et al. 2007). These physical characteristics act as measurable proxies of drivers behind species-environment relationships (Wilson et al. 2007; Lecours et al. 2015). Through the integration of these data via a variety of modeling techniques, a comprehensive map of seafloor habitats can be produced, aiding in the understanding of marine ecosystems and their drivers

(Brown et al. 2011). This approach allows scientists to pinpoint the habitat distribution for species at risk (Novaczek et al. 2017A), identify rare habitats, determine habitat vulnerability, and inform marine protected area planning and monitoring (Novaczek et al. 2017B; Proudfoot et al. 2020). The incorporation of local and traditional knowledge systems can enhance this process by integrating information about species presence in specific locations over longer time periods compared to the limited perspective provided by single snapshots from ground-truthing techniques. The collaboration, integration and engagement of local knowledge systems can contribute to identifying distributional patterns of ecologically significant habitats, species, and Vulnerable Marine Ecosystem (VME) indicators as demonstrated by the work of Misiuk et al. (2019), Rangeley et al. (2022), and Cote et al. (2023).

The Imappivut initiative is actively engaged in uncovering and mapping the spatial extent of important benthic habitats and species to support resource management strategies and decisions regarding protected areas in the region. Following consultations with local Inuit, the inclusion of ogak / Greenland cod (*Gadus ogac*) (Richardson 1836), or locally called rock cod, as a high-priority species for the initiative was determined due to its cultural significance and substantial role in subsistence practices throughout Nunatsiavut. Ogak is a demersal fish species and as a subspecies of Pacific cod (*Gadus macrocephalus*), its distribution ranges from the western and eastern Pacific to West Greenland and south to the Gulf of St. Lawrence in the Canadian Atlantic. With rising ocean temperatures, species distribution model predictions indicate increases in habitat coverage conducive to ogak egg survival in the northwest Atlantic and Eastern Canadian Arctic (Cote et al. 2021). However, a substantial 63% decrease in the extent of suitable juvenile growth habitats for Greenland cod is also projected by 2100 (Cote et al. 2021). In coastal Newfoundland, these fish have been shown to maintain a benthic lifestyle, feeding primarily on benthic organisms (e.g., Polychaeta) as evidenced by enriched ^{13}C levels (Knickle & Rose 2014a). Though they tend to remain near the coast for the duration of their life (Mikhail and Welch 1989), studies on ogak habitat associations are lacking (but see Knickle & Rose 2014b; Schornagel 2015). Their association with shallow, complex, and vegetated habitats, such as cobble and eelgrass (*Zostera marina*) beds, have been reported for juveniles and adults (Mikhail & Welch 1989; Laurel et al. 2003; Knickle & Rose 2014b). The local community of Nain in Nunatsiavut has observed the most successful ogak fishing endeavors in proximity to the shoreline, where these fish are sought out among cobbles and boulders eroded from cliffsides (Mary Denniston and Liz Pijogge, personal communication). These fishing sites, handed down through generations, hold immense significance and have been vital for Indigenous community members. The addition of this traditional ecological knowledge offers a unique opportunity to incorporate Inuit interactions into conventional western scientific methods of establishing habitat interactions of this important species.

This study aims to address gaps in ecological understanding in the nearshore marine waters of Nain, Nunatsiavut, by comprehensively mapping benthic habitats, with specific emphasis on those pertinent to ogak fishing sites identified by local harvesters. Aligned with the Imappivut initiative, this research seeks to establish an understanding of the benthic habitats in Nain's nearshore waters and their relationship with ogak habitat use. Additionally, this study will demonstrate the effectiveness of habitat mapping integrated with local ecological knowledge to fill baseline ecological knowledge gaps in northern ecosystems. Through the combined perspectives of Inuit and Western science, the mapping and analysis of critical benthic habitats aims to contribute to conservation and management strategies in the face of climate change across Nunatsiavut.

3.2 Methods

3.2.1 Study Area

This research was conducted within the nearshore marine waters of Nain, Nunatsiavut (56◦N, 61◦W; Fig 3.1), a region at the border between a subarctic and polar climate (Roy et al. 2021). Extending 20 km offshore and encompassing 48,690 km^2, the coastal marine waters of Nunatsiavut are invaluable for Labrador Inuit who rely on a variety of marine species including ogak for subsistence. Situated as the northernmost and largest community in Nunatsiavut, Nain has a distinct landscape including an archipelago that has played an integral role in the region's history, boasting a legacy of abundant hunting and fishing grounds. Open to the Labrador Sea, Nain’s coastline encompasses extensive and seasonally-persistent land-fast ice, small and episodic areas of open water surrounded by sea ice (i.e., polynyas), and is composed of several islands, exposed headlands, extensive fjords, and protected inlets. Much of Nain’s coastline is unmapped; therefore, there is a limited understanding of the spatial distributions and roles of benthic habitats.

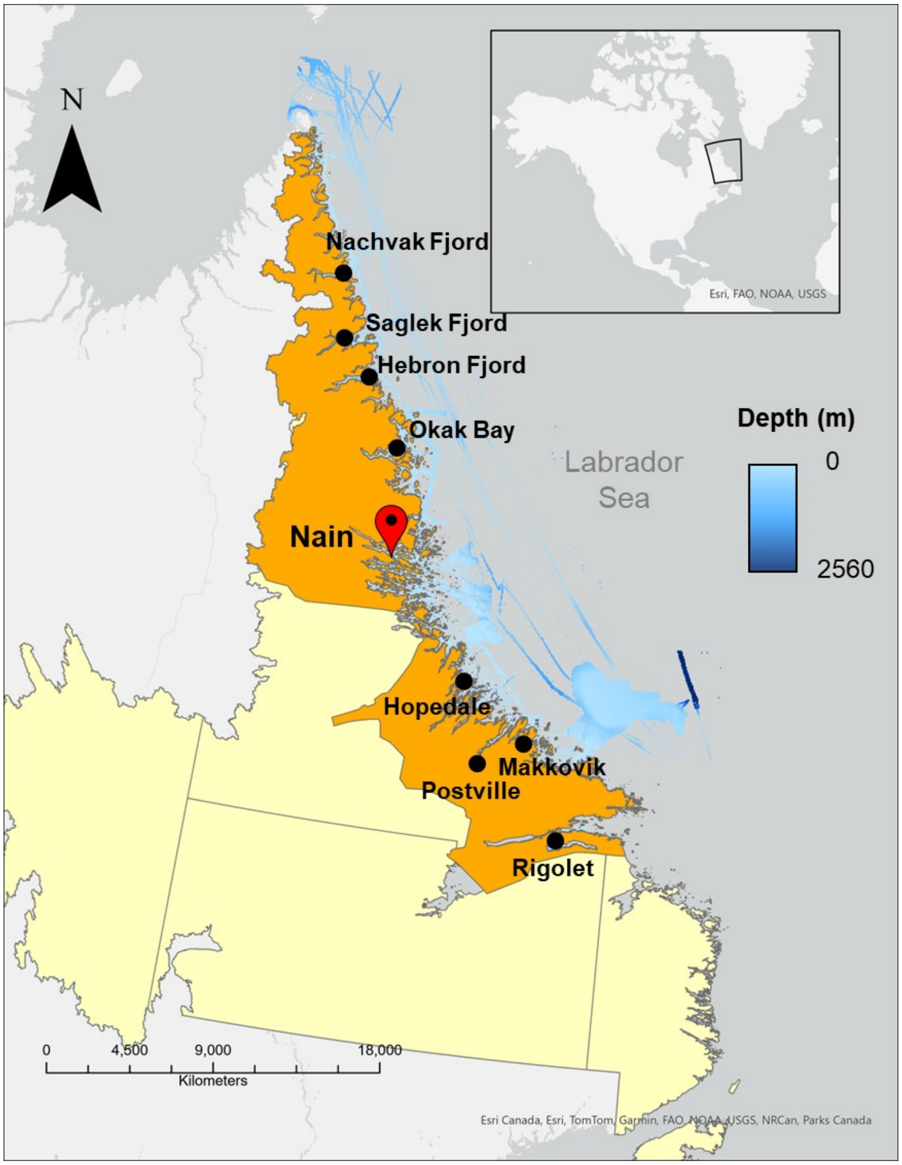


Figure 3.1 Communities within Nunatsiavut's territory (orange). Study location is Nain, Nunatsiavut. Available bathymetric coverage in Labrador Sea from the Canadian Hydrographic Service's Non-Navigational Bathymetry data (NONNA) is also present. Inset displays Labrador coast. Common bays and fjords in northern Nunatsiavut are listed.

3.2.2 Bathymetry

A consolidation of digital non-navigational bathymetric sources managed by the Canadian Hydrographic Service was downloaded surrounding Nain's nearshore and coastal marine ecosystem at a spatial resolution of 100 meters. The bathymetric data were patchy and contained multiple gaps in coverage (Fig 3.2). To fill these gaps, the interpolation of these data was performed using Empirical Bayesian Kriging (EBK) in ArcGIS Pro 2.8. Where classical kriging methods are limited in accounting for errors introduced by estimating a singular semivariogram model, EBK achieves this by estimating the spatial relationship of the input data through multiple simulated semivariogram models (Krivorouchko 2012; Zou et al. 2015; Novaczek et al. 2019). The use of multiple simulated semivariograms allows for more precise bathymetric interpolations and estimations of standard error (Novaczek et al. 2019). In combination with the bathymetric data, a digital elevation model (DEM) from Natural Resources Canada within the area of interest was used for the interpolation process to define land areas, reduce artefacts, and reduce false bathymetric predictions. A gridded resolution of 50 m effectively reduced the number of interpolation artefacts in areas of low data density (Novazcek et al. 2019). Using 100 iterative semivariogram models, EBK simulated new data for each known depth value. Bayes' Rule was used in this process, where a weight is assigned to each semivariogram, demonstrating how well the observed data can be generated from the respective semivariogram (Krivorouchko 2012; Novazcek et al. 2019). The weighted distribution of the 100 semivariograms was then used to interpolate unknown depth values within the neighbourhood of each local model. Neighbouring models were assigned high overlap (overlap factor = 5) which requires more processing time, but produces a smoother output surface. The bathymetric raster was then clipped to remove all land data points (>0m).

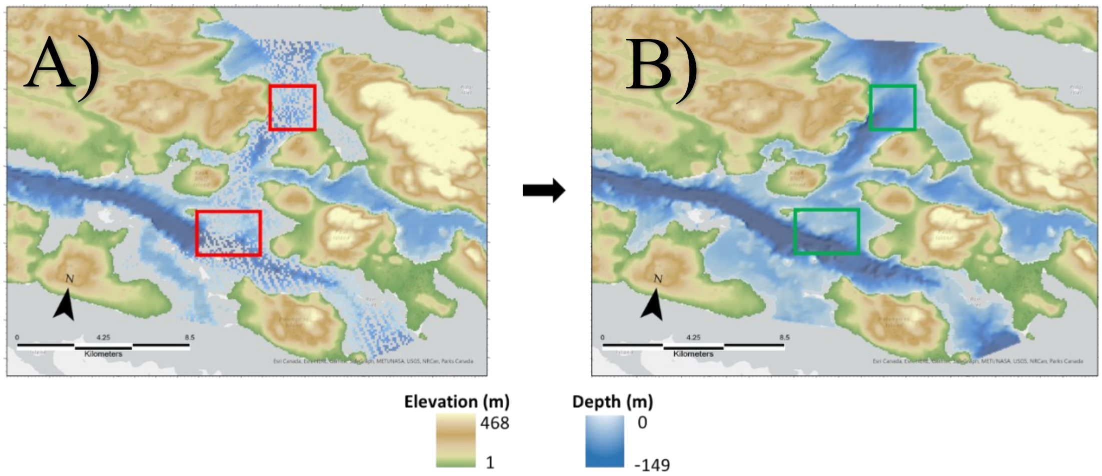


Figure 3.2 Empirical Bayesian Kriging performed on non-navigational bathymetric data compiled by the Canadian Hydrographic Service. Original bathymetry (A) with selected areas of low density (red squares) interpolated after kriging (green squares; B).

3.2.3 Site Selection & Ground-Truthing

Residents of Nain who fish for ogak year-round in a subsistence fishery disclosed important locations near the community. These locations were provided for this study by the NG. Based on their expertise, ogak are commonly caught within Metre Bay (sometimes referred to as Meta Bay) and in proximity to Two-Mile Bay, with a few individuals venturing off into Nain Bay and Paul Island (Fig 3.3) (B. King & M. Denniston, personal communication). Using the newly derived bathymetric surface, a Generalized Random Tessellation Stratified (GRTS) survey design (Stevens & Olsen 2004) was employed to select ground-truthing locations. This method was chosen to ensure samples were distributed across the bathymetric range of the area. From October 3-12, 2022 on board the *MV Inuttatik*, a total of 75 ground-truthing points, including the five community-identified fishing locations, were sampled using drop-camera surveys and CTD casts (Star Oddi *SeaStar* 8.17). At each site, 5-minute video transects were employed using a *SubC Imaging* Coastal Rayfin camera (1920 x1080 pixels, 30 frames per second). Specifications for this camera include two Aquorea Mk3 LED (15000 lumens), two MantaRay parallel lasers spaced 10 cm apart, and 4K video recording capabilities.

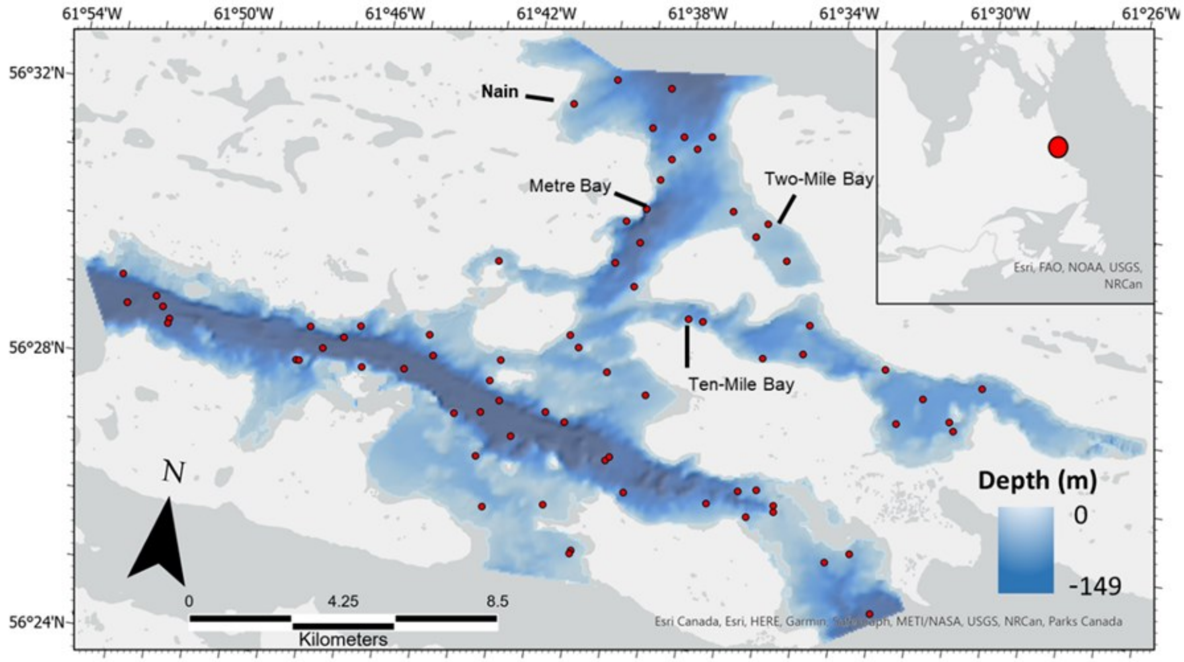


Figure 3.3 Drop-camera video survey locations (n = 75) from GRTS design. Harvester-identified fishing locations are present, but remain undisclosed and grouped with additional sites in red. Insert represents study extent on Labrador coast.

3.2.4 Environmental Data

Bathymetric derivatives

The continuous bathymetric surface of Nain's nearshore was used to derive continuous terrain features to help explain faunal assemblage patterns (Appendix; Table B1). Based on recommendations from Lecours et al. 2017, this study used a set of local terrain attributes that can account for approximately 70% of the structure of a topographic surface. These attributes can act as effective proxies for other influential variables which are difficult to measure directly and impact faunal distributions (e.g., seabed hydrodynamics) (Lecours et al. 2017; Mackin-Mclaughlin et al. 2022; Nemani et al. 2022). These attributes included eastness and northness (i.e., orientation), slope (i.e., steepness gradient) (Wilson et al. 2007), relative difference to mean value (RDMV) (i.e., topographic position), and standard deviation (SD) (i.e., roughness) of bathymetry. Additional attributes and measurements were also explored. Measures of curvature (mean, profile, and planar curvature) were derived to describe the rate of change of the seabed and to identify contours (e.g., ridges, valleys, mounds) (Walbridge et al. 2018; Wilson et al. 2007). To identify topographic highs and lows, relative seabed position was derived using the bathymetric position index (BPI) (Lundblad et al. 2006; Misiuk et al. 2018; Walbridge et al. 2018; Wilson et al., 2007). Vector ruggedness measure (VRM) (Sappington et al. 2007) was also derived to provide further information on seafloor structure, as it quantifies seafloor roughness by incorporating slope and aspect into a single measurement (Mackin-Mclaughlin et al. 2022).

The spatial scale, referring to the spatial resolution and geographic extent (Lecours et al. 2015), of the explanatory features mentioned above is crucial for understanding the complex dynamics and ecological processes within a benthic ecosystem. To capture these dynamics, the Multi-Scale Geomorphometric Terrain Attributes (MultiscaleDTM) package in R was employed (Ilich et al. 2021). This package utilizes the 'k×k-window' or 'roving window' method, as defined in Misiuk et al. (2021), to calculate terrain attributes from the gridded digital bathymetry raster at multiple scales. The scale of these attributes is dependent on the source data resolution and the size of the window used for analysis. In this context, features were derived at 10 scales, using focal window sizes ranging from raster cells at 3×3 to 21×21, totaling 100 features, and capturing information from 150 to 1050 m (Appendix: Table 3.1). This multiscale approach ensures that scale-dependent patterns and processes are effectively captured (Porskamp et al. 2018; Shang et al. 2021).

Distance to coast, salinity, and temperature

A continuous layer measuring the distance from the coast was calculated relative to each pixel using the ‘Euclidean Distance’ tool in ArcGIS Pro 2.8. This layer describes variability in benthic faunal and grain size distribution (Misiuk et al. 2018; Vassallo et al. 2018; Nemani 2022). To derive continuous layers of bottom temperature (°C) and salinity (ppu), similarly to the continuous bathymetry layer, EBK was employed. Using 100 iterative semivariogram models, EBK simulated new data for all known temperature and salinity values from the CTD data (Krivorouchko 2012; Novazcek et al. 2019). The weighted distribution of the 100 semivariograms was then used to interpolate unknown temperature and salinity values with neighbouring models assigned a high overlap (overlap factor = 5).

3.2.5 Video Survey Data

Video Analysis

The Monterey Bay Aquarium Research Institute's (MBARI) Video Annotation and Reference System (VARS) (Schlining & Stout 2006) was used to review and annotate all 75 drop-camera video samples. All videos were annotated in a randomized order to reduce human annotation biases (e.g., fatigue) (Durden et al. 2016). For every organism greater than 5 cm (i.e., half the distance of the camera lasers) taxa identification was performed to the lowest taxonomic level possible. Species identification was not always possible due to suspended sediment, and rapid camera drift speed; therefore, identification required the use of morphotypes (Howell et al. 2019). These morphotypes were based on the production of an image catalogue for the Nain region. Taxa identification was performed with aid from expert advice and published species identification guides (Nozères et al. 2014A; Nozères et al. 2014B; Salvo et al. 2018; Lacasse et al. 2020).

Therefore, it is important to note that the reported taxa in this study may encompass multiple species, suggesting that the actual species count at these sites is likely higher than documented. Observed faunal abundances were compiled in a site by species matrix.

Substrates were classified into six substrate classes (Fig 3.4) guided by the Coastal and Marine Ecological Classification Standard (Federal Geographic Data Committee 2012). The distance between the two reference lasers was measured and used to estimate grain size of the sediment. There are limitations in using videos for substrate identification; differentiating between mud and sand cannot be reliably achieved and as such, were combined into the Fine Sediments category. Biophysical features were also used to help classify the substrates, such as the presence / absence of any sediment bedform features (e.g., bioturbation), and the presence of characterizing biological elements (e.g., diatom mats, coralline algae) based on similar methodology to the classification of terrestrial landscapes (Zajac et al. 2003; Zajac 2008; Brown et al. 2012; Proudfoot 2019). Rhodoliths with Mixed Gravel was a biogenic substrate class denoted by a high coverage of crustose algae that formed rounded calcareous nodules and branching patterns (rhodoliths; likely *Lithothamnion glaciale*) and contained a mixture of gravel substrates (i.e., pebbles, cobbles, boulders) enveloped by encrusting coralline algae. Fine Sediments was composed entirely of sand and mud with many indications of bioturbation. Fine Sediments with Mixed Gravel was a class composed mostly of mud and/or sand, but had multiple patches of large pebbles, cobbles, and boulders often enveloped by encrusting coralline algae. Fine Sediments with Shellhash was a class composed of mud and/or sand, but had an extensive coverage of broken scallop and mussel shells. The Fine Sediments with Seaweeds class was composed mostly of mud and/or sand with a high density of seaweeds (*Agarum clathratum*, *Saccharina longicruris*, *Lithothamnion* spp., *Rhodophyta* spp.) dispersed overtop the sediment. Diatomaceous Fine Sediments was composed mostly of fine sediments overlain with microalgal mats.

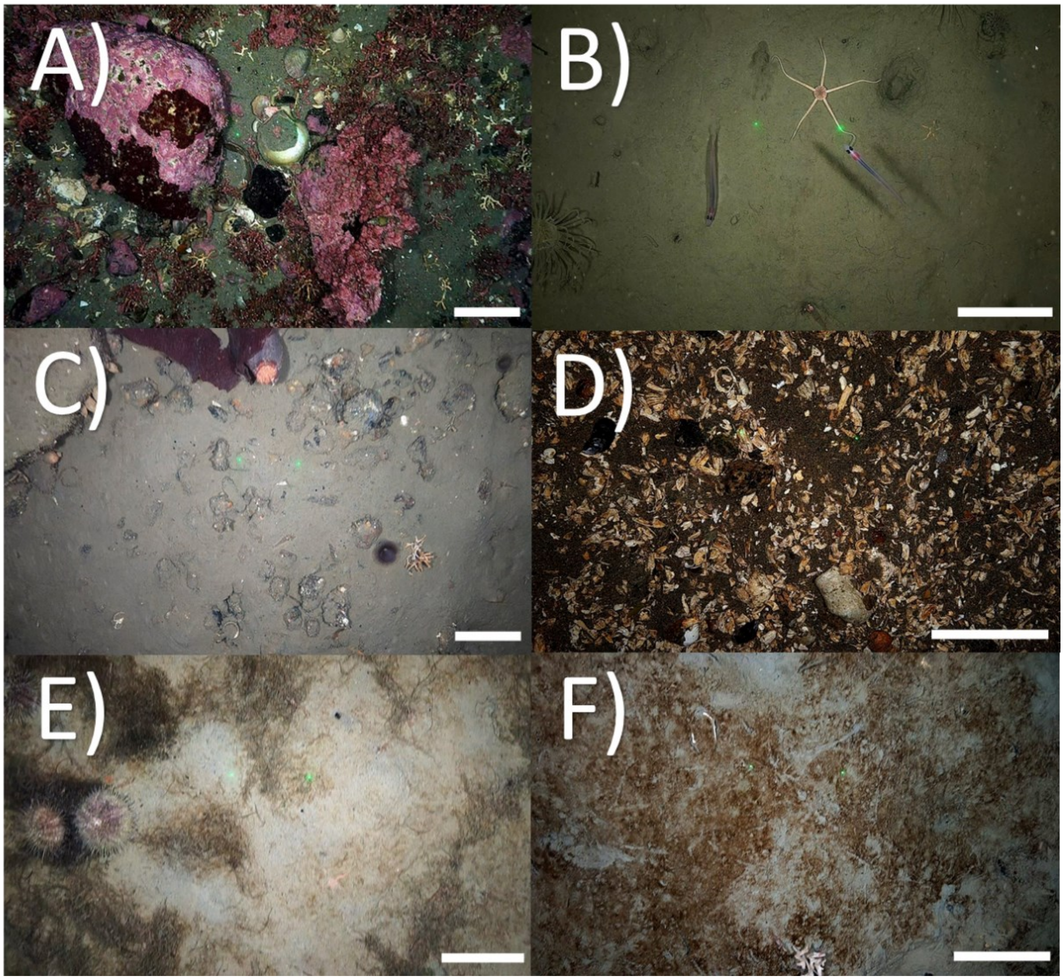


Figure 3.4 Images of the substrate classes identified during video annotation: A) Rhodoliths with Mixed Gravel, B) Fine Sediments, C) Fine Sediments with Mixed Gravel, D) Fine Sediments with Shellhash, E) Fine Sediments with Seaweed, and F) Diatomaceous Fine Sediments. White bar for scale is 10 cm.

3.2.6 Data Preparation & Analysis

Cluster Analysis

Faunal abundances were classified into benthic faunal assemblages using a Hellinger transformation and a hierarchical cluster analysis approach. The 'unweighted pair group method using arithmetic averages' (UPGMA) algorithm (Borcard et al., 2018; Everitt et al. 2001; Legendre & Legendre 1998) was selected to derive faunal assemblages. Taxa with three or fewer observations in all 75 videos were removed from the data set prior to analysis to reduce the variability caused by these low abundances. To determine the size and cutoff of each cluster, fusion level values and silhouette widths were optimized (Borcard et al. 2018). To assess the dissimilarities between clusters, an Analysis of Similarities (ANOSIM) test was performed using the Bray-Curtis dissimilarity index to calculate the dissimilarity matrix.

Dominant and indicator taxa were derived to demonstrate the biological composition of each assemblage. Dominant taxa consist of the most abundant species within a community that may highly influence the occurrence and distribution of other species and overall community structure (Smee 2010; Nemani 2022). These organisms have abundances greater than the individual group assemblage mean (Borcard et al. 2018). Indicator taxa were then used to measure the association between a species and assemblage by assessing the relative abundance and frequency of each species per grouping. The indicator value index (0-1) contains estimates on (1) the probability that the surveyed site belongs to the target assemblage given that a specific species was present (i.e., specificity) and (2) the probability of finding a species in sites belonging to the assemblage (i.e., fidelity or sensitivity) (Dufrêne and Legendre 1997; De Cáceres & Legendre 2009). A value closer to 1 would indicate a higher probability for both estimates. For this study, the threshold to assign significant indicator species to an assemblage was an indicator value greater than 0.75 due to the high number of potential candidates for some assemblages. Essentially, the method aims to identify ideal indicator species found exclusively for each assemblage (Mouillot et al. 2002; Dufrene and Legendre 1997) and is useful for monitoring changes to the sites associated with their specific assemblage (McGeoch & Chown 1998; Kubosova et al. 2010).

Feature Selection and Collinearity

To determine the level of importance the multi-scale bathymetric derivatives have on influencing each assemblage, a Boruta Feature Selection algorithm was employed (Kursa &

Rudnicki 2010; Kursa 2020). This algorithm assesses the importance of variables by using 'shadow attributes', defined as randomly shuffled versions of the original variables with the same distribution of values (Kursa & Rucnicki 2010). The Boruta wrapper compares the originally inputted variable with its 'shadow attribute', wherein a variable is deemed more important if it reliably contributes more to the model than its respective shadow variable. All variables across 10 scales were inputted into the algorithm, and only variables identified by Boruta as "tentative" or "important" were selected for training. To further achieve model parsimony, and support model performance, these selected features were assessed for collinearity using Spearman's rank correlation (Dormann et al. 2013). If the correlation coefficient was greater than 0.7 for two variables, the feature most collinear to all other features was rejected from the algorithm. Multiple studies have found success employing the Boruta algorithm for feature selection (Nemani et al. 2022; Mackin-McLaughlin et al. 2022; Diesing & Thorsnes 2018), and it has outperformed other feature selection methods (e.g., Vita, Recurrent relative variable importance) (Degenhardt et al. 2019). After inputting all variables across 10 scales, the Boruta algorithm identified mean curvature (5x5), VRM (5x5), and SD (21x21) as relevant features to be included in the model. The Boruta algorithm was employed again using the selected features above in addition to bathymetry, distance to coast, temperature, and salinity.

Statistical Modelling

Modelling species assemblages against environmental variables was achieved using a supervised machine learning approach to produce full-coverage habitat maps. The selected approach in the R package 'caret', known as random forest (RF), is a modelling technique that consists of multiple decision trees, like a 'forest', where predictions are obtained through majority voting (Breiman 2001; Franklin 2009). Comparisons between different techniques have consistently demonstrated the reliable and accurate performance of RF (Robert et al. 2015; Pillay et al. 2020; Nemani et al. 2022) for mapping benthic habitats. Decision trees in RF are constructed using bootstrap aggregation (i.e., 'bagging'), in which data are subsampled and split using random subsets of predictor features rather than the entire dataset. Final predictions (i.e., classes for the full-coverage area) are then decided based on a majority vote among individual trees (Breiman 2001; Franklin 2009). Observations not used for each bootstrap sample (i.e., 'out-of-bag' samples) are then used to assess feature importance and estimate model error (Breiman 2001; Franklin 2009; Diesing et al. 2014; Guisan et al. 2017). The RF model was run with and without substrate classifications extracted from ground-truthing videos to assess whether fine-scale substrate information improved model performance. Model parameters were optimized through a tuning grid search that systematically explored different mtry values. At each split when growing the individual trees (n = 500) in the random forest, two randomly selected predictor variables were determined to be the optimal choice for the mtry parameter (mtry = 2). Using the RF model and the environmental data layers, full-coverage predictive maps were produced to display the distribution of benthic assemblages. Since substrate classification was not a spatially continuous layer, full-coverage predictions were based on the model containing only bathymetric terrain features, distance to the coast, temperature, and salinity.

Model Assessment

A leave-one-out cross validation (LOOCV) approach was used to estimate model performance (Stone 1974; Shao & Er 2016). To assess prediction accuracy, a confusion matrix was computed containing the following measures:

i) False positive errors: Number of times the model predicted a class was present, but it was not truly observed.

ii) False negative errors: Number of times the model predicted that a class would not be present, but it was truly observed.

iii) Sensitivity & Specificity: Probability that a class is correctly predicted (i.e., true positive rate & true negative rate).

iv) Precision score: number of correctly-identified members of a class divided by the number of times that class was predicted by the model.

v) F1 score: Number of times the model made a correct prediction across the entire dataset (i.e., combination of precision and sensitivity scores).

vi) Balanced accuracy: The average sensitivity score obtained for each class.

vii) Overall accuracy: A general measure of accuracy calculated by summing and dividing correctly classified values by the total number of values (Congalton 1991).

viii) Kappa statistic: Measures instances that may have been correctly classified by random chance (Cohen 1960).

To rank the predictive importance of each variable in the model, a variable importance plot was derived. The Gini importance index was used for RF, which serves as a computationally efficient approximation to entropy. It calculates how frequently a specific variable was chosen for a split and the extent to which it contributes to distinguishing between different classes (Menze et al. 2009). Specifically, the decrease in Gini impurity from an optimal split is documented and summed up for every node across all trees in the forest (Nembrini et al. 2018). This process is carried out separately for each variable (Menze et al. 2009; Nembrini et al. 2018).

3.3 Results

3.3.1 Substrate classes

Rhodoliths with Mixed Gravel was a biogenic substrate class observed in 11 shallow sites distributed close to the shoreline (Appendix: Fig 3.14). Similarly, Diatomaceous Fine Sediments was distributed in shallow sites near the coastline, often in sheltered bays, and was observed in nine sites. Fine Sediments was the most common substrate class and was observed in 31 deep sites that were mostly found within the fjord in the southern portion of the survey area. Fine Sediments with Mixed Gravel was patchily distributed within 19 sites that were commonly found on the outskirts of deep basins and channels. Fine Sediments with Shellhash was only observed in three sites distributed in close proximity south of Paul Island. The Fine Sediments with Seaweeds class was found in two sites near the town of Nain and south of Paul Island (Appendix: Fig 3.14).

3.3.2 Epifaunal assemblages

Across the 75 drift-videos, 44,809 individual organisms belonging to 50 morphotaxa were identified. The phyla with the largest representation throughout the entire survey were Echinoderms (40%) and Cnidarians (35%). Green sea urchins (*Strongylocentrotus droebachiensis*) (n = 8,495), brittle stars (Ophiuroidea spp.) (n = 3,298), and scarlet sea cucumbers (*Psolus fabricii*) (n = 2,594) were the most common echinoderms, while Cnidarians were mostly dominated by *Cerianthus* spp. with 14,768 individuals. In comparison, the remaining phyla (Chordata (8%), Annelida (7%), Arthropoda (5%), Bryozoa (2%), Porifera (2%), and Mollusca (1%)) were represented in smaller proportions throughout the survey.

The benthic observations clustered into three faunal assemblages (Fig 3.5) explained a large (R=0.707) and significant (p=0.001) proportion of the variation observed. Comprised mostly of sites with Fine Sediments with Mixed Gravel (76%; Fig 3.6), and some classified as Fine Sediments *(*19%) and Rhodoliths with Mixed Gravel (5%), the first assemblage had the smallest spatial extent at 28% of all video surveys (n = 21). This assemblage was found predominately within intermediate depths of 35-55 m. In total, 8,558 individuals across 47 morphotaxa were identified in Assemblage 1, where scarlet sea cucumbers were most common and formed dense aggregations on large boulders and cobbles. The indicator taxa for this assemblage were organisms that typically attach themselves to harder substrates, including tunicates (Ascidiacea spp. & *Halocynthia pyriformis*) and erect bryozoans (Bryozoa spp. 2). There were 18 dominant species within this assemblage (Appendix: Fig 3.15), including scarlet sea cucumbers, sea potatoes (*Boltenia ovifera*), sponges (Porifera spp.), and Iceland scallop (*Chlamys islandica*). Three community-identified ogak fishing locations were grouped into this assemblage, located within Metre Bay and at the mouth of Ten-Mile Bay. An individual ogak was documented on video while surveying a site in this assemblage, located north of Metre Bay.

Situated closest to the shoreline and found predominately in shallower depths (15-20 m), Assemblage 2 was comprised of 25 sites (33%) with a majority being classified in Rhodoliths with Mixed Gravel (40%; Fig 3.6). In addition, many sites in this assemblage also showed evidence of high primary productivity, with a considerable coverage of seaweeds (*Agarum clathratum*, *Saccharina longicruris*, Lithothamnion spp., Rhodophyta spp.) and diatom mats. Across 47 morphotaxa, 14,096 individuals were identified within Assemblage 2, with green sea urchins (*Strongylocentrotus droebachiensis*) being most common (n = 7,179) and the sole indicator taxon for this assemblage. Assemblage 2 consisted of 13 dominant taxa (Appendix: Fig 3.15), including a variety of sea cucumbers (*Psolus fabricii*, *Cucumaria frondosa*, *Psolus phantapus*), scallops, anemones (*Urticina felina*) and sea stars (*Leptasterias polaris*). An individual ogak was also captured on camera occupying a site in this assemblage, located at the mouth of Two-Mile Bay. Furthermore, two community-identified ogak fishing locations were grouped into this assemblage, found in Two-Mile Bay and above Metre Bay.

While the other assemblages shared the most similarities in the dendrogram, Assemblage 3 was most unique and had the largest spatial extent of all video surveys at 39% (n = 29). Sites within the third assemblage were mostly found further from the coastline at depths of 35-90 meters and were composed entirely of Fine Sediments (Fig 3.6), with some sites overlain by diatoms. This assemblage contained 22,155 individuals across 41 morphotaxa. Tube-dwelling anemones (Ceriantharia spp.; likely *Pachycerianthus borealis*) were most common and formed extensive fields across the seabed, particularly within sites covered in benthic diatoms. Characterized by tube-dwelling anemones, tube worms (Sabellida spp.), and brittle stars, this assemblage was the most homogeneous compared to the other assemblages. There were 10 dominant taxa (Appendix: Fig 3.15) in the third assemblage which included the indicator taxa mentioned above as well as shrimp (*Pandalus* spp.), snake blennies (*Lumpenus lampretaeformis* and *Leptoclinus maculatus*), green sea urchins, sea cucumbers (*Psolus phantapus*), sponges, and slime tube worms (*Myxicola infundibulum*). This assemblage did not contain any community-identified ogak fishing locations or ogak video observations.

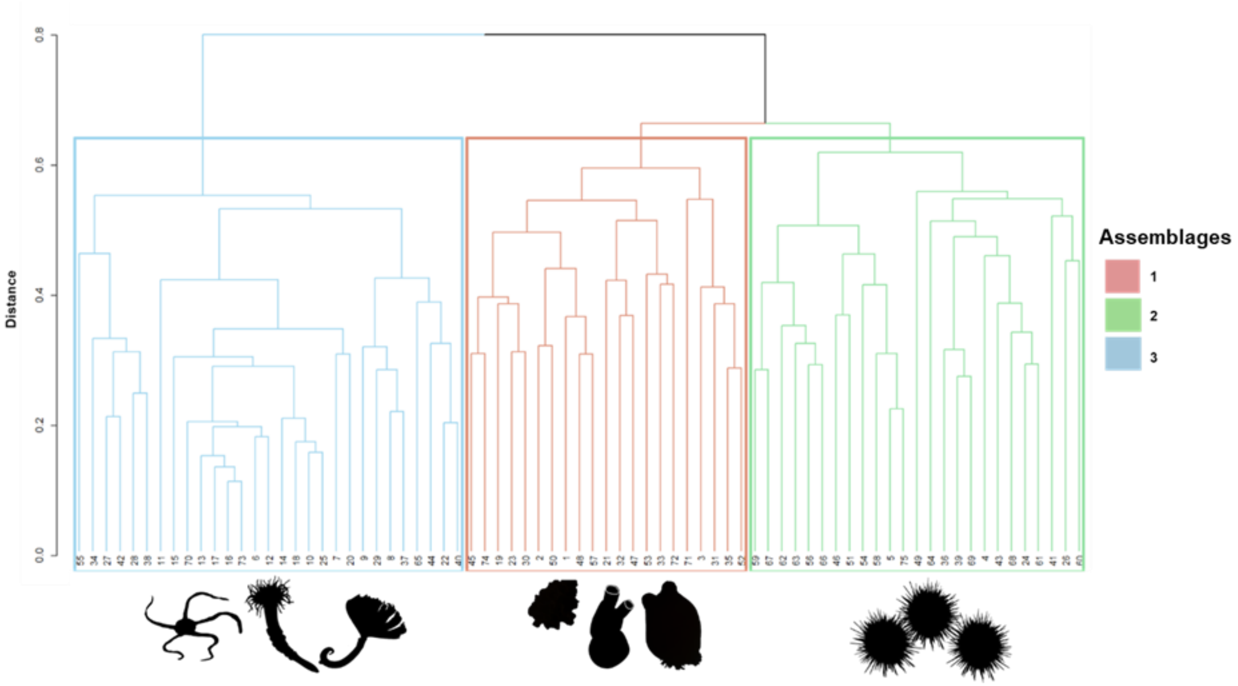


Figure 3.5 Dendrogram, based on hierarchical clustering (UPGMA) with three epifaunal assemblages. Indicator taxa silhouettes represent each assemblage.

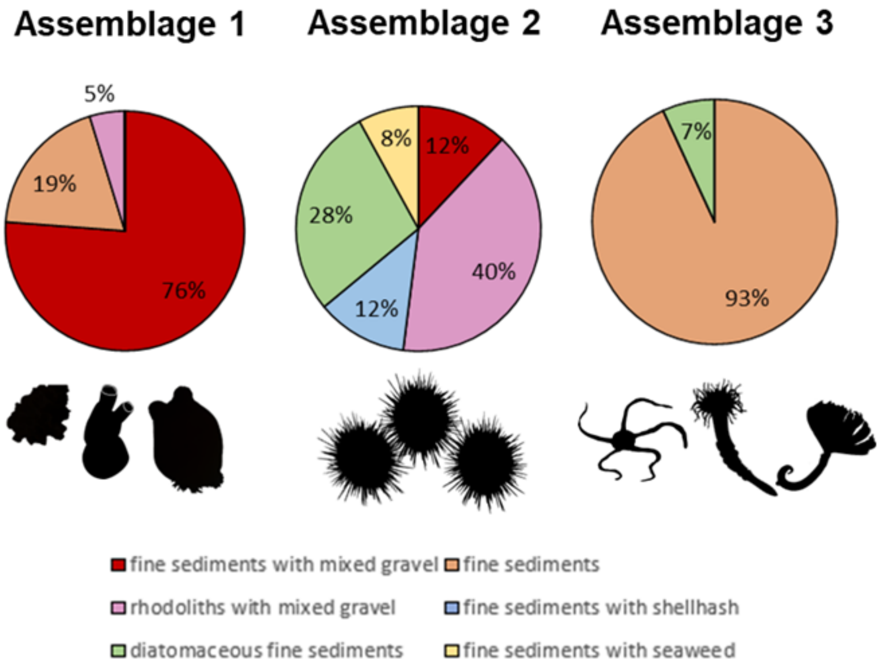


Figure 3.6 Percentage of sites relative to substrate classification for each epifaunal assemblage.

Assemblage 1 exhibited the highest taxa richness, followed by Assemblage 2 and 3 respectively. Species accumulation curves indicated that the taxa/morphotype richness of each assemblage were adequately represented (Fig 3.7). However, it is likely that the constraints of video surveys underrepresented the taxa richness of all or some of these assemblages.

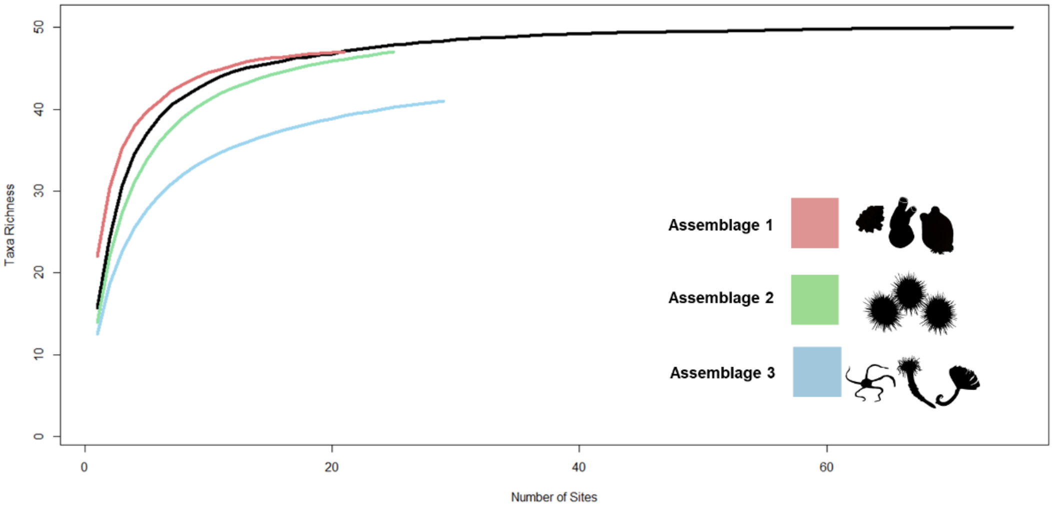
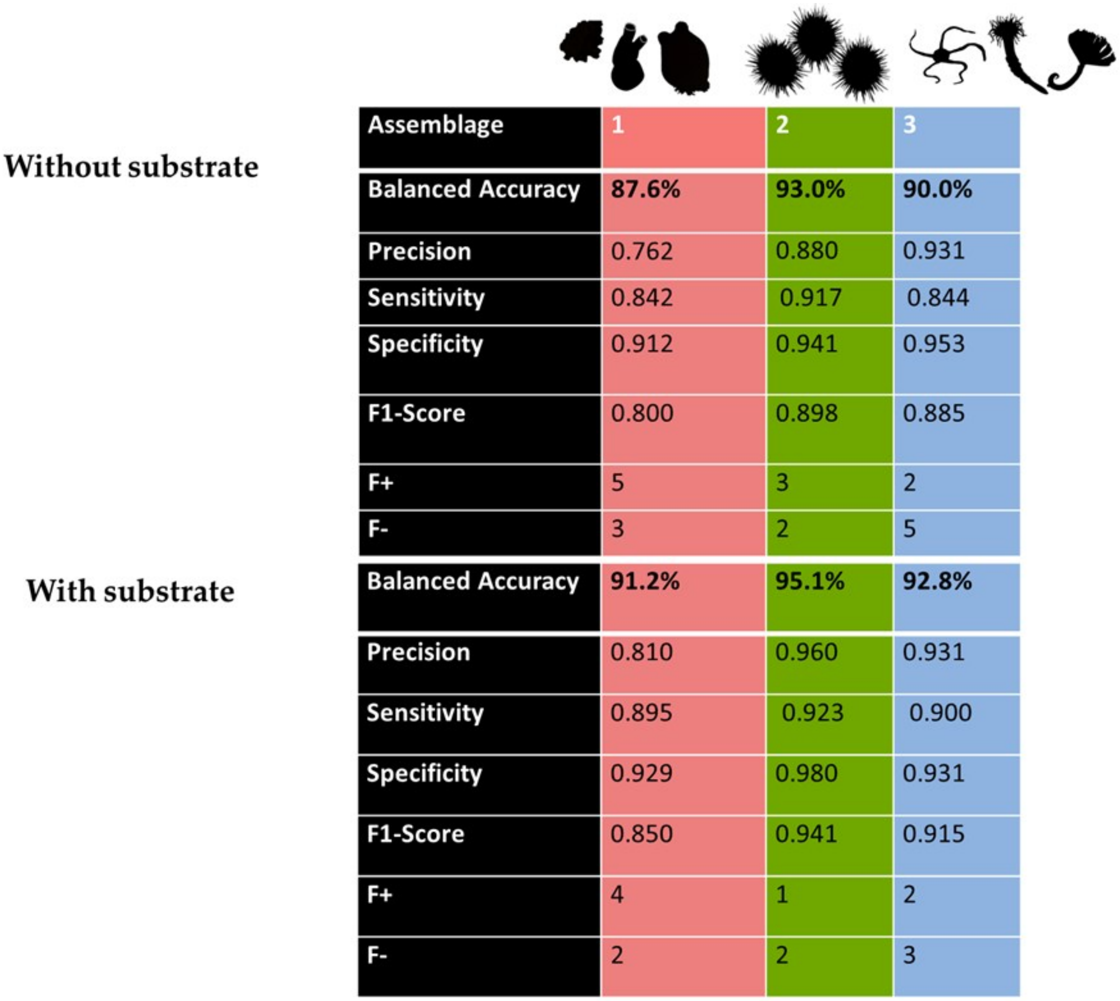


Figure 3.7 Species accumulation curve for each faunal assemblage and for the total number of taxa observed across all sites included in the analysis (black).

3.3.3 Model performance & predicted distribution

There were 5 variables included in the epifaunal models succeeding the Boruta selection algorithm and assessment of collinearity, and 10 variables in the substrate model (listed in Figure 3.10). Without substrate classifications, the RF model accuracy was 86.7% (kappa = 0.80); however, when substrate features were included, model accuracy was improved to 90.7% (kappa = 0.86) (Fig 3.8). The first assemblage was overestimated relative to the others in both RF models as displayed by the lower precision score (76.2% without substrate and 81% with substrate) and higher number of false positive predictions (n = 5 and 4, respectively). The model with substrate improved the sensitivity values for Assemblage 3 from 84.4% with 5 false negatives to 90% with 3 false negatives. Overall, the model without substrate accurately predicted the spatial extent of each assemblage with relatively high balanced accuracies, and both models predicted Assemblage 2 more confidently.



	Assemblage	1	2	3
Without substrate	**Balanced Accuracy**	**87.6%**	**93.0%**	**90.0%**
	Precision	0.762	0.880	0.931
	Sensitivity	0.842	0.917	0.844
	Specificity	0.912	0.941	0.953
	F1-Score	0.800	0.898	0.885
	F+	5	3	2
	F-	3	2	5
With substrate	**Balanced Accuracy**	**91.2%**	**95.1%**	**92.8%**
	Precision	0.810	0.960	0.931
	Sensitivity	0.895	0.923	0.900
	Specificity	0.929	0.980	0.931
	F1-Score	0.850	0.941	0.915
	F+	4	1	2
	F-	2	2	3

Figure 3.8 Confusion matrices for assemblage prediction accuracy assessment. Both Random Forest models with (above) and without (below) substrate features are shown.

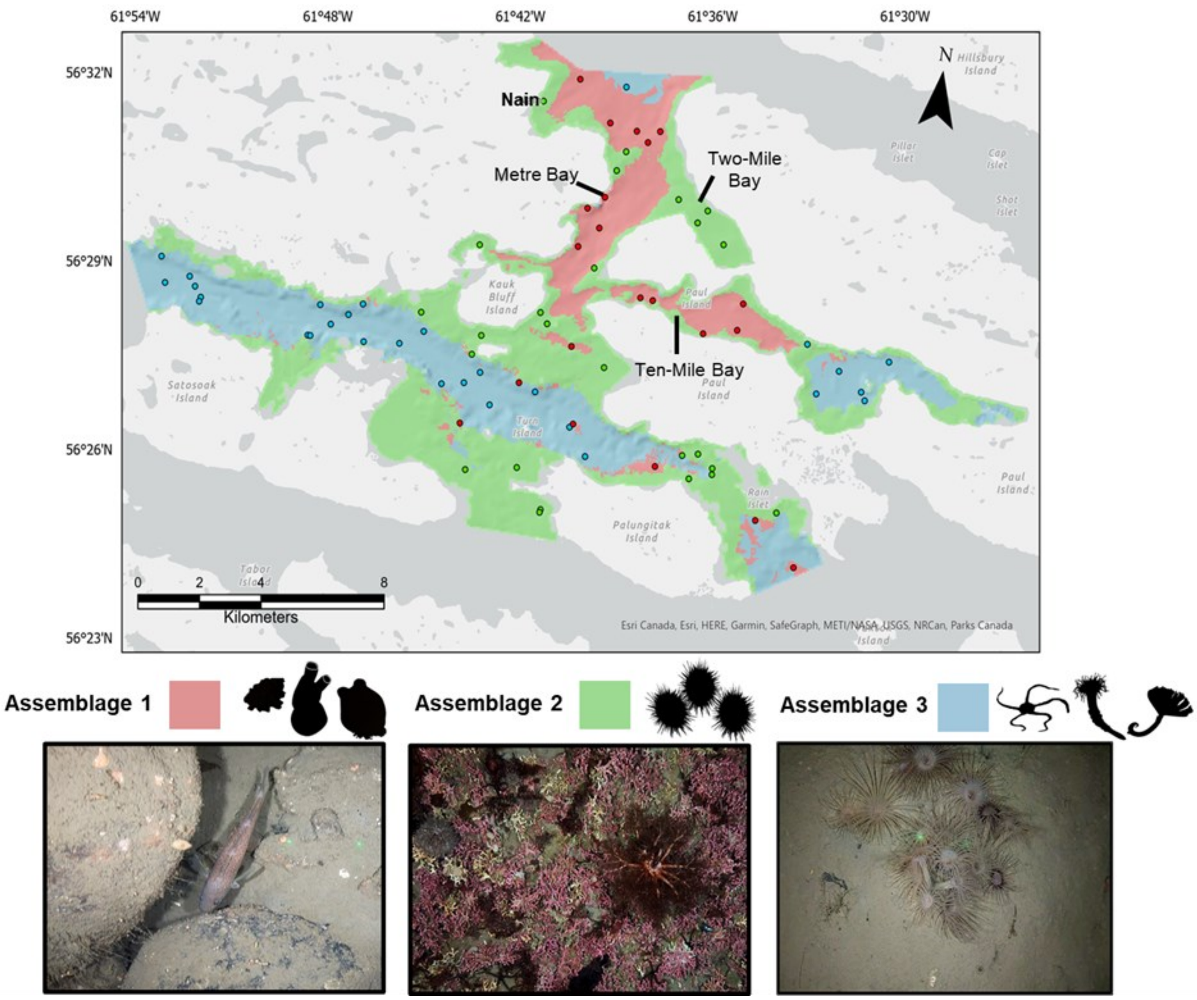


Figure 3.9 Predicted spatial coverage of the three identified assemblages by the Random Forest model across the survey area in Nain, NL. Representative photographs of assemblages are included. Sample stations are coloured based on the observed associated assemblage.

Assemblage-environment relationships

According to the RF model, bathymetry was the most important variable for predicting the distribution of the epifaunal assemblages (Fig 3.10). Intermediate depths were associated with Assemblage 1 (mean ± SD; 46.439 ± 20.271), while shallower areas distributed near the coastline were associated with Assemblage 2 (17.786 ± 9.086). Assemblage 3 was associated with deeper sites than both other assemblages (61.821 ± 31.898) and was mostly distributed farther from the coastline (e.g., the center of a fjord near the southern portion of the survey). Salinity was shown to be the second most important variable for predicting the distribution of these assemblages for the model without substrate (Fig 3.10A). The first two assemblages were associated with intermediate to lower salinity values in contrast to Assemblage 3, which was associated with higher salinities.

When substrate classifications were added to the RF model, Fine Sediments appeared to be more important than salinity for predicting assemblage distribution. Fine Sediments were associated mostly with Assemblage 3. Fine Sediments with Mixed Gravel was also highly important and was mostly associated with Assemblage 1. The remaining substrate classifications were ranked least important in the model, including Rhodoliths with Mixed Gravel found throughout the second assemblage.

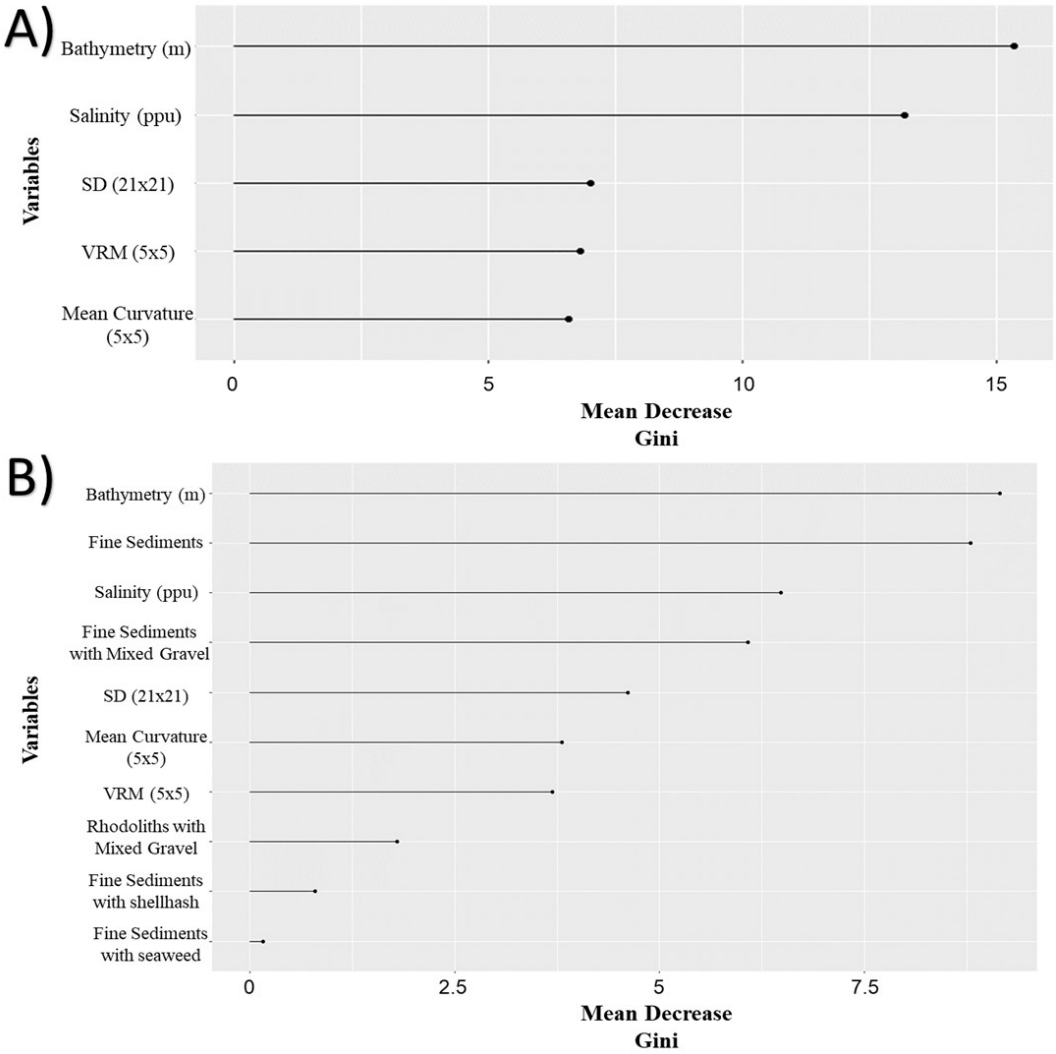


Figure 3.10 Variable importance determined from the Random Forest (RF) model without (A) and with substrate (B) for the epifaunal assemblages.

3.4 Discussion

The spatial representation of epifaunal assemblages in Nain's nearshore marine environment serves as a crucial step in addressing key knowledge gaps identified by Labrador Inuit and the NG. This includes a deeper understanding of the environmental drivers shaping the distribution of the benthic community and the habitats associated with ogak, a fish relied upon for subsistence practices throughout Nunatsaivut. The study highlights the importance of structurally complex nearshore habitats, like rhodolith beds, within significant ogak fishing locations, providing insights into the habitat associations of these fish. Additionally, the identification of various VME indicator taxa highlights the need for further exploration throughout the region to safeguard areas of high biodiversity. Overall, the habitat map generated in this study is intended to support the Imappivut initiative, contributing to the protection of vital habitats for local communities and to help resource users mitigate the impacts of a changing environment.

3.4.1 Epifaunal assemblages, spatial distribution and environmental relationships

Distinct differences in taxa composition, richness and substrate were identified within the three epifaunal assemblages identified. Ascidians and erect bryozoans characterized Assemblage 1, located in the center and northern part of the survey at intermediate depths, and were observed attached to large cobbles and boulders densely scattered on fine sediments. While this assemblage was not documented previously in the region, it featured a high abundance of sea cucumbers which were documented in video surveys as one of the most abundant organisms of Nain’s inner archipelago (Rangeley et al. 2022). Green sea urchins characterized Assemblage 2 which was found close to the shoreline at shallow depths and included rhodolith beds. These urchins have been documented as a common occurrence in other coralline algae covered habitats due to their grazing behavior (Jørgensbye & Halfar 2017). In Greenland, Jørgensbye & Halfar (2017) described a rhodolith habitat within a sheltered fjord and observed green sea urchins in high abundance. In Nachvak fjord, farther north in Nunatsiavut, sea urchins were found to dominate coralline algae habitats throughout scuba surveys (Friedlander et al. 2023). Previous descriptions of epifaunal assemblages conducted on the Labrador coast have also indicated that in 40% of surveyed quadrats throughout the Nain archipelago, sea urchins were observed, typically found on harder substrates (Rangeley et al. 2022). Brittle stars, tube worms (Sabellida spp.) and cerianthids (Ceriantharia spp.) were found to have widespread distribution and high abundance, especially in deep sites with fine sediment throughout Assemblage 3. These taxa were previously documented as a biotope in the region (Rangeley et al. 2022), specifically in fjords and fjards in Okak and Hebron. Consistent with our nearshore survey, this biotope was primarily observed within inner fjord and fjard sites, characterized by less exposure compared to coastal headlands.

Various studies (Neves et al. 2014; Schückel et al. 2015; Bekkby et al. 2019; Nemani et al. 2022; Mackin-McLaughlin et al. 2022) consistently emphasize the significant role of depth in shaping the distribution of benthic biota. Bathymetry was observed as the most important variable in this study. However, depth acts as a proxy for other interconnected variables, such as light availability, temperature, salinity, and wave action, which are more complex to assess directly (Elith & Leathwick 2009). Shallowest sites, associated with Assemblage 2, had high substrate diversity (e.g., biogenic, rocky, fine sediments), yet higher taxa richness was observed for Assemblage 1 at intermediate depths. However, the species accumulation curve suggested that Assemblage 2 had not reached its asymptote and likely harbored higher taxa richness relative to Assemblage 1 which plateaued. Typically, the higher biogenic habitat complexity represented in Assemblage 2 would support more unique taxa as found in other Arctic studies (e.g., Włodarska-Kowalczuk et al. 2012; Davies et al. 2015; Carpenter et al. 2020; Rangeley et al. 2022); therefore, it is likely that the extensive coverage of rhodoliths and other seaweeds in this assemblage inhibited the visual observation of many benthic taxa, causing it to be underrepresented. Assemblage 3 was mostly found in deeper waters farther from the coastline with higher salinities, colder temperatures, and finer substrates. The assemblage displayed lower faunal richness than the shallower assemblages occurring on complex, harder substrates.

Substrate variability has a profound impact on the composition of benthic communities, as it influences benthic feeding modes and the survival of organisms from their larval to adult stages (Snelgrove & Butman 1994; Roy et al. 2014). Moreover, substrate type and complexity can act as a proxy for currents, with coarser and harder substrate often occurring in stronger seafloor current regimes (Snelgrove & Butman 1994; Roy et al. 2014; Rangeley et al. 2022). As seen in the variable importance plot, the addition of substrate classifications yielded important results for predicting the distribution of assemblages. Performance for RF improved in all cases when substrate features were included in the model; however, their discontinuous coverage rendered these variables unsuitable for continuous spatial prediction. Overall, there is value added by including fine-scale substrate information as previously underscored by Mackin-McLaughlin et al. (2022), but this may not be needed for all applications.

3.4.2 Ogak benthic habitat associations

The community-identified fishing locations fell within the assemblages (i.e., Assemblages 1 and 2) representing higher substrate complexity whose areas contained two observations of ogak within the video. In contrast, the most homogeneous assemblage (i.e., Assemblage 3) did not contain any ogak observations or fishing locations. These results suggested that ogak in Nain tend to associate with more structurally complex habitats, often characterized by an elevated coverage seaweeds and rhodolith beds. Previous studies have found that ogak to prefer shallow, productive waters with high macroalgal coverage, and rocky outcroppings (Morin et al. 1991; Knickle 2013; Knickle & Rose 2014b; Dalley et al. 2017; Devine 2018). Recent underwater scuba surveys in Nunatsiavut found that outside Nachvak Fjord, ogak dominated fish biomass in areas with high coverage of kelp and boulders with few megabenthic invertebrates present (Friedlander et al. 2023). Interestingly, these fish were not found in high abundance within the fjord, which lacked kelp.

The association with structural complexity may be due to a variety of benefits including increased shelter, protection from predators, reproductive success, and foraging opportunities. Studies have linked such associations more broadly with increased abundance, growth, and survival of various fish species (Heck et al. 2003; Dalley et al. 2017). Baited remote underwater video footage collected in Nain validate these associations and our results (B. King, personal communication). Here, a higher number of ogak were reported in sites with increased substrate complexity, including boulders, cobbles, and a high coverage of rhodolith beds and macroalgae (Fig 3.11). A previous study in southwest Scotland determined through scuba and fyke net surveys that gadoids consistently favor feeding above rhodolith beds rather than gravel, despite the greater vegetation cover provided by gravel (Kamenos et al. 2004b). The presence of rhodolith beds within Assemblage 2 likely provides abundant food resources particularly beneficial for supporting juvenile ogak and other gadoids, and may enhance the capacity of shallow-water nursery zones (Kamenos et al. 2004b).

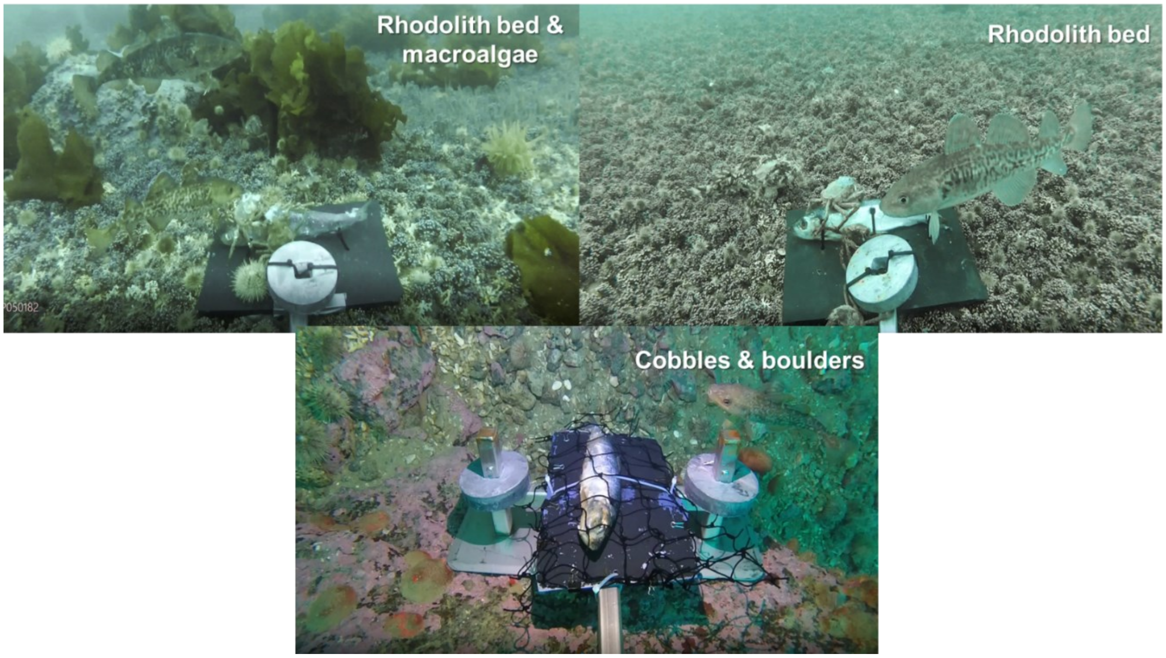


Figure 3.11 Baited remote underwater video frames of sites with high reports of ogak. Sites are located near Metre Bay, Nain, Nunatsiavut. Image source: Benjamin King.

A study conducted in Alaska, focusing on the habitat associations of juvenile ogak, reported a positive correlation between ogak densities and the percent cover of sand mounds created by burrowing sea cucumbers (Abookire et al. 2007). While the sea cucumber species examined in our study differed from those in the Alaskan study, we observed that sea cucumbers in Nain formed large aggregations throughout Assemblages 1 and 2, which may similarly contribute to the habitat associations of ogak. Sea cucumbers, such as *Psolus fabricii* and *Cucumaria frondosa*, along with other megabenthic invertebrates, have recently been observed in underwater scuba surveys throughout Nachvak Fjord, in proximity to prime ogak habitats (Friedlander et al. 2023). Though this may be a coincidence, the abundance and dynamic habitat structure formed by sea cucumbers should be investigated further in relation to ogak habitat associations.

A small sample size of ogak was observed in the survey (n = 2); however, the purpose of the study was not to validate the existence of ogak in the community fishing locations, as their presence in these areas is well-known throughout the community. For generations these fishing locations have been used as a main source of subsistence. The objectives of this study were to deepen our understanding of the benthic habitats at these locations and in the broader area, with a focus on identifying ogak habitat associations. It is important to acknowledge that ogak may occupy and/or prefer other habitats nearby that were not designated as an important fishing location by community members. A similar situation is reflected in the observations conducted in Frobisher Bay, Nunavut (Misiuk et al. 2019). Here, traditional/local/Indigenous knowledge played a vital role in providing information about areas where clams are regularly harvested, which are often not comprehensively studied through scientific surveys (Misiuk et al. 2019). These knowledge systems were shown to be complementary to Western scientific methods, much like the fishing locations in this study. To further validate our findings, telemetry research being done in the region also indicate a tendency for ogak to remain in proximity to these fishing locations (Benjamin King, personal communication), reinforcing their association with these areas. Moreover, ogak exhibit a strong affinity for specific habitats, demonstrating a high degree of site fidelity (Knickle & Rose 2014a; Shapiera et al. 2014). This behavior can be advantageous and is not unique to ogak alone, as many fish species display limited movement and rely on familiarity with their preferred areas to locate productive feeding grounds, resting sites, and suitable shelter (Dodson 1997; Helfman et al. 2009; Knickle & Rose 2014a; Gatti et al. 2020).

3.4.3 Vulnerable marine ecosystems

Vulnerable marine ecosystems (VMEs) are biodiversity hotspots characterized by assemblages of benthic fauna and/or flora that are sensitive to environmental disturbance, physically fragile, and slow to recover from damage (FAO 2009).

Cerianthid fields

Cerianthid tube-dwelling anemones are considered indicators of VMEs due to their ecological significance, structural complexity, and vulnerability (Fuller et al. 2008; Murillo et al. 2011). These anemones were observed throughout Assemblage 3, forming sizeable fields on the muddy seafloor. Similar to observations in eastern Atlantic fjords (Buhl-Mortensen & Buhl-Mortensen 2014), associations between cerianthids and dominant taxa such as pandalid shrimps (*Pandalus* spp.), sea cucumbers (*Psolus* spp.), and sponges (Porifera spp.) were noted within this assemblage. Research has shown that cerianthid fields provided shelter and served as protective corridors while moving between habitats for juvenile redfish (Auster et al. 2003). Density thresholds have yet to be published relative to cerianthid field protection (Rangeley et al. 2022); however, the observation of 14,768 individuals forming fields within Assemblage 3 serves as a notable indication of a potential VME. These populations are highly susceptible to damage caused by bottom-trawling, which can lead to disruptions of associated benthic communities (Fuller et al. 2008).

Rhodolith beds & coralline crusts

Assemblage 2 should be considered carefully with respect to its management as it contained multiple sites with rhodolith beds (Fig 3.12). Based on the data observed in this study, rhodolith and other coralline algal communities are a widespread feature of Nain's nearshore marine environment. The rhodolith habitats could be categorized as a VME according to their functional significance, structural complexity, extended lifespan, and vulnerability relative to their slow recovery post-disturbance (e.g., trawling, scalloping) (Jørgensbye & Halfar 2017; Chimienti et al. 2019). The importance of these habitats for nurseries, regional biodiversity, carbon sequestration, and commercial fishery yields have been well-documented in the literature (Barbera et al. 2003; Kamenos et al. 2004b; Mao et al. 2020; Tuya et al. 2023). The association of these beds with scallops in previous studies is also notable (Barbera et al. 2003; Kamenos et al. 2004a), as they were observed as a dominant taxon (C. *islandica*) throughout Assemblage 2. This association is especially important as the economic interest in the Icelandic scallop fishery grows, aiming to bring diversification to the fishing sector in Nunatsiavut (Kourantidou et al. 2021; Schaible 2019; Barker 2019). Studies have highlighted the destructive effects of scallop dredging on rhodolith habitats, attributed to the physical disruption caused to the seafloor (Stewart & Howarth 2016). Notably, in one case, a >70% reduction in rhodolith beds was observed due to scallop dredging in Scotland, and recovery was absent over a four-year period (Hall-Spencer & Moore 2000). Furthermore, recent studies have revealed that rhodolith beds are recognized as refugias that enhance ecosystem resilience in the face of environmental stress (Fredericq et al. 2019; Voerman et al. 2022). The encrusting coralline algae, which was also plentiful in Assemblage 2, is unlikely to be sensitive to impact due to its resilient and robust structure; however, the associated fauna that coexist with it may still possess varying levels of sensitivity (Ross et al. 2023). Gaining a deeper understanding of the spatial distribution of these ecosystems in high-latitude regions is of utmost importance because they may play critical roles as breeding and nurturing areas for commercially significant fish and invertebrate species (Jørgensbye & Halfar 2017).

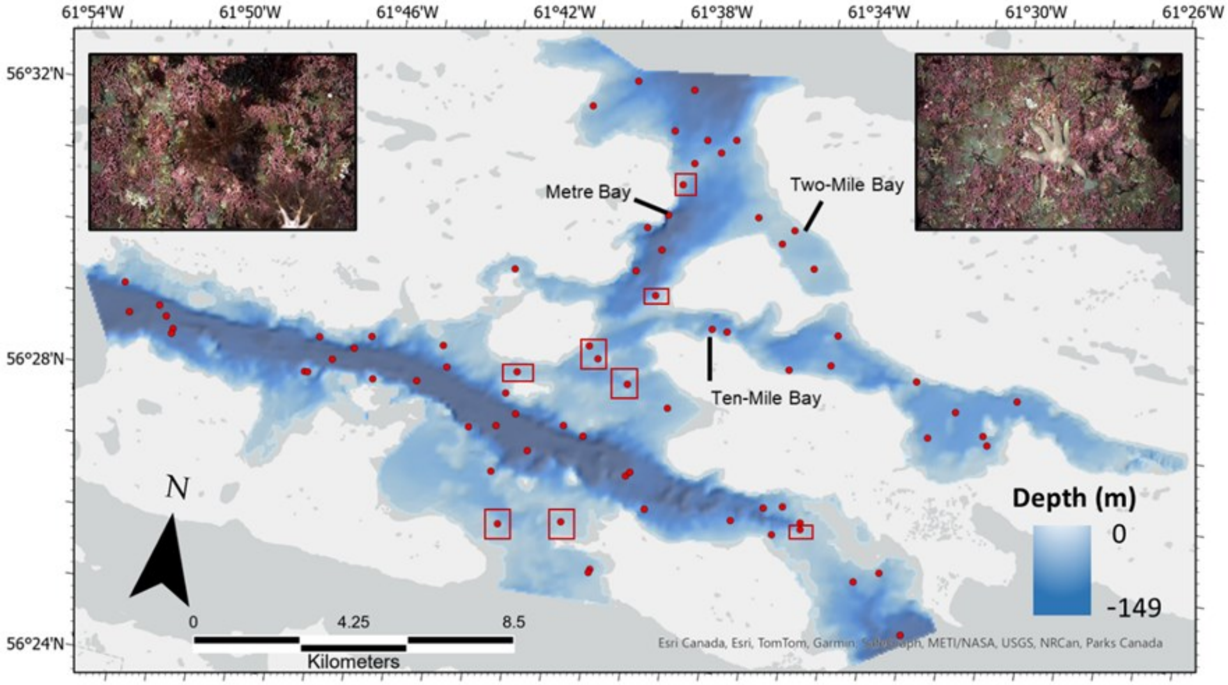


Figure 3.12 Approximate locations (red boxes) of rhodolith-dominated habitats based on drop-camera surveys. Representative photographs are shown on map.

Orange-footed sea cucumber

The orange-footed sea cucumber was observed as a dominant taxon throughout Assemblage 2 and formed large masses on boulders. Although this taxon is not considered a VME indicator on its own, it was recently documented in high abundance within an internationally listed conservation-relevant habitat in the Barents Sea, Norway (Ross et al. 2023). While our observations in Assemblage 2 share some similarities with the conservation-relevant habitat identified by Ross et al. (2023), including the dominance of the orange-footed sea cucumber, distinctions such as the absence of certain hydroids and bryozoans, and the lack of direct assessments for chlorophyll *a* concentration, make it challenging to precisely align our findings with their detailed criteria. Nevertheless, our study underscores the ecological significance and taxonomic richness within Assemblage 2.

Tunicates, erect bryozoans, sponges

Erect bryozoans (Bryozoa spp. 2, Bryozoa spp. 1), sponges, large ascidians like sea peaches (H. *pyroformis*) and stalked tunicates (B. *ovifera*) were dominant in Assemblage 1 while the latter was also dominant in Assemblage 2. However, the ascidians, sponges and bryozoans did not form fields on the seabed in this survey, and as such, their presence alone may not be indicative of a VME (Murillo et al. 2011; Kenchington et al. 2014). Despite the lack of these VME characteristics, these taxa were found throughout assemblages 1 and 2 and may provide significant structure for other benthic epifauna (e.g., ophiuroids, small fish) (Kenchington et al. 2007; Murillo et al. 2011; Beazley et al. 2013; Smith et al. 2001), ultimately enhancing species richness (Francis et al. 2014).

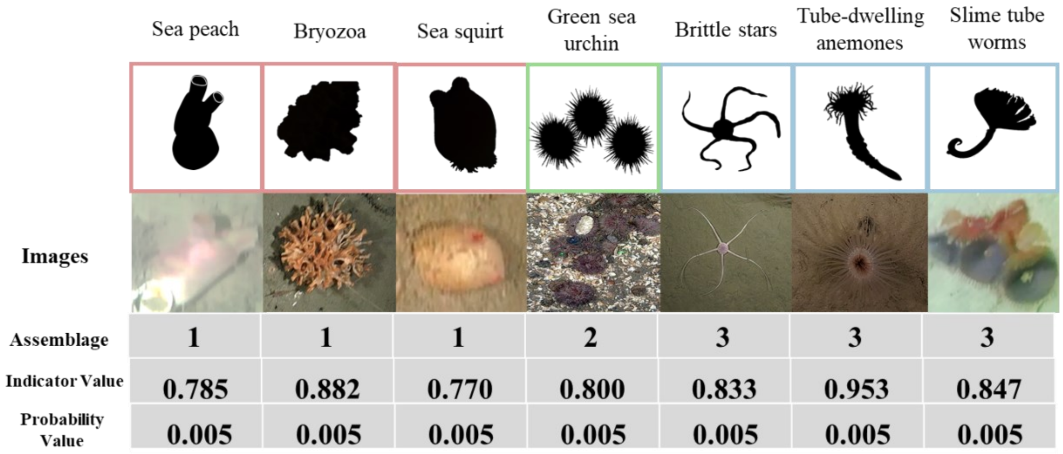
3.5 Conclusion

This study provides a benthic habitat map of the nearshore marine environment in Nain, Labrador, and describes habitats characteristics at ogak fishing locations to support the Imappivut initiative. The spatial representation of epifaunal assemblages and their environmental drivers can assist resource users in prioritizing habitats, mitigating environmental impacts, and preserving critical resources in the region. Habitats associated with local ogak fishing sites exhibited high substrate complexity, along with increased signs of productivity attributed to extensive rhodolith beds and macroalgal coverage. These conditions likely provided favorable opportunities for foraging, shelter, and reproductive success. Moreover, the identification of potential vulnerable marine ecosystems and their associated indicator taxa within the region highlights the need for conservation and protection measures. The insights gained from this study can allow the NG to pinpoint habitats requiring strategic management and ongoing monitoring, particularly those associated with ogak. This proactive approach ensures the preservation of their traditional way of life and economic prospects while upholding the ecological integrity of the ecosystem.

3.6 Appendix

Table 3.1 Environmental features calculated across multiple scales to model species assemblages.

Source layer	Derivative layer	Units	Scales (m)	Method
Bathymetry	Source bathymetry surface	m	50	
	Bathymetric position index (BPI) – topographic highs and lows	m	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	Vector Ruggedness Measure (VRM) - quantifies seafloor roughness by incorporating slope and aspect into a single measurement	unitless	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	Mean Curvature	Degrees/m	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	Profile curvature: rate of change of a slope (convex and concave contours in the surface)	Degrees/m	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	Planar curvature: perpendicular to slope (define ridges and valleys)	Degrees/m	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	Eastness: orientation of the seabed (sine transformed measure of aspect)	unitless	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	Northness: orientation of the seabed (cosine transformed measure of aspect)	unitless	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	RDMV- relative difference to the mean value (measure of topographic position – combines slope and aspect to decouple terrain ruggedness)	unitless	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	Slope – steepness of gradient	degrees	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
	SD - standard deviation of terrain variability	m	150, 250, 350, 450, 550, 650, 750, 850, 950, 1050	MultiscaleDTM
Distance to coast	dist2coast - distance from the coast relative to each pixel	m		Euclidean distance
Temperature	Temperature – bottom water temperature	°C		EBK
Salinity	Salinity – bottom water salinity	ppu		EBK



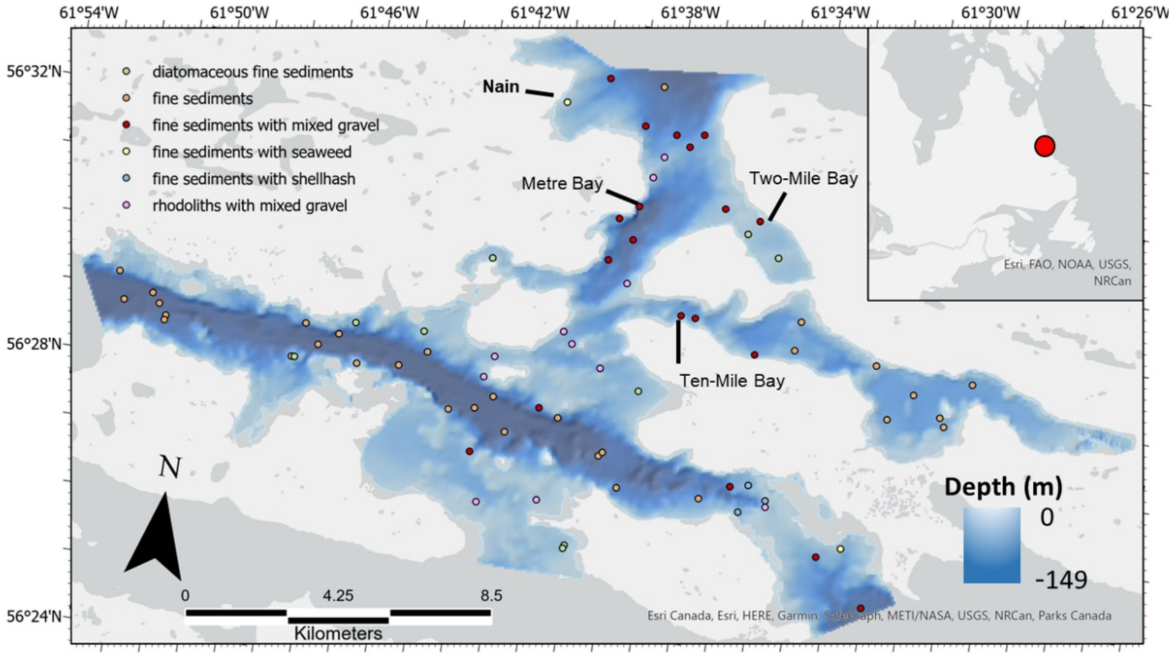
	Sea peach	Bryozoa	Sea squirt	Green sea urchin	Brittle stars	Tube-dwelling anemones	Slime tube worms
Assemblage	**1**	**1**	**1**	**2**	**3**	**3**	**3**
Indicator Value	**0.785**	**0.882**	**0.770**	**0.800**	**0.833**	**0.953**	**0.847**
Probability Value	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**

Figure 3.13 Indicator taxa with associated indicator and probability values for 3 epifaunal assemblages.

Table 3.2 Total abundance of morphotaxa throughout survey in Nain, NL. Status denotes dominant (x) and indicator taxa (*).

Status	Morphotaxa	Total abundance
	Actiniaria spp.	6
	Actinostola callosa	41
x	Ascidiacea sp.1	561
	Ascidiacea sp.2	55
x *	Ascidiacea sp.3	474
	Asterias sp.99	20
x	*Boltenia ovifera*	610
x	Bryozoa sp.004	234
x	Bryozoa sp.1	222
x *	Bryozoa sp.2	516
	Bryozoa sp.6	120
	Buccinum spp.	11
x *	Ceriantharia spp.	14768
	Chionoecetes opilio	56
x	*Chlamys islandica*	649
x	*Cottidae* spp.	229
x	*Crossaster papposus*	263
	Ctenodiscus crispatus	10
x	*Cucumaria frodosa*	714
	Haliclona sp.2	19
x *	*Halocynthia pyriformis*	93
	Henricia sanguinolenta	83
	Hyas araneus	44
	Hyas coarctatus	24
x	*Leptasterias polaris*	108
x	*Leptoclinus maculatus*	380
x	*Lumpenus lampretaeformis*	874
	Lycodes vahlii	63
	Myoxocephalus scorpius	36
	Myoxocephalus spp.	44
x *	*Myxicola infundibulum*	2511
	Neohela monstrosa	27
x *	Ophiuroidea sp.1	3288
	Ophiuroidea sp.2	128
	Pagurus spp.	22
x	*Pandalus* spp.	2066
	Polinices heros	4
x	Porifera sp.11	292
x	Porifera sp.13	424
	Porifera sp.21	41

Status	Morphotaxa	Total abundance
	Porifera sp.22	16
x	Porifera sp.3	319
x	*Psolus fabricii*	2594
x	*Psolus phantapus*	2072
x	Sabellida spp.	455
	Solaster endeca	13
	Stichaeus punctatus	5
	Stomphia coccinea	249
x *	*Stronglyocentrotus droebachiensis*	8495
x	*Urticina felina*	461



Esri, FAO, NOAA, USGS, NRCan

Esri Canada, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, NRCan, Parks Canada

Figure 3.14 Drop-camera video survey locations (n = 75) from GRTS design. Sites are colour coded by substrate type. Map includes bathymetric coverage compiled by the Canadian Hydrographic Service.

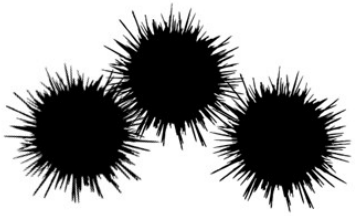
Assemblage	Indicators	Image	Dominant Taxa	Sample Size
1	Ascidians & bryzoans 		*Stronglyocentrotus droebachiensis, Psolus fabricii, Pandalus* spp., *Myxicola infundibulum, Boltenia ovifera*, Bryozoa.sp..2, *Psolus phantapus*, Ascidiacea sp.3, *Lumpenus lampretaeformis*, Ascidiacea sp.1, Porifera.sp.11, Porifera.sp.13, Bryozoa.sp..1, *Crossaster papposus, Cottidae* spp., Ophiuroidea.sp.1, *Halocynthia pyriformis, Chlamys islandica*	**21**
2	Green sea urchins 		*Stronglyocentrotus droebachiensis, Myxicola infundibulum, Psolus fabricii, Psolus phantapus, Cucumaria frodosa, Chlamys islandica, Crossaster papposus, Urticina felina,* Bryozoa.sp..004, *Leptoclinus maculatus, Leptasterias polaris, Boltenia ovifera, Cottidae* spp.	**25**
3	Brittle stars, tube-dwelling anemones, & tube worms 		Ceriantharia spp., Ophiuroidea.sp.1, *Pandalus* spp., Sabellida spp., *Lumpenus lampretaeformis, Stronglyocentrotus droebachiensis, Psolus phantapus, Myxicola infundibulum,* Porifera.sp.3, *Leptoclinus maculatus*	**29**

Figure 3.15 Images of epifaunal assemblages and dominant taxa observed for each species assemblages observed around Nain. Sample size refers to the number of drop-camera stations.

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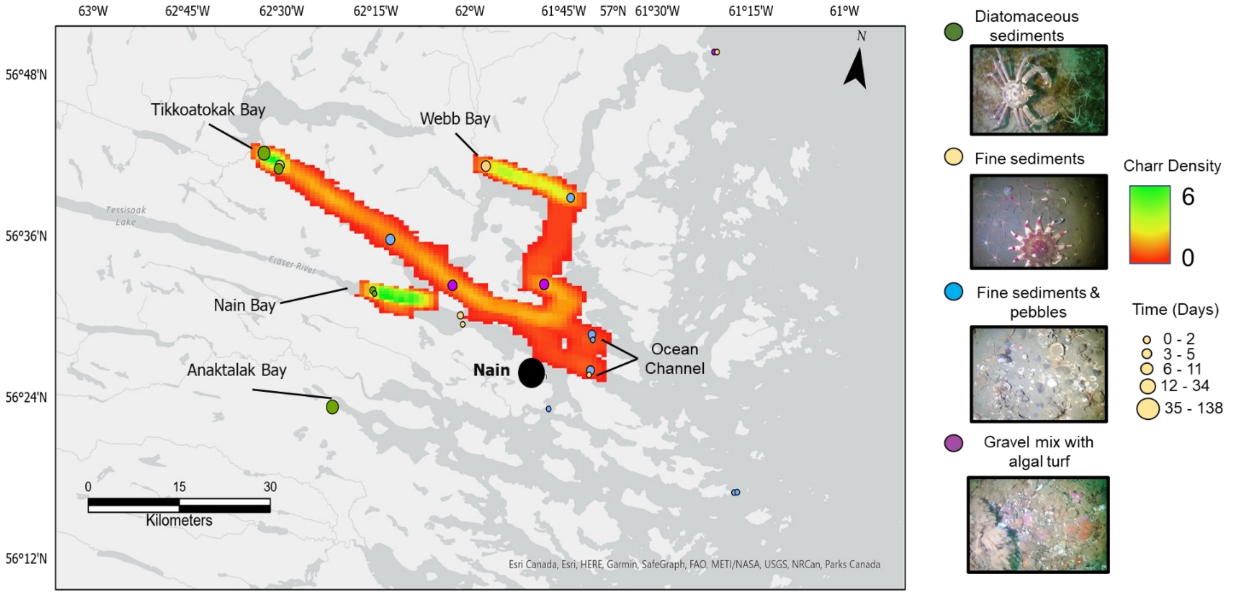
4 Conclusion

This chapter is meant to serve as a summary of the highlights and important findings in this research for community members in Nain and the Nunatsiavut Government. It is important to acknowledge that the new research avenues proposed upon concluding this study may not be the highest priority for local Inuit. Nevertheless, delving deeper into the intricacies of the benthic ecosystem contributes to the well-being of the broader marine environment.

iKaluk – Arctic charr

iKaluk associated habitats

We used underwater cameras, along with listening devices (acoustic receivers) from Fisheries and Oceans Canada, and fishing spots identified by local harvesters, to learn about the marine, benthic habitats of iKaluk. Within 125 videos, we identified 248,056 individual animals. We grouped sites into five categories by their dominant organism: 1) brittle stars; 2) a mix of northern red anemones and sea stars; 3) sea cucumbers and bryozoans; 4) a mix of clams, sea squirts, and bryozoans; and 5) tube-dwelling anemones. iKaluk with tags were often seen in estuarine habitats, especially in Tikkoatokak Bay, Nain Bay, Webb Bay, and Anaktalak Bay (Fig 4.1). These estuaries were dominated by mud or sand and covered in microalgal mats (benthic diatoms). The ocean floor in these habitats was full of brittle stars and tube-dwelling anemones.



Esri Canada, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, NRCan, Parks Canada

Figure 4.1 Arctic charr movement paths between acoustic receivers and substrate classes. Charr hotspots around Nain, highlighted in green and yellow. Receivers are coloured by dominant substrate class identified during video analysis.

We think that a high coverage of benthic diatoms (Fig 4.2) can tell us that the habitat is suitable for iKaluk. These phytoplankton are important for the food-chain in estuaries and may serve as rich foraging areas for iKaluk and their preferred prey, including capelin and sand lance. Overall, iKaluk were detected 71% of the time in these habitats, where they also spent the most amount of time. When assessing habitat suitability, this substrate was highest for iKaluk compared to the other available substrates observed in the survey. Other available substrates included fine sediments, fine sediments covered in pebbles, and a mixture of gravel covered in algae. As warming continues across Nunatsiavut, it is likely that an earlier spring bloom of phytoplankton will influence the benthic productivity in Nain, which may impact the feeding habits and habitat use of iKaluk. The timing and abundance of prey may be impacted, causing breaks in the charr food-web. Future research could investigate the abundance of prey within available iKaluk habitats, as well as the significance of benthic diatoms in Nain's iKaluk food web using stable isotopes and fatty acids.

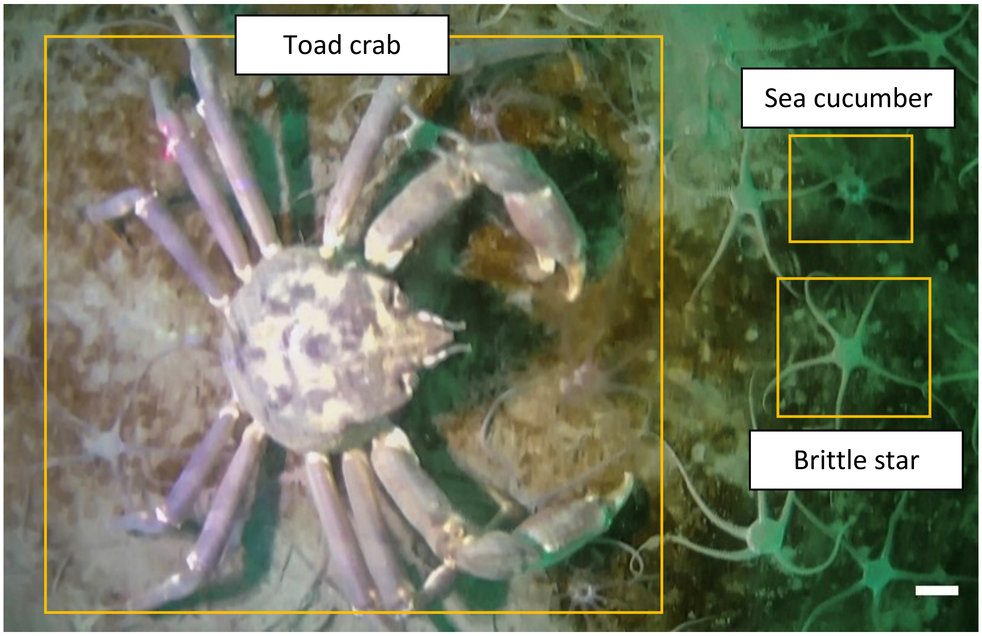


Figure 4.2 Estuarine habitat with benthic diatoms covering the seafloor. Animals in the photo include a toad crab, sea cucumbers, and many brittle stars. Benthic diatoms serve as a primary food source in estuarine food webs, making their presence and productivity essential for the overall ecological balance of these delicate habitats. White bar for scale is 2.5 cm.

Environmental change on iKaluk

When comparing the sizes of individual iKaluk that left their natal estuary and explored other habitats (vagrant) with those that remained in one habitat for the entire summer (sedentary), we found no significant difference in size. Typically, larger iKaluk are shown to venture farther from their natal estuaries, exploring a variety of habitats for food, or passing through to get to a different estuary. The finding that vagrant charr are not significantly larger than sedentary charr may support the observations of a decline in iKaluk sizes throughout the region by local harvesters. However, future research is needed to verify the relationship between fish size and non-estuarine habitat use.

The restricted movements observed in both vagrant and sedentary charr during this study are likely linked to the abundance of preferred prey in diatom-covered estuary habitats. However, it is also possible that these limited movements are due to a shift away from anadromy.

In the future, extended ice-free periods and increased rainfall due to climate change could enhance productivity in freshwater habitats, leading to greater availability of food. Consequently, there may be reduced reliance on migration between freshwater and saltwater for iKaluk during the summer. This reduction in life history diversity could pose a problem to iKaluk as a species and could also impact the availability of this fish for commercial and subsistence fisheries. Further research and monitoring should be done to confirm whether the limited movements observed in iKaluk during this study result from a shift away from anadromy and to understand the associated consequences. This may involve various research methods, including, but not limited to tagging, stable isotope analyses, and temperature and salinity monitoring.

Ogak - Rock cod

Ogak associated habitats

We used underwater video surveys within and around local ogak fishing locations to map the seafloor habitats present in Nain and to see which of these habitats ogak tend to associate with. Across the 75 drift-videos, a total of 44,809 individual animals were identified. Ittiks or sea urchins (count = 8,495), sea cucumbers (count = 5,380) brittle stars (count = 3,298), tube worms (2,966) and tube-swelling anemones (count = 14,768) were some of the most common animals observed throughout the study area. Additional animals in high abundance relevant for fisheries and economic opportunities included shrimp (count = 2,072) and scallops (count = 649). Our habitat map resulted in three groups (assemblages) of seafloor animals dominant in the study area, and these included 1) sea squirts and bryozoans; 2) sea urchins; 3) and a mix of tube-dwelling anemones, tube worms and brittle stars (Fig 4.3).

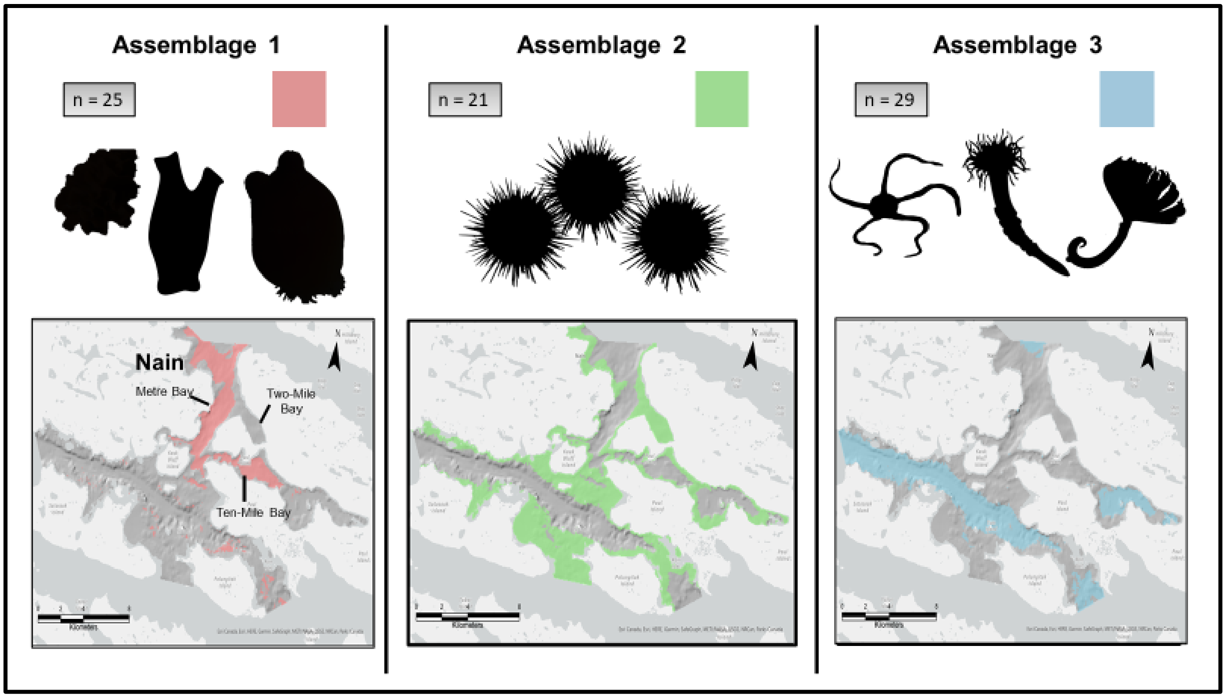


Figure 4.3 Seafloor animal assemblages in Nain, Nunatsiavut. Assemblages include: 1) Hard bottom, mid-depth with sea squirts and bryozoans; 2) Hard bottom, shallow with sea urchins (ittik); 3) and Soft bottom, deep with a mix of tube-dwelling anemones, tube worms and brittle stars. Number of sites surveyed shown (n).

Assemblage 1 was found slightly further from land at 35-55 meters depth and was found on rocky substrates (e.g., cobbles, boulders) with patches of sand or mud (Fig 4.4). Sea squirts and bryozoans were often found attached to the rocks in this assemblage. Assemblage 2 was found in shallow areas, close to land with a seafloor full of rhodolith beds (live rock), coralline algae, and gravel (Fig 4.5). This assemblage was covered in urchins, which are often found grazing in algal habitats, as well as sea cucumbers and a high number of scallops. Assemblage 3 was found in deeper areas further from land and had a seafloor entirely composed of sand and/or mud (Fig 4.6). This assemblage contained extensive fields of tube-dwelling anemones mixed with tube worms and brittle stars.

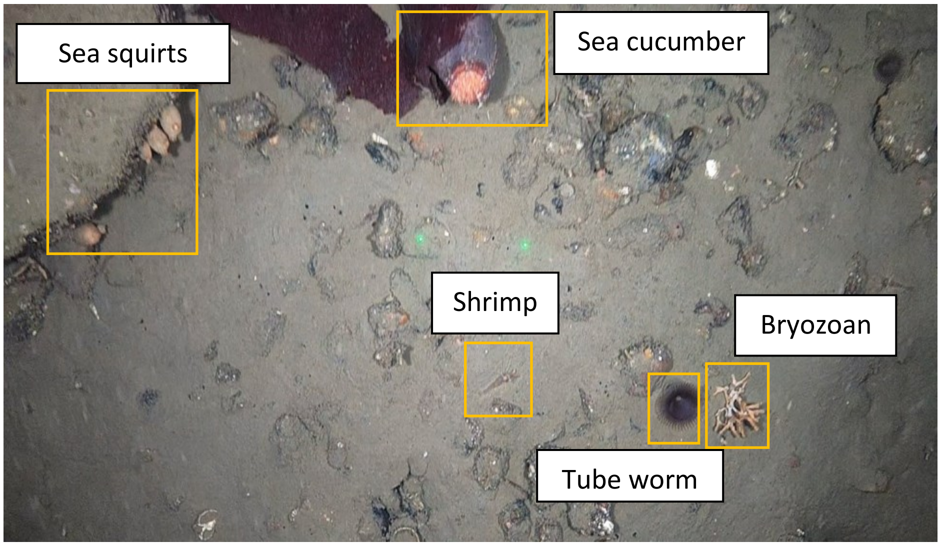


Figure 4.4 Example of a sea squirt and bryozoan habitat in Nain. Sandy and muddy seafloor covered in boulders and pebbles. Green lasers are distanced 10 cm for scale. Animals in photo are labelled.

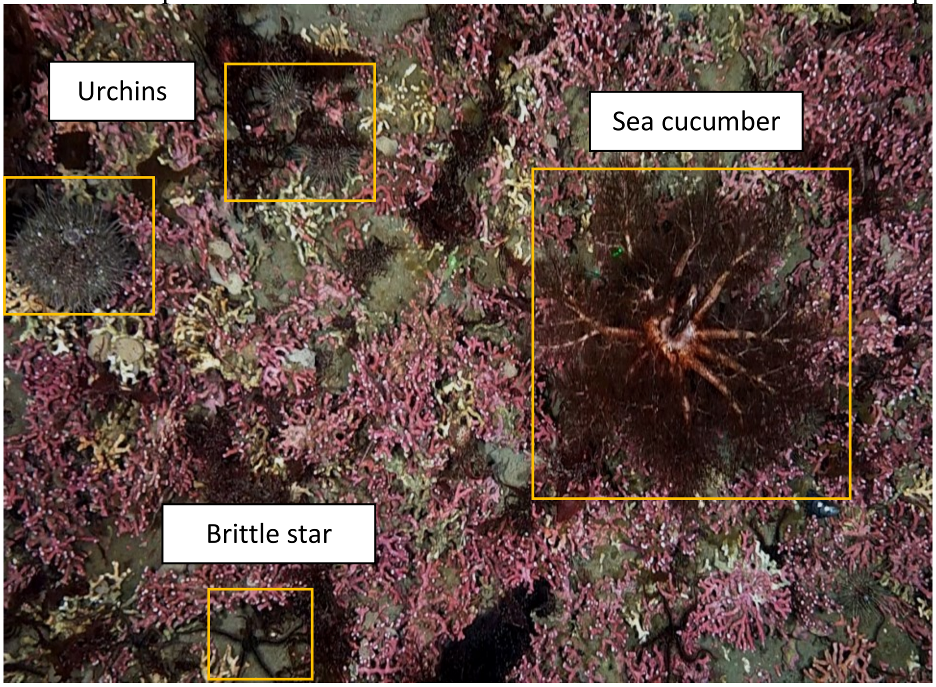


Figure 4.5 Example of an urchin dominated habitat in Nain. Branching rhodolith beds cover the seafloor. Green lasers are distanced 10 cm for scale.

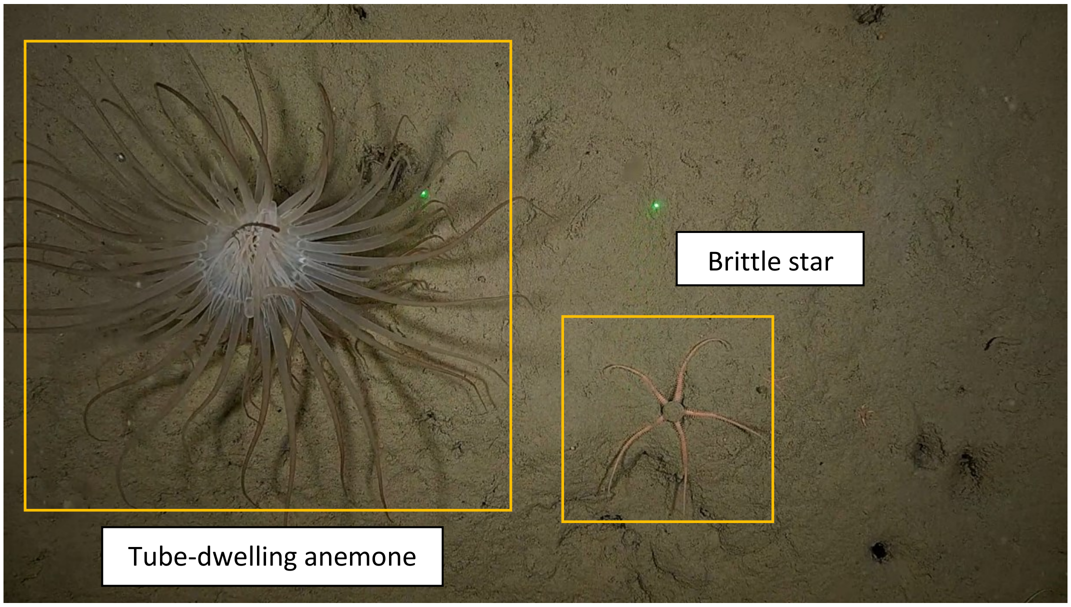


Figure 4.6 Habitat for a mix of tube-dwelling anemones, tube worms and brittle stars. Green lasers are distanced 10 cm for scale.

Based on our statistical models, ogak fishing locations shared by community members were grouped within assemblages 1 and 2. Assemblage 1 contained more fishing locations, while there were no fishing locations identified in Assemblage 3. Therefore, we believe that ogak in Nain may prefer habitats with more complexity and a high coverage of algae, which was shown in assemblages 1 and 2. Previous research have supported the findings here, where ogak were shown to prefer shallow productive waters, with a high coverage of algae, and rocky outcroppings and tended to remain near these habitats. The association with these complex habitats is likely because of the increased shelter, protection from predators, reproductive success, and foraging opportunities. Rhodolith and other coralline algal communities seem to be a widespread feature of Nain's nearshore marine environment, based on the findings of this study. The presence of rhodolith beds within Assemblage 2 likely provides abundant food resources particularly beneficial for supporting juvenile ogak and other codfish.

Vulnerable marine ecosystems

Vulnerable marine ecosystems (VMEs) are regions with an unusually rich biodiversity. They consist of collections of plants and/or animals that are highly sensitive to environmental disruptions, physically delicate, and slow to rebound from damage. Many animals within each assemblage described in this study are considered indicators of VMEs, and these included large sea squirts, erect bryozoans, sponges, and tube-dwelling anemones. Although the spatial coverage of some of these animals (sea squirts, bryozoans, sponges) did not seem to meet the specified criteria for a VME (Fig 4.7), their numbers should be monitored closely throughout the region. Tube-dwelling anemones formed dense fields on muddy bottoms throughout assemblage 3 in this study. Appropriate population densities at which protective measures should be applied to these animals have not been established yet. However, within Assemblage 3, 14,768 individuals formed dense fields in multiple sites, indicating a potential VME that requires further investigation (Fig 4.8). Special attention should be given to Assemblage 2 in terms of its management. This area comprises several sites with rhodolith beds and could serve as crucial habitats for rock cod populations by offering rich foraging opportunities (Fig 4.9). Rhodolith beds provide a rich environment for fish like rock cod to find food. The structure of these beds creates hiding spots for smaller marine creatures, attracting the attention of fish searching for a meal. These habitats possess the characteristics necessary to be classified as VMEs due to their functional significance, structural complexity, prolonged lifespan, and slow recovery after disturbances such as trawling and scalloping. It is crucial to gain a comprehensive understanding of the spatial distribution of these ecosystems in northern regions to ensure their proper conservation and management as environmental conditions continue to change.

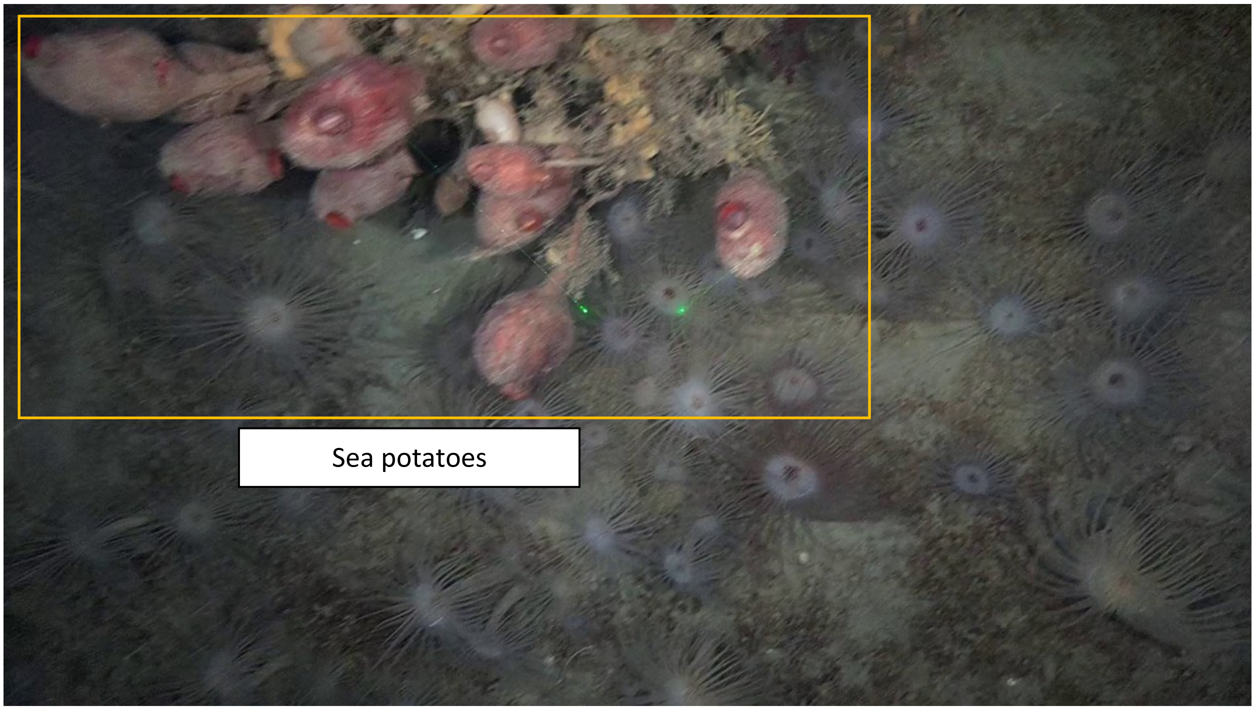


Figure 4.7 Sea potatoes, a type of sea squirt with long stalks, found on top of a boulder. These sea squirts are indicators of a vulnerable marine ecosystem. A field of tube-dwelling anemones is also seen in the photo.

Figure 4.8 Tube-dwelling anemone field on a seafloor covered in benthic diatom mats. These anemones burrow into the mud and are indicators of a vulnerable marine ecosystem.

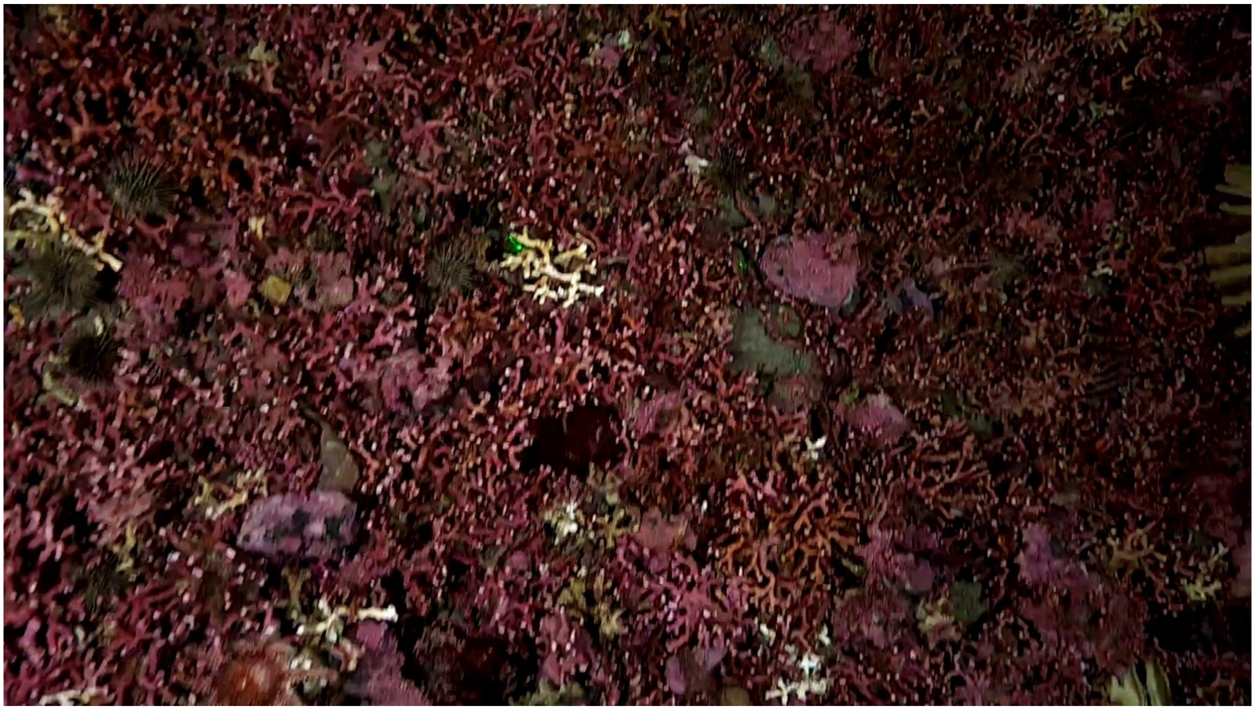


Figure 4.9 Rhodolith bed (live rock) habitat. These seaweeds are free-living and remain unattached to the seafloor.

Recommendations for management

Establishing a baseline & monitoring

Establishing a fundamental baseline on seabed species assemblages and habitats a is critical for management efforts. This baseline provides essential insights into marine ecosystem health, biodiversity conservation, sustainable resource management, and climate change impacts, forming the foundation for informed marine ecosystem management strategies. This should be done by integrating indigenous and local knowledge systems, targeting community-oriented research priorities, and incorporating traditional knowledge and perspectives into management strategies. Meaningful consultations and collaborations with communities are essential for culturally appropriate and effective management decisions. This integration allows for constructive dialogue and collaboration, leading to increased acceptance of conservation initiatives and the advancement of collaborative management approaches for coastal ecosystems.

Conservation of important habitats & taxa

To safeguard crucial habitats and species, it is vital to prioritize the protection of iKaluk and ogak-associated habitats. In the case of iKaluk, the emphasis is on prioritizing estuaries characterized by an extensive coverage benthic diatom mats. For ogak, the focus is on prioritizing nearshore habitats that exhibit elevated structural complexity and productivity, such as rhodolith beds. Additionally, focusing on the VMEs pinpointed in the study is essential to maintain the ecological balance of the local marine environment. This includes the preservation of rhodolith beds and fields of tube-dwelling anemones, which are extremely vulnerable to commercial fishing activities, like trawling. Assessing the resiliency of VME indicators and habitat-forming taxa found within these assemblages, such as sea squirts, erect bryozoans, tube-dwelling anemones, and other sensitive species, to disturbances and evaluating the effectiveness of current management measures are critical steps.

Management measures for these important habitats may include depth limits for fishing, gear restrictions, and closed areas where fishing is prohibited. Specifically, if restrictions are applied to limit bottom trawling in regions where VMEs are identified, such as rhodolith beds and tube-dwelling anemone fields, it would decrease human impacts on these sensitive areas. Establishing marine protected areas (MPAs) specifically to conserve important habitats identified in the study would serve in safeguarding these ecosystems from harmful activities. These areas are designed to regulate or restrict human activities to protect the habitats. Overall, implementing sustainable fishing practices for newly developing fisheries in Nunatsiavut (e.g., Icelandic scallop, whelk, shrimp) and considering the protection of habitats associated with iKaluk and ogak will contribute to the preservation of benthic biodiversity, ecosystem functioning, and important fisheries in the region.

5 Benthic video workshop in Nain, Nunatsiavut

Z. MacMillan-Kenny[1,3], K. Ortenzi[2], M. Graham[1,3], A. Templeton[3]

2023

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Benthic Video Workshop in Nain, Nunatsiavut 2023

Z. MacMillan-Kenny[1], K. Ortenzi[2], M. Graham[1], A. Templeton[3]

Introduction

In Canada, northern coastlines are undergoing significant environmental change in response to the rapidly warming climate. Warmer conditions coupled with changes in ocean circulation and ecological processes (e.g., migration periods, prey availability) continue to cause profound changes to the ranges and ecology of northern fish, benthic ecosystems, and ecosystem services. These changes impact the social, cultural, and physiological well-being of Labrador Inuit within Nunatsiavut (Newfoundland and Labrador, Canada) whose livelihoods are intrinsically linked to the coastal marine environment. Establishing a baseline on information such as the distribution and composition of fauna, areas of high biodiversity, and sensitive habitats in the area is the first step to managing and adapting to the rapidly changing North. This benthic video workshop was organized as a community engagement activity to help highlight the importance of the seafloor and its connection to people. Moreover, the workshop emphasized the importance of imagery/video surveying methods that can help manage the local benthic ecosystem under the pressures of climate change.

Day 1

The first day of the workshop was centered around getting to know the participants and leaders through a connection to the benthic environment. Led by Kate Ortenzi, a network of benthic flora and fauna was created with the help of participants from the community and Nain's research center. This network showed the interconnections of the benthic environment and its importance to people of the community (Fig 1). Each participant shared the meaning of each benthic image to them and proceeded to connect the images together through a common theme of values which included stories, ecological relationships, and subsistence to name a few.

Figure 1 Benthic connective network activity led by Kate Ortenzi

Determining project purposes was discussed extensively to assist Myrah Graham with her benthic video research project based across Inuit Nunangat (Inuit homeland in Canada). Common research questions (i.e., comparative, descriptive, relationships) were discussed among participants. Emphasis on community priorities was made relative to the research questions. This allowed participants to share their feedback on selecting research questions important to the community when planning large-scale projects. Using the presented findings from Zach MacMillan-Kenny's habitat mapping project for rock cod (*Gadus ogac*) habitats in Nain, participants discussed the implications of these results. Discussions revolved around marine spatial planning, areas of high biodiversity, and fisheries management to protect resources in Nain's nearshore marine waters.

A full tutorial and demonstration on the underwater camera equipment was performed by Adam Templeton. Participants practiced using the equipment on land before using it to collect data in the field. Field safety protocols were also discussed to ensure that there was proper use of the equipment and that no one got hurt.

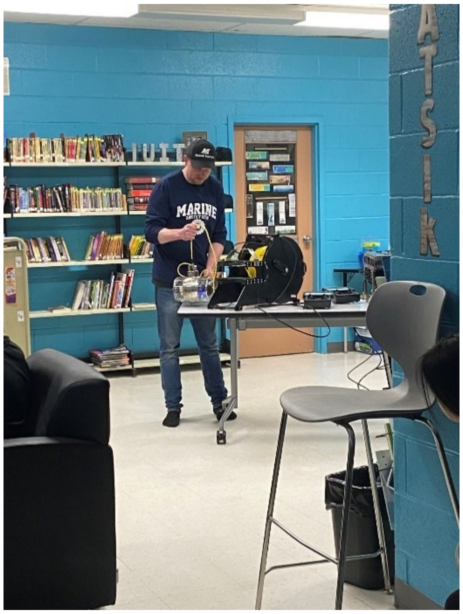


Figure 2 ROV and drop-camera demonstration by Adam Templeton

Day 2

Led by Zach MacMillan-Kenny and Myrah Graham, this part of the workshop was entirely focused on video data processing and analysis. To begin, identifications and annotations relative to seafloor imagery was explained. A species catalogue of the local area was developed to refer to during the annotation process. Participants first practiced annotating benthic imagery by hand using sticky notes and printed photographs of Nain's benthos (Fig 3). A full tutorial of the annotation software called BioImage Indexing, Graphical Labeling and Exploration (BIIGLE), was demonstrated to the participants. Using a volume of seafloor images, participants formed groups and practiced annotating images using the species identification catalogue (Fig 4). Once images were completed, methods to perform video annotations were explained and participants worked in their groups to annotate drop-camera videos from Nain's seafloor. A competition between groups was organized to identify which group was the fastest at annotating and which group was the most accurate. After practicing with annotations, participants and leaders discussed site selection and field preparation. Participants selected a local site to survey under the sea-ice using the DeepTrekker Pivot ROV. Completing the first 2 days allowed the participants to become familiar with the purpose and methodology behind benthic video surveys, so it was now time to take their knowledge into the field.

Figure 3 Annotation practice using sticky notes and species catalogue

Figure 4 Annotation practice using BIIGLE

Day 3

The final day of the workshop, led by Adam Templeton and Zach MacMillan-Kenny, focused on video data collection. The field component was crucial for displaying the trials and tribulations of this type of field work and helped participants learn the science behind video data collection. On skidoos, over a dozen participants drove across the sea-ice to reach our site in Anaktalak Bay situated southwest of Nain. After cutting through the 4.5 ft thick ice with a 5-foot chainsaw, the DeepTrekker DTPod drop-camera was deployed for an initial survey. Once the site was surveyed for hazards and participants had the chance to control the drop-camera to see the benthos in real-time, the DeepTrekker Pivot ROV was deployed. Participants took turns flying the ROV and identifying benthic creatures. A transect was performed (north, south, east, and west) from the center of the ice hole to collect video data on the benthos in Anaktalak Bay.

Figure 5 ROV deployment

Figure 6 Flying the ROV under sea-ice

Additional Days

The workshop was comprised of 3 days of learning that were built upon each other. In addition to this, an event was held at the local Illusuak Cultural Centre to share this research with other members of the community. Over 20 adults and their children attended this event that displayed results from previous video surveys as well as many components of the workshop (e.g., ROV demonstration, seafloor videos, networks, annotation practice). Three classes consisting of grades 4, 5, 6, 7, 8 and 9 were also taught at the local school in Nain (Jens Haven Memorial School). These hour-long classes allowed children to participate in identifying and labelling benthic fauna in local waters, learn about camera equipment and understand the importance of the seafloor ecosystem.

Summary

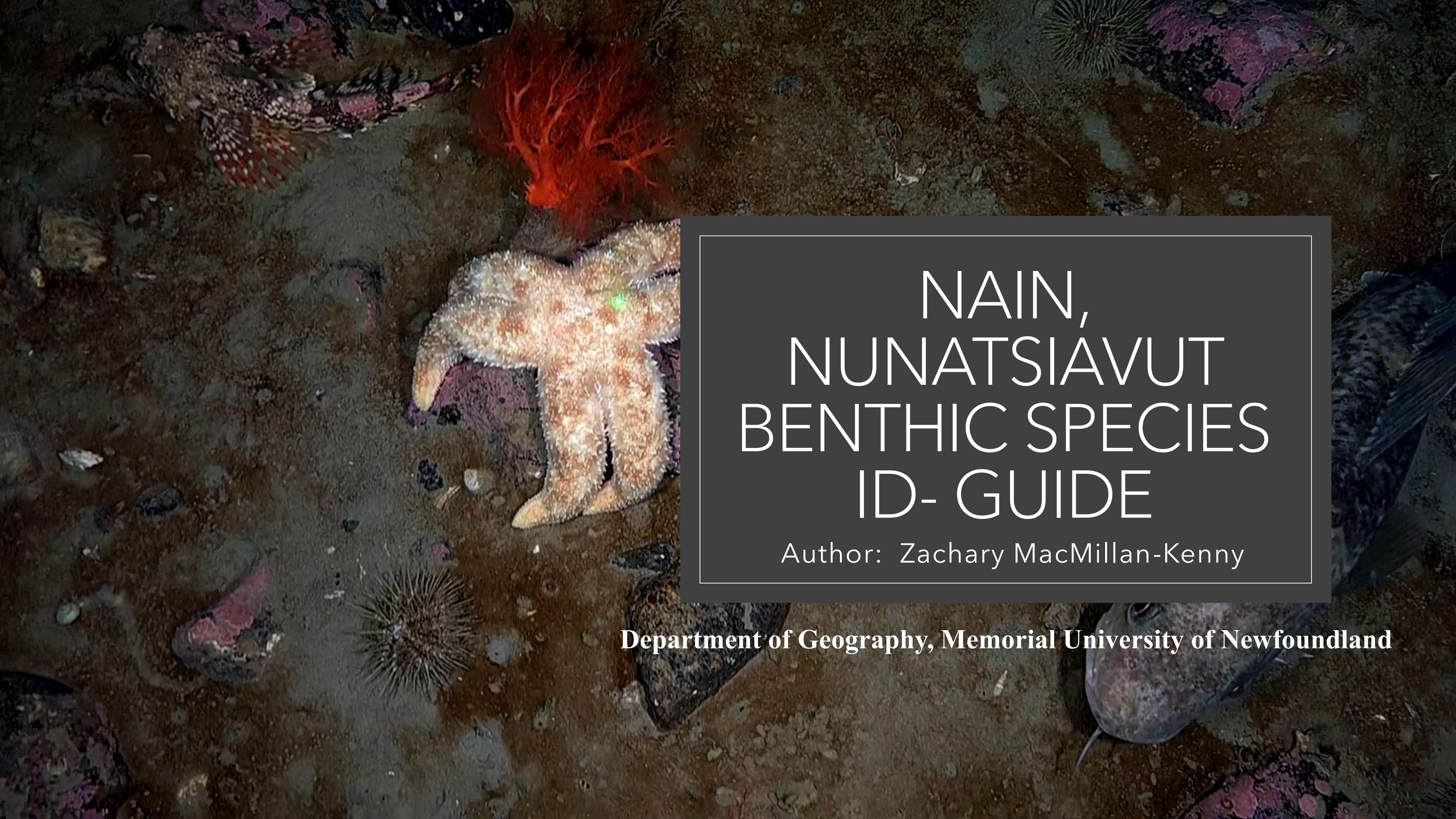
Overall, the benthic video workshop displayed the important connections between people and the seafloor. As climate change continues to threaten the marine ecosystem across Inuit Nunangat, understanding the importance of the benthic ecosystem is more pressing than ever. This workshop highlighted the importance of the benthic ecosystem for communities and demonstrated video and imagery survey methods to establish baselines, monitor changes, and target areas of importance to adapt to the rapidly changing North.

Additional Field Photos


DEEP TREKKER
DEEP TREKKER


STIHL

6 Benthic taxa catalogue for Nain, Nunatsiavut



NAIN, NUNATSIAVUT BENTHIC SPECIES ID- GUIDE

Author: Zachary MacMillan-Kenny

Department of Geography, Memorial University of Newfoundland

Outline

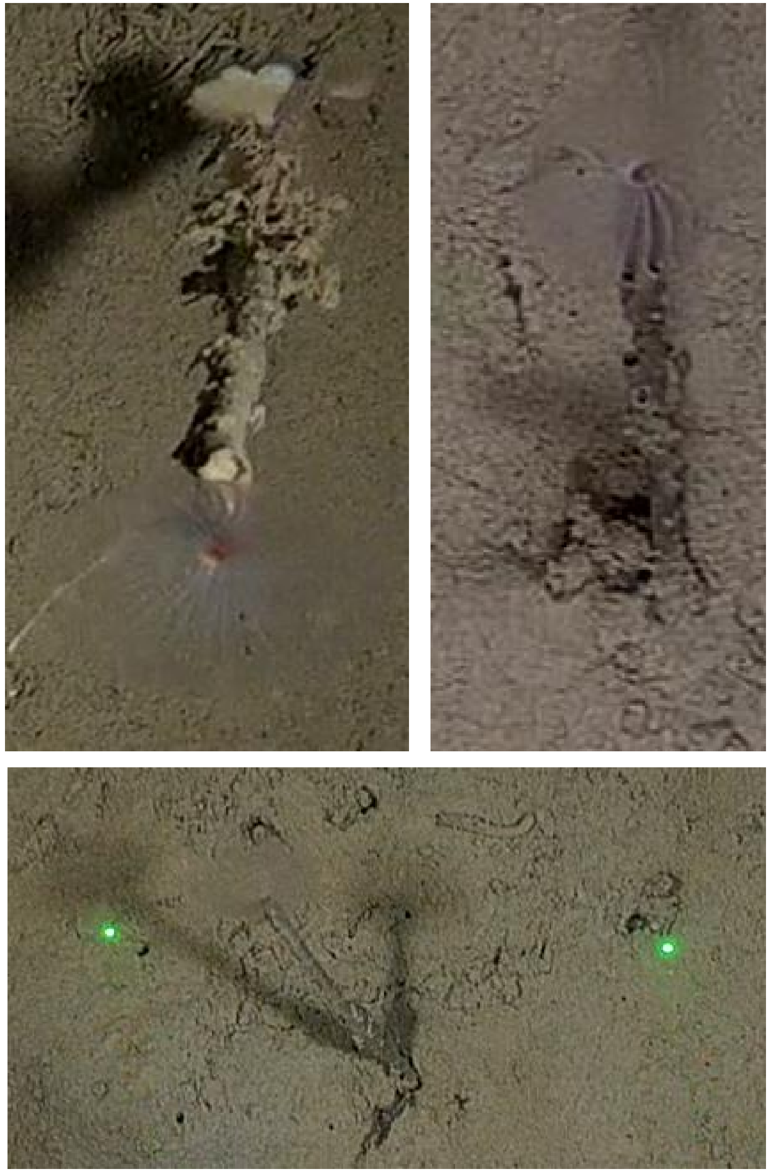
I. Annelida
II. Arthropoda
III. Bryozoa
IV. Chaetognatha
V. Chordata
VI. Ctenophora
VII. Cnidaria
VIII. Echinodermata
IX. Mollusca
X. Porifera

Myxicola infundibulum

- **Phylum:** Annelida
- **Class:** Polychaeta
- **Order:** Sabellida
- **Family:** Sabellidae
- **Genus:** Myxicola
- **Species:** *Myxicola infundibulum*

Sabellida spp.

- **Phylum:** Annelida
- **Class:** Polychaeta
- **Order:** Sabellida
- **Family:** Sabellidae
- **Genus:**
- **Species:**



Polychaeta spp.

- **Phylum:** Annelida
- **Class:** Polychaeta
- **Order:** Errantia
- **Family:** Phyllodocidae
- **Genus:** Phyllodoce
- **Species:**

Amphipoda spp.

- **Phylum:** Arthropoda
- **Class:** Malacostraca
- **Order:** Amphipoda
- **Family:** Hyalellidae
- **Genus:** Hyalella
- **Species:**

Chionoecetes opilio

- **Phylum:** Arthropoda
- **Class:** Malacostraca
- **Order:** Decapoda
- **Family:** Oregoniidae
- **Genus:** Chionoecetes
- **Species:** *Chionoecetes opilio*

Hyas araneus

- **Phylum:** Arthropoda
- **Class:** Malacostraca
- **Order:** Decapoda
- **Family:** Oregoniidae
- **Genus:** Hyas
- **Species:** *Hyas araneus*

Hyas coarctatus

- **Phylum:** Arthropoda
- **Class:** Malacostraca
- **Order:** Decapoda
- **Family:** Oregoniidae
- **Genus:** Hyas
- **Species:** *Hyas coarctatus*

Pagurus spp.

- **Phylum:** Arthropoda
- **Class:** Malacostraca
- **Order:** Decapoda
- **Family:** Paguridae
- **Genus:** Pagurus
- **Species:**

Pandalus spp.

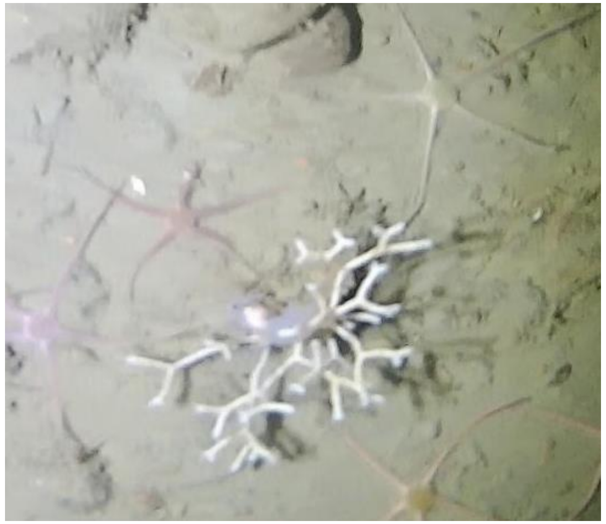
- **Phylum:** Arthropoda
- **Class:** Malacostraca
- **Order:** Decapoda
- **Family:** Pandalidae
- **Genus:** Pandalus
- **Species:** *Pandalus borealis / Pandalus montagui*

Neohela monstrosa

- **Phylum:** Arthropoda
- **Class:** Malacostraca
- **Order:** Amphipoda
- **Family:** Unciolidae
- **Genus:** Neohela
- **Species:** *Neohela monstrosa*

Bryozoan sp.1

- **Phylum:** Bryozoa
- **Class:**
- **Order:**
- **Family:**
- **Genus:**
- **Species:**



Bryozoan sp.2

- **Phylum:** Bryozoa
- **Class:**
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Bryozoan sp.4

- **Phylum:** Bryozoa
- **Class:**
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Bryozoan sp.6

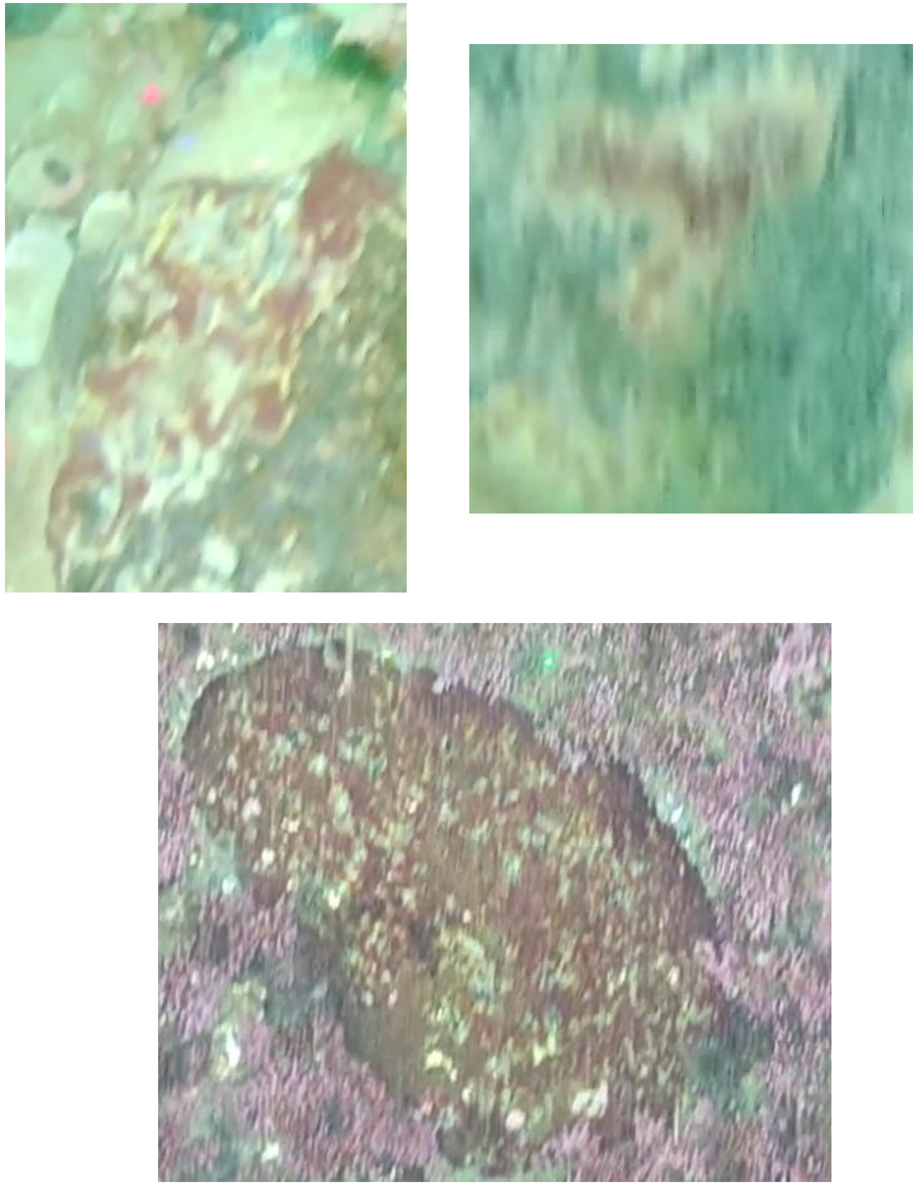
- **Phylum:** Bryozoa
- **Class:**
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Bryozoan sp.003

- **Phylum:** Bryozoa
- **Class:**
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Bryozoan sp.004

- **Phylum:** Bryozoa
- **Class:**
- **Order:**
- **Family:**
- **Genus:**
- **Species:**



Sagittidae spp.

- **Phylum:** Chaetognatha
- **Class:** Sagittoidea
- **Order:** Aphragmophora
- **Family:** Sagittidae
- **Genus:**
- **Species:**

Gadus morhua

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Gadiformes
- **Family:** Gadidae
- **Genus:** Gadus
- **Species:** *Gadus morhua*

Gadus ogac

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Gadiformes
- **Family:** Gadidae
- **Genus:** Gadus
- **Species:** *Gadus ogac*

Cottidae spp.

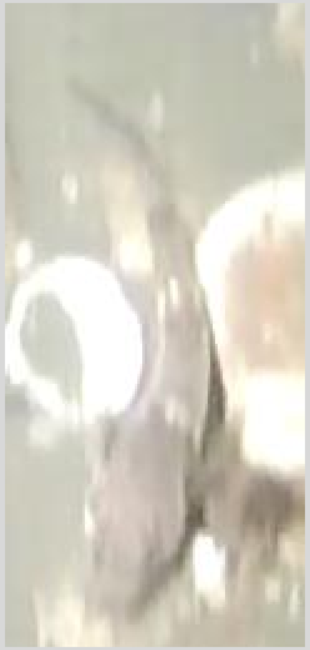
- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Cottiidae
- **Genus:** Myoxocephalus
- **Species:**

Zoarcidae sp.1

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Zoarcidae
- **Genus:**
- **Species:**

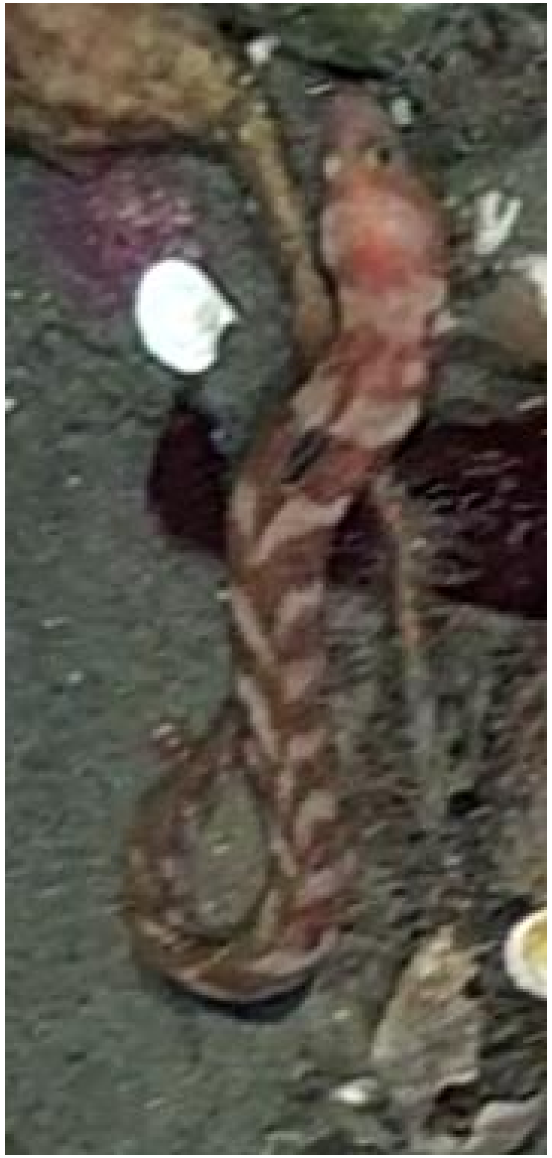
Zoarcidae sp.2

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Zoarcidae
- **Genus:**
- **Species:**



Zoarcidae sp.3

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Zoarcidae
- **Genus:**
- **Species:**



Lycodes vahlii

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Zoarcidae
- **Genus:** Lycodes
- **Species:** *L. vahlii*

Myoxocephalus spp.

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Cottiidae
- **Genus:** Myoxocephalus
- **Species:**

Myoxocephalus Scorpius

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Cottidae
- **Genus:**
- **Species:**

Liparis spp.

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Liparidae
- **Genus:** Liparis
- **Species:**

Stichaeus punctatus

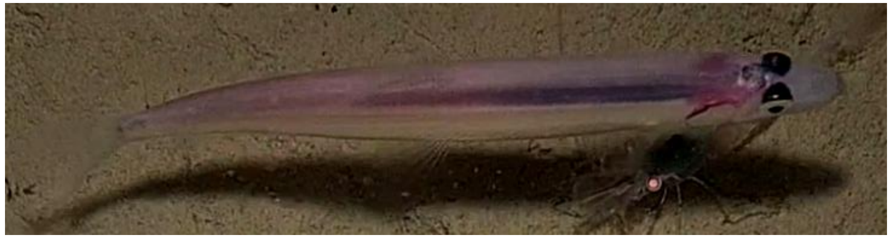
- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Stichaeidae
- **Genus:** Stichaeus
- **Species:** *S. punctatus*

Boreogadus saida

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Gadiformes
- **Family:** Gadidae
- **Genus:** Boreogadus
- **Species:** *Boreogadus saida*

Lumpenus lampretaeformis

- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Stichaeidae
- **Genus:** Lumpenus
- **Species:** *Lumpenus lampretaeformis*



Leptoclinus maculatus

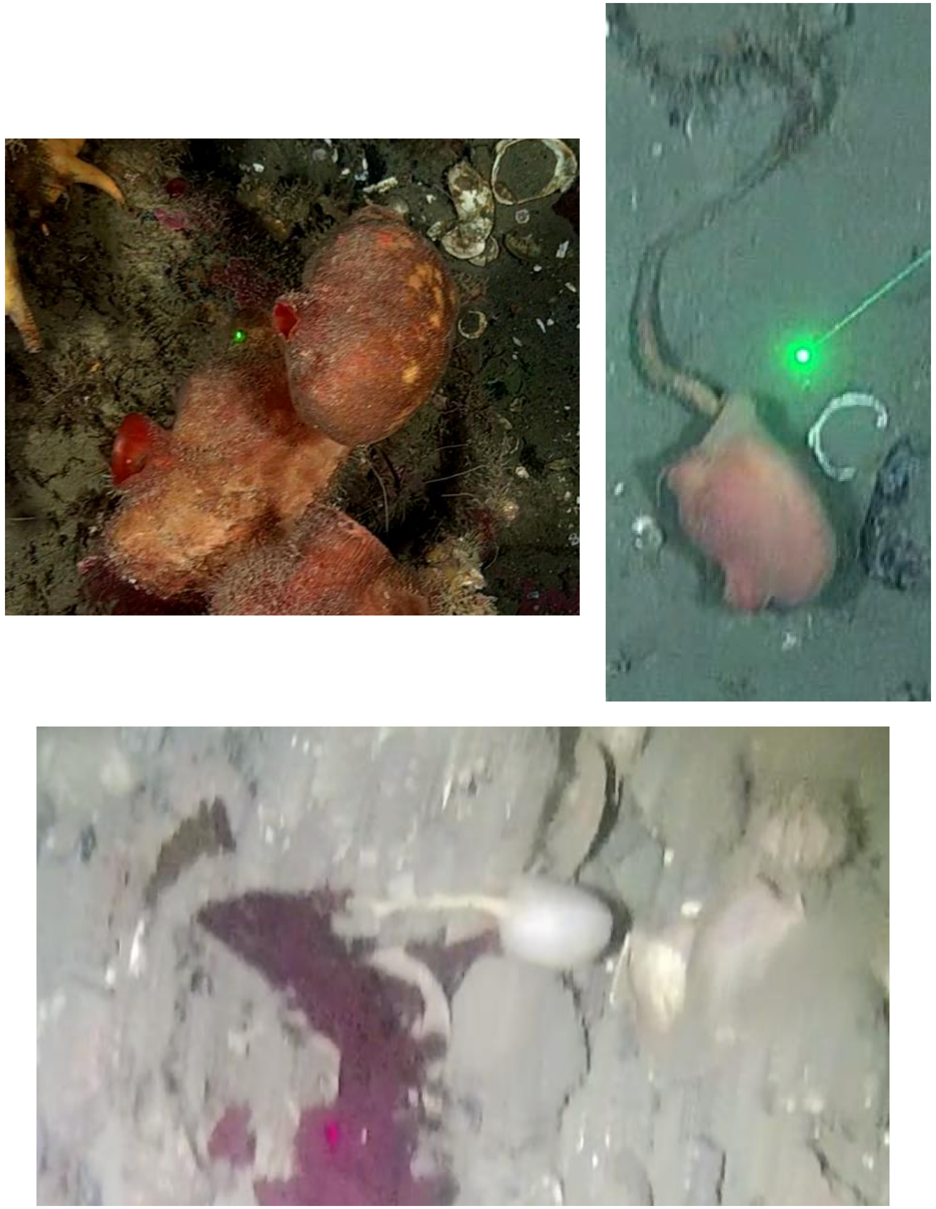
- **Phylum:** Chordata
- **Class:** Actinopterygii
- **Order:** Scorpaeniformes
- **Family:** Stichaeidae
- **Genus:** Leptoclinus
- **Species:** *Leptoclinus maculatus*

Amblyraja radiata

- **Phylum:** Chordata
- **Class:** Chondrichthyes
- **Order:** Rajiformes
- **Family:** Rajidae
- **Genus:** Amblyraja
- **Species:** *Amblyraja radiata*

Boltenia ovifera

- **Phylum:** Chordata
- **Class:** Ascidiacea
- **Order:** Stolidobranchia
- **Family:** Pyuridae
- **Genus:** Boltenia
- **Species:** *B. ovifera*



Halocynthia pyriformis

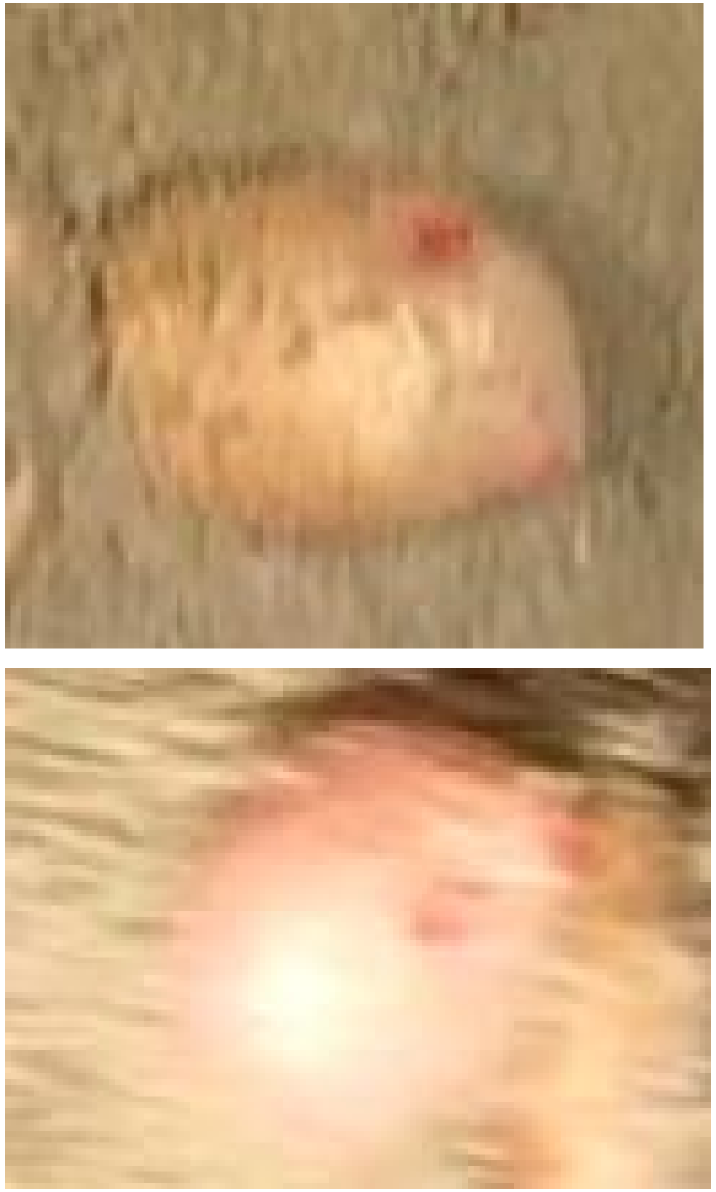
- **Phylum:** Chordata
- **Class:** Ascidiacea
- **Order:** Pleurogona
- **Family:** Halocynthia
- **Genus:** Boreogadus
- **Species:** *Halocynthia pyriformis*

Ascidiacea sp.2

- **Phylum:** Chordata
- **Class:** Ascidiacea
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Ascidiacea sp.3

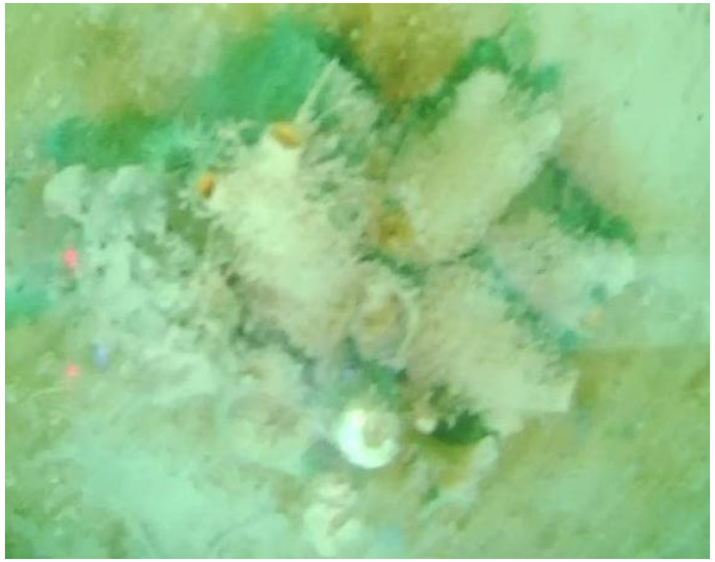
- **Phylum:** Chordata
- **Class:** Ascidiacea
- **Order:**
- **Family:**
- **Genus:**
- **Species:**



Chordata

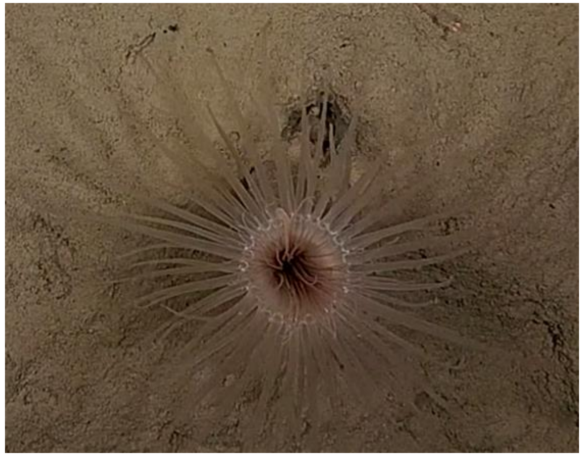
Ascidiacea sp.1

- **Phylum:** Chordata
- **Class:** Ascidiacea
- **Order:**
- **Family:**
- **Genus:**
- **Species:**



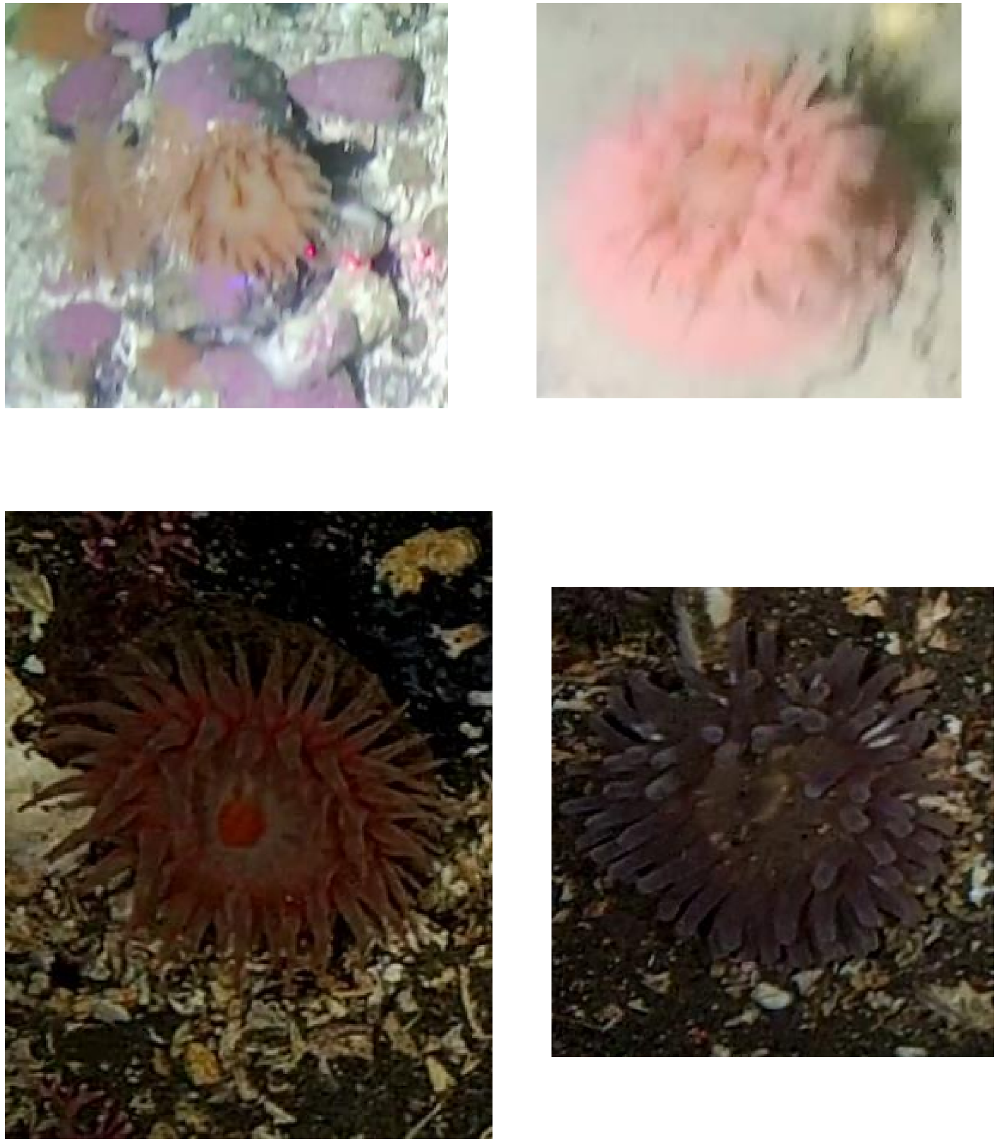
Ceriantharia spp.

- **Phylum:** Cnidaria
- **Class:** Ceriantharia
- **Order:** Spirularia
- **Family:** Cerianthidae
- **Genus:**
- **Species:**



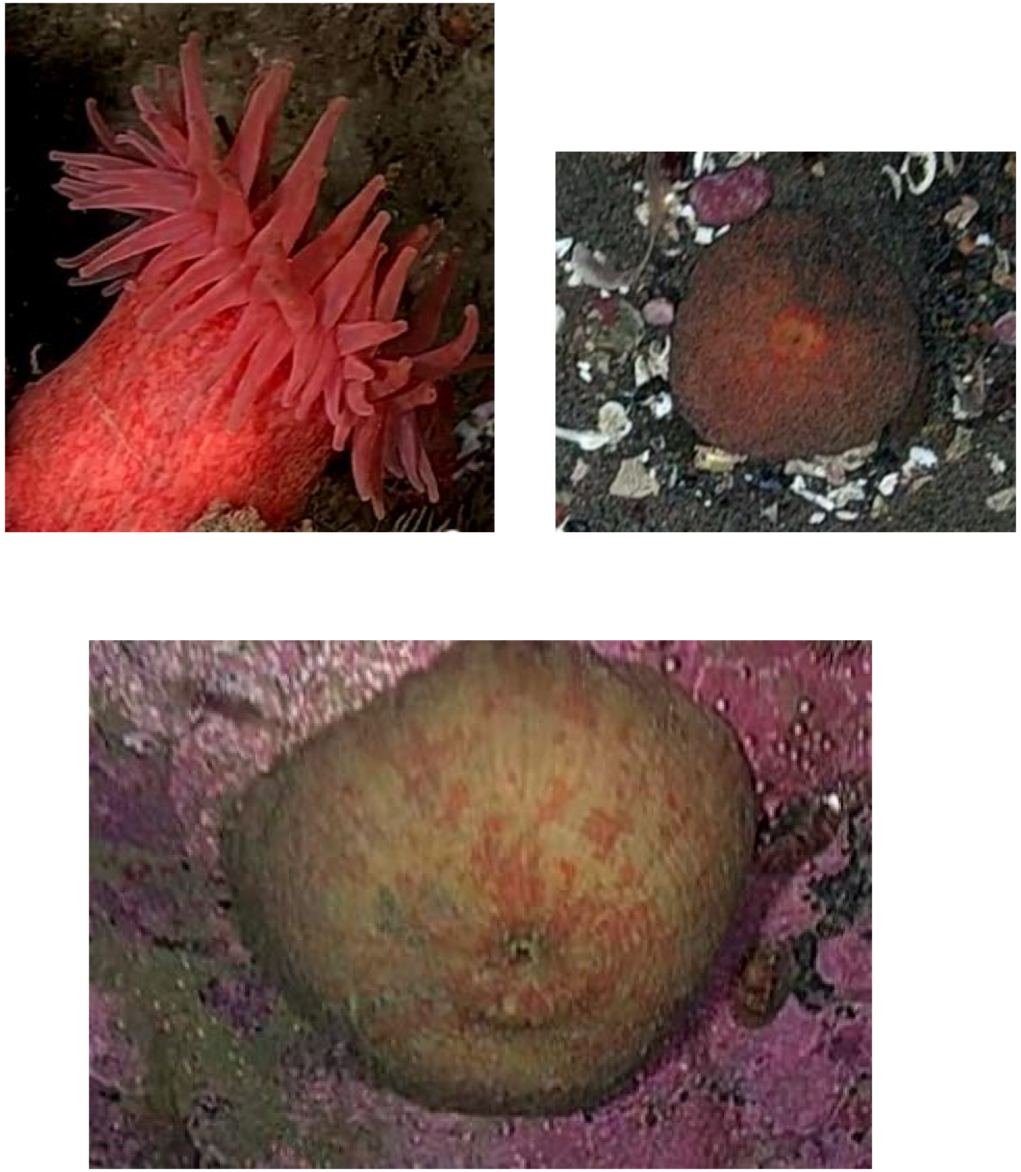
Urticina felina

- **Phylum:** Cnidaria
- **Class:** Anthozoa
- **Order:** Actiniaria
- **Family:** Actiniidae
- **Genus:** Urticina
- **Species:** *Urticina felina*



Stomphia coccinea

- **Phylum:** Cnidaria
- **Class:** Anthozoa
- **Order:** Actiniaria
- **Family:** Actinostolidae
- **Genus:** Stomphia
- **Species:** *S. coccinea*



Actiniaria spp.

- **Phylum:** Cnidaria
- **Class:** Anthozoa
- **Order:** Actiniaria
- **Family:** Actinostolidae
- **Genus:** Stomphia
- **Species:**

Actinostola callosa

- **Phylum:** Cnidaria
- **Class:** Anthozoa
- **Order:** Actiniaria
- **Family:** Actinostolidae
- **Genus:** Actinostola
- **Species:** *A. callosa*

Halcampa arctica

- **Phylum:** Cnidaria
- **Class:** Anthozoa
- **Order:** Actiniaria
- **Family:** Halcampidae
- **Genus:** Halcampa
- **Species:** *Halcampa arctica*

Cnidaria sp.1

- **Phylum:** Cnidaria
- **Class:**
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Ptychogena lactea

- **Phylum:** Cnidaria
- **Class:** Hydrozoa
- **Order:** Leptothecata
- **Family:** Laodiceidae
- **Genus:** Ptychogena
- **Species:** *Ptychogena lactea*

Gersemia fruticosa

- **Phylum:** Cnidaria
- **Class:** Octacoralia
- **Order:** Alcyonacea
- **Family:** Nephtheidae
- **Genus:** Gersemia
- **Species:** *Gersemia fruticosa*

Gersemia rubiformis

- **Phylum:** Cnidaria
- **Class:** Octacoralia
- **Order:** Alcyonacea
- **Family:** Nephtheidae
- **Genus:** Gersemia
- **Species:** *Gersemia rubiformis*

Nephtheidae sp. 3

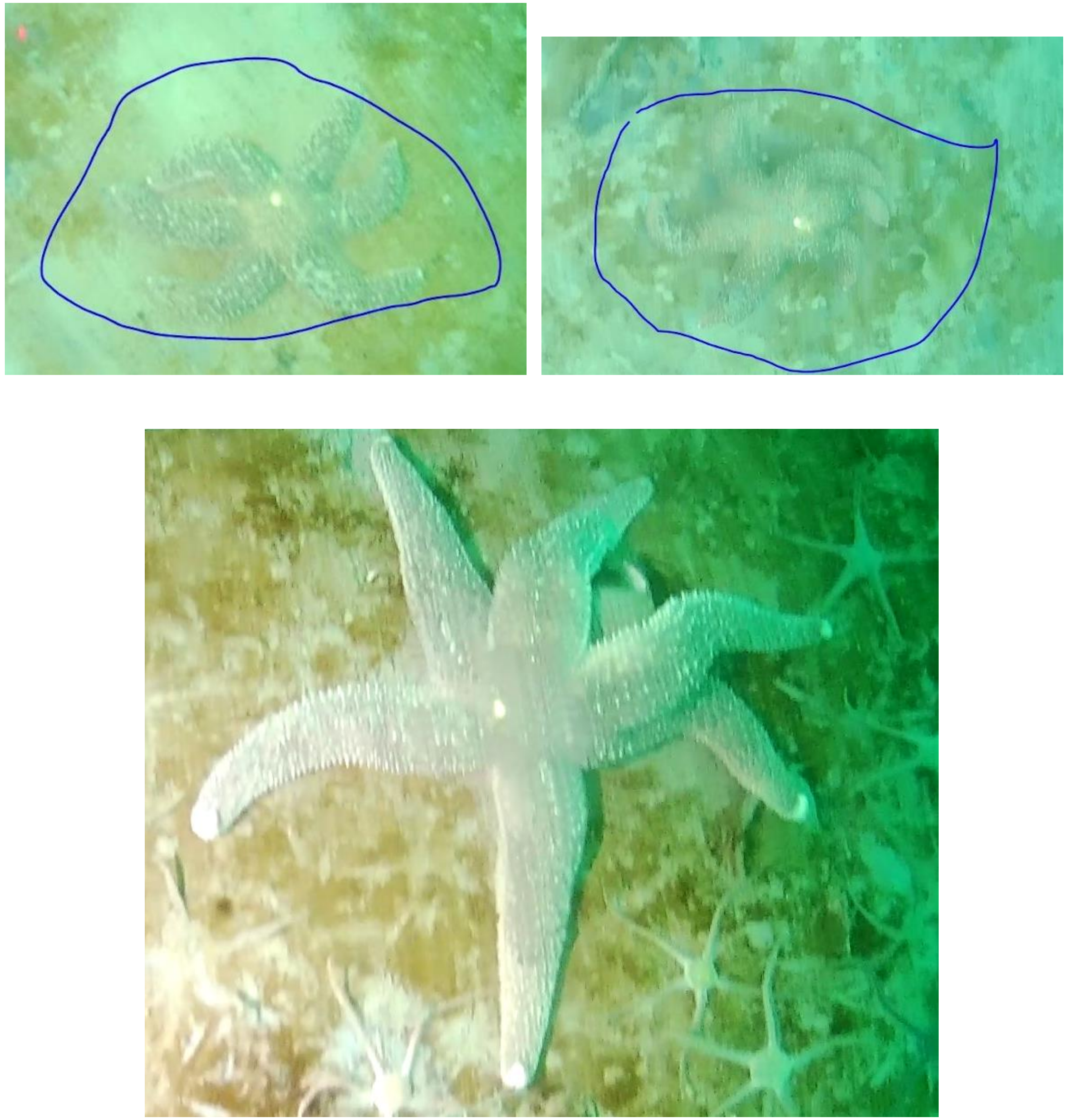
- **Phylum:** Cnidaria
- **Class:** Octacoralia
- **Order:** Alcyonacea
- **Family:** Nephtheidae
- **Genus:**
- **Species:**

Henricia sanguinolenta

- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:** Spinulosida
- **Family:** Echinasteridae
- **Genus:** Henricia
- **Species:** *Henricia sanguinolenta*

Asterias forbesi

- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:** Forcipulatida
- **Family:** Asteriidae
- **Genus:** Asterias
- **Species:** *Asterias forbesi*



Leptasterias polaris

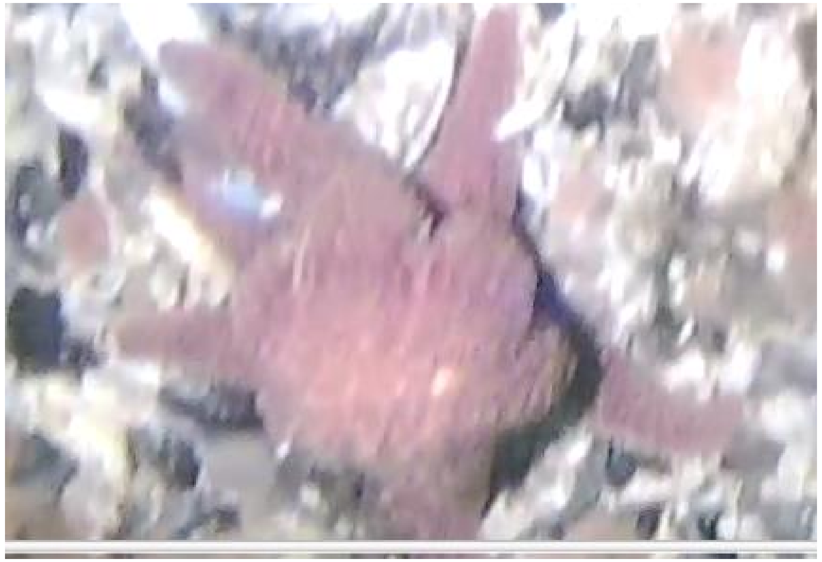
- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:** Forcipulatida
- **Family:** Asteriidae
- **Genus:** Leptasterias
- **Species:** *Leptasterias polaris*

Asterias sp.4

- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:** Forcipulatida
- **Family:** Asteriidae
- **Genus:** Leptasterias
- **Species:**

Asteroidea sp.11

- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:**
- **Family:**
- **Genus:**
- **Species: *could be spawning**



Ctenodiscus crispatus

- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:** Paxillosida
- **Family:** Ctenodiscidae
- **Genus:** Ctenodiscus
- **Species:** *Ctenodiscus crispatus*

Asterias sp.99

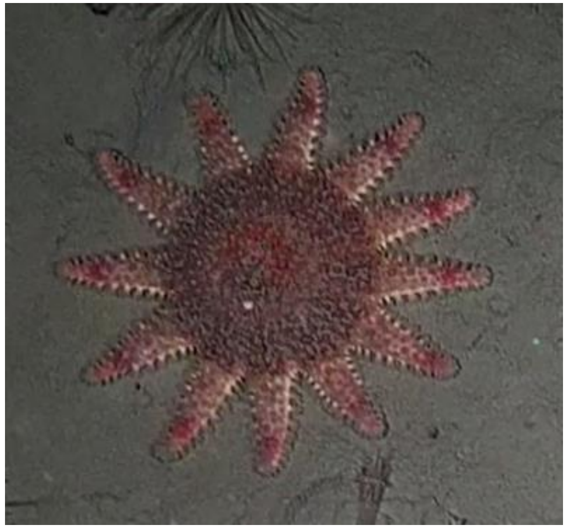
- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:** Forcipulatida
- **Family:** Asteriidae
- **Genus:** Asterias
- **Species:**

Asteroidea spp.003

- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

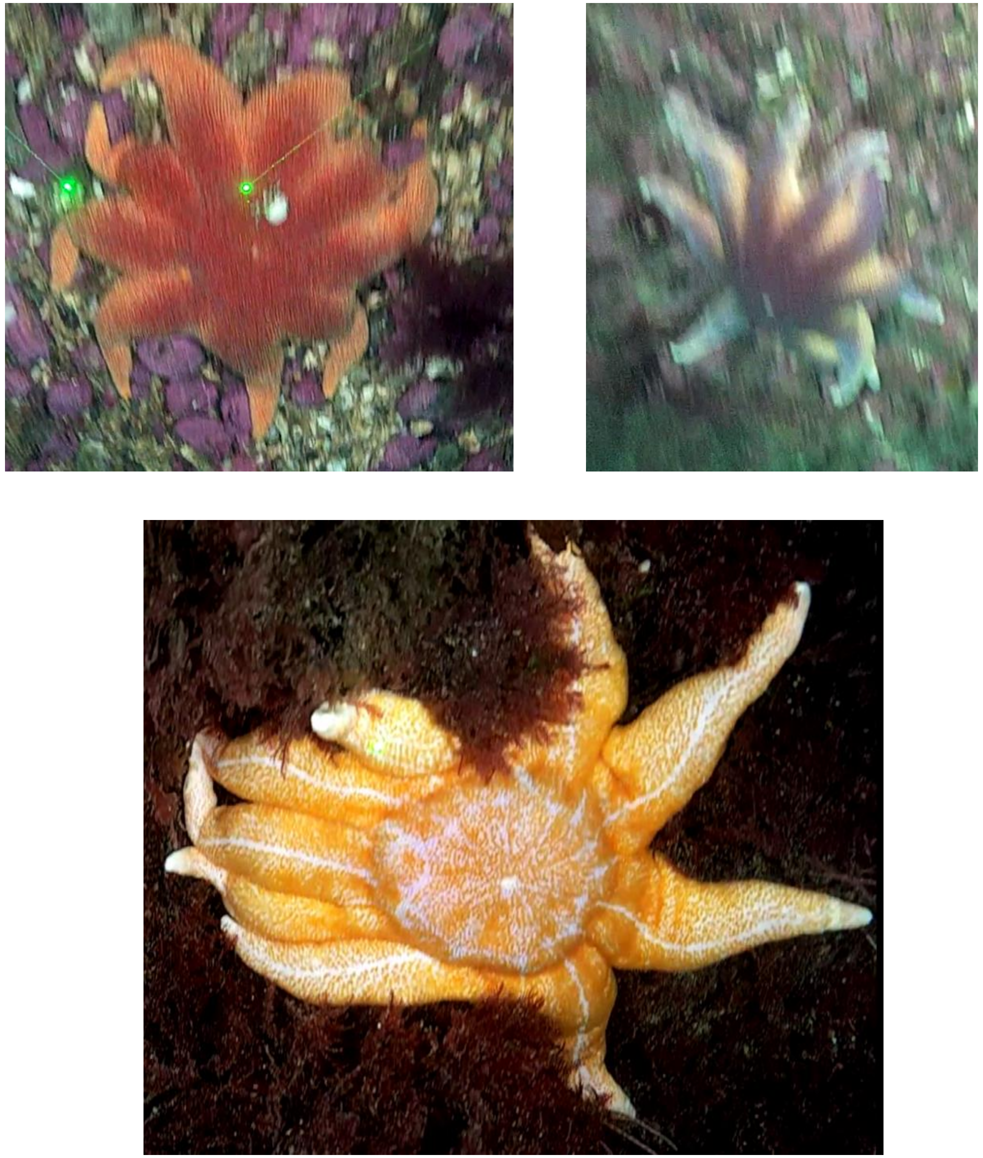
Crossaster papposus

- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:** Velatida
- **Family:** Solasteridae
- **Genus:** Crossaster
- **Species:** *Crossaster papposus*



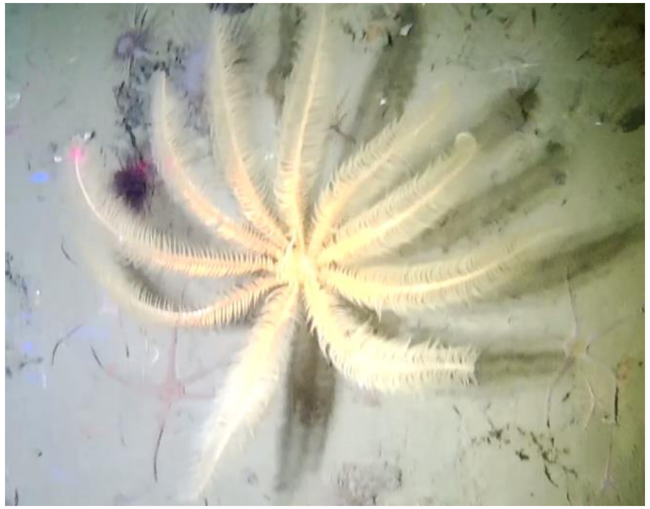
Solaster endeca

- **Phylum:** Echinodermata
- **Class:** Asteroidea
- **Order:** Velatida
- **Family:** Solasteridae
- **Genus:** Solaster
- **Species:** *Solaster endeca*



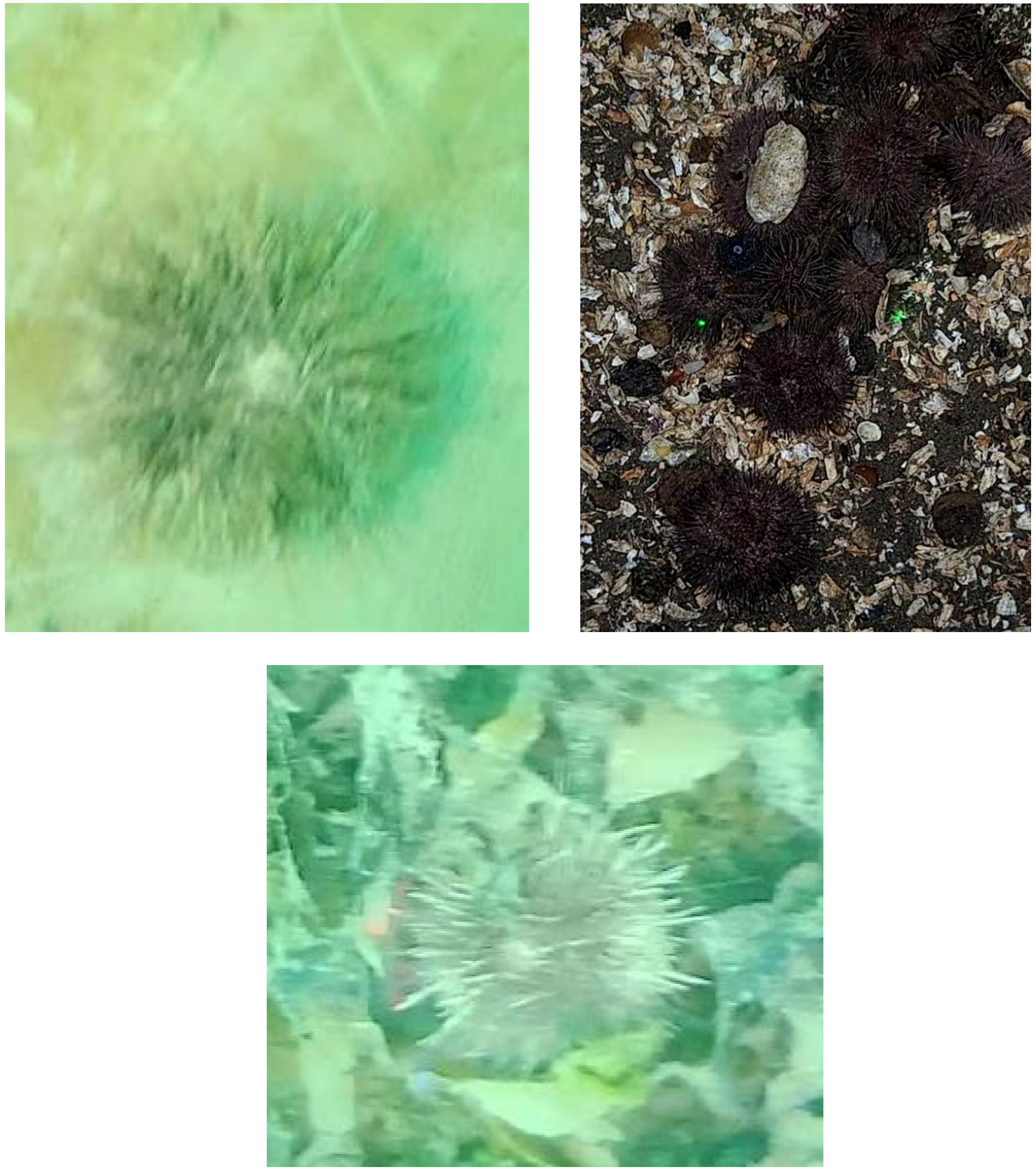
Heliometra glacialis

- **Phylum:** Echinodermata
- **Class:** Crinoidea
- **Order:** Comatulida
- **Family:** Antedonidae
- **Genus:** Heliometra
- **Species:** *Heliometra glacialis*



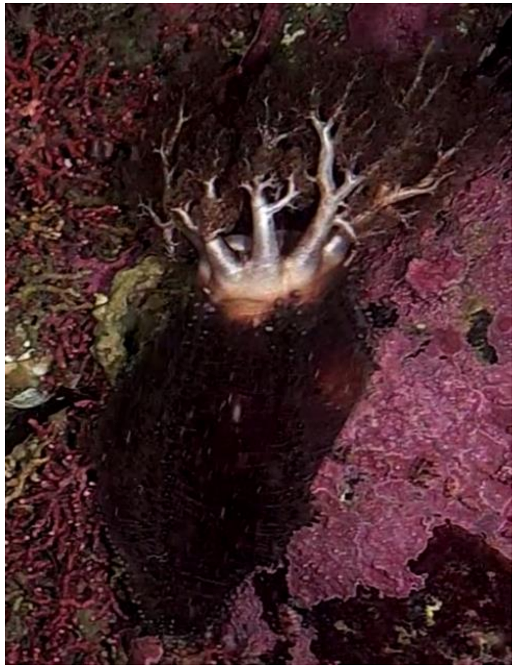
Stronglyocentrotus droebachiensis

- **Phylum:** Echinodermata
- **Class:** Echinoidea
- **Order:** Echinoida
- **Family:** Stronglyocentrotidae
- **Genus:** Stronglyocentrotus
- **Species:** *Stronglyocentrotus droebachiensis*



Cucumaria frondosa

- **Phylum:** Echinodermata
- **Class:** Holothuroidea
- **Order:** Dendrochirotida
- **Family:** Cucumariidae
- **Genus:** Cucumaria
- **Species:** *Cucumaria frondosa*

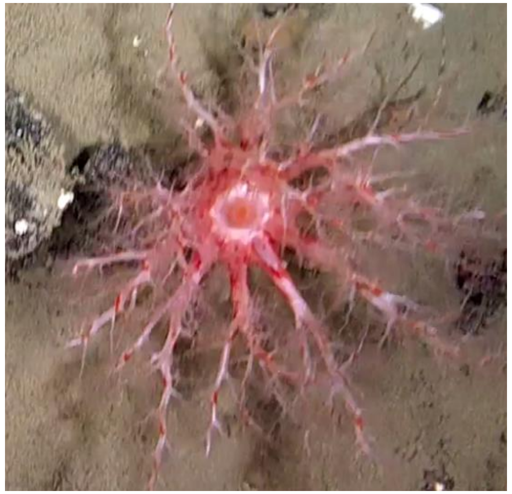


Psolus sp.1

- **Phylum:** Echinodermata
- **Class:** Holothuroidea
- **Order:** Dendrochirotida
- **Family:** Psolidae
- **Genus:** Psolus
- **Species:**

Psolus phantapus

- **Phylum:** Echinodermata
- **Class:** Holothuroidea
- **Order:** Dendrochirotida
- **Family:** Psolidae
- **Genus:** Psolus
- **Species:** *Psolus phantapus*

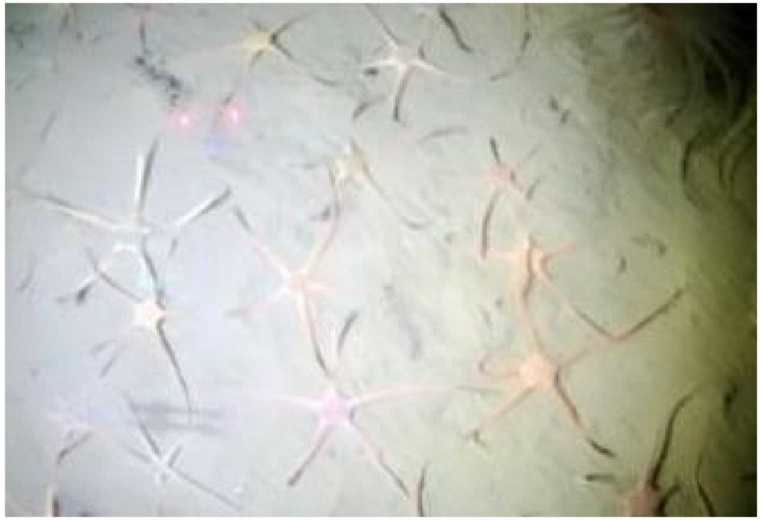


Psolus fabricii

- **Phylum:** Echinodermata
- **Class:** Holothuroidea
- **Order:** Dendrochirotida
- **Family:** Psolidae
- **Genus:** Psolus
- **Species:** *Psolus fabricii*

Ophiuroidea sp.1

- **Phylum:** Echinodermata
- **Class:** Ophiuroidea
- **Order:** Ophiurida
- **Family:** Ophiuridae
- **Genus:** Ophiura
- **Species:** Likely *Ophiura sarsii*

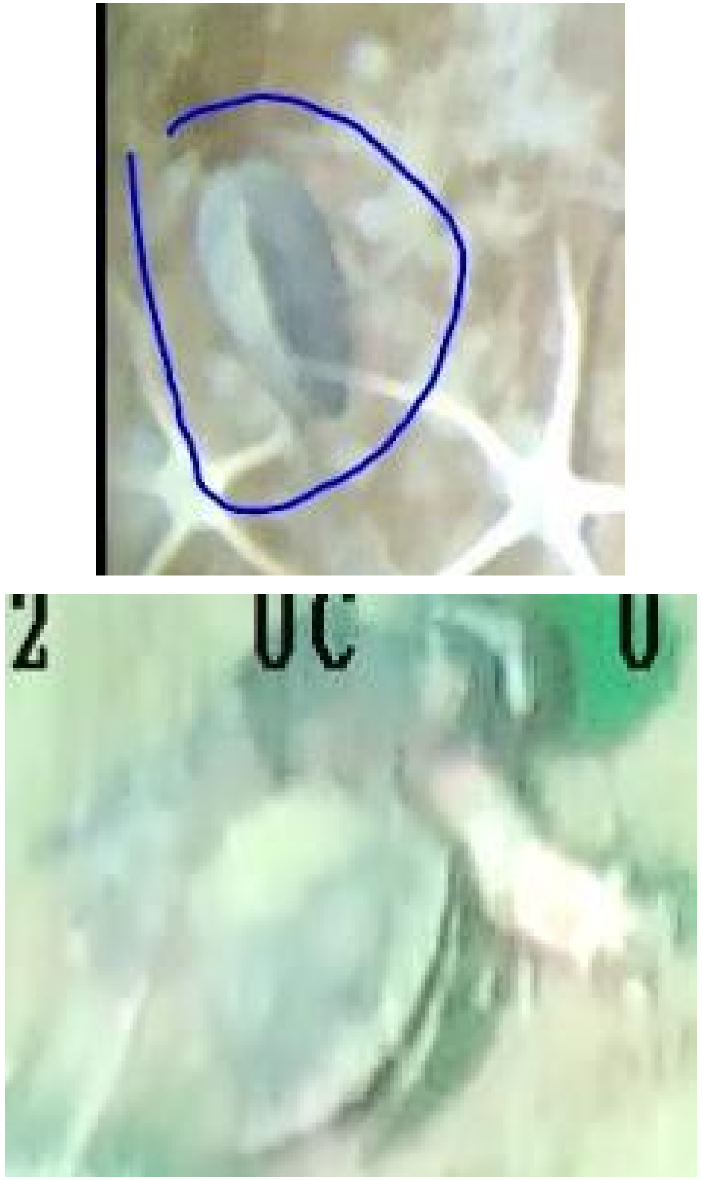


Ophiuroidea sp.2

- **Phylum:** Echinodermata
- **Class:** Ophiuroidea
- **Order:** Ophiacanthida
- **Family:** Ophiacanthidae
- **Genus:** Ophiacantha
- **Species:** *Ophiacantha bidentata*

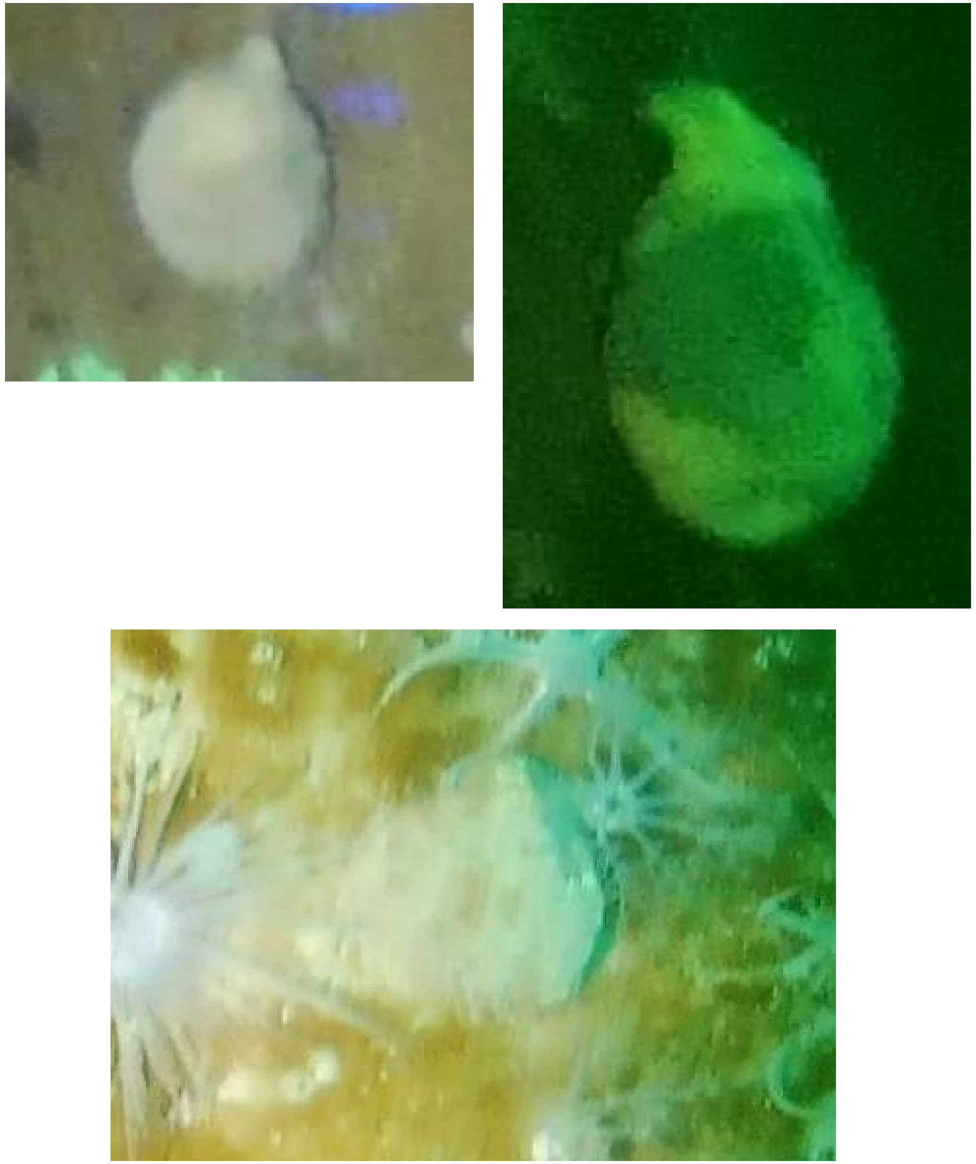
Mya truncata

- **Phylum:** Mollusca
- **Class:** Bivalvia
- **Order:** Myida
- **Family:** Myidae
- **Genus:** Mya
- **Species:** *Mya truncata*



Portlandia arctica

- **Phylum:** Mollusca
- **Class:** Bivalvia
- **Order:** Nuculanida
- **Family:** Yoldiidae
- **Genus:** Portlandia
- **Species:** Portlandia arctica



Chlamys islandica

- **Phylum:** Mollusca
- **Class:** Bivalvia
- **Order:** Pectinida
- **Family:** Pectinidae
- **Genus:** Chlamys
- **Species:** *Chlamys islandica*

Arctica islandica

- **Phylum:** Mollusca
- **Class:** Bivalvia
- **Order:** Venerida
- **Family:** Aecricidae
- **Genus:** Arctica
- **Species:** *Arctica islandica*

Ischnochiton sp.1

- **Phylum:** Mollusca
- **Class:** Polyplacophora
- **Order:** Chitonida
- **Family:** Ischnochitonidae
- **Genus:** Ischnochiton
- **Species:**

Polinices heros

- **Phylum:** Mollusca
- **Class:** Gastropoda
- **Order:** Littorinimorpha
- **Family:** Naticidae
- **Genus:** Polinices
- **Species:** *Polinices heros*

Buccinum spp.

- **Phylum:** Mollusca
- **Class:** Gastropoda
- **Order:** Neogastropoda
- **Family:** Buccinidae
- **Genus:** Buccinum
- **Species:**

Cuthona gymnota

- **Phylum:** Mollusca
- **Class:** Gastropoda
- **Order:** Nudibranchia
- **Family:** Cuthonidae
- **Genus:** Cuthona
- **Species:** *Cuthona gymnota*

Haliclona oculata

- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:** Haplosclerida
- **Family:** Chalinidae
- **Genus:** Haliclona
- **Species:** *Haliclona oculata*

Haliclona sp.2

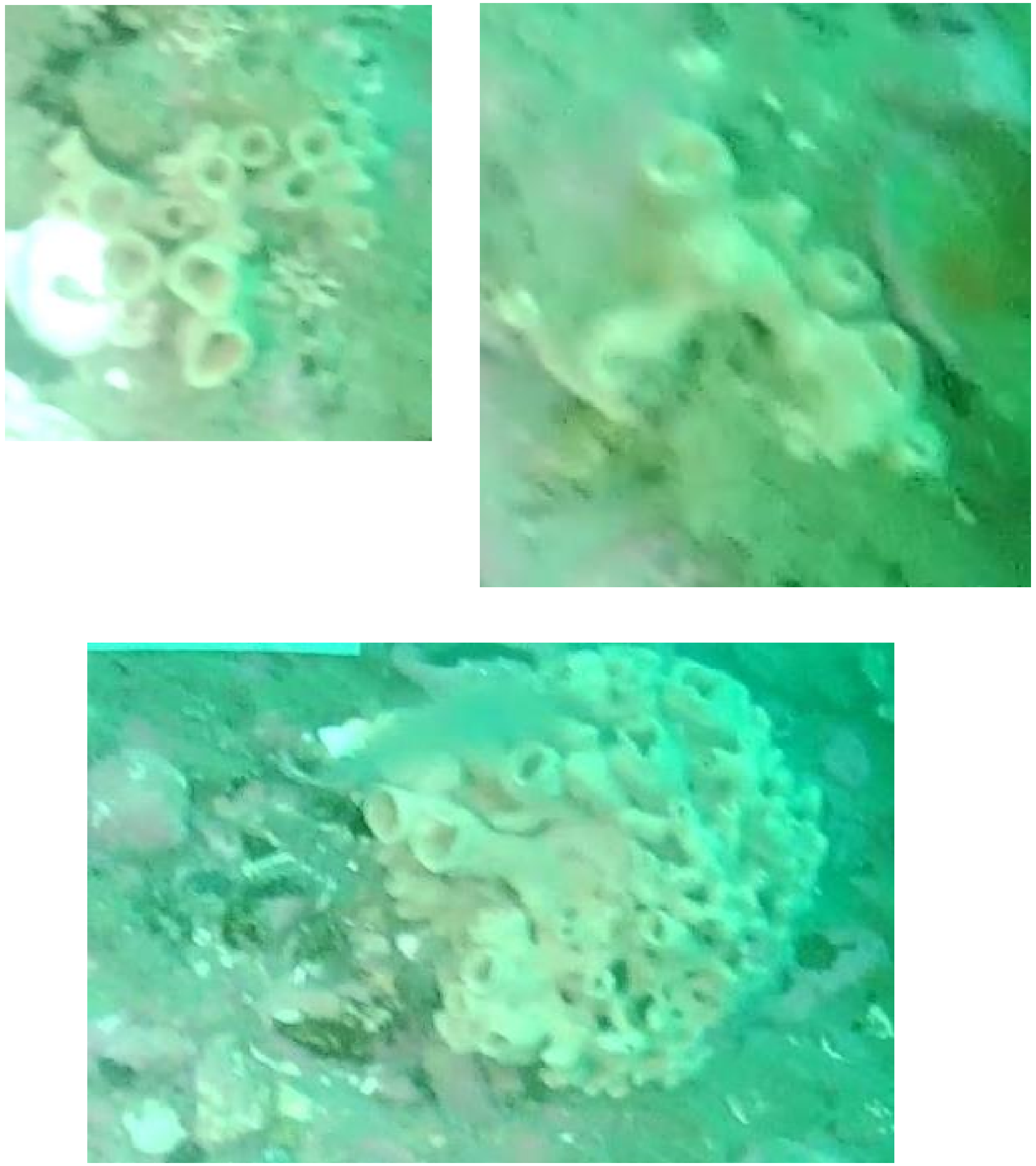
- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:** Haplosclerida
- **Family:** Chalinidae
- **Genus:** Haliclona
- **Species:**

Porifera sp.3

- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Porifera sp.5

- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:**
- **Family:**
- **Genus:**
- **Species:**



Porifera sp.11

- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:**
- **Family:**
- **Genus:**
- **Species: *may be coralline algae**

Porifera sp.55

- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Porifera sp.13

- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Porifera sp.21

- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Porifera sp.22

- **Phylum:** Porifera
- **Class:** Demospongiae
- **Order:**
- **Family:**
- **Genus:**
- **Species:**

Scypha spp.

- **Phylum:** Porifera
- **Class:** Calcarea
- **Order:** Leucosolenida
- **Family:** Sycettidae
- **Genus:** Scypha
- **Species:**