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Comparing demersal fish and large mobile decapod crustacean assemblages in nearshore marine habitats across a boreal–sub-Arctic gradient using baited cameras

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ABSTRACT: Arctic and sub-Arctic ecosystems are experiencing changes in environmental conditions, altering marine biodiversity through shifts in species distributions and composition. Coastal ecosystems in northern environments are vulnerable to continued environmental change, but the remoteness of these areas and challenges associated with sampling shallow, structurally complex habitats have limited studies on nearshore communities. We compared the composition and relative abundances of nearshore assemblages in 7 coastal locations spanning 10° latitude of boreal and sub-Arctic habitats in Newfoundland and Labrador, Canada, using baited remote underwater video (BRUV). We identified 14 taxa, including 11 fish species and 3 decapod crustaceans. Species richness and diversity was generally higher in southern relative to northern locations, and spatial distributions differed across taxa. Greenland cod *Gadus macrocephalus ogac* and large cottids *Myoxocephalus* spp. were the most common taxa in northern areas and the only species observed across the entire environmental gradient. In contrast, we observed Atlantic cod *G. morhua*, winter flounder *Pseudopleuronectes americanus*, and cunner *Tautogolabrus adspersus* exclusively in southern locations. In addition to community variability across locations, habitat differences contributed more to variation in community-level abundances than to the abundances of most individual taxa. BRUVs provided an effective method for comparing nearshore assemblages across northern coastal habitats that are challenging to other common sampling methods. Further studies incorporating BRUVs could track variability in nearshore assemblages over longer time scales and offer an accessible method for coastal communities to monitor change across habitats.

KEY WORDS: Coastal ecosystem · Marine habitats · Nearshore communities · Baited remote underwater video

1. INTRODUCTION

Accelerated warming of Arctic and sub-Arctic ecosystems (Rantanen et al. 2022) and associated large-scale environmental changes (Fox-Kemper et al. 2021) have already altered marine biodiversity through shifts in species abundances, distributions, and composition (Wassmann et al. 2011, Fossheim et al. 2015, Stevenson & Lauth 2019, Mueter et al. 2021). Coastal ecosystems within these northern environ-

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ments are particularly vulnerable to changing ocean conditions (Harley et al. 2006, Hewitt et al. 2016), and continued environmental change can lead to shifts in the composition of nearshore assemblages (von Biela et al. 2023). Changes in species distributions and composition can impact ecosystem services (Pecl et al. 2017), including fisheries resources (Madin et al. 2012, Pinsky & Fogarty 2012), and will heavily impact northern coastal communities that rely on nearshore species and habitats for subsistence activities (Ford 2009, Wesche & Chan 2010, Dombrowski et al. 2013). Identifying changes in coastal assemblages through time requires dedicated monitoring efforts (Barceló et al. 2016, Morris & Green 2021) and an understanding of environmental influences on species distributions and composition. However, the structural complexity that typifies many northern nearshore habitats can limit the efficacy of typical sampling gear (e.g. nets), hindering surveys of coastal assemblages.

As an accessible and cost-effective sampling option (Watson & Huntington 2016, Bergshoeff et al. 2017) baited remote underwater video (BRUV) systems offer a versatile approach for studying demersal and benthic communities, including estimating species abundances and diversity and characterizing habitat associations (Mallet & Pelletier 2014, Whitmarsh et al. 2017). BRUVs are particularly well-suited for studying nearshore Arctic and sub-Arctic environments, as they can be deployed through sea ice (B. G. C. King pers. obs.) and in structurally complex coastal habitats associated with sea ice (e.g. boulder barricades) that are inaccessible using other sampling methods. The non-destructive and non-extractive nature of BRUVs maintains the integrity of benthic environments, effectively eliminating mortality and minimizing disturbance, making cameras an ideal technology for sampling sensitive or vulnerable habitats and protected areas (Cappo et al. 2003, Kelaher et al. 2014, Morris et al. 2024). Collectively, these characteristics make BRUVs a practical option for sampling northern coastal habitats, including marine communities in boreal, sub-Arctic, and Arctic environments (Dalley et al. 2017, Devine et al. 2019, Rangeley et al. 2022).

Newfoundland and Labrador, situated in eastern Canada, has ~30 000 km of coastline that includes boreal and sub-Arctic nearshore habitats. Structurally complex substrates including rocky shorelines, unconsolidated cliffs, and boulder flats characterize many of these habitats. These boreal and sub-Arctic coastal areas are exposed to cold Arctic water brought by the Labrador Current flowing south from the Canadian Arctic to the Grand Banks off Newfoundland. Sea ice covers coastal environments in Labrador for 6–7 mo of the year, and while seasonal ice coverage typifies most of Newfoundland, nearshore areas of southern coastlines generally remain ice-free. Coastal communities, particularly along Labrador, rely on landfast ice and nearshore habitats as infrastructure and as important sources of subsistence harvest (DFO 2021, McCarney et al. 2024). However, challenging sampling conditions (e.g. remoteness, large geographic area, structurally complex habitats, seasonal ice coverage) have limited research on species distributions in nearshore coastal habitats in many areas (DFO 2021). Studies on coastal marine assemblages in northern Labrador include historical presence–absence data from otter and beam trawl surveys (Backus 1957) as well as distributions of demersal fish (e.g. Gadidae, Cottidae, Pholidae, Stichaeidae, and Cyclopteridae) from visual surveys (Friedlander et al. 2023) and benthic invertebrates (e.g. bryozoans, poriferans, cnidarians, annelids, molluscs, echinoderms, and arthropods) from underwater video transects and drop deployments in deeper (>20–230 m) areas (Rangeley et al. 2022) across a few fjord environments. Ongoing environmental changes and the importance of these areas to coastal communities collectively add the need for a greater understanding of existing species distributions and community composition across this boreal–sub-Arctic environmental gradient.

In this study, we used BRUV deployments to assess nearshore assemblages across a boreal–sub-Arctic gradient in coastal Newfoundland and Labrador. We combine data from coastal study sites spanning >10° latitude (48.5°–59.4° N) to investigate community composition and habitat associations along this gradient. Our objectives were to (1) characterize assemblages in these nearshore locations, (2) assess how community composition varies across locations and habitats, and (3) evaluate how assemblages vary seasonally within nearshore environments. Characterizing these assemblages both across and within coastal locations enables assessments of communities within a northern marine ecosystem experiencing environmental change.

2. MATERIALS AND METHODS

2.1. Study sites and BRUV deployments

We assembled data from BRUV surveys to compare nearshore assemblages over a relatively large (>10° latitude) boreal–sub-Arctic gradient. Collectively, these surveys comprised 158 BRUV deployment sets from 2016–2021 across 7 nearshore locations in coastal Newfoundland and Labrador, Canada (Fig. 1). In Newman Sound (Newfoundland), we deployed 9 sets from 15–17 November 2016 and another 64 sets (8 repeat sets at 8 sites) from 29 July–11 December 2019. Deployment depths in 2016 were either 2 or 20 m, and in 2019 were ⩽10 m. In Labrador, we deployed 56 sets from 5–9 October 2017 in Kangalaksiorvik, Nachvak, Saglek, and Okak; 11 sets from 11–19 November 2019 near Nain, Labrador; and 18 sets from 1–6 August 2021 in and adjacent to the Gilbert Bay Marine Protected Area (MPA). Deployment depths in Kangalaksiorvik, Nachvak, Saglek, and Okak were ⩽10 m; near Nain ranged from 6.5–10.5 m; and in Gilbert Bay ranged from 10–23 m. Sea ice had not yet set in these coastal locations during our deployments. Table S1 in the Supplement at www.int-res.com/articles/suppl/m755p029_supp.pdf summarizes deployment information for each BRUV set.

BRUV frame design differed across locations (Fig. S1), as separate research groups independently completed deployments across years. The 2016 Newman Sound deployments included a GoPro Hero 3^+ in a waterproof case mounted on a wooden dowel rod approximately 50 cm above the seafloor secured at the center of a 5-gallon bucket. An additional wooden dowel rod transecting the top of the bucket extended away from the camera as an approximately 1 m bait arm, baited with a mesh bag containing ~100 g of canned 'sardines in water'. Two perpendicular dowel rods transected the base for added stability. Deployments in Kangalaksiorvik, Nachvak, Saglek, and Okak used the same setup as the 2016 Newman Sound sets but instead included polyvinyl chloride (PVC) pipes in place of wooden dowel rods, a GoPro Hero 4 in a waterproof case, and a 1 × 1 m square plastic mesh fastened to the base of the frame to discourage aquatic vegetation from obstructing the field of view. For the 2019 Newman Sound deployments, we used a GoPro Hero 3^+ in a waterproof case secured to a stainless-steel stand approximately 50 cm above the seafloor. A stainless-steel bait arm extending ~50 cm away from the base of the stand and above the seafloor held a mesh bait bag baited with ~300 g of whole Atlantic herring. The baited camera deployments near Nain used the same setup as the 2019 Newman Sound sets except that the bait was fastened to a plastic platform in place of a bait bag. The BRUV system for the 2021 deployments in Gilbert Bay included a Mobius Maxi ActionCam in waterproof housing affixed to the top of a modified crab pot (with mesh removed) approximately 50 cm above the seafloor. A PVC pipe secured to the bottom of the pot extended away from the camera as an approximately 1 m bait arm baited with a mesh bag containing ~100 g of canned 'sardines in water'.

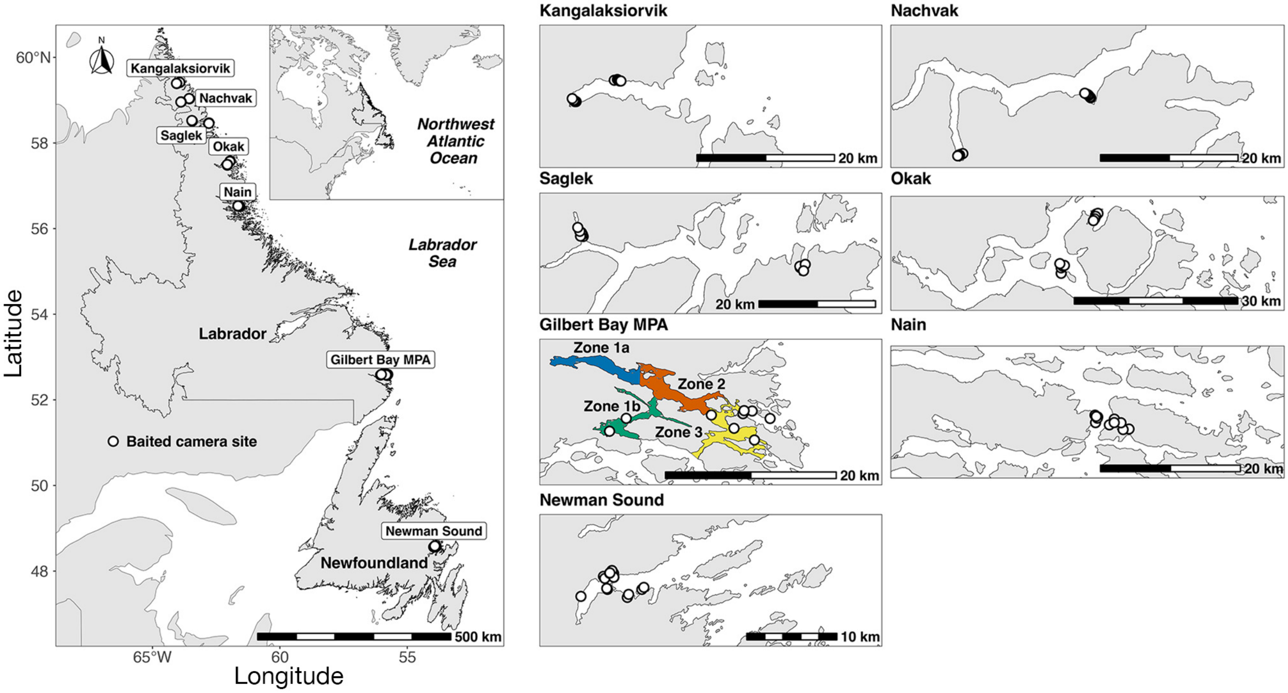

Fig. 1. Baited remote underwater video deployment sites included in community comparisons (white circles) across 7 nearshore locations along coastal Newfoundland and Labrador, Canada

2.2. Video analysis

We collected approximately 145 h of video footage with deployment times ranging from 16–188 min (Table S1). Deployments with an altered field of view (e.g. obstructed views of the seafloor, poor lighting or visibility, or where the camera was not deployed in an upright position) were removed, resulting in 138 of the 158 deployments being retained for further analysis. We analyzed the videos from each deployment in full, identifying all demersal fishes and mobile decapod crustaceans that entered the field of view to the lowest possible taxonomic classification (example images in Fig. S2), with gadid fishes further subdivided into juveniles or adults. We recorded the presence of several benthic invertebrates, including sea urchins, sea stars, brittle stars, shrimps, whelks, bivalves, and anemones, but omitted them from our analysis because quantifying relatively stationary benthic invertebrate communities was beyond the fish and large mobile decapod crustacean focus of our study. We watched each video deployment in 1 min intervals and quantified relative abundances by recording the maximum number of individuals per species or taxon visible within a single image (MaxN) in each of the intervals through each deployment. This method ensured that individuals that entered, left, and re-entered the field of view did not artificially inflate our relative abundance estimates (Langlois et al. 2020). Recording MaxN for taxa in 1 min intervals also allowed for tracking relative abundances throughout deployments and ensured that the largest MaxN was recorded and used for subsequent analyses. MaxN tends to underestimate fish abundance (Cappo et al. 2003), and as such, our counts were conservative estimates of relative abundance. To evaluate how well BRUV deployments sampled species richness, we generated species accumulation curves as a function of BRUV deployment times as well as species richness rarefaction and extrapolation curves as a function of the number of deployments in each location, and compared how differences in these effort metrics may have influenced our results.

We visually characterized benthic habitat in each deployment following a semi-quantitative scale method derived from the medium scale approach (Clua et al. 2006). Specifically, we classified habitat based on types of biogenic cover (macroalgae, seagrass, rhodoliths) as well as fine- and coarse-grain substrates (sensu Wentworth 1922) and estimated the percent composition that each habitat separately occupied in the field of view (example images in Fig. S3). Differences between fine-grain soft sediments were not readily distinguishable in all our videos, so we use the term 'soft sediments' to encompass mud, clay, silt, and/or sand. We use 'coarse substrates' to denote the presence of gravel, cobble, and boulders. Percent composition for visible substrate coverage and biogenic cover included the following categories: 0 (none or not visible), 1 (>1 to <25%), 2 (>25 to <50%), 3 (>50 to <75%), and 4 (>75 to 100%).

2.3. Community comparisons

We calculated species richness and the Shannon diversity index for each of the deployments and used each metric as a response variable in a generalized linear model (GLM) to compare assemblages across locations and habitats. Species richness was modelled in a GLM with a Conway-Maxwell Poisson error distribution (with a log link function), which is appropriate for count data with overdispersion (Sellers & Premeaux 2021), and Shannon diversity in a GLM with a Tweedie error distribution (with a log link function), which is appropriate for continuous response variables that include zeros (Kokonendji et al. 2021). Location (categorical) and the categorial percent composition for each habitat component (soft sediments, coarse substrates, macroalgae, rhodoliths, and eelgrass) were incorporated as explanatory variables in each of the GLMs, and the 'glmmTMB' package (Brooks et al. 2017) was used to generate each model. Model suitability was evaluated using residual diagnostic plots available from the 'DHARMa' package (Hartig 2021). Likelihood ratios (LRs) assessed the likelihood of each model as compared to a null model (Royall 1997), and analysis of deviance (ANODEV) quantified the contribution of the explanatory variable to each model. We omitted deployments in December from Newman Sound to improve temporal consistency across all our sites for this spatial comparison.

We visualized community composition comparisons through a cluster analysis dendrogram and nonmetric multidimensional scaling (nMDS) ordinations. We generated these visualizations from zero-adjusted Bray-Curtis dissimilarity matrices (Clarke et al. 2006) of square-root transformed MaxN values from taxa observed in each BRUV deployment. Multivariate GLMs were used to compare communities across locations and habitats as well as species differences within community comparisons. Vectors on nMDS ordinations indicated species with significant abundance differences among communities from each location or habitat. We again omitted deployments in

December from Newman Sound to improve temporal consistency across sites for this spatial comparison.

Grouped locations represented different study areas for species and community comparisons as follows: northern Labrador (Kangalaksiorvik, Nachvak, Saglek, Okak, Nain), southern Labrador (Gilbert Bay), and Newfoundland (Newman Sound). Using the same approach described above, we compared communities among locations and habitats in northern Labrador, among the deployment areas and habitats within Gilbert Bay, and between seasons (summer–autumn) and among habitats in Newman Sound. For the seasonal comparison in Newman Sound, summer sets included deployments from July–September and autumn sets included deployments from November–December. We omitted the deployments from 2016 because these sets did not span the entirety of these seasonal time frames. We restricted multivariate GLM permutations by site to account for repeat sampling in the Newman Sound analysis. All analyses were conducted in the R (v.4.1.2) statistical environment (R Core Team 2021), specifically using the 'vegan' package (Oksanen et al. 2022) for nMDS ordinations and species accumulation calculations, the 'iNEXT' package (Chao et al. 2014, Hsieh et al. 2016) for species richness rarefaction and extrapolation curves, the 'dendextend' package (Galili 2015) for the cluster analysis dendrogram, the 'mvabund' package for multivariate GLMs (Wang et al. 2012, 2022, Warton et al. 2012), and the suite of 'tidyverse' packages (Wickham et al. 2019) for all data cleaning and visualization.

3. RESULTS

3.1. Baited camera observations

We identified 14 taxa, including 11 fish species spanning 8 families as well as 3 decapod crustaceans (Table 1). Spatial distributions differed across taxa. Only Greenland cod *Gadus macrocephalus ogac* and large cottids *Myoxocephalus* spp. were observed in all locations. Small cottids (Family Cottidae) occurred at most locations (except Newman Sound), and although these cottids likely included multiple species, subtle species differences within this family were not apparent from our video imagery, precluding species-level identification. We observed Atlantic cod *G. morhua* and winter flounder *Pseudopleuronectes americanus* only in Gilbert Bay and Newman Sound, whereas cunner *Tautogolabrus adspersus*, white hake *Urophycis tenuis*, rock gunnel *Pholis gunnellus*, Atlantic rock

Table 1. Summary of taxa observed from baited remote underwater video deployments with mean maximum number of individuals (MaxN) and associated SDs along with number of deployments (n) reported for each location

Taxa	Family	Kangalaksiorvik (n = 10)	Nachvak (n = 12)	Saglek (n = 10)	Okak (n = 11)	Nain (n = 11)	Gilbert Bay (n = 12)	Newman Sound (n = 72)
		Mean MaxN (SD)						
Greenland cod *Gadus macrocephalus ogac*	Gadidae	0.4 (0.52)	7.08 (10.7)	4.2 (3.12)	2.18 (1.47)	0.82 (1.33)	4.5 (2.91)	0.53 (1.15)
Greenland cod (juvenile)	Gadidae	0 (0)	0 (0)	0 (0)	0 (0)	1.82 (2.36)	1.92 (3.42)	0.17 (0.73)
Large cottids *Myoxocephalus* spp.	Cottidae	0.6 (0.7)	1 (1.35)	1.2 (1.14)	0.82 (0.6)	0.82 (0.75)	1 (0.74)	0.35 (0.67)
Small cottids	Cottidae	0.6 (0.84)	3.83 (4.13)	2.3 (2.58)	3.55 (3.33)	2.73 (2.15)	0.5 (0.9)	0 (0)
Toad crab *Hyas* spp.	Oregoniidae	0 (0)	0 (0)	0 (0)	1.36 (1.69)	2.36 (2.91)	1.42 (1.52)	0 (0)
Arctic shanny *Stichaeus punctatus*	Stichaeidae	0 (0)	0 (0)	0 (0)	0.18 (0.4)	0 (0)	0.25 (0.62)	0 (0)
Eelpout *Lycodes* sp.	Zoarcidae	0 (0)	0 (0)	0 (0)	0.09 (0.3)	0 (0)	0 (0)	0 (0)
Skate *Amblyraja* sp.	Rajidae	0 (0)	0 (0)	0 (0)	0 (0)	0.09 (0.3)	0 (0)	0 (0)
Atlantic cod *Gadus morhua*	Gadidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4.42 (5.92)	1.67 (2.56)
Atlantic cod (juvenile)	Gadidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.08 (3.45)	1.44 (2.17)
Winter flounder *Pseudopleuronectes americanus*	Pleuronectidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.08 (0.29)	0.56 (0.85)
Cunner *Tautogolabrus adspersus*	Labridae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5.22 (7.83)
White hake *Urophycis tenuis*	Gadidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (0.17)
Rock gunnel *Pholis gunnellus*	Pholidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.03 (0.17)
Atlantic rock crab *Cancer irroratus*	Cancridae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1.03 (1.29)
American lobster *Homarus americanus*	Nephropidae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.11 (0.4)

crab *Cancer irroratus*, and American lobster *Homarus americanus* were only observed in Newman Sound. We observed toad crabs *Hyas* spp. in Gilbert Bay, Nain, and Okak, and Arctic shanny *Stichaeus punctatus* in these same locations (except Nain). Single camera sets captured solitary individuals of skate *Amblyraja* sp. and eelpout *Lycodes* sp. in the Nain and Okak deployments, respectively. Species accumulation curves plateaued across deployment times in each location (Fig. S4). Species richness rarefaction and extrapolation curves flattened across the number of deployments in Kangalaksiorvik, Nachvak, Saglek, and Newman Sound, and were nearly asymptotic for the number of deployments in Okak, Nain, and Gilbert Bay (Fig. S5). Collectively, these accumulation curves indicate that our deployment efforts sampled nearshore assemblages sufficiently to identify differences in species richness and community composition across this boreal—sub-Arctic environmental gradient. Biogenic cover in habitats included several macroalgal species (laminariaceaen kelps, colander kelp *Agarum clathratum*, *Fucus* spp., rockweed *Ascophyllum nodosum*, filamentous *Desmarestia* sp., sea lettuce in Family Ulvaceae, bootlace weed *Chorda filum*) as well as eelgrass *Zostera marina*, and encrusting algae included rhodoliths (spherical aggregations of crustose red algae). Benthic habitat varied across study sites (Fig. S6), with eelgrass only observed in Newman Sound and rhodoliths only in the Nain and Okak deployments.

3.2. Community comparisons

Species richness and Shannon diversity indices were generally higher in southern Labrador (Gilbert Bay) and Newfoundland (Newman Sound) relative to northern Labrador (Kangalaksiorvik, Nachvak, Saglek, Okak, Nain; Fig. 2 & Fig. S5). The LRs for location in the GLMs of species richness and Shannon diversity (ANODEV, $\chi^2 = 32.8$, LR = 1.35×10^7, and $\chi^2 = 23$, LR = 9.98×10^4, respectively; Table 2) were larger than for habitat composition, demonstrating that models including location were more effective in explaining variation in the response variables and supported differences among locations. The LRs for percent composition of fine-grain soft sediments in the field of view were higher than any other habitat component (Table 2).

Table 2. Analysis of deviance of the generalized linear models for species richness and Shannon diversity as a function of location and different habitat composition each with an associated likelihood ratio (LR). Significant p-values ($p \leqslant 0.05$) and LRs are shown in **bold**

Parameter	Species richness				Shannon diversity			
	df	χ^2	p	LR	df	χ^2	p	LR
Location	6	32.8	**<0.001**	**1.35×10^7**	6	23	**<0.001**	**9.98×10^4**
Soft sediments	4	8.66	0.07	76	4	10.1	**0.039**	**154**
Coarse substrates	4	5.11	0.277	12.8	4	3.25	0.517	5.08
Macroalgae	4	1.12	0.892	1.75	4	0.608	0.962	1.36
Rhodoliths	4	1.88	0.758	2.56	4	1.96	0.742	2.67
Eelgrass	4	4.6	0.331	9.97	4	1.76	0.78	2.41

Cluster analysis primarily arranged communities into 3 groups: northern Labrador (Kangalaksiorvik, Nachvak, Saglek, Okak, Nain), southern Labrador (Gilbert Bay), and Newfoundland (Newman Sound), although some sites overlapped across this gradient (Fig. 3) and nMDS ordinations illustrated similar community clusters (Fig. 4A). Multivariate GLMs supported community differences across locations (ANODEV, deviance = 688, $p < 0.001$) and habitats composed of soft sediments, coarse substrates, macroalgae, or rhodoliths (Table 3). Abundance differences across locations were evident for several taxa, including Greenland cod, Atlantic cod, sculpins, winter flounder, Arctic shanny, cunner, toad crabs, and Atlantic rock crabs (Fig. 4A, Table 3). Small cottids were the only taxon with significant abundance differences across habitats, and were associated with areas primarily composed of soft sediments (Fig. 4B).

Location-specific differences in communities were evident across the environmental gradient. In northern Labrador, communities appeared to overlap among locations and habitats (Fig. 5), but multivariate GLMs supported community differences across locations (ANODEV, deviance = 129, $p < 0.001$) as well as fine-grain soft sediment habitats (ANODEV, deviance = 68, $p < 0.001$; Table S2). The abundances of Greenland cod, small cottids, and toad crabs differed across locations (Fig. 5A, Table S2), and small cottids differed significantly in abundance in habitats composed of fine-grain soft sediments (Fig. 5B, Table S2).

In Gilbert Bay (southern Labrador), communities from different deployment areas clustered together but largely overlapped when compared across habitats (Fig. 6). Multivariate GLMs supported community differences across deployment areas (ANODEV, deviance = 57.6, $p = 0.006$) and additionally across habitats composed of coarse-grain substrates (ANODEV, deviance = 45.7, $p < 0.001$; Table S3). Greenland

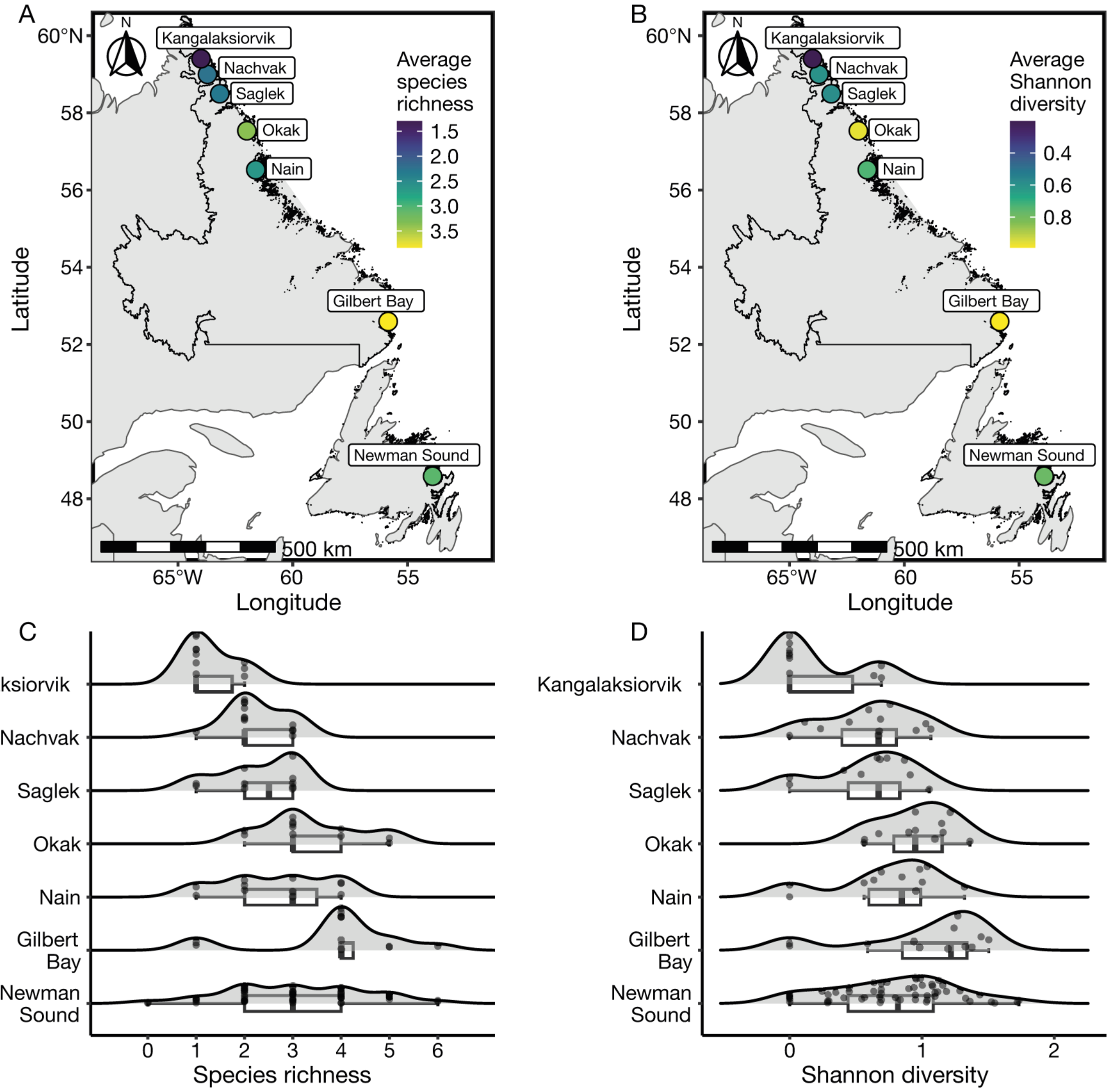

Fig. 2. Average (A) species richness and (B) Shannon diversity values calculated from deployments across coastal locations. Distribution of (C) species richness and (D) Shannon diversity values from deployments across locations. Boxplots in (C) and (D) illustrate the median (centre line), interquartile range (IQR) (left end: lower quartile; right end: upper quartile), and 1.5 × the IQR (whiskers)

cod abundances differed across deployment areas (Fig. 6A, Table S3) inside and outside the MPA, and higher abundances of Atlantic cod were associated with habitats largely composed of coarse-grain substrates (Fig. 6B, Table S3).

In Newman Sound (Newfoundland), communities clustered between seasons but overlapped across habitats (Fig. 7). Multivariate GLMs supported seasonal community differences (ANODEV, deviance = 135, $p < 0.001$) and assemblage differences across habitats composed of soft sediments or macroalgae (Table S4). Abundance differences for Atlantic cod, winter flounder, and cunner differentiated communities between seasons (Fig. 7A, Table S4). Abundances did not appear to differ significantly across contrasting habitats for any individual taxa.

4. DISCUSSION

We identified differences in the composition of nearshore assemblages across a boreal—sub-Arctic gradient spanning >10° of latitude extending from Newfoundland to northern Labrador, as well as seasonal changes in assemblages within coastal Newfoundland. Habitat composition contributed more to variation in community-level abundances than to relative abundances of most individual taxa. BRUVs provided a well-suited, non-extractive approach for assessing nearshore assemblages in structurally complex habitats across northern environments. Our results contribute to characterizations of nearshore communities in a data-deficient northern ecosystem and show that assemblages in northern locations support subsets of species from communities farther south in our study area.

The nearshore environments of northern Labrador (Kangalaksiorvik, Nachvak, Saglek, Okak, and Nain) generally supported fewer species relative to communities in southern Labrador (Gilbert Bay) and Newfoundland (Newman Sound). Greenland cod and large cottids (*Myoxocephalus* spp.) were common in northern areas and were the only taxa observed across all locations. Both Greenland cod (Morin & Dodson 1986, Morin et al. 1991) and *Myoxocephalus* cottids (Oikari 1978, Whoriskey et al. 1994) can tolerate variable temperatures and salinities, contributing to their ubiquity across nearshore coastal habitats of Newfoundland and Labrador, and indeed across their distribution ranges in the North Atlantic and Arctic Oceans (Scott & Scott 1988, Coad & Reist 2018). We observed these species across a transitional environment that included the current northern limits of boreal species (e.g. Atlantic cod, winter flounder, and cunner; Scott & Scott 1988, Coad & Reist 2018) to the Arctic and sub-Arctic regions of Labrador; however, these ranges may shift with environmental change.

In contrast, we observed Atlantic cod and winter flounder only in southern Labrador (Gilbert Bay) and Newfoundland (Newman Sound), and cunner were exclusive to Newman Sound. Our results suggest that the current northern range limits for winter flounder and cunner extend to southern Labrador and Newfoundland, respectively, which aligns with historical distribution records (Scott & Scott 1988). Atlantic cod populations previously attained relatively high abundances off northern Labrador before subsequently declining in the 1980s (Murphy et al. 1992, DFO 1996). These populations have not been regularly surveyed for nearly 2 decades and the most recent estimates indicate that abundances have remained low

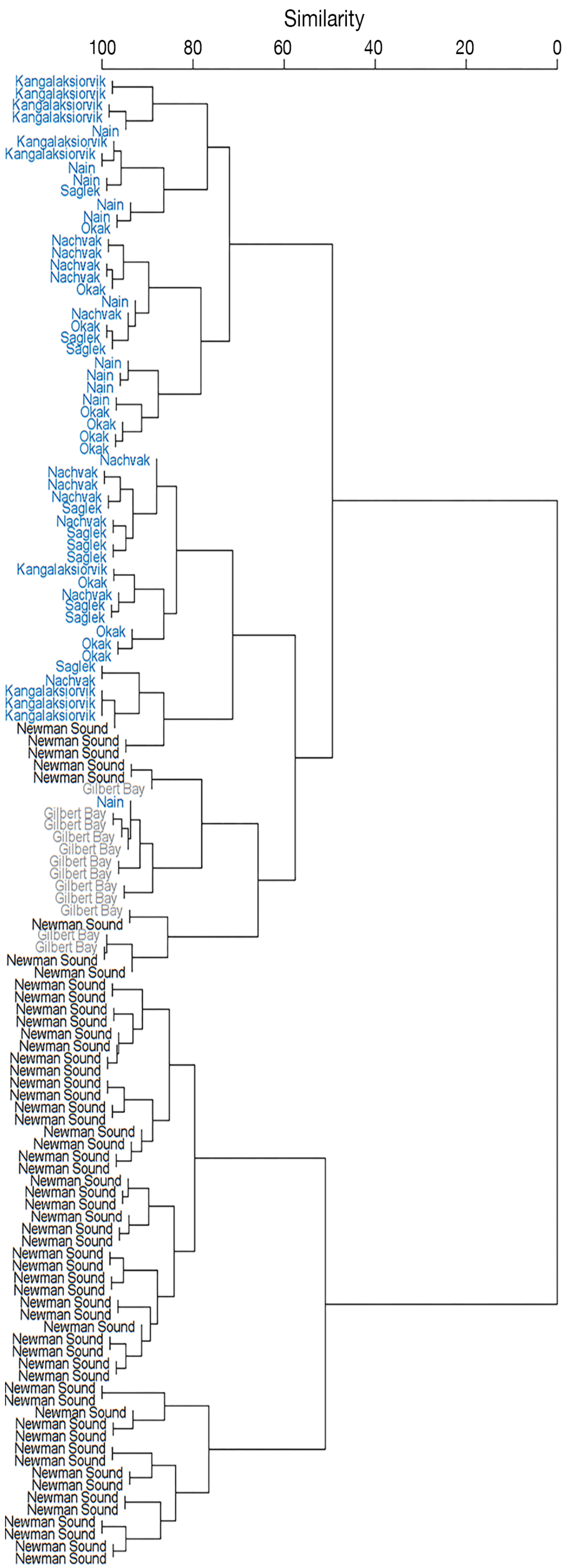

Fig. 3. Cluster analysis dendrogram representing community assemblages from nearshore locations along coastal Newfoundland and Labrador. Blue, grey, and black colours correspond to baited remote underwater video deployments from northern Labrador (Kangalaksiorvik, Nachvak, Saglek, Okak, Nain), southern Labrador (Gilbert Bay), and Newfoundland (Newman Sound), respectively

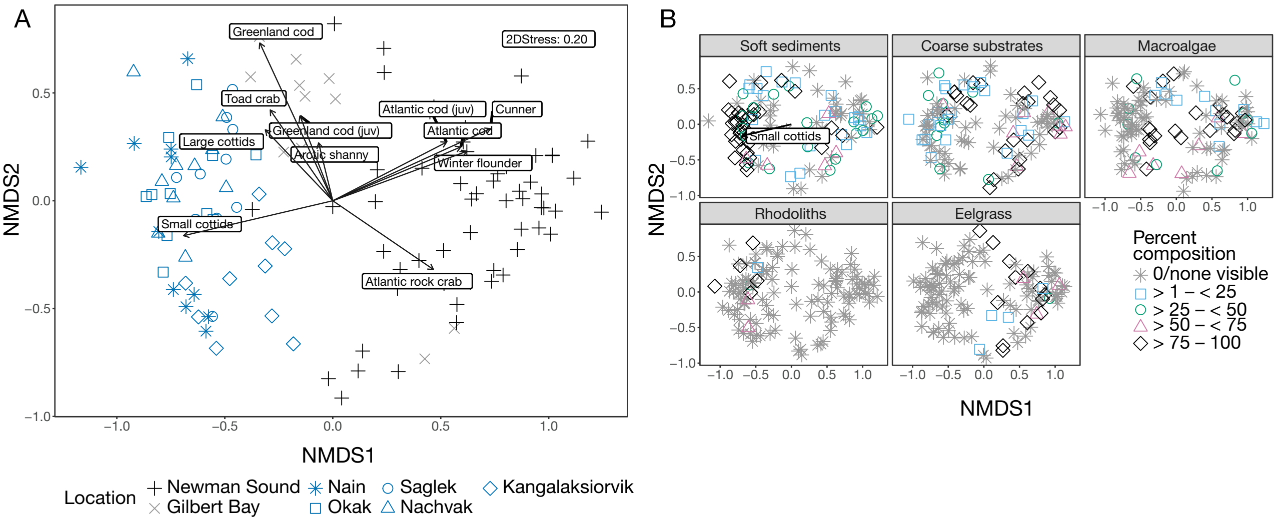

Fig. 4. Non-metric multi-dimensional scaling (nMDS) ordinations of square-root transformed MaxN taxa abundances obtained from baited remote underwater video deployments in nearshore locations along coastal Newfoundland and Labrador. Colours and symbols correspond to (A) study locations and (B) percent composition for each type of identified habitat. In (A), blue, grey, and black colours correspond to deployments from northern Labrador (Kangalaksiorvik, Nachvak, Saglek, Okak, Nain), southern Labrador (Gilbert Bay), and Newfoundland (Newman Sound), respectively

(Smedbol et al. 2002, Worcester et al. 2009). Although we did not observe Atlantic cod in nearshore locations across northern Labrador, they likely occur in low abundance in deeper environments off the coast given that small numbers have been reported as incidental bycatch in offshore shrimp fisheries (Orr et al. 2010). BRUV deployments in coastal locations could help to identify distributional changes in fish (including commercially and ecologically important species such as Atlantic cod) assemblages across these northern environments.

Implementation of protected areas in northern Labrador and increased interest in marine management by the Nunatsiavut Government (representing the Inuit of northern Labrador) requires knowledge of coastal assemblages and accessible methods to monitor change through time. In northern Labrador, we observed abundance differences for Greenland cod, small cottids, and toad crab among some locations; small cottids were the only taxon with abundance differences associated with contrasting habitat composition (fine-grain soft sediments). As the small cottids identified likely included multiple species, the abundance differences could be related to contrasting species distributions across fine-grain soft sediment habitats. Despite some variation in individual species abundances, Greenland cod, sculpins, and toad crabs comprised the bulk of the taxa observed in these deployments, consistent with observations within Nachvak Fjord in northern Labrador (Friedlander et al. 2023). Our observations, concurrent with other recent studies (Rangeley et al. 2022, Friedlander et al. 2023), contribute to comparisons of community composition across coastal locations and habitats in nearshore environments along the northern Labrador coast. Additional BRUV deployments could represent a practical method for coastal communities to monitor changes in nearshore assemblages over longer time scales as well as surveying structurally complex habitats in data-deficient areas.

Annual MPA monitoring data indicates changes in fish community composition in the Gilbert Bay MPA during the past 20 yr (Morris & Green 2021). Our BRUV data demonstrated community differences among areas inside and outside the MPA, and less so among habitats. A portion of the local Gilbert Bay Atlantic cod population resides within the MPA year-round, while some individuals move seaward in summer to headlands outside MPA boundaries (Green & Wroblewski 2000, Morris et al. 2014, King et al. 2024), and we indeed observed Atlantic cod across these areas, particularly in habitats with structurally complex coarse-grain substrates (e.g. cobbles, boulders). Coincident with a decline in Gilbert Bay Atlantic cod abundance, increases in catch rates of other demersal fish species (e.g. Greenland cod, winter flounder, and shorthorn sculpin *Myoxocephalus scorpius*) indicate changes in fish community composition (Morris & Green 2021). We also observed Greenland cod in the inner MPA (Zone 1b) as well as in

Table 3. Analysis of deviance associated with the multivariate generalized linear model for species relative abundances as a function of location and habitat composition as well as individual species differences compared across all study locations. Deviance (D) from likelihood ratio tests and p-values ($p \leq 0.05$ in **bold**) are included for each variable

All locations (Kangalaksiorvik, Nachvak, Saglek, Okak, Nain, Gilbert Bay, Newman Sound)

	Overall				Greenland cod		Greenland cod (juvenile)		Large cottids		Small cottids		Toad crab		Arctic shanny		Eelpout	
Parameter	df	Res. df	D	p	D	p	D	p	D	p	D	p	D	p	D	p	D	p
Location	6	115	688	**0.001**	74.1	**0.001**	33.1	**0.001**	21.7	**0.002**	98	**0.001**	75.8	**0.001**	14.1	**0.03**	4.81	0.572
Soft sediments	4	111	99.5	**0.002**	7.72	0.704	13.3	0.193	4	0.991	24.5	**0.001**	3.63	0.991	5.01	0.961	1.58	0.991
Coarse substrates	4	107	110	**0.003**	4.58	0.925	15.4	0.116	12.4	0.219	11.6	0.26	14.1	0.149	6.79	0.731	1.83	0.925
Macroalgae	4	103	87.4	**0.008**	10.9	0.399	4.07	0.820	2.77	0.824	11.2	0.399	5.56	0.82	2.96	0.824	0	0.824
Rhodoliths	4	99	34.6	**0.021**	7.91	0.304	1.35	0.915	11.2	0.12	0.85	0.915	11.8	0.094	1.39	0.915	0	0.956
Eelgrass	4	95	39.8	0.334	0.76	0.999	9.06	0.529	2.56	0.986	0	0.999	0.003	0.999	0	0.999	0	0.999

All locations (continued)

	Skate		Atlantic cod		Atlantic cod (juvenile)		Winter flounder		Cunner		White hake		Rock gunnel		Atlantic rock crab		American lobster	
Parameter	D	p	D	p	D	p	D	p	D	p	D	p	D	p	D	p	D	p
Location	4.81	0.572	95.8	**0.001**	60.8	**0.001**	49.4	**0.001**	85.3	**0.001**	3.12	0.862	3.12	0.862	54.8	**0.001**	9.79	0.151
Soft sediments	0.9	0.991	4.08	0.991	4.04	0.991	13.4	0.193	3.07	0.991	1.61	0.991	1.61	0.991	9.1	0.548	1.87	0.991
Coarse substrates	0.67	0.925	2.44	0.925	10.1	0.372	3.94	0.925	3.16	0.925	2.77	0.925	0.74	0.925	13.4	0.17	6.34	0.77
Macroalgae	0	0.824	5.87	0.82	11.1	0.399	7.04	0.739	5.96	0.82	2.96	0.824	6.37	0.791	1.83	0.824	8.75	0.585
Rhodoliths	0	0.956	0	0.956	0	0.956	0	0.956	0	0.956	0	0.915	0	0.915	0	0.956	0	0.956
Eelgrass	0	0.999	7.52	0.713	0.73	0.999	6.01	0.822	3.5	0.976	0	0.999	0	0.999	3.74	0.976	5.89	0.822

outer seaward areas (MPA Zone 3 and outside the MPA), supporting observations of changing demersal fish community abundances within Gilbert Bay. Our deployments also documented other species (e.g. small cottids, Arctic shanny, toad crab) as well as small juvenile gadids in outer seaward areas (MPA Zone 3) that other sampling methods may not capture. BRUV deployments identified differences in nearshore assemblages across the MPA and, concurrent with established MPA monitoring efforts, could help track fish community trends in the Gilbert Bay MPA moving forward.

In Newman Sound, we identified seasonal differences in communities characterized by low abundances of Atlantic cod, winter flounder, and cunner in our autumn deployments. In Newfoundland and Labrador, adult Atlantic cod reside in coastal habitats in the summer but typically move out of these areas through autumn as water temperatures decline, migrating to deeper, warmer water over winter (Templeman 1979, Lear & Green 1984, Brattey 2013). However, at least some juvenile Atlantic cod (ages 0–2) overwinter in Newman Sound (Cote et al. 2004, Geissinger et al. 2022), despite their absence in our autumn deployments. Winter flounder complete seasonal movements to avoid sub-zero water temperatures (Hanson & Courtenay 1996, DeCelles & Cadrin 2010) and pack ice (Van Guelpen & Davis 1979). In contrast to seasonal movements, cunner overwinter in rock crevices and enter a metabolically depressed state of torpor (Green & Farwell 1971, Costa et al. 2013), re-emerging when water temperatures warm in spring. Our results, consistent with previous studies (Cote et al. 2013, Dalley et al. 2017), support seasonal variation in nearshore fish communities in coastal Newfoundland. Environmental conditions along coastal Labrador presumably contribute to seasonality in demersal fish communities in these northern areas (DFO 2021), and BRUV deployments through sea ice could be an effective approach to investigate these potential changes in nearshore assemblages.

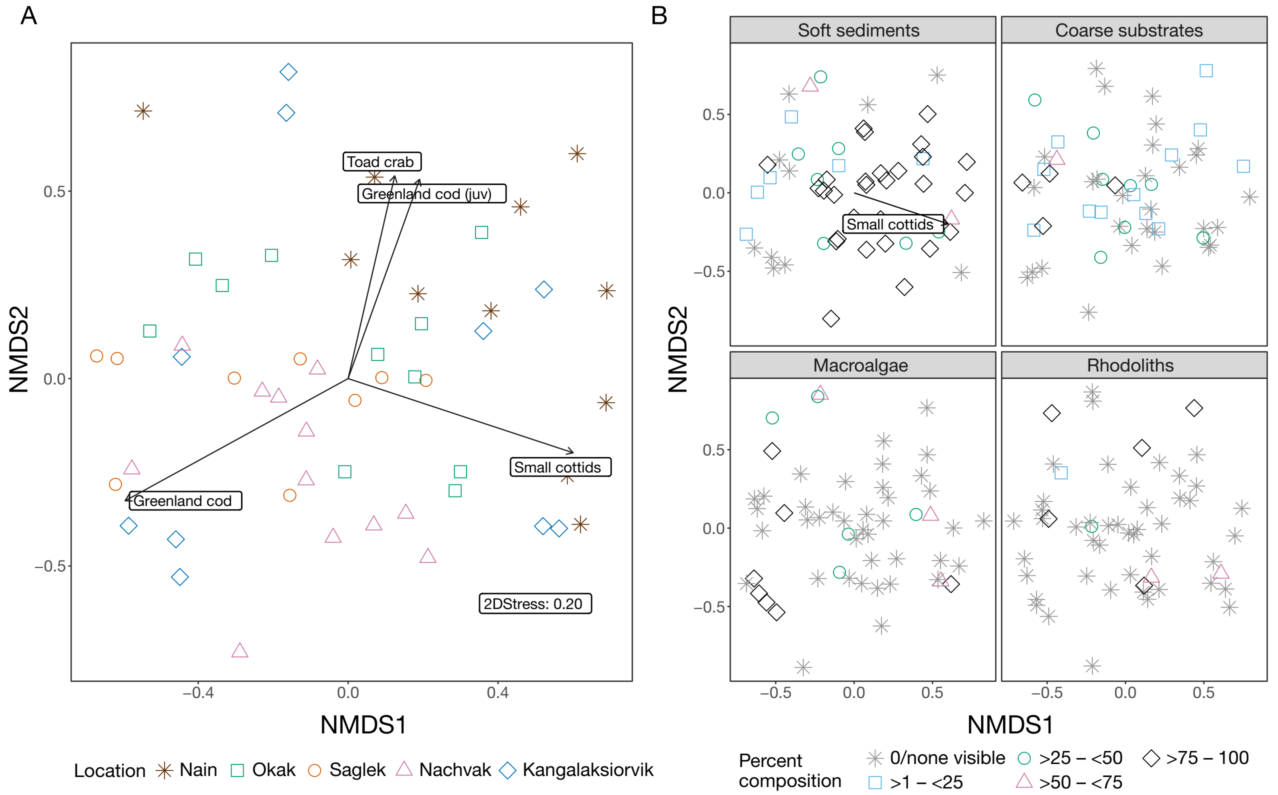

Fig. 5. Non-metric multi-dimensional scaling (nMDS) ordinations of square-root transformed MaxN taxa abundances obtained from baited remote underwater video deployments in nearshore locations in northern Labrador (Kangalaksiorvik, Nachvak, Saglek, Okak, Nain). Colours and symbols correspond to (A) study locations and (B) percent composition for each identified habitat

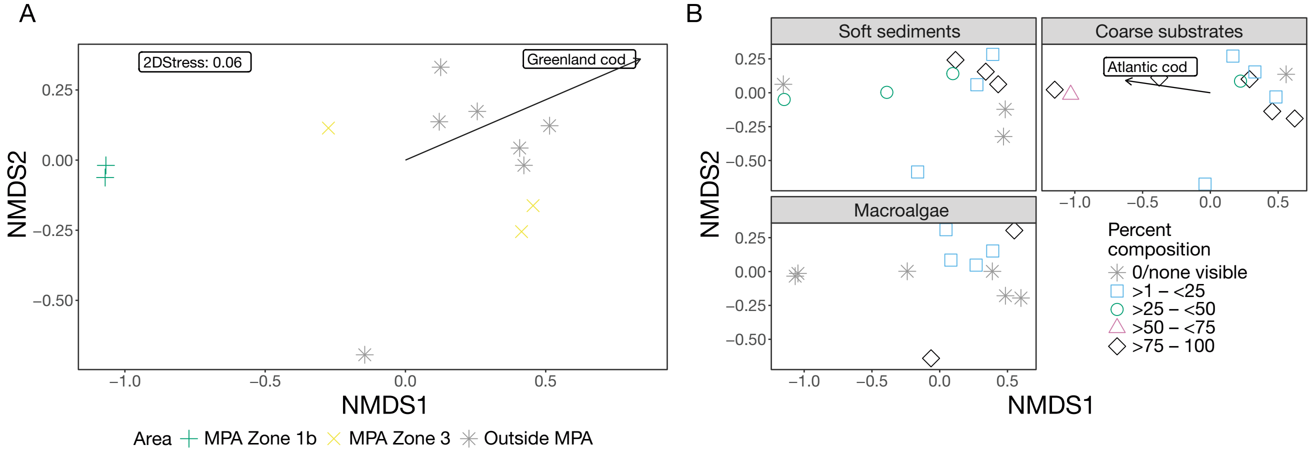

Fig. 6. Non-metric multi-dimensional scaling (nMDS) ordinations of square-root transformed MaxN taxa abundances obtained from baited remote underwater video deployments in nearshore sites in Gilbert Bay (southern Labrador). Colours and symbols correspond to (A) deployment areas and (B) percent composition for each identified habitat

Community differences were apparent among some habitats for northern Labrador, Gilbert Bay, and Newman Sound, and habitat composition varied among locations. Despite observing eelgrass exclusively in Newman Sound (Newfoundland) and rhodoliths in Nain and Okak (northern Labrador), these habitats occur throughout our study area. Eelgrass occurs in Labrador but with far fewer observations compared to distributions in Newfoundland (Murphy et al. 2021). Rhodoliths occur in Newman Sound (Proudfoot et al.

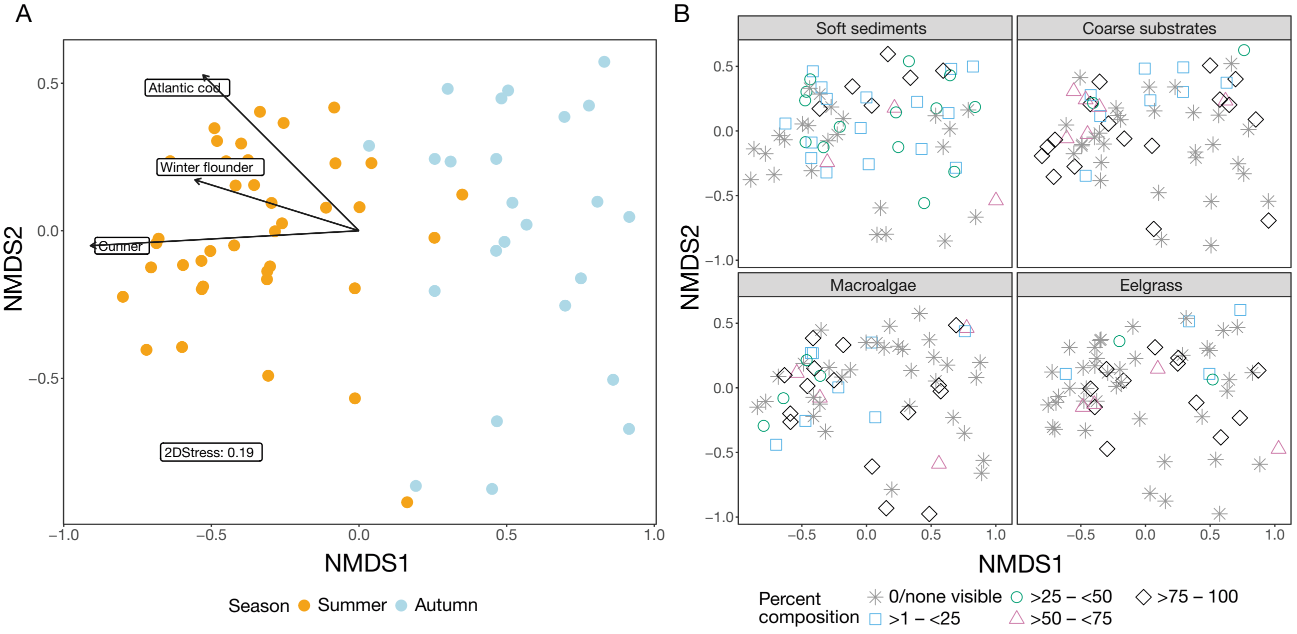

Fig. 7. Non-metric multi-dimensional scaling (nMDS) ordinations of square-root transformed MaxN taxa abundances obtained from the 2019 BRUV deployments in nearshore coastal sites in Newman Sound (Newfoundland), showing differences in (A) seasons and (B) percent composition for each identified habitat

2020, R. S. Gregory pers. obs.) and Gilbert Bay (Copeland et al. 2013, C. J. Morris pers. obs.) but were not recorded in our deployments in these locations. Our analyses demonstrated little variation in abundance differences among habitats for most species, except for small cottids associated with fine-grain soft sediments in northern Labrador, and Atlantic cod associated with coarse-grain substrates in Gilbert Bay. Overall, habitat composition contributed to community-level abundance differences more so than most individual taxa-level abundances. Community variability across habitats may indicate differences in habitat quality (Cote et al. 2013), but testing such differences requires community data over longer time periods than what is currently available for most parts of our study area.

We acknowledge caveats to our conclusions based on data set limitations and BRUV deployment methodology. Our deployments captured a variety of demersal and benthic taxa but are inherently biased towards species that respond to bait and particularly scavenging predators (Dalley et al. 2017). Indeed, bait differences can influence the taxa observed in BRUV deployments (for review see Whitmarsh et al. 2017, Jones et al. 2021). However, bait in this study (sardines and herring) were both oily fishes (effective bait type for fish assemblage comparisons; Dorman et al. 2012, Wraith et al. 2013, Walsh et al. 2017), and oily fish bait weight does not appear to influence the relative abundance, species richness, or assemblage composition estimated from baited camera footage (Hardinge et al. 2013, Jones et al. 2020). We therefore infer that bait differences here did not contribute substantially to the variation we observed in nearshore assemblages. We identified and enumerated some cryptic species (e.g. Arctic shanny, rock gunnel) but could only complete family-level identification of small cottids, which limited community analysis. Additionally, deployment depths were relatively homogeneous within each location, and our data set cannot definitively discount potential community differences across depths for locations included in the study. BRUV deployments over depth gradients in each location would provide a more comprehensive survey of assemblages across these northern environments. Changes in BRUV designs across locations resulted in some field-of-view differences impacting the backfields of some videos, and our findings therefore offer conservative estimates of relative abundances and species diversity. Our data set did not account for interannual variability among study sites, and the large geographic extent precluded temporal consistency across deployments. Fish assemblages in nearshore areas of coastal Newfoundland demonstrate community variability on interannual scales (Methven et al. 2001), including in Newman Sound (Cote et al. 2013). However, data of similar temporal resolution do not yet exist for nearshore habitats in northern Labrador. Local and Indigenous knowledge is extensive in many parts of this coastline (McCarney et al. 2024) and could support interannual comparisons.

Changing ocean conditions will lead to redistributions of communities, particularly in northern environments, where shifts in species distributions have already occurred (Fossheim et al. 2015, Stevenson & Lauth 2019, Mueter et al. 2021, von Biela et al. 2023). The transport of cold Arctic water by the Labrador Current over coastal areas (DFO 2021) may currently deter the spatial expansion of boreal species further north along Newfoundland and Labrador. Accordingly, the Arctic and sub-Arctic communities in northern Labrador may be less vulnerable to changes in composition compared to boreal and sub-Arctic communities further south in Newfoundland. Indeed, invasive species like green crab *Carcinus maenas* are present in some parts of Newfoundland but only in coastal areas that are not directly exposed to the Labrador Current (DFO 2011, Matheson et al. 2016). However, incursions of boreal species including sea lamprey *Petromyzon marinus* and striped bass *Morone saxatilis* have occurred in some parts of southern Labrador (Van Leeuwen et al. 2021). Projected increases in ocean warming in the Northwest Atlantic at rates faster than the global average (Saba et al. 2016) could enable additional incursions from boreal taxa. Gadid fishes respond behaviourally to changes in temperature, and Atlantic cod populations in the Northwest Atlantic have historically shifted distributions in response to warming and cooling ocean conditions (Rose et al. 1994, 2000). Habitat suitability modelling based on egg survival and juvenile growth rates projected poleward shifts in gadid distributions consistent with current temperature projections in the northwest (Cote et al. 2021) and northeast (Dahlke et al. 2018) Atlantic. Temperature changes are also predicted to influence the distributions of sculpins and cunner (Rose 2005) and have contributed to distributional shifts for winter flounder (Nye et al. 2009). Fish and invertebrate assemblages in environments offshore from Newfoundland and Labrador have previously undergone substantial compositional shifts in line with changes in environmental conditions (Gomes et al. 1995, Pedersen et al. 2017). Similar shifts may have occurred in nearshore areas, but were underreported as a result of sparse surveys in coastal areas. How distributions of nearshore assemblages may shift in the Northwest Atlantic with changing environmental conditions remains unclear and will require continued studies on communities in coastal habitats that incorporate environmental data over long time scales.

The inability to characterize and track variation in nearshore assemblages in structurally complex habitats limits the identification of areas with potentially high conservation value, and by association, weakens any capacity to implement management measures to protect vulnerable or ecologically important habitats. Unlike extractive approaches (net-based bottom contact sampling, gillnets, benthic longlines, angling, etc.), BRUV deployments provide a non-invasive approach for surveying such habitats because they do not ensnare benthic structures or selectively remove taxa. These deployments currently require substantial user time investment for video footage analysis, and software automation of video and image processing (e.g. Ayyagari et al. 2023) will likely help to alleviate these time-consuming efforts.

Our study assessed nearshore assemblages in coastal habitats and identified differences in community composition and species distributions across a boreal—sub-Arctic environmental gradient in Newfoundland and Labrador. Seasonal differences in communities were apparent in Newfoundland, and additional BRUV deployments may help to identify if similar seasonality exists for communities in Labrador. Our results contribute to understanding differences in species distributions in data-deficient northern areas, and provide an essential foundation from which future studies can monitor change. BRUV deployments were a well-suited approach to compare marine assemblages in structurally complex nearshore habitats in a northern coastal ecosystem.

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