



Sponge communities in the eastern Canadian Arctic: species richness, diversity and density determined using targeted benthic sampling and underwater video analysis

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Abstract

The sponge diversity of the eastern Canadian Arctic remains largely unknown. Sponges of the three marine ecoregions which make up the eastern Canadian Arctic and sub-Arctic are described from collections using remote operated vehicle (ROV), box core, and Agassiz trawl. In total, 161 sponges were collected between 2015 and 2017, and 60 different species were identified. ROV surveys covered a range of benthic habitats, but sponges seen in video could only be identified to morphotypes. Twenty-seven distinct sponge morphotypes were identified from ROV surveys of six sites in the study region, but only fifteen of these were commonly encountered and unambiguously identified at the different sites. Transects were carried out in a non-linear manner due to ROV limitations, and covered varied benthic habitats ranging from soft sand to steep bedrock cliffs. The highest number of species identified from specimens collected was in the Northern Labrador marine ecoregion (46 species), while the highest number of morphotypes identified from ROV video was in the Baffin Bay/Davis Strait ecoregion at a dive site near Pond Inlet (17 morphotypes). Several species collected and morphotypes counted were found across different ecoregions, but smaller sponges could not be identified from ROV video. Sponge density was estimated from exploratory ROV video and ranged from 0.008 ind. m⁻² in Lancaster Sound to 0.371 ind. m⁻² at a site near Pond Inlet. The combined collections and video analysis show the importance of using different collection and observation methodologies to properly understand the biodiversity of benthic habitats that are difficult to access.

Keywords Sponge · Visual survey · Eastern Canadian Arctic · Sponge community · Biodiversity

Introduction

Generally, the more remote a region and the deeper a marine habitat the less is known about species diversity (Archambault et al. 2010). The deep basins and the continental shelf in the remote Canadian Arctic and sub-Arctic harbor a wide range of plankton, fish, mammal, and bird species which

are important economic resources, particularly for inhabitants of northern regions (Darnis et al. 2012), but the actual biodiversity of Canadian Arctic waters remains relatively under-described compared to regions of a similar latitude in the NE Atlantic. Some animal groups such as arthropods, annelids, and molluscs have been well-studied in the Canadian Arctic (Curtis 1975; Wacasey et al. 1979, 1980; Piepenburg et al. 2011; Squires 2011), but surprisingly only recently was a near complete list of the number of fish species found in the Canadian Arctic published (Mecklenburg et al. 2011; Coad and Reist 2019). Sessile benthic species are often overlooked in biodiversity studies (Archambault et al. 2010; Kenchington et al. 2011a; Piepenburg et al. 2011; Darnis et al. 2012; Roy et al. 2015). Sponges (Phylum Porifera) are one of the most poorly recorded taxa in the Canadian north with an order of magnitude fewer species of sponge known from eastern Canada than from similar latitudes globally (Sarà et al. 1992; Ackers et al. 2007; Picton and Goodwin 2007; Downey et al. 2012; Van Soest et al.

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2012; Lehnert and Stone 2016). Sponges play an important ecological role in the formation of biogenic habitat and are documented to form critical nursery habitat for many fish and invertebrate species (Klitgaard 1995; Chu and Leys 2010; Hogg et al. 2010; Kenchington et al. 2013; Maldonado et al. 2017). Sponges are increasingly the focus of efforts to preserve fragile habitats (Lindholm et al. 2004; Howell 2010; Kenchington et al. 2011a; Bell et al. 2015; Grant et al. 2018, 2019). The Canadian Arctic is opening to escalating industrial and commercial exploration, particularly in deep water ecosystems. As industrial use of aquatic environments typically comes at the loss of species biodiversity (Eriksson et al. 2010; Hewitt and Thrush 2010; Love et al. 2013) it will be important to understand the present diversity of taxa in the Canadian Arctic, and more practically, whether current regional delineations adequately represent the boundaries of benthic species assemblages.

Marine Ecoregions of the World (MEOWs) (Spalding et al. 2007) were developed to estimate diversity and distribution of species globally and are often used in broad scale descriptions of biogeographic patterns (Van Soest et al. 2012; Keith et al. 2013; Cullain et al. 2018). MEOWs were originally based on available species distribution data, but because little is known about the dispersal abilities and recruitment of species living below 200 m, MEOWs tend to be biased towards distribution barriers for well-known pelagic species. Canadian oceans contain approximately 7% of the world's 232 MEOWs (Spalding et al. 2007; Archambault et al. 2010). Of the 17 marine ecoregions surrounding Canada, three occur in the eastern Canadian Arctic and sub-Arctic: Northern Labrador, Baffin Bay/Davis Strait and Lancaster Sound (Spalding et al. 2007). Although the designation of MEOWs reviewed more than 230 sources, there was a dearth of knowledge from the Arctic at the time they were delineated, especially in eastern Canada (Archambault et al. 2010; Piepenburg et al. 2011). Because the ecoregions represent a considerable portion of the Canadian continental shelf, knowledge of the marine fauna in each is important for managing human activities to sustain biodiversity.

The distribution of some sponge species in the North Atlantic is known from recent work using trawl data (Kenchington et al. 2011a; Murillo et al. 2012, 2018; Knudby et al. 2013) as well as from ROV and towed camera video (Beazley and Kenchington 2015; McIntyre et al. 2016). Additional work in the region is aimed at using large data sets to predict the distribution of dense sponge aggregations, called sponge grounds, based on environmental and geological parameters (Knudby et al. 2013; Murillo et al. 2016). The species that make up sponge grounds are reported to occur throughout the North Atlantic (Klitgaard and Tendal 2004; Kenchington et al. 2011a; McIntyre et al. 2016), and some of these species are described as being indicator taxa for vulnerable marine ecosystem (VME) designation (ICES

2009; Hogg et al. 2010; Kenchington et al. 2015). Work using imagery from remotely operated vehicles (ROVs) or drop cameras often focuses on a designated set of large, easily identifiable sponges to describe the benthos. The sponges counted most often are from the order Tetractinellida (e.g., *Geodia*, *Stelletta*, and *Craniella*), a group of sponges that are recognizable due to their large size and often spheroid shape (Beazley et al. 2013; McIntyre et al. 2016), and Hexactinellid sponges such as *Pheronema* and *Vazella* (Kenchington et al. 2010; McIntyre et al. 2016). However, similar sponge aggregations in the NE Atlantic dominated by *Geodia* species are also home to up to 50 different sponge species (Klitgaard and Tendal 2004). This suggests that similar sponge assemblages in the NW Atlantic dominated by the same large sponges could harbor a great diversity of sponge species which have yet to be reported.

Over 9100 species of marine and freshwater sponges are known globally, with the majority of these species described from shallow water and warm climate regions (Van Soest et al. 2012). Sponges are difficult to identify from images (Hooper and Van Soest 2002; Leys et al. 2004), thus specimens are often required to determine taxonomic placement. Sponge spicule morphology and their arrangement in the body are the primary means for classification (Cárdenas 2010), but in many cases molecular analysis is needed to confirm species or higher rank taxonomic affinities (Morrow and Cárdenas 2015; Vargas et al. 2015). Given the importance of sponges for benthic-pelagic coupling (Dayton et al. 1974; Kahn et al. 2015) and habitat formation (Bett and Rice 1992; Klitgaard 1995; Klitgaard and Tendal 2004; Buhl-Mortensen et al. 2010), accurately understanding the sponge fauna of a region is important for conservation management of the whole ecosystem.

Here we set out to characterize the sponge fauna of three MEOWs along the eastern Canadian shelf. We surveyed nearshore bays and outer continental shelf habitats and collected sponges using ROV, trawls, and grabs, with a goal to compare patterns of distribution, density, and community composition of sponges. Our aim was to explore the diversity of sponges and their patterns of distribution in the three eastern Canadian MEOWs.

Methods

Study area

Research cruises in the eastern Canadian Arctic and sub-Arctic were conducted as part of the ArcticNet Hidden Biodiversity project aboard the *CCGS Amundsen* between 2015 and 2017. The study area encompassed latitudes from 60° to 78° N, from the Northern Labrador shelf to Nares Strait and crossed three Marine Ecoregions of the World (MEOWs):

Northern Labrador, Baffin Bay/Davis Strait, and Lancaster Sound (Spalding et al. 2007) (Fig. 1a). The eastern Canadian Arctic is bounded by the Labrador Sea to the south and by Baffin Bay to the north. The Labrador Sea is a large marginal sea that reaches a depth of 3400 m but becomes shallower northward (Clarke and Drinkwater 2006). Davis Strait, a 300 km wide passage that connects the North Labrador Sea to Baffin Bay, is substantially shallower than the adjoining seas due to the influence of the Baffin Island shelf to the west and neighboring Greenland shelf to the east. Baffin Bay has a maximum depth of 2400 m. While the fish species composition of Baffin Bay and the Canadian Arctic Archipelago (which includes Lancaster Sound) is considered to be Arctic, the fish species composition of the Labrador Sea is considered to be boreal (Christiansen et al. 2013, 2014). Baffin Bay is also home to the highly productive North Water polynya

which is influenced by cold Arctic water flowing southward along the Canadian Arctic Archipelago and warmer inflow of water northward from the Atlantic (Ingram et al. 2002).

Remote operated vehicle (ROV) survey sites and some benthic sampling locations were selected based on reported areas of high sponge and coral abundance (Kennington et al. 2010, 2011a; Knudby et al. 2013) and particular emphasis was given to deep, hard-bottom habitats where collection of benthic organisms is not possible using traditional sampling methods such as large survey trawls.

Sampling methods

Sponges were collected by ROV, box core, and Agassiz trawl. ROV dives were carried out using a Sub-Atlantic SuperMohawk (SuMO) submersible. Sponges were

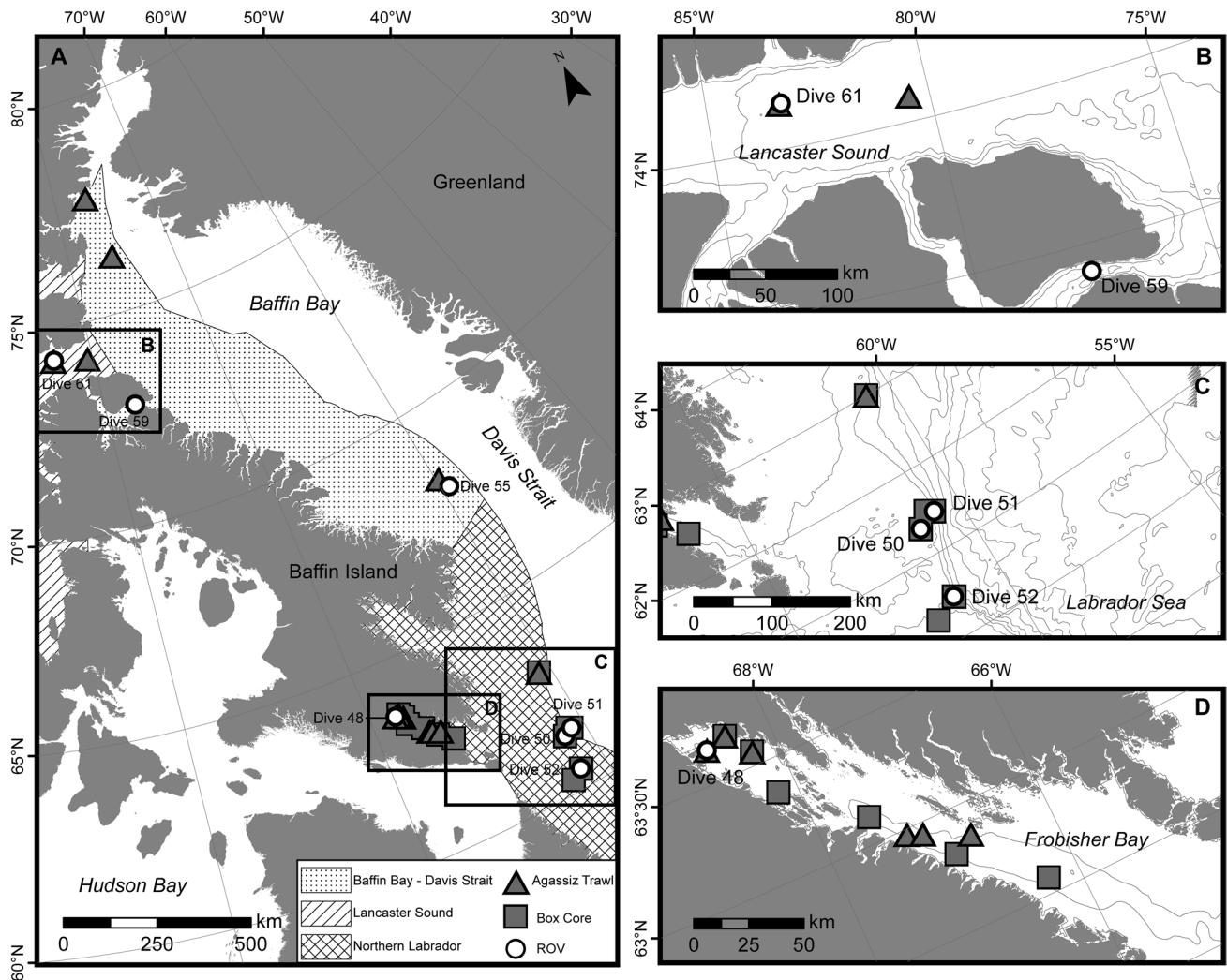


Fig. 1 Study locations. **A** Map showing study area in the eastern Canadian Arctic and sub-Arctic with Marine Ecoregions of the World (MEOWs) overlaid. **B** Lancaster Sound and Pond Inlet. **C** North Lab-

rador Sea. **D** Frobisher Bay. Sample sites shown by type: triangles Agassiz trawl, squares box core, and circles ROV

collected by the two ROV manipulator arms and brought on board in a hydraulic sampling skid. Sponges collected using the ROV were photographed in situ before collection. The Agassiz trawl (0.5 m height \times 3 m width, 40 mm net mesh size, with a 5 mm cod end liner towed for 3 min at 1.5 knots) and a box core (BX 650 MK III 50 cm \times 50 cm, penetration depth 60 cm) were deployed in several sites throughout the study area, including areas where the ROV was not deployed (Fig. 1). The size of the trawl net opening did not appear to preclude the collection of larger sponges. Sponge pieces were collected opportunistically using all benthic sampling methods, but whole sponge weights were not recorded. Sponges collected by ROV, box core, and Agassiz trawl were photographed on board with a scale for size reference, preserved in either 95% ethanol or frozen, and transported to the University of Alberta for identification. Collection information for all specimens is available in Online Resource 1. Continuous high definition video imagery was collected in 2016 and 2017 using a SubC Imaging 1Cam Alpha HD Color Zoom camera. Two parallel lasers 6 cm apart provided a scale in the center of the camera's field of view (FOV).

ROV dive locations

ROV dive locations are shown in Fig. 2a. Dive sites in the Northern Labrador MEOW included NE Hatton Basin (dive 50, Fig. 2b), Hatton Basin '*Primnoa rich*' (dive 51, Fig. 2c), and Saglek Bank (dive 52, Fig. 2d). The dive sites in the Baffin Bay/ Davis Strait MEOW included Disko Fan (dive 55, Fig. 2e) and Pond Inlet (dive 59, Fig. 2f). A single dive occurred in the Lancaster Sound MEOW (dive 61, Fig. 2g). Dive numbers reflect the fact that some dives were canceled due to weather, that dives were shortened for collections only, or dives were dedicated to other activities, thus video was not analyzed for those dives. Dive 48 (Frobisher Bay, Fig. 2h) also occurred in the Northern Labrador MEOW, but was excluded from video analysis because it occurred in 2015 before modifications of the ROV laser; however, because considerable sponge collections occurred in Frobisher Bay, these were used for similarity calculations. Precise dive locations, depth ranges and bottom time are shown in Table 1.

Sponge species identifications

Sponge spicules were isolated from 1 cm² pieces that included ectosome and choanosome. Pieces of sponge were placed in undiluted household bleach overnight to digest tissue, rinsed four times in distilled water allowing spicules to settle for 15 min between rinses, and twice in 95% ethanol. Cleaned spicules were dried onto glass slides, mounted in DPX (Sigma-Aldrich, St. Louis, USA) and imaged with a compound or stereomicroscope with a QImaging QiCam

or Retiga 2000R using EMPIX northern Eclipse v8. DNA analysis was also used to confirm taxonomic identities. DNA was extracted from ethanol-stored tissues using the DNeasy Blood and Tissue kit (Qiagen, Valencia, USA). Molecular identities, CO1 or 28S, were assessed following methods described previously (Dinn et al. 2019), and partial sequences are available in Dinn (2018). Sponges analyzed using this integrated taxonomic approach were identified to lowest possible taxon. Some specimens could not be identified if the specimen was heavily damaged or contaminated with spicules from another specimen. Specimens collected and taxonomically identified in the lab were used for similarity calculations.

Similarity between ecoregions

For analyses of species similarity between ecoregions, the Northern Labrador MEOW was separated into two regions, Frobisher Bay and the north Labrador shelf. The Baffin Bay/ Davis Strait MEOW was divided into Disko Fan, northern Baffin Bay, and Pond Inlet. The Lancaster Sound MEOW was not subdivided because sponges were only collected in one region of the sound. Similarity values between regions where sponges were collected were calculated based on a Jaccard similarity coefficient using presence/absence data.

Quantification of sponge abundance, density and diversity from ROV video

The linear distance of the ROV path was calculated using ROV waypoints (collected each second) plotted in ArcMap 10.7 using the Points to Line tool and the Canada Lambert Conformal Conic projected coordinate system (Table 1). To give a realistic estimate of the distance covered compared to a vertex to vertex distance measurement of waypoints, a Polynomial Approximation with Exponential Kernel (PAEK) was applied to the linear distance using a 50 m linear smoother in ArcGIS 10.7 (Fig. 2, Table 1). The smoothed distance accounts for instances when the ROV may have been in collection mode where slight differences in position may have increased the overall linear distance. Smoothing also accounts for times when the ROV may have turned around and individual sponges would have entered the field of view (FOV) more than once. Video transects were not carried out at uniform speeds or in straight lines and so height from the bottom and FOV were not constant. The width of the field of view of the ROV was measured from extracted frames taken at 50 m intervals using ImageJ 1.51 and the 6 cm laser markers emitted by the ROV. To estimate the area covered by each transect, the median FOV value for each dive was multiplied by the total smoothed distance covered by the ROV (Table 1).

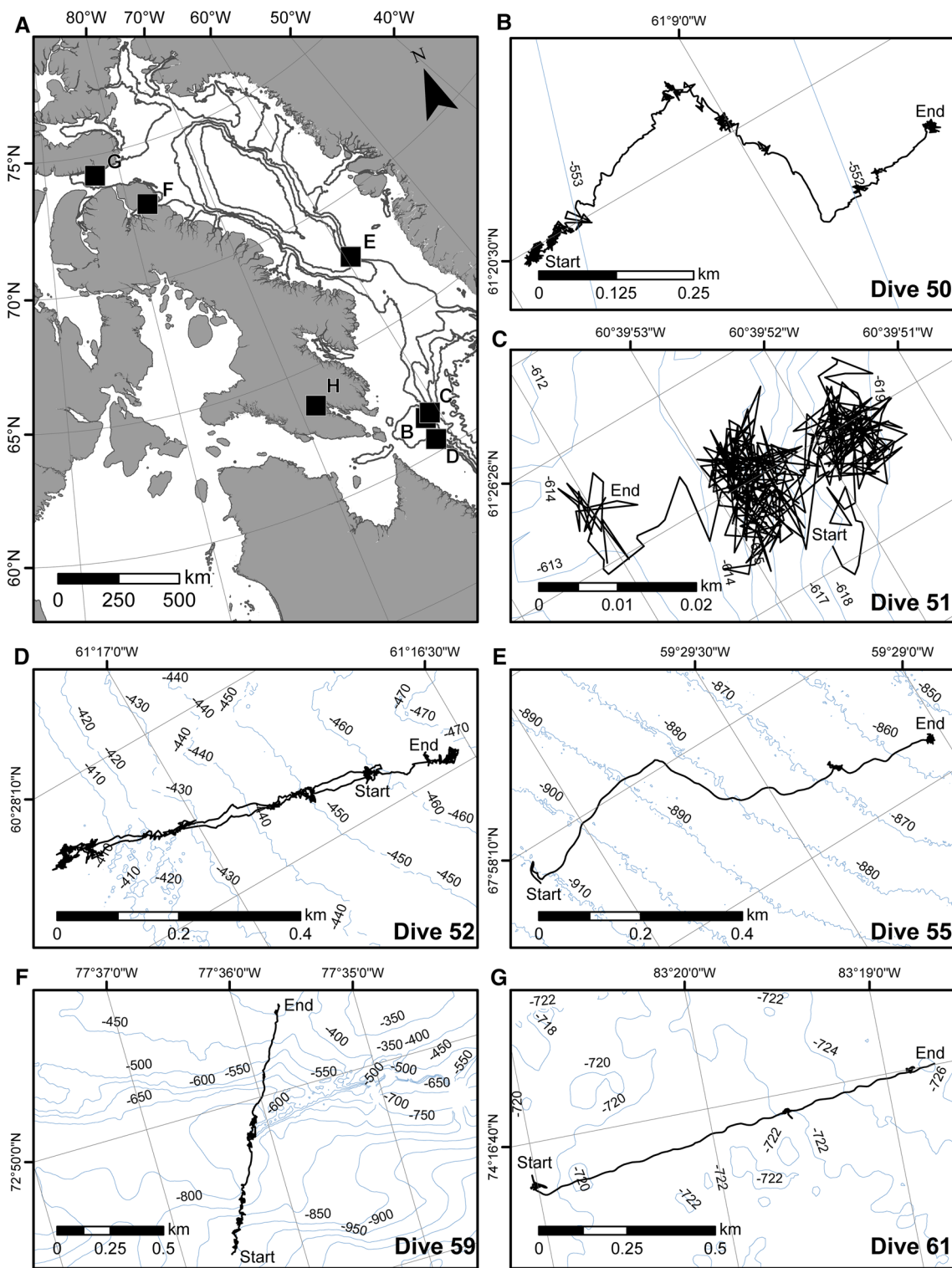


Fig. 2 Locations and transect paths of ROV dives. **A** ROV dive sites. **B** Dive 51, NE Hatton Basin. **C** Dive 51, Hatton Basin 'Primnoa rich'. **D** Dive 52, Saglek Bank. **E** Dive 55, Disko Fan. **F** Dive

59, Pond Inlet. **G** Dive 61, Lancaster Sound. **H** Inner Frobisher Bay (ROV transect not shown). ROV transects visualized using a 50 m PAEK linear smoother

Table 1 Locations of ROV dives in the eastern Canadian Arctic

Dive number and site name	Date	Start/end latitude, longitude	Median FOV (m)	Linear path (m)/smoothed path (m) ^a	Area covered ^a (m ²)	Bottom time	Depth range (m)	Total number of sponges counted
48—Inner Frobisher Bay	25-10-2015	63.6392°, -68.6253°/63.6384°, -68.6303°	—	2463/—	—	4:10	55–147	582 ^b
50—NE Hatton Basin	19-07-2016	61.3415°, -61.1571°/61.3401°, -61.1445°	6.852	6945/4521	30,980	1:48	523–574	1669
51—NE Hatton Basin 'Primnoa rich'	19-07-2016	61.4401°, -60.6645°/61.4402°, -60.6650°	1.384	2020/2003	2771	0:59	592–632	161
52—Saglek Bank	21-07-2016	61.4672°, -61.2781°/60.4670°, -61.2763°	4.620	6978/951	22,873	3:13	361–473	4811
55—Disko Fan	25-07-2016	67.9688°, -59.5032°/67.9675°, -59.4839°	2.301	3031/1678	8866	2:35	853–934	1327
59—Pond Inlet	01-08-2017	72.8274°, -77.6099°/72.8368°, -77.5940°	6.852	6832/4448	12,963	4:52	410–876	4812
61—Lancaster Sound	03-08-2017	74.2778°, -83.3121°/74.2767°, -83.3500°	1.384	4571/2734	6291	3:42	713–748	50

^aThe smoothed path and area covered are based on a 50 m Polynomial Approximation with Exponential Kernel (PAEK) smoother

^bSponges from this dive were counted by Lara Miles at Memorial University. Designation of individuals may have differed

For each dive, all sponges larger than two centimeters in diameter were assigned to morphotypes as an observer saw them enter the FOV of the ROV high definition video. Each sponge was only counted once and was annotated with position data collected by the ROV. Morphotypes were named with knowledge gained from the identification of specimens collected. The primary and secondary substrate throughout the dive was annotated each second using categories derived from Neves et al. (2014): sediments < 2 cm were classified as sand; 2–6 cm sediments were classified as pebbles; 6–26 cm sediments were classified as cobbles; sediments > 26 cm were classified as boulders; and unbroken solid rock was classified as bedrock. Dive 55 included sponges growing on *Keratosis* coral branches. The primary substrate was determined to be the main substrate throughout the whole field of view. A secondary substrate, if present, was noted if more than one substrate type was present but did not fill the field of view. The density of sponge morphotypes (number of each sponge morphotype per m²) was estimated for the entire dive by dividing the number of each individual sponge morphotype counted by the area covered. Richness was calculated for morphotypes by counting the total number of sponge morphotypes seen in a dive. Three indices of diversity were calculated based on morphotypes counted in each dive: the Shannon diversity index (H), Simpson's diversity index (1-D) and the evenness index (J). An ordination of sponge morphotypes in association with both dive site and substrate type using morphotype count data was analyzed by non-metric multidimensional scaling (nMDS) using Bray–Curtis dissimilarity in R using the metaMDS function from the vegan package (Online Resource 2).

Results

Sponges identified from collected material

A total of 161 sponge specimens were collected (Online Resource 1). Of these 36% were collected by Agassiz trawl, 39% by box core, and 25% by ROV. Box cores were used in all ecoregions, but sponges were only present in cores from the Northern Labrador ecoregion. Of the 161 specimens, 60 different sponge species were identified (Table 2, Online Resource 3), 17 of which could only be identified to the genus level but were considered to be unique based on skeleton morphology and/or molecular analysis. In the Northern Labrador MEOW, 115 sponges were collected, in Baffin Bay/Davis Strait 43 sponges were collected, and in the Lancaster Sound marine ecoregion, only three sponges were collected. In the Northern Labrador marine ecoregion (which includes dives 50, 51, and 52), a total of 32 species were identified, and 14 additional sponges were identified to the genus level. In the Baffin Bay/Davis Strait marine ecoregion

Table 2 List of sponge taxa collected in each of the three MEOWs of the eastern Canadian Arctic

Species	NL	BB	LS
Class Demospongiae			
<i>Antho</i> (<i>Acarinia</i>) <i>signata</i> (Topsent, 1904)	+	–	–
<i>Axinella arctica</i> (Vosmaer, 1885)	+	+	–
<i>Biemna variantia</i> (Bowerbank, 1858)	+	–	–
<i>Chondrocladia</i> (<i>Chondrocladia</i>) <i>grandis</i> (Verrill, 1879)	–	+	+
<i>Cladorhiza oxeata</i> Lundbeck, 1905	+	+	–
<i>Craniella</i> cf. <i>cranium</i> (Müller, 1776)	+	–	–
<i>Craniella polyura</i> (Schmidt, 1870)	+	–	–
<i>Craniella</i> sp. Schmidt, 1870	+	–	–
<i>Crella</i> (<i>Yvesia</i>) <i>pyrula</i> (Carter, 1876)	–	+	–
<i>Forcepia</i> (<i>Forcepia</i>) <i>fabricans</i> (Schmidt, 1874)	+	–	–
<i>Geodia barretti</i> Bowerbank, 1858 ^a	+	–	–
<i>Geodia macandrewii</i> Bowerbank, 1858 ^a	+	–	–
<i>Halichondria</i> (<i>Eumastia</i>) <i>sitiens</i> (Schmidt, 1870)	+	–	–
<i>Halichondria</i> (<i>Halichondria</i>) <i>panicea</i> (Pallas, 1766)	+	–	–
<i>Halichondria</i> sp. Fleming, 1828	+	–	–
<i>Haliclona</i> (<i>Flagellia</i>) <i>porosa</i> (Fristedt, 1887)	–	+	–
<i>Haliclona</i> (<i>Haliclona</i>) <i>urceolus</i> (Rathke & Vahl, 1806)	+	+	–
<i>Haliclona</i> sp. 1 Schmidt, 1862	–	+	–
<i>Haliclona</i> sp. 2 Schmidt, 1862	+	–	–
<i>Hymedesmia</i> (<i>Hymedesmia</i>) <i>paupertas</i> (Bowerbank, 1866)	+	–	–
<i>Hymedesmia</i> sp. Bowerbank, 1864	+	–	–
<i>Hymeniacion</i> sp. Bowerbank, 1858	+	–	–
<i>Iophon koltuni</i> (Morozov, Sabirov, & Zimina, 2019)	+	–	–
<i>Iophon piceum</i> (Vosmaer, 1882)	+	–	–
<i>Iotroata affinis</i> (Lundbeck, 1905)	–	+	–
<i>Janulum spinispiculum</i> (Carter, 1876)	+	–	–
<i>Lissodendoryx</i> (<i>Lissodendoryx</i>) <i>complicata</i> (Hansen, 1885)	–	+	–
<i>Lissodendoryx</i> (<i>Lissodendoryx</i>) <i>indistincta</i> (Fristedt, 1887)	+	–	–
<i>Lissodendoryx</i> (<i>Lissodendoryx</i>) <i>lundbecki</i> Topsent, 1913	–	+	–
<i>Lissodendoryx</i> sp. Topsent, 1892	+	–	–
<i>Lycopodina cupressiformis</i> (Carter, 1874)	+	–	–
<i>Lycopodina lycopodium</i> (Levinsen, 1887)	+	–	–
<i>Lycopodina tendali</i> Hestetun, Tompkins-Macdonald & Rapp, 2017	–	+	–
<i>Lycopodina</i> sp. 1 Lundbeck, 1905	–	+	–
<i>Melonanchora elliptica</i> Carter, 1874	+	–	–
<i>Mycale</i> (<i>Anomomycale</i>) <i>titubans</i> (Schmidt, 1870)	+	–	–
<i>Mycale</i> (<i>Mycale</i>) <i>lingua</i> (Bowerbank, 1866)	+	+	–
<i>Phorbas microchelifer</i> (Cabioc, 1968)	–	+	–
<i>Phorbas</i> sp. Duchassaing & Michelotti, 1864	+	–	–
<i>Plicatellopsis bowerbanki</i> (Vosmaer, 1885)	–	+	–
<i>Plocamionida ambigua</i> (Bowerbank, 1866)	+	–	–
<i>Plocamionida</i> sp. Topsent, 1927	+	–	–
<i>Polymastia uberrima</i> (Schmidt, 1870) ^a	+	–	–
<i>Polymastia andrica</i> de Laubenfels, 1949 ^a	–	–	+
<i>Polymastia grimaldii</i> (Topsent, 1913)	+	–	–
<i>Polymastia thielei</i> Koltun, 1964 ^a	+	+	–
<i>Pseudosuberites</i> sp. Topsent, 1896	–	+	–
<i>Quasillina brevis</i> (Bowerbank, 1861)	+	–	–
<i>Spinularia sarsii</i> (Ridley & Dendy, 1886)	+	–	–
<i>Tedania</i> (<i>Tedania</i>) <i>suctorica</i> (Schmidt, 1870)	+	–	–

Table 2 (continued)

Species	NL	BB	LS
<i>Tentorium semisuberites</i> (Schmidt, 1870)	+	+	–
<i>Tethya norvegica</i> Bowerbank, 1872	+	–	–
<i>Tetilla sibirica</i> (Fristedt, 1887)	+	–	–
<i>Thenea</i> cf. <i>muricata</i> (Bowerbank, 1858)	–	+	–
<i>Thenea</i> sp. 1 Gray, 1867	+	–	–
<i>Thenea</i> sp. 2 Gray, 1867	+	+	–
Class Calcarea			
Sycettidae cf. <i>Sycon</i> Dendy, 1893	+	+	–
<i>Sycinula</i> cf. <i>penicillata</i> Schmidt, 1869	+	–	–
<i>Sycon</i> sp. Risso, 1827	+	–	–
Class Hexactinellida			
<i>Asconema</i> spp. Kent, 1870	+	+	–

± Symbols indicate the occurrence/ absence of taxa, bold species names are those counted as morphotypes in ROV video analysis

^aDenotes multiple species which make up single morphotypes within the same genus (NL Northern Labrador, BB Baffin Bay, LS Lancaster sound)

(which includes dives 55 and 59), a total of 16 species were identified (six of which also occurred in Northern Labrador) and six additional sponges were identified to genus (three of which also occurred in Northern Labrador). In the Lancaster Sound marine ecoregion, two species of sponge were identified, one of which was also collected in the Baffin Bay/Davis Strait marine ecoregion. Forty-three specimens were not identified, either because of spicule contamination during the collection process, or because the specimen was too damaged. Specimens which were unable to be identified are listed as “unknown” in Online Resource 1.

Using the Jaccard similarity index, sponges identified from Frobisher Bay were 13% similar to those in the north Labrador Sea (shelf) and 13.5% similar to those in Disko Fan (Table 3). Species identified from the north Labrador Sea (shelf) were 28% similar to sponges in Disko Fan. Only 12.5% of the sponges identified from Disko Fan were similar to those from northern Baffin Bay, while 33.3% of sponges identified from Pond Inlet were similar to those identified in Lancaster Sound.

Habitat types in each dive site

Each ROV dive occurred over different types of substrate (Fig. 3). The primary and secondary sediment types in each dive, as well as the density of sponges in 100 m segments along the linear ROV path, are shown in Fig. 4. Although video from the area was not analyzed, many specimens were collected from Frobisher Bay, which included a dive in the inner bay (dive 48) that consisted of soft bottom habitat with bedrock outcrops. The soft bottom regions were dominated by *Tetilla sibirica* and *Iophon koltoni*, and the bedrock outcrops by *Mycale lingua* and *I. koltoni* (Fig. 3a). The Northern Labrador Sea sites, NE Hatton Basin (dive 50), Hatton Basin ‘*Primnoa rich*’ (dive 51) and Saglek Bank (dive 52), had the most heterogeneous substrates consisting of patches of sand and rocks ranging in size from small pebbles to large boulders (Figs. 3b and 4a–c). Disko Fan (dive 55) had a sand or mud seafloor baffled by dense bushes of *Keratoisis* corals (Figs. 3c and 4d). The dive site at Pond Inlet (dive 59) had mixed

Table 3 Jaccard similarity coefficient values showing percent similarity of species identified by ecoregion

Sampling location	NLS (Frobisher Bay)	NLS (Shelf)	BB (Disko Fan)	BB (North)	Pond Inlet	Lancaster Sound
NLS (Frobisher Bay)	100					
NLS (Shelf)	13	100				
BB (Disko Fan)	13.5	28	100			
BB (North)	11.1	6.9	12.5	100		
Pond Inlet	3.6	0	6.3	0	100	
Lancaster Sound	0	0	0	0	33.3	100

NLS North Labrador Sea, BB Baffin Bay

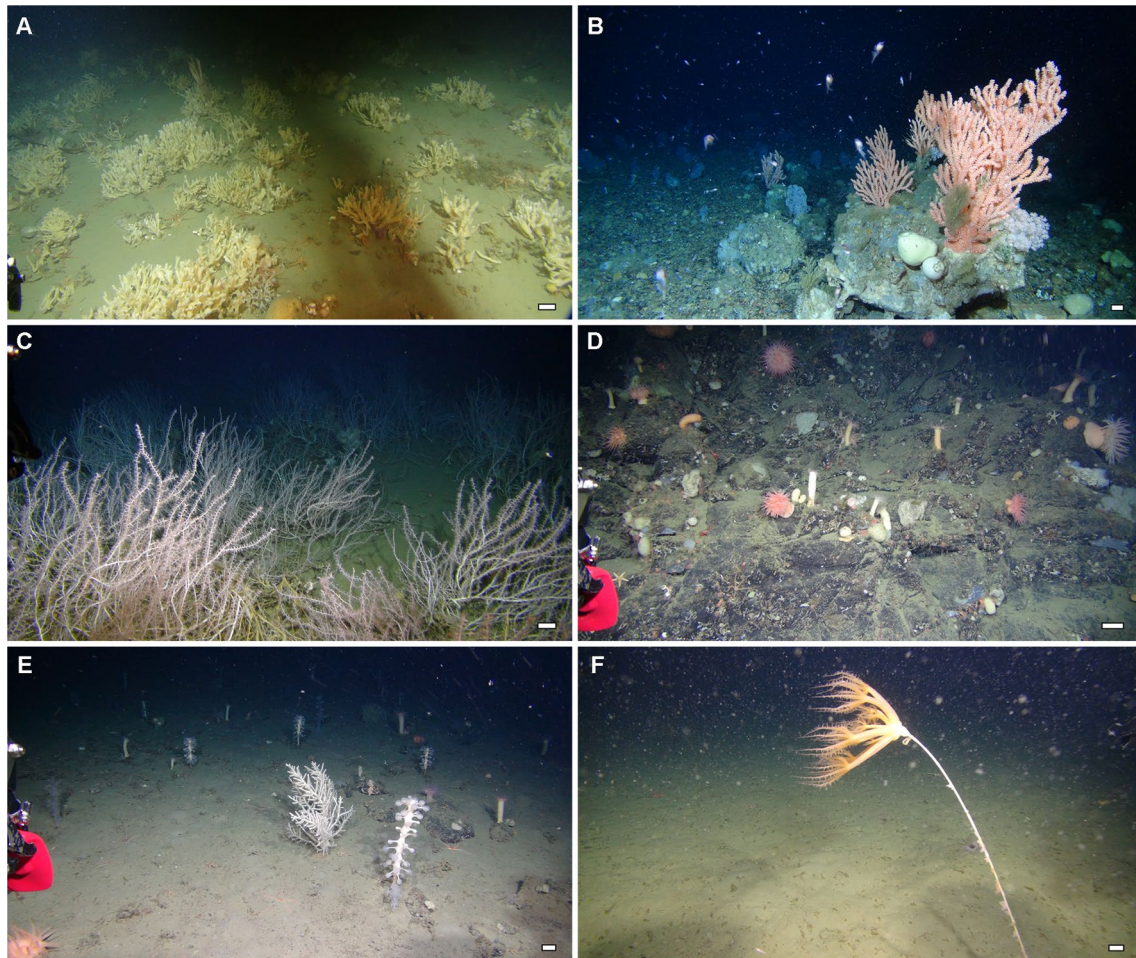


Fig. 3 Characteristic seafloor types at dive sites. **A** Soft sediment and *Lophon kolluni* sponge gardens of inner Frobisher Bay (Dive 48). **B** Rocky substrate in the North Labrador Sea (Dive 52). **C** Sandy bottom with dense *Keratoisis* coral forests in Disko Fan (Dive 55). **D**

Steep bedrock cliff of Pond Inlet (Dive 59). **E** Sand flat in Pond Inlet with carnivorous sponges and anemones (Dive 59). **F** Sand substrate with *Umbellula* sea pen (Dive 61). Scale bar is 6 cm. Images are courtesy of ArcticNet/CSSF/DFO

substrate with regions of steep bedrock walls and shelves with fine sand (Figs. 3d, e and 4e). Encrusting sponges were common on bedrock while large carnivorous sponges and anemones were seen in softer sediments. Lancaster Sound, dive 61, consisted of homogeneous soft sediment, and while there were many large *Umbellula* sea pens, few sponges were seen throughout the dive (Figs. 3f and 4f). An nMDS ordination of sponge morphotypes revealed that morphotypes cluster by dive location rather than by substrate based on a Bray–Curtis dissimilarity index of count data (Online Resource 2), but some substrates were only present in certain dives (i.e., *Keratoisis* coral in dive 55 and bedrock in dive 59).

Sponge morphotypes identified from ROV video

A total of 12,830 individual sponges were counted from the ROV video and 27 distinct sponge morphotypes were identified and used to calculate diversity between sites. However, only 15 morphotypes were routinely encountered and could be reliably identified at all sites (Fig. 5). The remaining 12 morphotypes were uncommon and could not be identified to a taxon, and thus are considered together as a category of ‘unknown’ sponges when calculating density (Online Resource 4). The most common sponge morphotypes encountered are shown in Fig. 5 and include: *Geodia* spp., a morphotype including at least two species, *Geodia barretti* and *Geodia macandrewii*; yellow encrusting sponges, likely *Hexadella* sp. (McIntyre et al. 2016) or *Aplysilla sulfurea* (ICES 2009); white encrusting sponges, representing a range of species including collected species such as *Janulum*

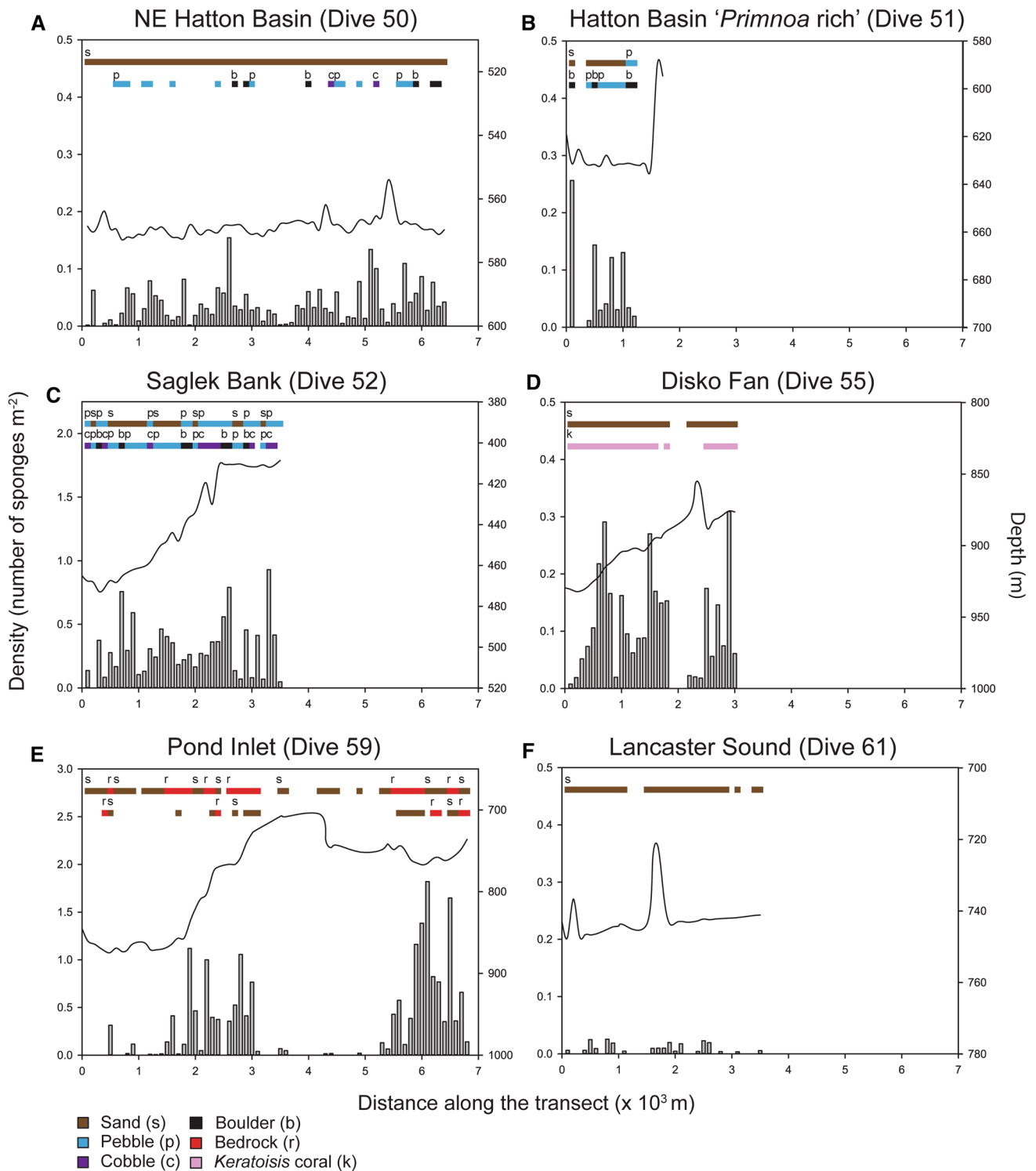


Fig. 4 Substrate types, density, and depth of sponges counted from ROV video along the linear distance covered. Primary substrate is noted by colored squares at the top of the graph, and secondary substrate type is noted below. Substrate transitions are shown by letters above primary and secondary substrate bars. Blank sections of substrate bars are due to sections of transect when the bottom was not visible. **A** Dive 50 NE Hatton Basin (truncated to 6500 m length). **B**

Dive 51 Hatton Basin 'Primnoa rich' (truncated to 1200 m length). **C** Dive 52 Saglek Bank (truncated to 3500 m length). **D** Dive 55 Disko Fan (truncated to 3000 m length). **E** Dive 59 Pond Inlet (truncated to 6800 m length). **F** Dive 61 Lancaster Sound (truncated to 3700 m length). Density of sponges was calculated at 100 m intervals along the linear dive distance

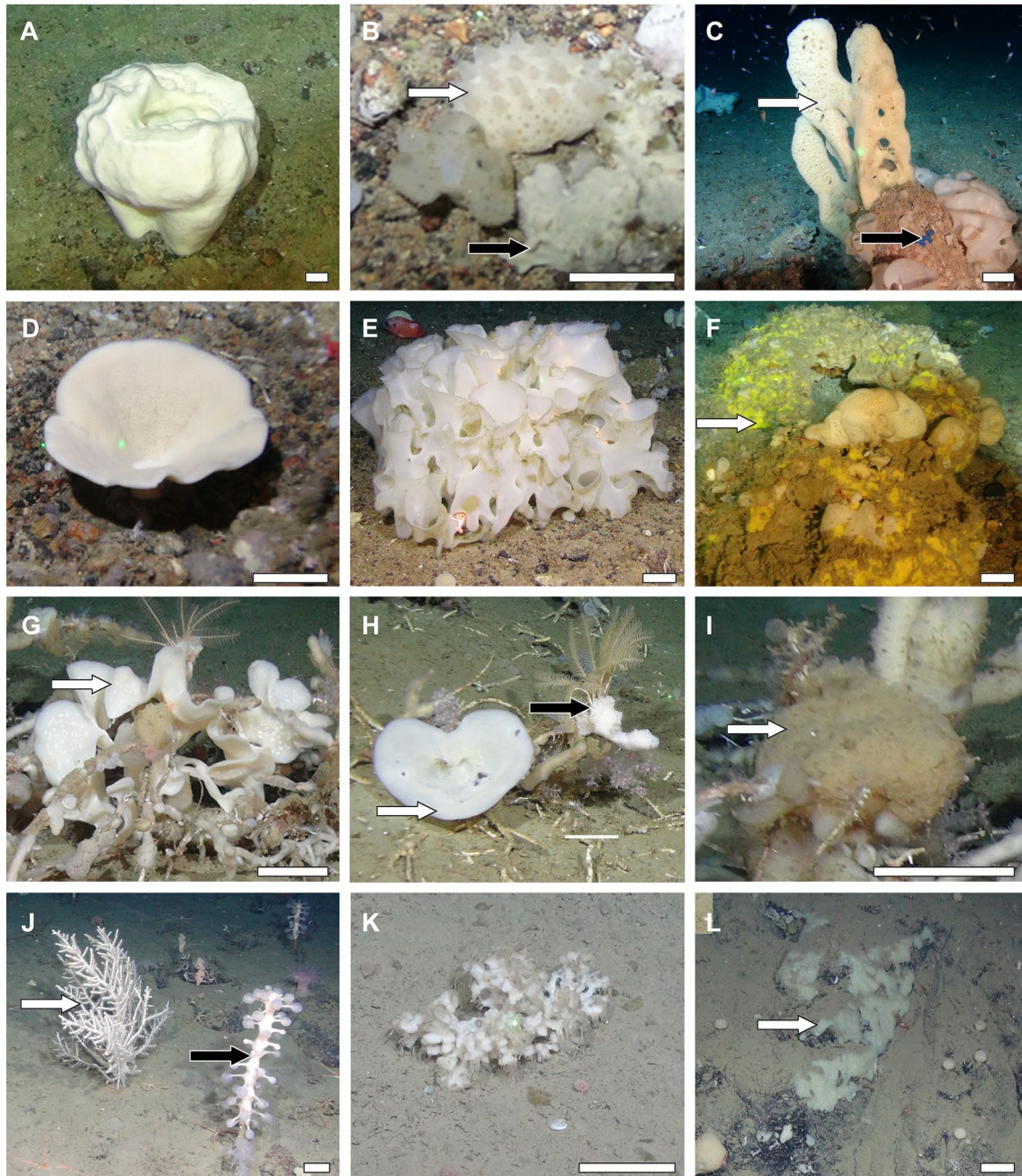


Fig. 5 Common sponge morphotypes seen during ROV dives. **A** *Geodia* spp. **B** *Polymastia* spp. (white arrow), White encrusting (*Janulum spinispiculum*) (black arrow). **C** *Mycale lingua* (white arrow), *Hymedesmia* (*Hymedesmia*) *paupertas* (black arrow). **D** *Axinella arctica*. **E** *Asconema* spp. **F** Yellow encrusting (white arrow). **G** *Hali-*

clona sp. **H** *Plicatellopsis bowerbanki* (white arrow), *Phorbas microchelifer* (black arrow). **I** *Iotrata affinis* (white arrow). **J** *Cladorhiza oxeata* (white arrow), *Chondrocladia grandis* (black arrow). **K** *Lisosodendoryx lundbecki*. **L** White encrusting (white arrow). Scale bars 6 cm

spinispiculum, *Melonanchora elliptica*, *Antho* (*Acarinia*) *signata*, *Tedania* (*Tedania*) *suctorica*, and *Pseudosuberites* sp. A *Polymastia* spp. morphotype was seen at all sites and represents several species (Table 2).

Dive sites had different diversity indices (Table 4). Pond Inlet (dive 59) was the richest, with 17 different sponge morphotypes, but had low diversity ($H=1.535$, $1-D=0.659$) and

evenness ($J=0.542$). Sites in the North Labrador Sea (dives 50, 51, and 52) contained between eight and twelve morphotypes per dive and had high diversity ($H=1.680$ – 1.896 , $1-D=0.777$ – 0.821) and evenness ($J=0.763$ – 0.808). At the Disko Fan site (dive 55) only 7 morphotypes were counted, and there was low diversity ($H=1.273$, $1-D=0.622$) and low evenness ($J=0.654$). Lancaster Sound (dive 61) was the least

Table 4 Diversity indices for each ROV dive site based on counted sponge morphotypes

Index	Dive number					
	50 (<i>N</i> =1669)	51 (<i>N</i> =161)	52 (<i>N</i> =4811)	55 (<i>N</i> =1327)	59 (<i>N</i> =4812)	61 (<i>N</i> =50)
Richness (<i>S</i>)	12	8	10	7	17	2
Shannon's diversity index (<i>H</i>)	1.896	1.680	1.827	1.273	1.535	0.692
Simpson's Index of diversity (1- <i>D</i>)	0.821	0.777	0.820	0.622	0.659	0.509
Evenness (<i>J</i>)	0.763	0.808	0.793	0.654	0.542	0.999

diverse ($H=0.692$, $1-D=0.509$) and the two morphotypes encountered were the most evenly distributed ($J=0.999$).

Dives 50, 51, and 52 in the Northern Labrador MEOW had similar composition of morphotypes where *Geodia* spp., *Polymastia* spp., and *Asconema* spp. were most common (Fig. 6a–c). Dive 55 on the western Greenland slope in the Baffin Bay MEOW was composed mostly of sponges growing on *Keratoisis* corals and some growing on soft sediments. There, *Asconema* spp. and the fan-shaped *Plicatellopsis bowerbanki* were most common (Fig. 6d). Dive 59, the nearshore site near Pond Inlet in the Baffin Bay MEOW was composed of encrusting species growing on

bedrock walls and large carnivorous sponges anchored in soft sediments, with *Polymastia* spp. morphotype the most common (Fig. 6e). Dive 61 had the most homogeneous substrate and only two sponge morphotypes were seen (Fig. 6f).

The density of commonly encountered morphotypes is given in Table 5. The overall density of sponges was highest in dive 59 (0.371 ind m^{-2}) and reasonably high in dive 52 (0.210 ind m^{-2}), while the lowest densities were encountered in dive 61 (0.008 ind m^{-2}) and dive 51 (0.036 ind m^{-2}).

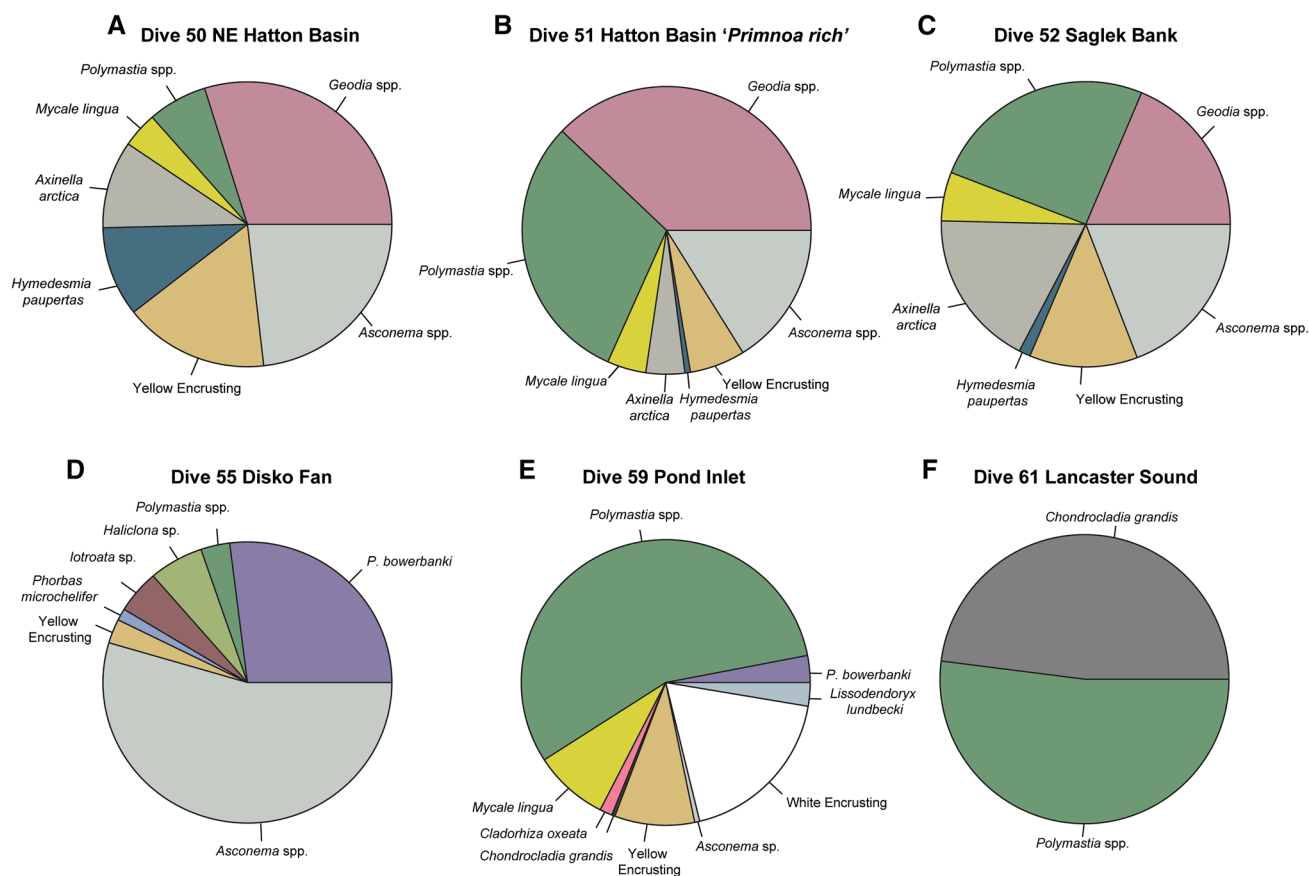


Fig. 6 Pie-charts showing the percent of total abundance of sponge morphotypes identified in each ROV dive. **A** Dive 50 NE Hatton Basin. **B** Dive 51 Hatton Basin *Primnoa* rich. **C** Dive 52 Saglek Bank. **D** Dive 55 Disko Fan. **E** Dive 59 Pond Inlet. **F** Dive 61 Lancaster Sound

Table 5 Sponge densities (individuals m⁻²) for most common morphotypes in each ROV transect, and the overall sponge density for each dive

	Dive number					
	50	51	52	55	59	61
<i>Polymastia</i> spp.	0.004	0.018	0.053	0.005	0.201	0.004
<i>Asconema</i> spp.	0.012	0.009	0.040	0.082	0.002	–
Yellow encrusting	0.009	0.004	0.025	0.004	0.032	–
<i>Mycale lingua</i>	0.002	0.003	0.012	–	0.030	–
<i>Geodia</i> spp.	0.016	0.002	0.039	–	–	–
<i>Axinella arctica</i>	0.005	0.003	0.037	–	–	–
<i>Hymedesmia paupertas</i>	0.005	0.001	0.003	–	–	–
<i>Plicatellopsis bowerbanki</i>	–	–	–	0.040	0.011	–
<i>Iotroata affinis</i>	–	–	–	0.007	–	–
<i>Haliclona</i> sp.	–	–	–	0.009	–	–
<i>Phorbas microchelifer</i>	–	–	–	0.002	–	–
<i>Cladorhiza oxeata</i>	–	–	–	–	0.001	–
<i>Chondrocladia grandis</i>	–	–	–	–	0.005	0.004
White encrusting	–	–	–	–	0.066	–
<i>Lissodendoryx lundbecki</i>	–	–	–	–	0.010	–
Unknown sponges	0.001	–	0.001	–	0.013	–
Total density	0.054	0.036	0.210	0.150	0.371	0.008

Densities are calculated using a smoothed ROV path

Discussion

This study used specimens collected from trawls, box cores, and by ROV and used underwater video imagery to describe species richness, density, and diversity of sponges in three marine ecoregions of the eastern Canadian Arctic. Although trawls and box cores did not collect a representative sample of all morphotypes seen in ROV video transects, collected specimens were used to associate species with morphotypes seen in underwater imagery.

Sponge species richness and distribution in the Canadian Arctic

Species richness of the specimens collected was highest in the Northern Labrador MEOW (46 species) and lowest in Lancaster Sound (two species), while the density and number of sponge morphotypes counted from ROV video was highest in a site in the Baffin Bay/Davis Strait MEOW, dive 59 Pond Inlet (17 morphotypes). Most specimens (115 individuals) were collected in Northern Labrador, particularly in Frobisher Bay (Dinn et al. 2019). Sponge species richness could only be assessed based on specimens that were identified by spicules or DNA, but from ROV video annotation it was clear that in each region there were sponge morphotypes that were not collected, such as the yellow encrusting morphotype and twelve others that were not ultimately identified (Online Resource 4). In total 60 unique sponge taxa were identified, increasing the number of sponge records from Northern Labrador to 46, Baffin Bay/Davis Strait to

29, and the two sponge species collected in Lancaster Sound were the first records georeferenced from the ecoregion (Van Soest et al. 2019). The number of sponge species described from these northeastern Canadian MEOWs remains an order of magnitude lower than reported from similar latitude regions in the eastern Atlantic (Van Soest et al. 2012, 2019).

A growing body of research describes sponge richness in the Canadian Arctic (Tompkins-Macdonald et al. 2017; Baker et al. 2018; Dinn and Leys 2018; Murillo et al. 2018; Dinn et al. 2019, 2020). Collections aboard the *CCGS Amundsen* targeted hard-bottom environments using smaller gear which are not used in annual surveys that rely on large fisheries trawls (Kenchington et al. 2011a; Murillo et al. 2018). Only six specimens were collected shallower than 100 m during this three-year sampling program, so sponge communities within the SCUBA zone (<60 m) of the Canadian Arctic and sub-Arctic ecoregions are underrepresented in the present collections. Murillo et al. (2018) reported 93 sponge species from Northern Labrador, Baffin Bay/Davis Strait, and the Hudson Bay Complex marine ecoregions (Spalding et al. 2007) using large trawl surveys, but the taxonomic and distribution records are not reflected in a particular biodiversity database. It is therefore difficult to track the true species richness for a given region in eastern Canada.

From both ROV video annotation and collections, some species were only recorded from a single ecoregion. *Hymedesmia* (*Hymedesmia*) *paupertas*, *Geodia barretti*, and *Geodia macandrewii* were only collected and recorded from the Northern Labrador sites, and *Plicatellopsis bowerbanki*, *Lissodendoryx lundbecki*, *Iotroata* sp. and *Phorbas*

microchelifer were only collected in the Baffin Bay/Davis Strait MEOW. The *Polymastia* spp. morphotype was the only morphotype seen in all sites, while *Asconema* sp. and the unidentified ‘Yellow encrusting’ morphotype were recorded from five of six dives. The *Polymastia* spp. morphotype was found to represent at least three species, *P. uberrima*, *P. andrica*, and *P. thielei*. Another species *P. grimaldii* was only found in Frobisher Bay and is generally larger than the other congeners. Although *P. andrica* was the only *Polymastia* species identified from a trawl in Lancaster Sound, it is not known whether all morphotypes counted in the ROV imagery from that site were a single species as none were collected during the dive. Cup and vase-shaped sponges encountered in the visual survey in the Northern Labrador Sea were considered as the *Axinella arctica* morphotype, and similarly shaped sponges from Baffin Bay/Davis Strait were considered to be the *Plicatellopsis bowerbanki* morphotype as representative samples of each were identified based on spicule and molecular taxonomy from the respective ecoregions. *Plicatellopsis bowerbanki* ranges from the Gulf of St. Lawrence to the high-Arctic (Lambe 1900; Brunel et al. 1998; Dinn et al. 2020), suggesting that the dive sites in the north Labrador Sea may have also included *P. bowerbanki*, but the morphotype may have been confused with *A. arctica* or another fan-shaped species. Species-level distinctions of certain morphotypes were only possible because voucher specimens were collected and taxonomically identified, however, it is possible that any given morphotype may represent a mixture of species with similar growth forms.

Use of multiple sampling methodologies

A physical sample for taxonomic analysis was not collected for each morphotype seen in video. Many collected sponges were also too small (< 2 cm) to be accurately identified from the HD video, and most small and encrusting species (e.g., *T. norvegica*, *A. titubans*, *H. paupertas*) were collected using box core rather than ROV or Agassiz trawl. In a recent report from the Sea of Okhotsk, Downey et al. (2018) found that small Agassiz trawls were the most successful method for specimen collections, where over 90% of species morphotypes identified in the region were collected by this type of net. In eastern Canada, sponges are routinely collected by Alfredo, Campelen, Cosmos, and *Nephrops* trawls, which are larger and are towed for longer than Agassiz trawls (Kenchington et al. 2010, 2011a; Knudby et al. 2013; Murillo et al. 2018). A number of sponge species that we collected in box cores were not previously recorded by decades of government trawl surveys (Murillo et al. 2018). Species that were not reported before from the region include *H. (H.) paupertas*, *P. ambigua*, *A.(A.) signata*, *L. lycopodium*, *Q. brevis*, *M.(A.) titubans*, and *H.(E.) sitiens*. Other species such as

P. microchelifer, and *I. affinis* were not previously recorded from the region and were only collected here by ROV. Overall sponge catchability in trawls is low, mainly due to the small size and fragile nature of many species (Wassenberg et al. 2002). Accounts of catchability of sponges using a trawl net and camera suggest that sponges less than 30 cm in size have catchability of less than 20%, and overall sponge catchability for all size classes was about 14% (Wassenberg et al. 2002). Large sponges that pass into the net are often broken into pieces (Wassenberg et al. 2002; Kenchington et al. 2011b) which can give a biased account of sponge abundance and biomass. Sponge catchability is also understandably low in box cores due to the limited area sampled by a single core and the likelihood of a particular core landing in a patch of sponge (Kenchington et al. 2011b). In our study, we were unable to use box cores and trawls at all sites. Dive 59 (Pond Inlet) occurred over a steep bedrock cliff which limited sampling methods to ROV only. Box cores only successfully collected sponges in Northern Labrador but not in the other ecoregions, possibly due to the heterogeneous substrates in Northern Labrador which may lead to less patchy sponge communities and thus a higher likelihood of the box landing in a patch of sponge (Bergquist and Sinclair 1968; Bergquist 1978; Pansini and Musso 1991; Roy et al. 2014). Box cores also collected more sponge taxa than the other collection methods, particularly small encrusting species which were not collected by trawls and were difficult to collect by ROV. Therefore, differences in species similarity between sites could be due to catchability of sponges with different gear types on varied sediment, rather than a true absence of the species occurrence in a given area.

The ROV used in this study benefited from a neutral angle FOV compared to a bird’s eye view seen in towed camera surveys (Beazley and Kenchington 2015; McIntyre et al. 2016). In this type of ROV survey, the diagnostic growth forms of sponge species are more readily seen, however, the area covered becomes difficult to estimate in non-linear transects. The dive sites chosen may also not be representative of the actual biodiversity of a MEOW, where the area surveyed may over or underrepresent the biodiversity of the whole region. Dives which occurred previously in Frobisher Bay, Navy Board Inlet, and Home Bay were not included because they were analyzed separately (Miles and Edinger 2016), and the ROV laser was modified prior to dives in 2016. The video analysis methodology was attempted for Dive 48, Frobisher Bay, despite the modifications to the ROV lasers, but the sprawling, finger-like growth form of the most abundant sponge *Iophon koltuni* was problematic as counting individual sponges was subjective (Dinn et al. 2019). Future video analysis work may benefit from assessing area covered by particular sponge morphotypes rather than by counting individuals.

Sponge species span ecoregions in the Canadian Arctic

Sponges in the eastern Canadian Arctic appear to group into assemblages as reported by Murillo et al. (2018). Although the Davis Strait sill appears to separate some higher Arctic and southern Baffin shelf assemblages, *P. thielei* and *Asconema* spp. were collected in that study and appear to group in an assemblage which extends from the northern tip of Labrador to Jones Sound (Murillo et al. 2018). This suggests that sponge communities may not be restricted to particular ecoregions. While our surveys suggest that there may be some overlap in species identified between regions, such as the North Labrador Sea and Baffin Bay (Disko Fan) and between Pont Inlet and Lancaster Sound, firm conclusions about comparative diversity cannot be made due to the lack of consistent sampling effort between sites. Using morphotypes identified from video to compare sponge community structure is an unbiased method to compare sponge habitats that are difficult to sample, however, the certainty of species-level identifications is low, and site-wise comparisons are difficult when ROV transects are not standardized. As the transects in this study did not maintain a consistent FOV between sites, smaller sponges may not have been accurately counted in all dives which could affect the calculated densities.

The Davis Strait sill occurs southeast of the most easterly portion of Baffin Island, separating the deep water of Baffin Bay and the Labrador Sea (Johnson et al. 1969; Azetsu-Scott et al. 2012). This sill separates the Northern Labrador and Baffin Bay/Davis Strait MEOWs (Spalding et al. 2007), yet from the collections here and reports of some Polymastid (Plotkin et al. 2018) and Cladhorizid (Hestetun et al. 2017) sponges, and a species of *Plicatellopsis* (Dinn et al. 2020), the sill itself does not appear to be a barrier to distribution of some species. Species like *C. grandis* are found in northern Baffin Bay, but are also found on the Grand Banks and Gulf of St. Lawrence to the south (Hestetun et al. 2017). *C. grandis* is a peculiar sponge, not only because it is carnivorous thus has particular food requirements, but it also has extensive root tufts to anchor it into the sediment (Vacelet and Boury-Esnault 1995; Hestetun et al. 2017) suggesting that particular soft sediment habitat is required for this species. *P. andrica* and *P. thielei* have been reported previously from the Grand banks (Plotkin et al. 2018) but were collected here further north of the Davis Strait sill into Baffin Bay. However, *P. uberrima* was not collected here north of the sill, and Plotkin et al. (2018) do not report a northward distribution in eastern Canada, although the species does extend north of Svalbard in the NE Atlantic. The *Polymastia* spp. morphotype was the most abundant in the Pond Inlet (dive 59) dive site, but the morphotype likely represented several different species. *Plicatellopsis bowerbanki* was

recently reported from the Gulf of St. Lawrence (Dinn et al. 2020) and was also collected here in northern Baffin Bay. Confirmation of species identity from ROV video requires collection of all morphotypes, which is not always possible given time constraints of individual dives.

Sponge habitat quantification and vulnerable sponge aggregations

Sponge distributions can be influenced by a suite of oceanographic features. Large-scale environmental gradients of megabenthic community characteristics are not clear in the Canadian Arctic based on depth and surface productivity (Roy et al. 2014). Rather, meso-scale processes likely shape the benthic food supply and community structure throughout the region (Roy et al. 2014), leading to disparate benthic communities which might otherwise be predictably similar. Sponge aggregations in the North Atlantic have been shown to occur in areas of strong bottom currents (Davison et al. 2019) and high near-bed suspended particulate concentrations (Roberts et al. 2018). Furthermore, most sponges preferentially settle on hard substrates which are not consistently distributed throughout the Canadian Arctic (Bergquist and Sinclair 1968; Ginn et al. 2000; Roy et al. 2014). It is also likely that the orientation of sediment in relation to oceanographic flow regimes and food supply processes dictate the settlement and survival of sponges even more than substrate type itself (Bergquist 1978). From these dives it is apparent that bottom type varies along the eastern Canadian exclusive economic zone, but it is not clear where transition areas between these habitat types occur. Sponges also appear to grow on a variety of substrates in varied densities as seen from the ROV video. Based on non-metric multidimensional scaling of the morphotype count data, morphotypes appear to group by dive location rather than by substrate. Since some substrates were only present in single dive sites, the analysis of associations of substrate and morphotype warrant additional study with standardized replicate transects. As video was not collected from all sample sites, and substrate type at each site was also not consistently quantified from box cores, the prediction of sponge species occurrence based on substrate alone requires future study.

Areas of high sponge abundance and biodiversity, i.e., “sponge grounds” (Klitgaard and Tendal 2004; Hogg et al. 2010), are of interest to fishers and managers to protect vulnerable habitat and to reduce unwanted bycatch. Since the 2006 United Nations General Assembly Resolution 61/105 (UNGA, 2006) which calls upon regional fisheries management organizations to implement measures to identify and protect species considered to form vulnerable marine ecosystems (VME), the Canadian Government has been attempting to delineate where VME species occur and implement measures to protect these areas from fishing efforts (Kennington

et al. 2015). Large catches of *Geodia* species are common in the eastern Canadian Arctic and Hudson Bay complex, with some catches exceeding 600 kg per 15-min trawl tow (Kenchington et al. 2010). Several species of sponge found in the eastern Canadian Arctic are considered VME indicator species: those that form deep-sea sponge aggregations (*Geodia* spp., *Stelletta* spp., *Thenea muricata*, etc.), sponges that can form hard-bottom sponge gardens (*Mycale lingua*, *Polymastia* spp., *Axinella* sp., *Craniella cranium*, etc.), and glass sponges (*Asconema foliatum*) have all been reported (Hogg et al. 2010; Beazley and Kenchington 2015; Murillo et al. 2018) and all but *Stelletta* spp. were collected here. It is therefore clear that vulnerable species exist throughout much of the eastern Canadian shelf, especially since *Polymastia* species occur within each of the three MEOWs. Dense gardens of the sponge *Iophon koltuni* were described from Frobisher Bay previously (Dinn et al. 2019), but *Iophon* is not currently considered as a VME indicator taxon. Sponge densities calculated from the visual survey are generally lower than the density of VME species collected in the Rosemary Bank seamount MPA in the NE Atlantic, where sponge densities from video could reach 1.2 ind. m⁻² for *Craniella longipilis* (McIntyre et al. 2016), but the *Polymastia* spp. morphotype was particularly dense in the Pond Inlet dive site at 0.201 ind. m⁻², suggesting similar sites with steep rock walls in glacierized fjords may represent an important habitat for this and other species.

Conclusions

Our descriptions of sponge communities and biodiversity based on three different collection methodologies paired with underwater imagery provided a comprehensive lens with which to view the interaction of biogeography and habitat. We also attempted to quantify sponges from non-standard underwater transects to estimate density. The collection and identification methods used here are useful tools to understand benthic biodiversity of sessile animals such as sponges. From this work, it is clear that the marine ecoregions defined in eastern Canada may not accurately separate sponge assemblages despite potential biogeographic barriers. The discrepancies between species that were collected and morphotypes counted, and the presence of taxonomically ambiguous morphotypes seen in the ROV video suggest that multiple sampling methods are required to accurately assess sponge biodiversity in eastern Canada. Although this work increases the known biodiversity of the region, more than 40 specimens remain unidentified, and so the total biodiversity of the region is still underestimated. Recent fisheries closures in the eastern Canadian Arctic and sub-Arctic based on sponge and coral biomass alone

emphasize the need to better describe the biodiversity of these ecologically important areas in the Canadian North.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

References

- Ackers RG, Moss D, Picton BE, Stone SMK, Morrow CC (2007) Sponges of the British Isles—a colour guide and working document, 1992nd edn. Marine Conservation Society, Belfast
- Archambault P, Snelgrove PVR, Fisher JAD et al (2010) From sea to sea: Canada's three oceans of biodiversity. *PLoS ONE* 5:e12182. <https://doi.org/10.1371/journal.pone.0012182>
- Azetsu-Scott K, Petrie B, Yeats P, Lee C (2012) Composition and fluxes of freshwater through Davis Strait using multiple chemical tracers. *J Geophys Res Ocean* 117(C12):1–12. <https://doi.org/10.1029/2012JC008172>
- Baker E, Odenthal B, Tompkins G, Walkusz W, Siferd T (2018) Sponges from the 2010–2014 Paamiut Multispecies Trawl Surveys, Eastern Arctic and SubArctic: Class Demospongiae, subclass Heteroscleromorpha, order Poecilosclerida, families *Crelidae* and *Myxillidae*. *Can Tech Rep Fish Aquat Sci* 3253:76
- Beazley LI, Kenchington EL (2015) Epibenthic megafauna of the Flemish pass and sackville spur (Northwest Atlantic) Identified From *in situ* benthic image transects. *Can Tech Rep Fish Aquat Sci* 3127:496
- Beazley LI, Kenchington EL, Murillo FJ, Sacau MD (2013) Deep-sea sponge grounds enhance diversity and abundance of epibenthic megafauna in the Northwest Atlantic. *ICES J Mar Sci* 70:1471–1490. <https://doi.org/10.1093/icesjms/fst124>
- Bell JJ, Mcgrath E, Biggerstaff A et al (2015) Global conservation status of sponges. *Conserv Biol* 29:42–53. <https://doi.org/10.1111/cobi.12447>
- Bergquist PR (1978) Sponges. University of California Press, Berkeley & Los Angeles
- Bergquist PR, Sinclair ME (1968) The morphology and behaviour of larvae of some intertidal sponges. *New Zeal J Mar Freshw Res* 2:426–437. <https://doi.org/10.1080/00288330.1968.9515247>
- Bett BJ, Rice AL (1992) The influence of hexactinellid sponge (*Phoronema carpenteri*) spicules on the patchy distribution of macrobenthos in the porcupine seabight (bathyal ne atlantic). *Ophelia* 36:217–226. <https://doi.org/10.1080/00785326.1992.10430372>

- Brunel P, Bossé L, Lamarche G (1998) Catalogue of the marine invertebrates of the Estuary and Gulf of Saint Lawrence. Can Spec Publi Fish Aquat Sci. <https://doi.org/10.1139/9780660803661>
- Buhl-Mortensen L, Vanreusel A, Gooday AJ et al (2010) Biological structures as a source of habitat heterogeneity and biodiversity on the deep ocean margins. *Mar Ecol* 31:21–50. <https://doi.org/10.1111/j.1439-0485.2010.00359.x>
- Cárdenas P (2010) Phylogeny, taxonomy and evolution of the Astrophorida (Porifera, Demospongiae). PhD Thesis. University of Bergen
- Christiansen JS, Mecklenburg CW, Karamushko OV (2014) Arctic marine fishes and their fisheries in light of global change. *Glob Chang Biol* 20:352–359. <https://doi.org/10.1111/gcb.12395>
- Christiansen JS, Reist JD, Brown RJ et al (2013) Arctic Biodiversity Assessment Chapter 6. Fishes. <https://arcticbiodiversity.is>. Accessed 19 May 2020
- Chu JWF, Leys SP (2010) High resolution mapping of community structure in three glass sponge reefs (Porifera, Hexactinellida). *Mar Ecol Prog Ser* 417:97–113. <https://doi.org/10.3354/meps08794>
- Clarke A, Drinkwater KFR (2006) The Canadian encyclopedia. Labrador sea. <https://www.thecanadianencyclopedia.com/en/article/labrador-sea>. Accessed 14 Feb 2018
- Coad BW, Reist JD (2019) Marine fishes of Arctic Canada. University of Toronto Press, Toronto
- Cullain N, McIver R, Schmidt AL, Lotze HK (2018) Spatial variation of macrofaunal communities associated with *Zostera marina* beds across three biogeographic regions in Atlantic Canada. *Estuaries Coasts* 41:1381–1396. <https://doi.org/10.1007/s12237-017-0354-7>
- Curtis MA (1975) The marine benthos of Arctic and sub-Arctic continental shelves. *Polar Record* 17:595–626. <https://doi.org/10.1017/S0032247400032691>
- Darnis G, Robert D, Pomerleau C et al (2012) Current state and trends in Canadian Arctic marine ecosystems: II. Heterotrophic food web, pelagic-benthic coupling, and biodiversity. *Clim Change* 115:179–205. <https://doi.org/10.1007/s10584-012-0483-8>
- Davidson JJ, van Haren H, Hosegood P, Piechaud N, Howell KL (2019) The distribution of deep-sea sponge aggregations (Porifera) in relation to oceanographic processes in the Faroe-Shetland Channel. *Deep Res Part I* 146:55–61. <https://doi.org/10.1016/j.dsr.2019.03.005>
- Dayton PK, Robilliard GA, Paine RT, Dayton LB (1974) Biological accommodation in the benthic community at McMurdo Sound, Antarctica. *Ecol Monogr* 44:105–128. <https://doi.org/10.2307/1942321>
- Dinn C, Leys SP (2018) Field guide to sponges of the Eastern Canadian Arctic. Department of Biological Sciences, Education and Research Archive, University of Alberta, Edmonton. <https://doi.org/10.7939/R3DF6KJ4G>
- Dinn C (2018) Sponge fauna of the Eastern Canadian Arctic and Subarctic. Master's Thesis. University of Alberta. <https://doi.org/10.7939/R32B8VT6Z>
- Dinn C, Edinger E, Leys SP (2019) Sponge (Porifera) fauna of Frobisher Bay, Baffin Island, Canada with the description of an *Iophon* rich sponge garden. *Zootaxa* 4576:301–325. <https://doi.org/10.11646/zootaxa.4576.2.5>
- Dinn C, Leys SP, Roussel M, Methe D (2020) Geographic range extensions of stalked, flabelliform sponges (Porifera) from eastern Canada with a new combination of a species of *Plicatellopsis* in the North Atlantic. *Zootaxa* 4755(2):301–321. <https://doi.org/10.11646/zootaxa.4755.2.6>
- Downey RV, Griffiths HJ, Linse K, Janussen D (2012) Diversity and distribution patterns in high Southern latitude sponges. *PLoS ONE* 7:e41672. <https://doi.org/10.1371/journal.pone.0041672>
- Downey RV, Fuchs M, Janussen D (2018) Unusually diverse, abundant and endemic deep-sea sponge fauna revealed in the Sea of Okhotsk (NW Pacific Ocean). *Deep Res Part II* 154:47–58. <https://doi.org/10.1016/j.dsr2.2018.02.005>
- Eriksson BK, van der Heide T, van de Koppel J et al (2010) Major changes in the ecology of the Wadden Sea: Human impacts, ecosystem engineering and sediment dynamics. *Ecosystems* 13:752–764. <https://doi.org/10.1007/s10021-010-9352-3>
- Ginn BK, Logan A, Thomas MLH (2000) Sponge ecology on sublittoral hard substrates in a high current velocity area. *Estuar Coast Shelf Sci* 50:403–414. <https://doi.org/10.1006/ecss.1999.0563>
- Grant N, Matveev E, Kahn AS, Leys SP (2018) Suspended sediment causes feeding current arrests *in situ* in the glass sponge *Aphrocallistes vastus*. *Mar Environ Res* 137:111–120. <https://doi.org/10.1016/j.marenvres.2018.02.020>
- Grant N, Matveev E, Kahn AS et al (2019) Effect of suspended sediments on the pumping rates of three species of glass sponge *in situ*. *Mar Ecol Prog Ser* 615:79–101. <https://doi.org/10.3354/meps12939>
- Hestetun JT, Tompkins-Macdonald GJ, Rapp HT (2017) A review of carnivorous sponges (Porifera: Cladorhizidae) from the Boreal North Atlantic and Arctic. *Zool J Linn Soc* 181:1–69. <https://doi.org/10.1093/zoolinnean/zlw022>
- Hewitt JE, Thrush SF (2010) Empirical evidence of an approaching alternate state produced by intrinsic community dynamics, climatic variability and management actions. *Mar Ecol Prog Ser* 413:267–276. <https://doi.org/10.3354/meps08626>
- Hogg MM, Tendal OS, Conway KW et al (2010) Deep-sea sponge grounds: reservoirs of biodiversity. UNEP-WCMC Biodiversity Series No. 32, Cambridge
- Hooper JNA, Van Soest RWM (2002) *Systema Porifera*. Springer, Boston
- Howell KL (2010) A benthic classification system to aid in the implementation of marine protected area networks in the deep/high seas of the NE Atlantic. *Biol Conserv* 143:1041–1056. <https://doi.org/10.1016/j.biocon.2010.02.001>
- ICES (2009) Report of the ICES-NAFO working group on deep-water ecology (WGDEC), 9–13 March 2009, ICES CM 2009\ACOM:23. p 94
- Ingram RG, Bâcle J, Barber DG et al (2002) An overview of physical processes in the North Water. *Deep Sea Res Part II Top Stud Oceanogr* 49:4893–4906. [https://doi.org/10.1016/S0967-0645\(02\)00169-8](https://doi.org/10.1016/S0967-0645(02)00169-8)
- Johnson GL, Closuit AW, Pew JA (1969) Geologic and geophysical observations in the Northern Labrador Sea. *Arctic* 22:56–58. <https://doi.org/10.14430/arctic3192>
- Kahn AS, Yahel G, Chu JWF, Tunnicliffe V, Leys SP (2015) Benthic grazing and carbon sequestration by deep-water glass sponge reefs. *Limnol Oceanogr* 60:78–88. <https://doi.org/10.1002/lno.10002>
- Keith DA, Rodríguez JP, Rodríguez-Clark KM et al (2013) Scientific foundations for an IUCN red list of ecosystems. *PLoS ONE* 8:e62111. <https://doi.org/10.1371/journal.pone.0062111>
- Kenchington E, Lirette C, Cogswell A et al (2010) Delineating coral and sponge concentrations in the biogeographic regions of the East Coast of Canada using spatial analyses. *DFO Can Sci Advis Sec Res Doc* 41:202
- Kenchington E, Link H, Roy V et al (2011) Identification of mega- and macrobenthic ecologically and biologically significant areas (EBSAs) in the Hudson Bay Complex, the Western and Eastern Canadian Arctic. *DFO Can Sci Advis Sec Res Doc* 71:52
- Kenchington E, Murillo FJ, Cogswell A, Lirette C (2011) Development of encounter protocols and assessment of significant adverse impact by bottom trawling for sponge grounds and sea pen fields in the NAFO regulatory area. *NAFO SCR Doc* 75:6005

- Kenchington E, Power D, Koen-Alonso M (2013) Associations of demersal fish with sponge grounds on the continental slopes of the northwest Atlantic. *Mar Ecol Prog Ser* 477:217–230. <https://doi.org/10.3354/meps10127>
- Kenchington E, Beazley L, Murillo FJ, Tompkins-Macdonald GJ, Baker E (2015) Coral, sponge, and other vulnerable marine ecosystem indicator identification guide, NAFO area. NAFO Sci Coun Stud 2015:1–74. <https://doi.org/10.2960/S.v47.m1>
- Klitgaard AB (1995) The fauna associated with outer shelf and upper slope sponges (Porifera, Demospongiae) at the Faroe Islands, northeastern Atlantic. *Sarsia* 80:1–22. <https://doi.org/10.1080/00364827.1995.10413574>
- Klitgaard AB, Tendal OS (2004) Distribution and species composition of mass occurrences of large-sized sponges in the northeast Atlantic. *Prog Oceanogr* 61:57–98. <https://doi.org/10.1016/j.pocean.2004.06.002>
- Knudby A, Kenchington E, Murillo FJ (2013) Modeling the distribution of *Geodia* sponges and sponge grounds in the Northwest Atlantic. *PLoS ONE* 8:e82306. <https://doi.org/10.1371/journal.pone.0082306>
- Lambe LM (1900) Sponges from the coasts of Northeastern Canada and Greenland. *Trans R Soc Canada* 6:19–49
- Lehnert H, Stone RP (2016) A comprehensive inventory of the Gulf of Alaska sponge fauna with the description of two new species and geographic range extensions. *Zootaxa* 4144:365–382. <https://doi.org/10.11646/zootaxa.4144.3.5>
- Leys SP, Wilson K, Holeton C, Reiswig HM, Austin WC, Tunnicliffe V (2004) Patterns of glass sponge (Porifera, Hexactinellida) distribution in coastal waters of British Columbia, Canada. *Mar Ecol Prog Ser* 283:133–149. <https://doi.org/10.3354/meps283133>
- Lindholm J, Auster P, Valentine P (2004) Role of a large marine protected area for conserving landscape attributes of sand habitats on Georges Bank (NW Atlantic). *Mar Ecol Prog Ser* 269:61–68. <https://doi.org/10.3354/meps269061>
- Love MS, Saiki MK, May TW, Yee JL (2013) Whole-body concentrations of elements in three fish species from offshore oil platforms and natural areas in the Southern California Bight, USA. *Bull Mar Sci* 89:717–734. <https://doi.org/10.5343/bms.2012.1078>
- Maldonado M, Aguilar R, Bannister RJ et al (2017) Sponge grounds as key marine habitats: a synthetic review of types, structure, functional roles, and conservation concerns. *Marine Animal Forests*. Springer, Cham, pp 1–39
- McIntyre FD, Drewery J, Eerkes-Medrano D, Neat FC (2016) Distribution and diversity of deep-sea sponge grounds on the rosemary bank seamount, NE Atlantic. *Mar Biol* 163:143. <https://doi.org/10.1007/s00227-016-2913-z>
- Mecklenburg CW, Møller PR, Steinke D (2011) Biodiversity of Arctic marine fishes: taxonomy and zoogeography. *Mar Biodivers* 41:109–140. <https://doi.org/10.1007/s12526-010-0070-z>
- Miles L, Edinger E (2016) Biodiversity and distributions of corals and sponges in Navy Board Inlet, Qikiqtarjuaq, Cape Dyer, and Frobisher Bay: analysis of remotely operated vehicle video. Memorial University Departments of Geology and Biology, St. John's, p 76
- Morrow C, Cárdenas P (2015) Proposal for a revised classification of the Demospongiae (Porifera). *Front Zool* 12:7. <https://doi.org/10.1186/s12983-015-0099-8>
- Murillo FJ, Muñoz PD, Cristobo J et al (2012) Deep-sea sponge grounds of the Flemish Cap, Flemish Pass and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): Distribution and species composition. *Mar Biol Res* 8:842–854. <https://doi.org/10.1080/17451000.2012.682583>
- Murillo FJ, Kenchington E, Lawson JM et al (2016) Ancient deep-sea sponge grounds on the Flemish Cap and Grand Bank, northwest Atlantic. *Mar Biol* 163:1–11. <https://doi.org/10.1007/s00227-016-2839-5>
- Murillo FJ, Kenchington E, Tompkins-Macdonald GJ et al (2018) Sponge assemblages and predicted archetypes in the eastern Canadian Arctic. *Mar Ecol Prog Ser* 597:115–135. <https://doi.org/10.3354/meps12589>
- Neves BM, Du Preez C, Edinger E (2014) Mapping coral and sponge habitats on a shelf-depth environment using multibeam sonar and ROV video observations: Learmonth Bank, northern British Columbia, Canada. *Deep Res Part II Top Stud Oceanogr* 99:169–183. <https://doi.org/10.1016/j.dsr2.2013.05.026>
- Pansini M, Musso B (1991) Sponges from trawl-exploitable bottoms of Ligurian and Tyrrhenian seas: distribution and ecology. *Mar Ecol* 12:317–329. <https://doi.org/10.1111/j.1439-0485.1991.tb00261.x>
- Picton BE, Goodwin CE (2007) Sponge biodiversity of Rathlin Island, Northern Ireland. *J Mar Biol Assoc United Kingdom* 87:1441–1458. <https://doi.org/10.1017/S0025315407058122>
- Piepenburg D, Archambault P, Ambrose WG et al (2011) Towards a pan-Arctic inventory of the species diversity of the macro- and megabenthic fauna of the Arctic shelf seas. *Mar Biodivers* 41:51–70. <https://doi.org/10.1007/s12526-010-0059-7>
- Plotkin A, Gerasimova E, Rapp HT (2018) Polymastiidae (Porifera: Demospongiae) of the Nordic and Siberian Seas. *J Mar Biol Assoc United Kingdom* 98:1273–1335. <https://doi.org/10.1017/S0025315417000285>
- Roberts EM, Mienis F, Rapp HT, Hanz U, Meyer HK, Davies AJ (2018) Oceanographic setting and short-timescale environmental variability at an Arctic seamount sponge ground. *Deep Res Part I Oceanogr Res Pap* 138:98–113. <https://doi.org/10.1016/j.dsr.2018.06.007>
- Roy V, Iken K, Archambault P (2014) Environmental drivers of the Canadian Arctic megabenthic communities. *PLoS ONE* 9:e100900. <https://doi.org/10.1371/journal.pone.0100900>
- Roy V, Iken K, Archambault P (2015) Regional variability of megabenthic community structure across the Canadian Arctic. *Arctic* 68:180–192. <https://doi.org/10.14430/arctic4486>
- Sarà M, Balduzzi A, Barbieri M, Bavestrello G, Burlando B (1992) Biogeographic traits and checklist of Antarctic demosponges. *Polar Biol* 12:559–585. <https://doi.org/10.1007/BF00236980>
- Spalding MD, Fox HE, Allen GR et al (2007) Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *Bioscience* 57:573–583. <https://doi.org/10.1641/B570707>
- Squires HJ (2011) Decapod crustacea of the Calanus expeditions in Frobisher Bay, Baffin Island, 1951. *J Fish Res Board Can* 19:677–686. <https://doi.org/10.1139/f62-045>
- Tompkins-Macdonald GJ, Baker E, Anstey L et al (2017) Sponges from the 2010–2014 paamiut multispecies trawl surveys, Eastern Arctic and Subarctic: class Demospongiae subclass Heteroscleromorpha order Poecilosclerida family Coelosphaeridae genera *Forcepia* and *Lissodendoryx*. *Can Tech Rep Fish Aquat Sci* 3224:76
- Vacelet J, Boury-Esnault N (1995) Carnivorous sponges. *Nature* 373:333–335. <https://doi.org/10.1038/373333a0>
- Van Soest RWM, Boury-Esnault N, Vacelet J et al (2012) Global diversity of sponges (Porifera). *PLoS ONE* 7:e35105. <https://doi.org/10.1371/journal.pone.0035105>
- Van Soest RWM, Boury-Esnault N, Hooper JNA et al (2019) World Porifera database. In: World Porifera database. <https://www.marinespecies.org/porifera>. Accessed 17 May 2019
- Vargas S, Kelly M, Schnabel K, Mills S, Bowden D, Wörheide G (2015) Diversity in a cold hot-spot: DNA-barcoding reveals patterns of evolution among Antarctic demosponges (class Demospongiae, phylum Porifera). *PLoS ONE* 10:e0127573. <https://doi.org/10.1371/journal.pone.0127573>

- Wacasey JW, Atkinson EG, Glasspoole L (1979) Zoobenthos data from upper Frobisher Bay, 1967–1973. Canadian Data Report of Fisheries and Aquatic Sciences No. 164. Ste. Anne de Bellevue
- Wacasey JW, Atkinson EG, Glasspoole L (1980) Zoobenthos Data from Inshore Stations of Upper Frobisher Bay 1969–1976. Canadian Data Report of Fisheries and Aquatic Sciences 205. Ste. Anne de Bellevue
- Wassenberg TJ, Dews G, Cook SD (2002) The impact of fish trawls on megabenthos (sponges) on the north-west shelf of Australia. Fish Res 58:141–151. [https://doi.org/10.1016/S0165-7836\(01\)00382-4](https://doi.org/10.1016/S0165-7836(01)00382-4)

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