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203

Uniqueness of Fishes and Habitat Utilization in Oil & Gas Lease Blocks Relative to Non-Lease Areas in the Canadian Beaufort Sea

Caractère unique des poissons et utilisation de l’habitat dans les blocs de concessions pétrolières et gazières par rapport aux zones non visées par une concession dans la mer de Beaufort

Canada

February 2016

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AR Majewski[1], KD Suchy*, SP Atchison[1], J Henry[1], SA MacPhee[1], W Walkusz[1], J Eert[2], M Dempsey[2], A Niemi[1], L de Montety[3], M Geoffroy[4], C Giraldo[1], C Michel[1], P Archambault[3], WJ Williams[2], L Fortier[4] and JD Reist[1]

[1]Fisheries and Oceans Canada
Freshwater Institute
501 University Crescent
Winnipeg, MB R3T 2N6

[2]Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, BC V8L 4B2

[3]Université du Québec à Rimouski
300 Allée des Ursulines
Rimouski, QC G5L 3A1

[4]Université Laval
2325 rue de l'Université
Québec City, Québec, Canada G1V 0A6

*Compiled and edited by:
Karyn D. Suchy
PO Box 1943
Gimli, MB R0C 1B0

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Acknowledgements

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Personnel for Main Component of the Project

Overall Program Lead and Principal Investigator:
Dr. Jim Reist
Department of Fisheries and Oceans, Freshwater Institute (DFO - FWI)
(Jim.Reist@dfo-mpo.gc.ca)

Fish

Principal Investigator:
Andy Majewski, DFO - FWI
(Andrew.Majewski@dfo-mpo.gc.ca)

Cruise Participants:

2012
Sheila Atchison, DFO - FWI
Lorena Edenfield, University of Alaska Fairbanks (UAF)
Andy Majewski, DFO - FWI*
Charlie Ruben, Kavik Stantec Inc.

2013
Leg 1: Sheila Atchison, DFO - FWI
Brittany Lynn, DFO - FWI, University of Manitoba (UofM)
Andy Majewski , DFO - FWI*

Leg 2: Sheila Atchison, DFO - FWI
Robert Young, DFO - FWI*
Desmond Ruben, Kavik-Stantec Inc.

2014
Leg 1: Andy Majewski, DFO - FWI*
Carolina Giraldo, DFO - FWI
Desmond Ruben, Kavik-Stantec Inc.

Leg 2: Sheila Atchison, DFO - FWI
Julie Henry, DFO - FWI
Joseph Illasiak, Kavik-Stantec Inc.

Physical Oceanography

Principal Investigator:
Dr. Bill Williams
Department of Fisheries and Oceans, Institute of Ocean Sciences (DFO - IOS)
(Bill.Williams@dfo-mpo.gc.ca)

Cruise Participants:
2012 and 2013
Jane Eert, DFO - IOS
Mike Dempsey, DFO - IOS

2014
Leg 1: Mike Dempsey, DFO - IOS
Leg 2: Hugh MacLean, DFO - IOS

Marine Primary Productivity
Principal Investigator:
Dr. Christine Michel, DFO - FWI
(Christine.Michel@dfo-mpo.gc.ca)

Cruise Participants:
2012
Guillaume Meisterhans, DFO - FWI

2013
Andrea Niemi, DFO - FWI

2014
Leg 1: Andrea Niemi, DFO - FWI
Leg 2: Guillaume Meisterhans, DFO - FWI

Zooplankton and Ichthyoplankton
Principal Investigator:
Dr. Wojciech Walkusz, DFO – FWI
(wojciech.walkusz@dfo-mpo.gc.ca)

Cruise Participants:
2012
Wojciech Walkusz, DFO - FWI

2013
Akash Sastri, DFO - FWI

2014
Leg 1: Kelly Young, DFO - IOS
Leg 2: Shannon MacPhee, DFO - FWI*

Epibenthic Invertebrates
Principal Investigator:
Dr. Philippe Archambault
Université du Québec á Rimouski (UQAR)
(philippe_archambault@uqar.qc.ca)

Cruise Participants:
2012 to 2014
Laure de Montety, UQAR

Sediments and Infauna

Principal Investigator:
Dr. Philippe Archambault, UQAR
(philippe_archambault@uqar.ca)

Program Coordinator:
Shannon MacPhee, DFO - FWI

Cruise Participants:
2012
Shannon MacPhee, DFO - FWI

2013
Shannon MacPhee, DFO - FWI
Ashley Stasko, University of Waterloo (UofW)
Tracey Loewen, UofM

2014
Leg 1: Ashley Stasko, UofW
Leg 2: Michelle Kamula, UofM

*Chief Scientist for each cruise leg

Note: University and other collaborators associated with lab-based components of the work are listed in Appendix 1.

Abstract

The BSMF project was developed as a multi-stakeholder initiative aimed to address information gaps for deep-water fish communities relevant to the regulatory review, assessment, and management of offshore oil and gas exploration and development in the Canadian Beaufort Sea. The BSMF project provides important basic knowledge as to what species are present, habitat parameters, and ecological linkages (e.g., food web connections), which together allow for an understanding of ecosystem structure and function. Prior to this project, only 70 fish species were known to occur in the region, most of which were found on the Canadian Beaufort Shelf, whereas offshore fish habitats remained virtually unstudied. The basic design of the survey was onshore to offshore transects with stations situated at key depths in order to sample shelf (40-200 m), upper-slope (200-500 m), and lower-slope (500+ m) habitats. A total of 184 stations were sampled from 2012-2014. Sixteen tentative new marine fish species (12 pending expert taxonomic verification) were recorded for the Canadian Beaufort Sea during the BSMF project. Benthic and mid-water trawling confirmed that there was low water column diversity and relatively high bottom diversity in marine fishes. Sampling of marine fishes in waters deeper than 200 m, coupled with information on water properties and different components of the food web, allowed us to determine that fish communities in the Canadian Beaufort Sea differ by habitat and by area. Ultimately, by increasing our knowledge of the fishes and their relationships to other important organisms harvested by Inuvialuit within this critical Arctic marine ecosystem, results from this project provide a benchmark from which environmental stressors and anticipated effects of climate change may be assessed.

Résumé

Le Projet sur les poissons marins de la mer de Beaufort (PMMB) a été mis en place en tant qu'initiative multi-intervenants visant à traiter les lacunes en matière d'information sur les poissons benthiques relativement à l'examen réglementaire, à l'évaluation, et à la gestion des activités d'exploration et de développement pétrolier et gazier dans la mer de Beaufort. Le Projet PMMB fournit d'importantes connaissances de base sur les espèces présentes, les caractéristiques des habitats et les liens écologiques (p. ex., liens entre les réseaux alimentaires) qui, ensemble, permettent une compréhension de la structure et du fonctionnement de l'écosystème. Avant la mise en œuvre de ce projet, seules 70 espèces de poissons avaient été répertoriées dans la région, surtout dans la partie canadienne du plateau de la mer de Beaufort, tandis que l'habitat des poissons de haute mer n'avait pratiquement jamais été étudié. Le modèle de base du levé consistait en des transects des côtes vers la mer avec des stations à des profondeurs clés pour échantillonner les habitats du plateau (de 40 m à 200 m), du versant ascendant (de 200 m à 500 m), et de la basse pente (plus de 500 m). Un total de 184 stations ont été échantillonnées entre 2012 et 2014. Seize nouvelles espèces de poissons marins possibles (12 en attente d'une vérification taxonomique par des experts) ont été répertoriées dans la partie canadienne de la mer de Beaufort dans le cadre du Projet PMMB. Du chalutage en eau profonde et mi-profonde a confirmé que la diversité des poissons marins était faible dans la colonne d'eau et qu'elle était relativement élevée dans les fonds marins. L'échantillonnage des poissons marins dans les eaux d'une profondeur supérieure à 200 m, combiné aux renseignements sur les propriétés des eaux et des divers éléments du réseau alimentaire, nous a permis de déterminer que les communautés de poissons dans la partie canadienne de la mer de Beaufort diffèrent selon l'habitat et la région. Au bout du compte, en approfondissant nos connaissances des poissons et de leurs liens avec d'autres organismes importants prélevés par Inuvialuit dans cet important écosystème marin arctique, les résultats de ce projet fournissent une référence à l'aide de laquelle les agresseurs environnementaux et les effets anticipés des changements climatiques peuvent être évalués.

1. Background Objectives and Scientific Approach

1.1 Project Funding Linkages

The Beaufort Sea Marine Fishes (BSMF) project was a multi-stakeholder project funded through several sources including the ESRF, which accounted for approximately 11% of total project funds and contributed to ship-time, equipment costs, and salary for staff to support field and lab activities and development of key program deliverables. The ESRF was leveraged using funds received from the BSMF project's primary funding source, the Beaufort Regional Environmental Assessment (2011-2014), administered through Indigenous and Northern Affairs Canada. Other funding was leveraged from government administered programs (Program for Energy Research and Development, Natural Resources Canada), co-management partners (Joint Secretariat of the Inuvialuit Settlement Region), other federal sources [Fisheries and Oceans Canada (DFO) International Governance Strategy and National Conservation Plan, DFO-Oceans Management and DFO in-kind] and funds leveraged by university partners (Universities of Manitoba, Waterloo, Rimouski and Laval).

1.2 Project Rationale

The BSMF project was primarily an exploratory survey to address knowledge gaps regarding the diversity and distributions of marine fishes in offshore deep-water areas of the Canadian Beaufort Sea. Recent oil and gas interest in the deep-water offshore regions of the Beaufort Sea has led to the need for baseline information on offshore fishes and their habitats to support project planning, regulatory decision processes, and conservation efforts. The BSMF project provides important basic knowledge as to what species are present, habitat parameters, and ecological linkages (e.g., food web connections), which together allow for an understanding of ecosystem structure and function. The BSMF project was not simply a fish study; rather, it was a comprehensive ecosystem study with many components, a central one of which focused on fishes. The deep-water offshore ecosystem is connected to the Arctic Ocean generally and to the shelf and coastal areas, the latter of which are most important to the Inuvialuit. Thus, offshore activities may influence coastal or shelf responses. In addition, activities in freshwater, coastal and shelf regions, and the Arctic Ocean generally, may have 'downstream' effects in the offshore zone of the Canadian Beaufort Sea. Another consideration during this study was climate change, which is rapidly and substantially altering all ecosystems in the Arctic. Accordingly, there is a need to establish current baseline conditions in the ecosystem, including inter-annual variability in order to detect and understand changes in the system. The establishment of baseline knowledge relevant to long-term monitoring of changes was an over-arching objective of the project. Coastal, shelf and deep-water offshore connectivity, climate variability and change, and inter-annual variation in the response(s) of the marine system, thus all fostered a multi-year design, development and delivery of both the offshore research and a linked coastal program.

1.3 Previous Beaufort Sea Research

The ecology of marine fishes and other food web components within the Beaufort Sea are not well known. Although sampling in the area has occurred for almost 100 years, it has previously been episodic, of limited duration, and focused mostly on nearshore coastal areas. To date, only 52 known species of marine fishes have been reported in the region[1,2]. In the 1970s the Beaufort Sea Project developed knowledge of **biota**, behaviour of oil in cold water, and oil spill counter measures in the coastal and shelf areas (to ~200 m depths). During the mid-1980s, scientific studies conducted by the Northern Oil and Gas Assessment Program (NOGAP) similarly focused mainly on sampling coastal and shelf fishes. Despite limited sampling along the outer shelf (100-200 m depths) region off the Mackenzie estuary[3-8], adult marine fishes were generally not sampled at deeper stations during these programs.

Throughout the late-1980s and early-1990s, there were also several attempts made to assess the potential for commercial fisheries in the Canadian Beaufort Sea[9-11], yet these attempts contributed little to the overall knowledge of marine fishes in waters deeper than 150 m[1]. The physical limitations of previous research vessels with regards to fishing resulted in only moderate success of sampling fish at depths of 100-200 m[12-14] or in deeper waters. In the 2000s the Northern Coastal Marine Studies (NCMS) program again focused upon the shelf areas due to sea-ice constraints, associated vessel limitations and lease developments at that time. This research examined the community structure and distribution of the **macrofauna**, **zooplankton**[15], larval and early juvenile fishes[16-17], and benthic adult fishes using small-scale research nets on the Canadian Beaufort Shelf[18] in relation to environmental variables. In 2008, an offshore (20-

500 m) fish and **invertebrate** pilot project[19] was carried out in the Alaskan Beaufort Sea and collaborative efforts are currently underway to partner with Alaskan researchers in order to continue the development of standardized methods for use in sampling and monitoring in the Beaufort Sea **ecosystem**.

Many of the biotic and oceanographic studies described above also helped to develop knowledge of organisms other than fishes. For example, activities including physical and chemical **oceanography**, **plankton** sampling in the upper portions of the water column, and **benthos** sampling through bottom grabs, can more easily be conducted either from 'ships of opportunity' (e.g., Coast Guard icebreakers) or from smaller vessels. On the other hand, sampling of fishes in the **pelagic** and **benthic** zones requires active fishing gears such as trawls. As mentioned above, earlier limitations of vessel capabilities associated with previous programs practically limited such efforts to smaller gear types and depths <150 m. Late clearing of winter sea ice and persistent and variable presence of summer sea ice also restricted the scope and nature of research activities. In summary, prior to this project a distinct gap in the knowledge base existed in regards to deeper areas and offshore fishes and their ecologies.

To date, there have been no comprehensive attempts to study marine fishes and their habitats in the deep waters of the Canadian Beaufort Sea. Fish communities and habitats in waters >150 m are virtually unstudied, which represents a high priority gap for environmental assessment of activities that are expected to have an impact on the region. Insufficient data and poor understanding of middle trophic levels (i.e., fishes pivotal in productivity relationships to marine mammals and birds), particularly in deeper waters, represent gaps precluding effective regulatory review of oil and gas developments. Hydrocarbon development discussions during the 1970s to early 2000s focussed upon nearshore and shelf deposits of natural gas and its transport. Accordingly, the knowledge gap noted above was of limited consequence. In the early 2000s, however, interest in offshore oil reserves on the slope and in deeper waters (e.g., to 1200+ meters) and associated lease sales highlighted the need for knowledge of deep-water fishes as part of responsible offshore oil and gas exploration, development, and management. The lack of baseline data regarding fish and supporting habitats in offshore marine waters impedes effective regulation and regional effects management of future exploration and development activities. In addition, the coastal, nearshore and slope sub-ecosystems in the Beaufort Sea are connected through physical and chemical processes as well as by biotic associations (e.g., fish migratory pathways). Therefore the ecological significance and uniqueness of areas proposed for oil and gas exploration and development must be assessed in the context of the broader ecosystem, thereby providing a baseline understanding of the distributions, diversity, relative abundances and key habitat associations for marine fishes.

The BSMF project was developed as a multi-stakeholder (Inuvialuit, territorial and federal governments, the oil and gas private sector, and universities) initiative aimed to address information gaps for deep-water fish communities relevant to the regulatory review, assessment, and management of effects associated with offshore oil and gas exploration and development in the Canadian Beaufort Sea. The work as proposed responded to knowledge gaps required to effectively plan and regulate oil and gas activities in the offshore. The work also entailed summarizing existing knowledge of fish occurrences and habitat associations geo-spatially, and integrating new findings with this knowledge to assess potential sensitivities of fishes, their habitats and ecosystem processes to oil and gas developmental activities. The overall goal of the BSMF project was to provide governments, Inuvialuit, and industry with knowledge to better prepare for oil and gas exploration and development in the offshore region of the Beaufort Sea.

1.4 Study Objectives

The main goals of the BSMF project were to:

1. Increase knowledge of this critical Arctic marine ecosystem, the fishes therein, and the structural and functional relationships to key biota harvested by Inuvialuit.
2. Establish pre-development baselines in the ecosystem within which developmental stressors may be assessed.
3. Provide a benchmark within which anticipated future effects of climate change may be assessed in the context of developmental impacts.

The BSMF project has several focal themes, and individual elements are designed to both provide key deliverables on their own and to allow for integration of findings to achieve a broader understanding of the ecosystem and its responses to existing and potential perturbations. Ultimately, by increasing our knowledge of the fishes and their relationships to other important organisms harvested by Inuvialuit within this critical Arctic marine ecosystem, we can provide a benchmark from which environmental stressors and anticipated effects of climate change may be assessed.

1.5 Study area

The Canadian Beaufort Sea is a highly structured system that varies spatially and by depth. In the west, the shelf is relatively narrow and the slope drops off rapidly to deep waters in the Arctic basin (Fig. 1). Further east, the Mackenzie River has a dominant influence by depositing large volumes of freshwater and sediments on the over 100 km wide shelf. Shallow embayments (e.g., Husky Lakes, Liverpool Bay) are present on the eastern margin of the Canadian Beaufort Shelf. Further east, the Beaufort Sea transitions to Amundsen Gulf and, along the coast, Franklin and Darnley bays are present as somewhat distinct coastal zones. Offshore of the Canadian Beaufort Shelf the slope drop-off rapidly transitions to deep Arctic waters of the Canada Basin. A wide shelf is also present along the western margin of Banks Island. A relatively shallow sill (~400 m depth) marks the western end of the relatively shallow Amundsen Gulf. Various large and small embayments also characterize the southern margins of Banks and Victoria islands.

Sea ice melt, freshwater inputs from the Mackenzie River, incoming surface and sub-surface flows along the coast, shelf and slope from the North Pacific Ocean via Bering Strait, the Beaufort Gyre north of the shelf containing Pacific, Atlantic and Eurasian-origin water, and deep Arctic basin water all contribute to oceanographic conditions in the region. Temperature and salinity, two basic aspects of marine waters that result in density differences among water masses, can be used to determine distinct layers in the water column. Similar to the spatial differences noted above, these depth layers provide distinct habitats within which specific types of fishes (and other biota) may associate. Additionally, transition zones between water layers, particularly where these physically intersect the bottom (e.g., along the slope), tend to concentrate planktonic food and thus these conditions also result in high concentrations of particular fishes. Therefore, collecting information on water mass structure also provides information on fish habitats, including regions where fishes may be more abundant.

Surface currents in the offshore zone of the Canadian Beaufort Sea are generally present as the anti-clockwise Beaufort Gyre. Close to shore, surface currents tend to be along shore and are heavily influenced by wind. Water from the Mackenzie River flows offshore of the Mackenzie Delta in a large, irregular plume that can extend to the shelf edge. The plume is then transported away from the delta by the influence of winds and Ekman transport. Deeper currents on the slope contain water that originates in the Pacific Ocean and the Atlantic Ocean and tend to be clockwise in orientation flowing eastward along the slope margin. As these currents can be forced upwards by the bottom **topography**, they likely supply nutrients to the shelf and eastern portions of the Canadian Beaufort Sea. The complex spatial and depth **heterogeneity** present in the Canadian Beaufort Sea results in a large variability in habitat structure and characteristics. The nature of the habitats influences the types of fishes and other biota present. Accordingly, the sampling design of the study was structured to investigate as wide a range of habitats as possible.

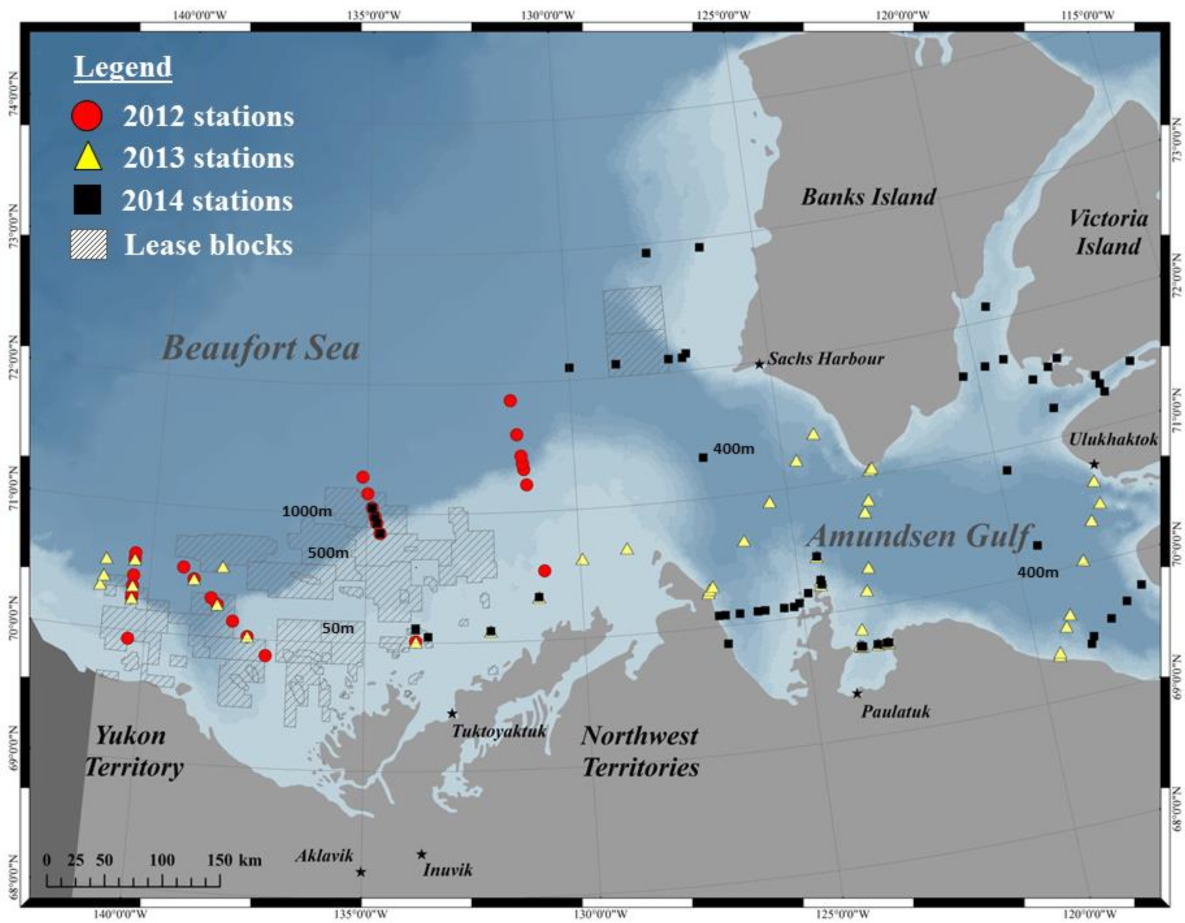


Figure 1 Sampling coverage from 2012 to 2014 including lease blocks.

1.6 Sampling Design

The BSMF project is the first comprehensive examination of the offshore fishes and their ecosystems for the Canadian Beaufort Sea. Accordingly, it was designed as an overview survey rather than an attempt to quantitatively estimate biota. Most Arctic environments, including the Canadian Beaufort Sea, vary over time at three scales: inter-annually (between years), over the annual cycle, and also within a season. The high spatial variation present in this area with regards to water masses across depths and bottom types, combined with the high inter-annual variability in the Canadian Beaufort Sea all necessitated a sampling design that covered a wide range of depths and was multiple years in duration. Moreover, some shallower sites along specific transects had been previously sampled during the NCMS program, thus re-sampling these extended the duration of possible inter-annual assessments. Given the nature of the BSMF project, the survey design focused on the 'summer' open-water season when navigation was possible (as noted below ice presence and movements affected activities in some years).

The BSMF project study area included the shallower waters of the Canadian Beaufort Shelf (≤ 200 m), and the upper (0-500 m) and lower (500-1000 m) slope and was bounded by the Beaufort Sea Large Ocean Management Area (LOMA). Sampling was also conducted to the east of the Canadian Beaufort Shelf within Amundsen Gulf. Sampling within Amundsen Gulf highlighted fish and fish habitats within the proposed Darnley Bay Marine Protected Area (MPA), currently known as the Anguniaqvia Niqiqyuam Area of Interest (ANAOI). The shelf at SW Banks Island was also sampled in 2014, along with several embayments within the Amundsen Gulf (e.g., Franklin Bay and Minto Inlet). The basic design of the survey was onshore to offshore lines or **transects** with stations situated at key depths to sample shelf (40-200 m), upper-slope (200-500 m), and lower-slope (500+ m) habitats (Figs 3-5, Tables 1-2). Seven depth stations generally comprised these lines in the southern and western areas. Once station sampling was completed along a given transect, the same transect was sampled again using hydroacoustics (see below) to identify aggregations of fish and assemblages of other biota in the water column. Lines were modified in Amundsen Gulf and associated embayments to accommodate both **bathymetry** and particular focal areas. Sampling lines in the central and western portions of the study area were also designed to intersect many of the lease blocks in the area and to include a target depth of 1000 m where possible. Repetitive sampling of parameters descriptive of physical and chemical oceanography, primary productivity, epifauna, sediments and benthic infauna, zooplankton, fish and hydroacoustics along key transects (and stations in some cases) was designed to address inter-annual variation in the system (Fig. 2). The sampling was not conducted specific to any lease blocks for oil or gas development, however, several transects and stations did intersect these blocks (Figs. 3-5). The results presented are in the regional context thus generally applicable to all lease blocks within the wider depth and spatial situations described above. As analyses continue, specific geo-spatial summaries will be developed and produced.

The 2012 field program was approximately four weeks long and focused on four primary transects that spanned the shelf and slope habitats in the southern Canadian Beaufort Sea between the Alaska/Yukon border and Cape Bathurst, Northwest Territories (Fig. 3). In 2013, sampling took place over approximately six weeks and was divided into two legs. Leg 1 focused on transects in the eastern portion of Amundsen Gulf while Leg 2 sampling was conducted as a joint Canada-US effort in collaboration with the University of Alaska Fairbanks and the US Bureau of Ocean Energy Management in the Yukon-Alaska trans-boundary region and included re-sampling of key 2012 transects to assess inter-annual variability as well as sampling a transect in US waters (A1, Fig. 4). Sampling in 2014 also extended over a six-week period with a focus on the central Beaufort Shelf and slope regions, in addition to Amundsen Gulf. Again in 2014, key transects from 2012 and 2013 were resampled to assess temporal variability.

As noted above, fishes and other biota can be preferentially associated with either pelagic or benthic habitats, or both. In Arctic waters the diversity of fishes in pelagic waters is low and the vast majority are associated with the bottom. Thus, the sampling design primarily focused on the bottom-sampling component of the project whereas the pelagic sampling component for fishes was modified to specifically target biomass concentrations identified by hydroacoustic methods. This bias towards sampling mainly at the bottom of the water column affects overall extrapolation of the project findings and thus should be kept in mind. In addition, three other practical issues further affected the sampling design: sea ice, weather, and vessel logistics. The sampling design was modified as required (e.g., in 2014 persistent ice along the middle of the Canadian Beaufort Shelf precluded re-sampling of deeper offshore stations and forced sampling of shallow areas along the Tuktoyaktuk Peninsula). Similarly, local weather, particularly winds, altered the sampling design in some situations as did logistical needs (e.g., refuelling locations and times, an approximately six-week maximum operational window in the Canadian Beaufort Sea). Finally, information on marine fishes generally remains unresolved with respect to spring

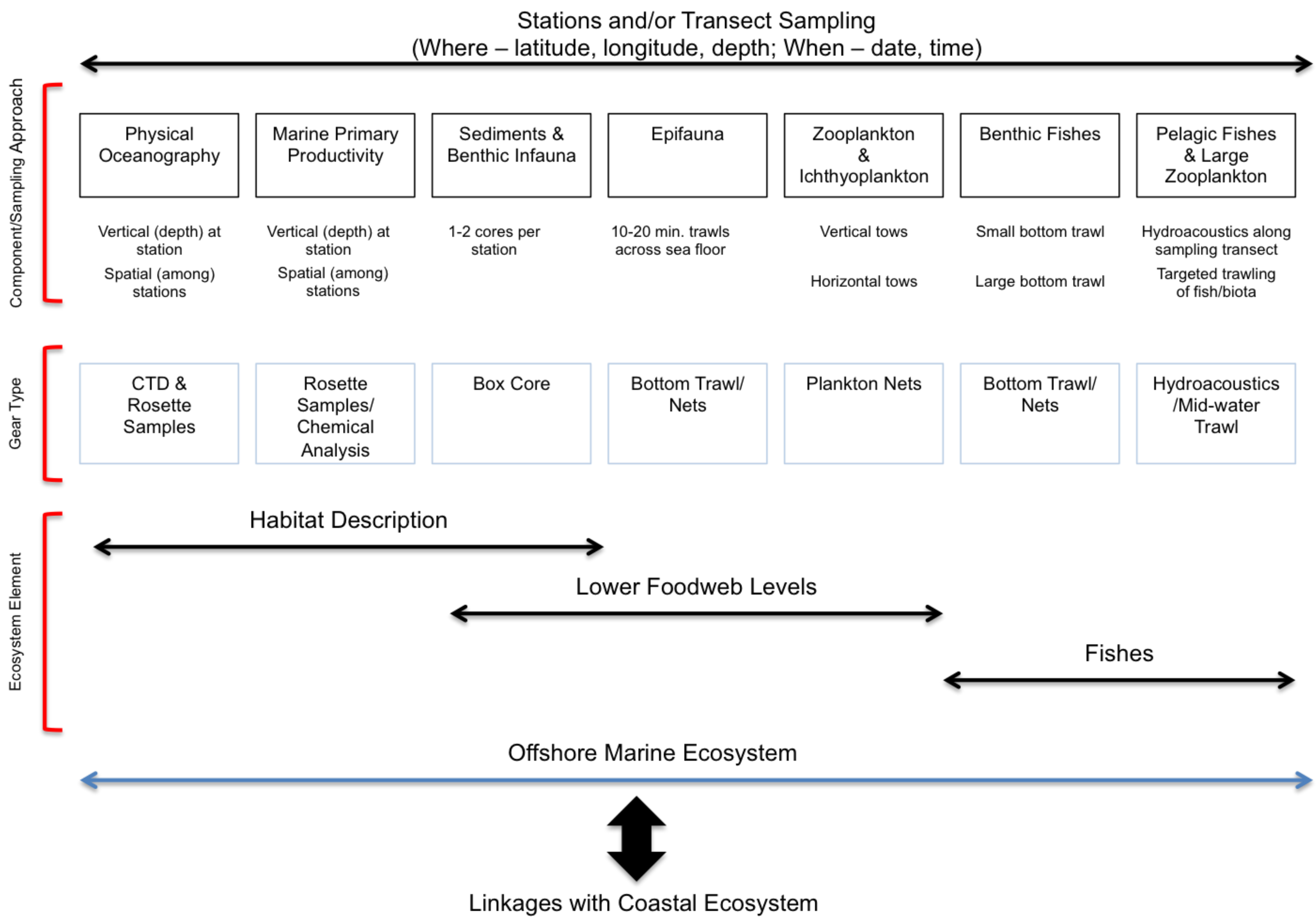


Figure 2 Field sampling activities.

(break-up), autumn (freeze-up), and winter (ice-covered) seasons for the Beaufort Sea due to the limited operational time and the geographic scale of the survey area. Thus, the findings presented herein primarily represent the summer (open-water) season.

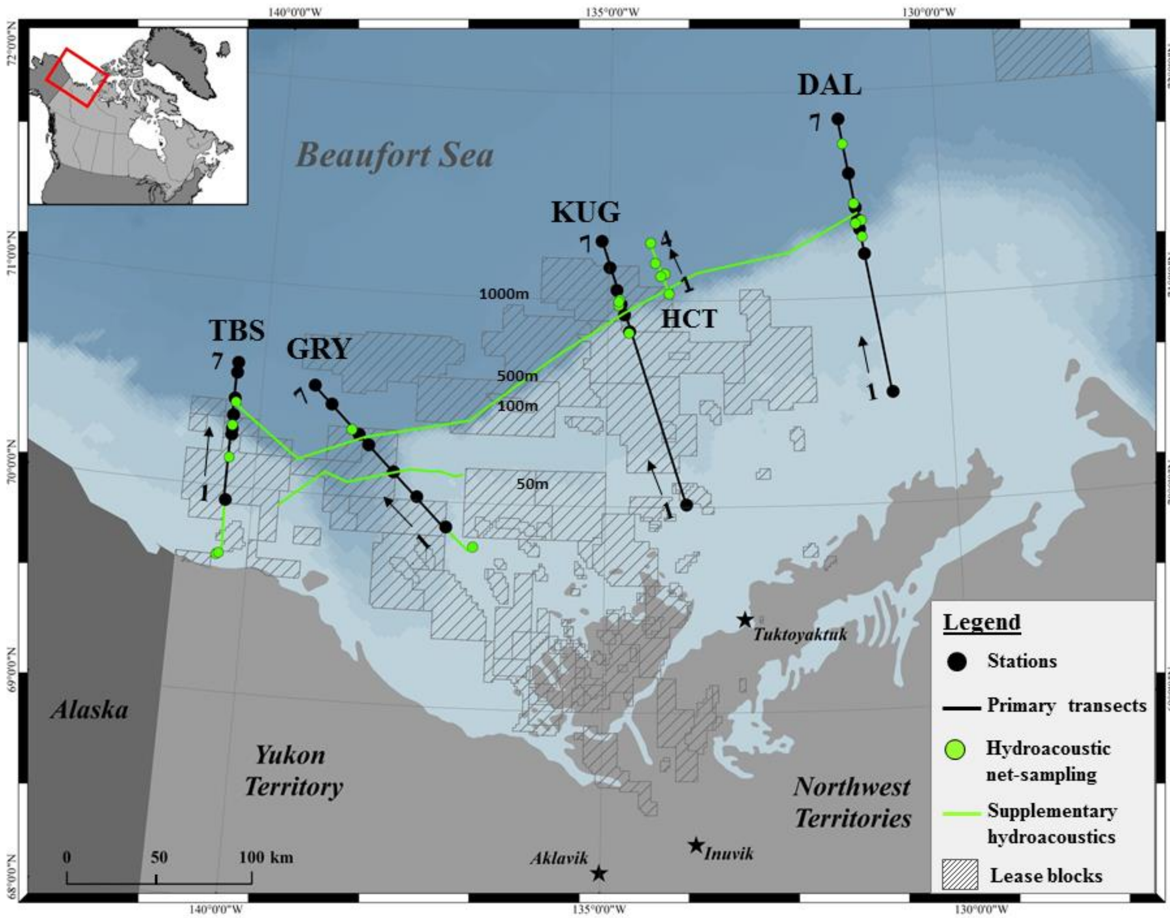


Figure 3 Map of stations and primary transects for 2012.

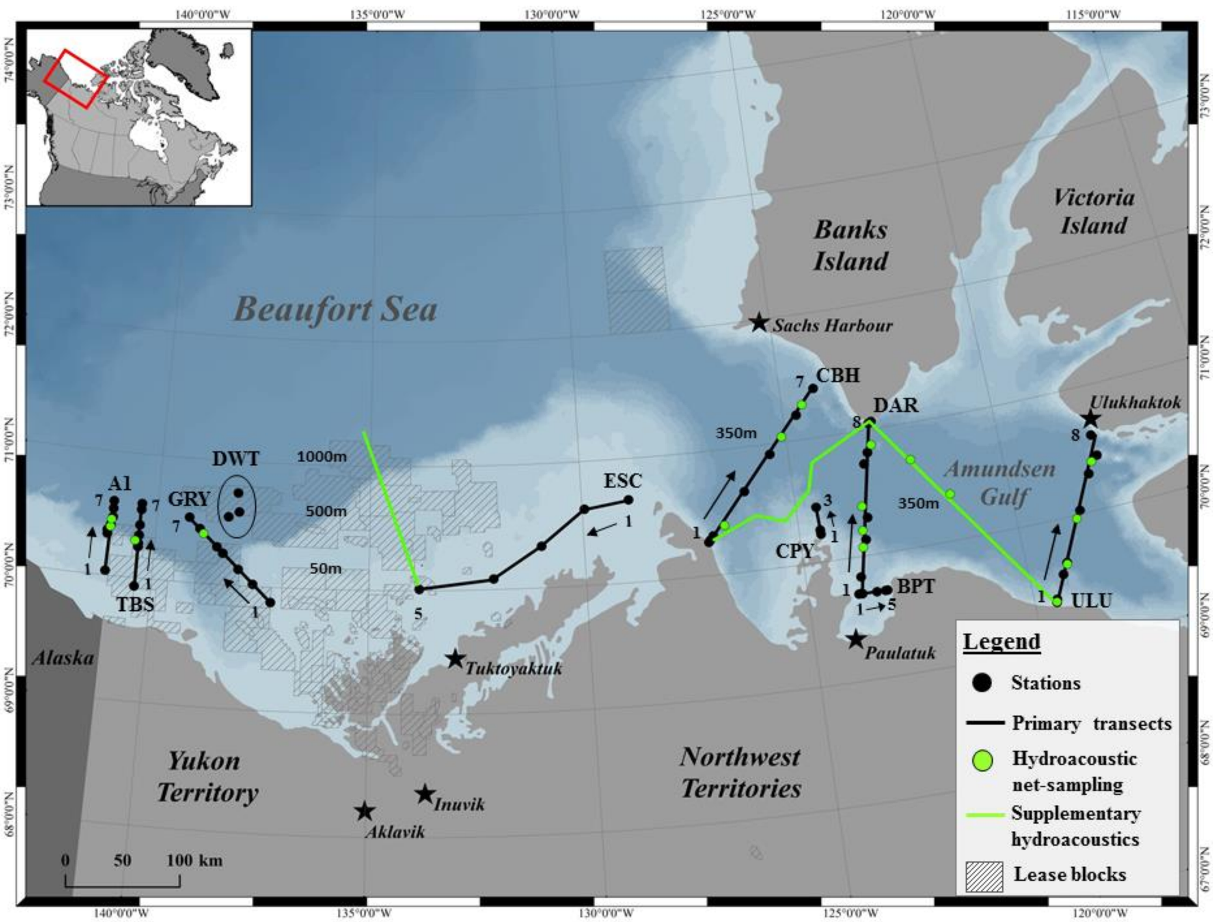


Figure 4 Map of stations and primary transects for 2013.

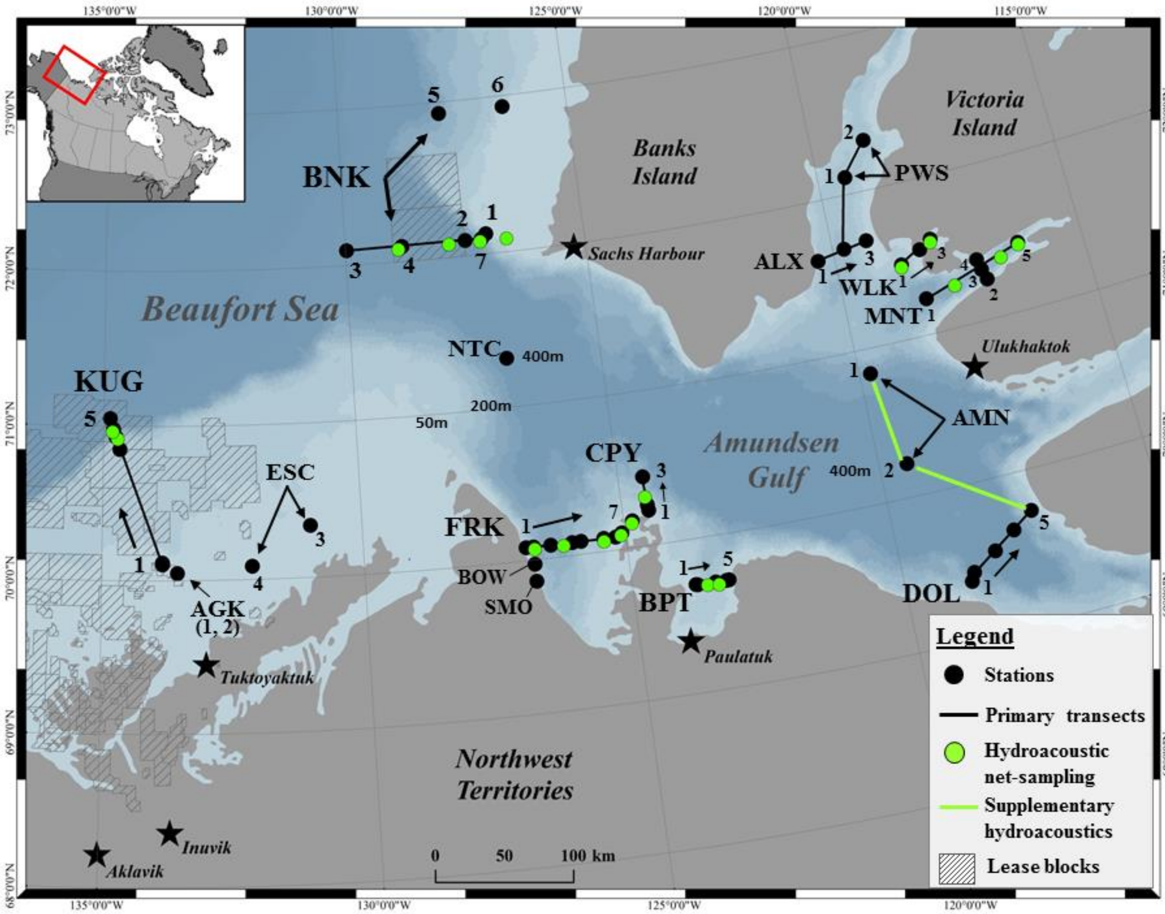


Figure 5 Map of stations and primary transects for 2014.

Table 1 Start and end coordinates (decimal degrees) and dates for all standardized station sampling transects.

Year	Transect name	Transect abbreviation	Start coordinates		End coordinates		Sampling dates	
			Latitude	Longitude	Latitude	Longitude	Start	End
2012	Dalhousie	dal	70.531	-130.878	71.865	-131.479	Aug 07	Aug 11
	Kugmallit	kug	70.011	-133.840	71.251	-135.072	Aug 13	Aug 17
	Garry	gry	69.876	-137.243	70.526	-139.229	Aug 19	Aug 23
	Transboundary	tbs	69.930	-140.377	70.602	-140.374	Aug 25	Aug 30
2013	Cape Parry	cpy	70.224	-124.500	70.448	-124.530	Aug 02	Aug 03
	Bennett Point	bpt	69.702	-123.850	69.699	-123.195	Aug 04	Aug 06
	Darnley Bay	dar	69.703	-123.819	71.061	-122.917	Aug 04	Aug 10
	Ulukhaktok	ulu	69.347	-119.514	70.602	-117.855	Aug 13	Aug 16
	Cape Bathurst	cbh	70.268	-127.103	71.393	-124.167	Aug 20	Aug 22
	Escape	esc	70.694	-128.871	70.011	-133.843	Aug 25	Aug 27
	Garry	gry	69.875	-137.242	70.524	-139.235	Aug 29	Aug 30
	Transboundary	tbs	69.930	-140.377	70.589	-140.425	Sep 02	Sep 04
	Alaskan 1	a1	70.038	-141.077	70.606	-141.039	Sep 05	Sep 06
	Deep-water	dwt	70.599	-138.329	70.746	-138.129	Sep 09	Sep 09
2014	Amauligak	agk	70.040	-133.545	70.102	-133.839	Aug 02	Aug 03
	Kugmallit	kug	70.013	-133.778	71.050	-134.875	Aug 02	Aug 05
	Banks Island (South)	bnk	72.130	-127.039	72.093	-129.972	Aug 08	Aug 09
	Banks Island (North)	bnk	72.929	-127.785	72.931	-126.393	Aug 10	Aug 10
	Escape	esc	70.335	-131.007	70.087	-132.129	Aug 14	Aug 14
	Franklin Bay	frk	70.082	-126.198	70.085	-126.911	Aug 17	Aug 19
	Bennett Point	bpt	69.700	-123.194	69.704	-123.820	Aug 22	Aug 23

Table 1 continued…

Year	Transect name	Transect abbreviation	Start coordinates		End coordinates		Sampling dates	
			Latitude	Longitude	Latitude	Longitude	Start	End
2014	Wise Bay	wis	70.105	-125.062	70.174	-124.835	Aug 25	Aug 25
	Cape Parry	cpy	70.226	-124.497	70.447	-124.521	Aug 25	Aug 26
	Minto Inlet	mnt	71.229	-118.366	71.437	-116.295	Aug 28	Aug 30
	Walker Bay	wlk	71.480	-118.695	71.597	-118.006	Sep 01	Sep 01
	Alexander Milne Point	alx	71.619	-120.337	71.683	-119.284	Sep 04	Sep 05
	Prince of Wales Strait	pws	72.109	-119.428	72.317	-118.875	Sep 05	Sep 05
	Amundsen Gulf	amn	70.839	-119.783	70.219	-119.471	Sep 07	Sep 07
	Dolphin Strait	dol	69.735	-117.386	69.379	-118.769	Sep 08	Sep 09

Table 2 Start and end coordinates (decimal degrees) and dates for all hydroacoustic sampling transects.

Year	Transect name	Transect abbreviation	Start coordinates		End coordinates		Sampling dates	
			Latitude	Longitude	Latitude	Longitude	Start	End
2012	Dalhousie	dal	71.865	-131.479	70.534	-130.838	Aug 11	Aug 12
	Kugmallit (uctd)	kug	71.133	-134.958	70.871	-134.697	Aug 16	Aug 16
	Kugmallit	kug	71.251	-135.072	70.011	-133.840	Aug 18	Aug 19
	Garry	gry	70.526	-139.229	69.718	-136.753	Aug 23	Aug 24
	Mackenzie trough (uctd)	mac	70.131	-138.637	70.069	-139.324	Aug 25	Aug 25
	Transboundary	tbs	70.601	-140.376	69.930	-140.377	Aug 28	Aug 29
	West to East	wte	70.408	-140.389	71.019	-134.027	Aug 30	Aug 31
	Hydroacoustic Transect	hct	71.019	-134.027	71.377	-131.242	Sept 1	Sept 2
2013	Darnley Bay	dar	71.061	-122.917	69.703	-123.820	Aug 11	Aug 11
	Ulukhaktok	ulu	70.602	-117.855	69.345	-119.517	Aug 17	Aug 18
	Uluhaktok (uctd)	ulu	69.709	-119.602	70.087	-120.569	Aug 19	Aug 19
	Cod	cod	69.553	-119.224	70.272	-127.090	Aug 18	Aug 19
	Cod (uctd)	cod	70.890	-122.545	70.663	-125.014	Aug 19	Aug 20
	Cape Bathurst	cbh	71.506	-123.870	70.273	-127.093	Aug 23	Aug 24
	Cape Bathurst (uctd)	cbh	70.371	-126.843	70.754	-128.378	Aug 24	Aug 25
	Garry	gry	70.524	-139.235	69.995	-137.546	Aug 31	Aug 31
	Transboundary	tbs	70.604	-142.043	69.930	-140.377	Sept 4	Sept 5
	Transboundary (uctd)	tbs	70.640	-140.383	69.927	-140.378	Sept 4	Sept 5
	Alaskan 1	a1	70.603	-141.042	69.980	-141.179	Sept 6	Sept 7
	Kugmallit	kug	70.054	-134.840	70.539	-134.377	Sept 10	Sept 11
	Deep-water (uctd)	dwt	70.826	-136.324	70.904	-134.726	Sept 11	Sept 11

Table 2 continued…

Year	Transect name	Transect abbreviation	Start coordinates		End coordinates		Sampling dates	
			Latitude	Longitude	Latitude	Longitude	Start	End
2014	Kugmallit	kug	71.050	-134.875	70.850	-134.673	Aug 5	Aug 6
	Banks Island (South)	bnk	72.098	-126.607	72.096	-129.305	Aug 11	Aug 12
	Franklin Bay	frk	70.084	-126.953	70.084	-125.468	Aug 20	Aug 21
	Bennett Point	bpt	69.705	-123.853	69.700	-123.193	Aug 24	Aug 24
	Cape Parry	cpy	70.471	-124.514	70.102	-125.056	Aug 27	Aug 27
	Minto Inlet	mnt	71.436	-116.298	71.231	-118.372	Aug 30	Aug 31
	Walker Bay	wlk	71.655	-117.985	71.481	-118.700	Sept 2	Sept 2
	Prince of Wales Strait	pws	72.110	-119.477	71.621	-120.335	Sept 6	Sept 6

1.7 F/V ***Frosti***

The field research program was conducted from the charter vessel F/V *Frosti*, a 39.9 m, class C ice-strengthened vessel certified for work in the Arctic by Transport Canada (Fig. 6). The F/V *Frosti* is a Canadian owned and operated factory stern trawler based out of Steveston, British Columbia. This vessel is capable of accommodating up to eight science staff in addition to six crew members and was crewed sufficiently to accommodate a 16-hour work day. The F/V *Frosti* was chosen because of its capability to fish bottom and mid-water trawls to 2000 m depth as well as for its boom and winch configuration, which facilitated deployment of a variety of different gear types. Due to the vessel's 5-m draft, work could also be conducted safely as shallow as 8 m in calm seas. Cruising speed is 9.5 knots and the vessel can work at sea for up to 35 days without refuelling, depending upon conditions.

Figure 6 F/V *Frosti*

2.0 Field Sampling Activity

2.1 Oceanography and Marine Productivity

2.1.1 Physical and Chemical Oceanography

Physical oceanographic measurements were collected in order to describe the water masses and oceanographic conditions (e.g., upwelling or currents) that constitute the habitats of fish and other organisms. The objectives of this component were to:

A. Characterise water masses and oceanographic conditions such as upwelling or currents that might affect the habitat which the biota experience.
B. Sample various locations on the Beaufort Sea; including shelf, off-shore/deep-waters, canyons, the Alaska Beaufort Shelf and the Mackenzie Trough.

Methods

At each station, measurements were collected using Conductivity/Temperature/Depth sensors (CTDs) and a rosette equipped with Niskin bottles (Table 3, Fig. 7). The Primary CTD (PCTD) was equipped with specific sensors to capture information on the temperature, **conductivity**, pressure, **turbidity**, fluorescence (chlorophyll *a*), and oxygen concentration of the water column. Sensors mounted outside the PCTD frames included the Benthos Altimeter and Biospherical/Licor underwater Photosynthetically Active Radiation (PAR) sensors as their operation required them to be located above or below the frame unit. PAR sensors are located above any object that could shadow or impede sunlight, while altimeters are mounted below any object that might provide a false reading between the altimeter and the sea floor. Niskin bottles were used to collect water samples needed for chemical measurements such as dissolved inorganic carbon (DIC), nutrients, bacteria, and **salinity** (the amount of salt in the water). Once in the water, the PCTD was lowered to 2 m and soaked for 2 minutes before profile observations/data collection began. The PCTD was lowered into the water column at a rate of approximately 0.8 m/s until it reached a depth of 5-10 m above the bottom. The PCTD was then brought back up to the surface while collecting measurements at specific depths along the way.

A backup CTD (BCTD) was used for checking oceanographic conditions during overnight sampling, hydroacoustic/mid-water trawl sites and/or when the weather was too rough to deploy a PCTD. The BCTD was activated upon leaving the deck and soaked (as per PCTD) for 2 minutes with a descent rate of 0.8 m/s. In addition, an Underway CTD (UCTD) consisting of a Seabird FastCat CTD (16 Hz) installed in a torpedo-like shell attached to a 500 lb test Spectra line by way of a 0.75 m long tailpiece provided high resolution watermass profiles during opportunistic hydroacoustic transects of the Canadian Beaufort and Alaskan Shelf, Mackenzie Trough and Amundsen Gulf. UCTD profiles supplied connective data between transects and produced higher resolution observations of upwelling and water mass phenomena. UCTD use increased spatial resolution sampling in accompaniment to hydroacoustic profiling and provided insight into fish/biota assemblages documented by echograms. UCTD probes were deployed while the vessel was underway (<13 kts); attainable deployment depth decreasing with increased speed.

Figure 7 Conductivity/temperature/depth (CTD) rosette onboard the F/V *Frosti*. The grey cylinders are the Niskin water sampling bottles opened at specific depths.

Table 3 Physical and chemical oceanographic sampling summary.

Year	Pressure	Temperature	Transmissivity	Fluorescence	PAR[1]	PAR reference	Turbidity	Salinity	Oxygen (mL/L)
2012	x	x	x	x	x			x	x
2013	x	x	x	x		x	x	x	x
2014	x	x	x	x	x	x	x	x	x

[1]PAR refers to photosynthetically active radiation

Results

The oceanographic survey performed during 2012 along four primary transects in the Canadian Beaufort Sea showed, in general, there was relatively little variability in regards to water mass distribution over the regional geographical scale. The upper water column was occupied by fresher and warmer waters of the Polar Mixed Layer (PML) that extended down to 50 m (Fig. 8). There was a very strong freshwater signal observed at the surface layer, particularly along transects located in the vicinity of Mackenzie River outflow (KUG and DAL) (Fig. 9). Below the PML there was a layer of wintertime-cooled Pacific-derived water (50-200 m). Below the temperature minimum of the Pacific Winter Water the temperature increased through the halocline to the temperature maximum of the Atlantic Water (350-450 m). Below this temperature maximum there is much weaker salinity stratification though the water continues to be of Atlantic-origin.

A larger scale oceanographic comparison, as performed in 2013, revealed differences between the Canadian Beaufort Sea and Amundsen Gulf (Fig. 10). In the Beaufort Sea proper (transect TBS and GRY), the surface layer (PML) was observed along entire transects, primarily due to dispersion of the vast amount of plume water from the Mackenzie River. In Amundsen Gulf, the upper water column was fresher along the south coast, whereas the north coast was more saline and colder. These results may suggest local differences in both the riverine input (e.g., more freshwater in the Darnley Bay area), current circulation and recent wind forcing.

In terms of year-to-year differences, observations along the GRY transect in years 2012 and 2013 point to relatively variable oceanographic conditions (Fig. 11). For example, in 2012 there was relatively less fresh water at the very top of the water column. The temperature of the Pacific Water Mass was lower in 2013 in comparison to 2012. In 2013, the surface water was remarkably fresher, which is expected to be due to the differences in the evolution of the Mackenzie River Plume between the 2 years.

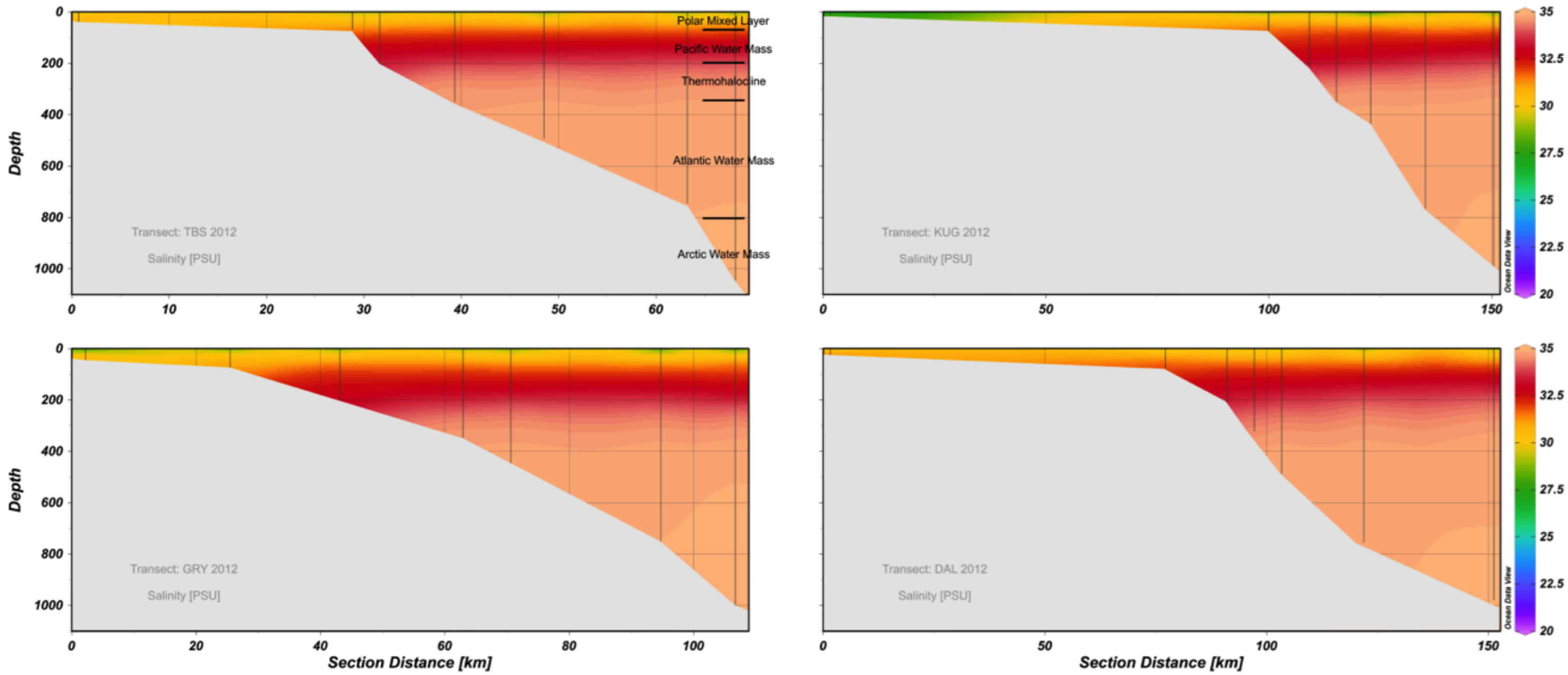


Figure 8 Salinity profiles for all transects sampled in the Beaufort Sea in 2012.

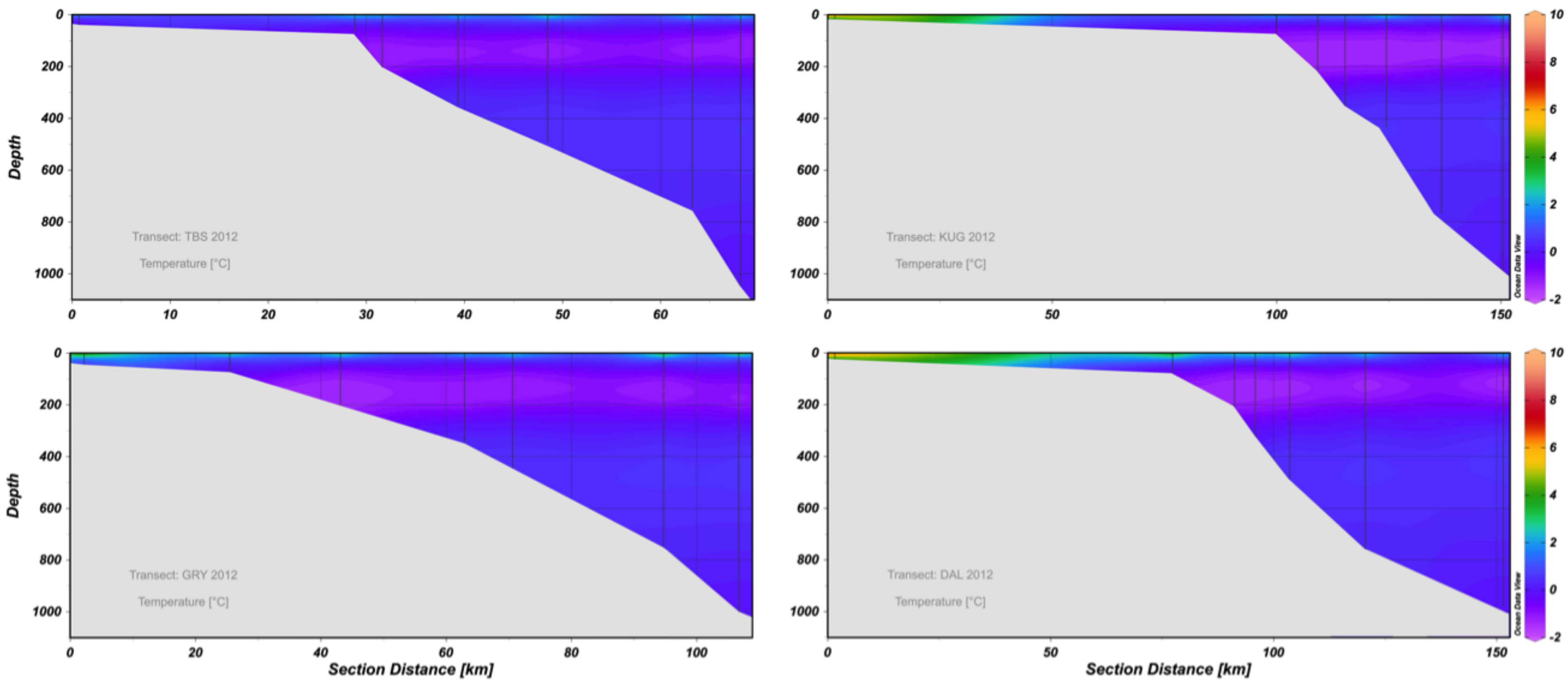


Figure 9 Temperature profiles for all transects sampled in the Beaufort Sea in 2012.

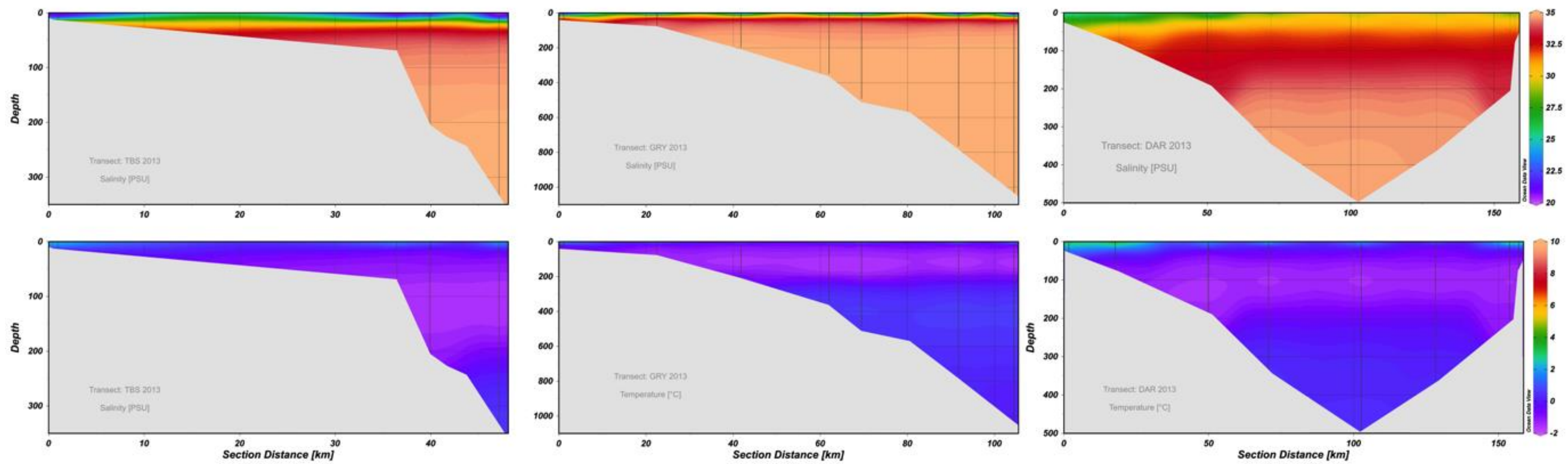


Figure 10 Beaufort Sea and Darnley Bay oceanography for 2013.

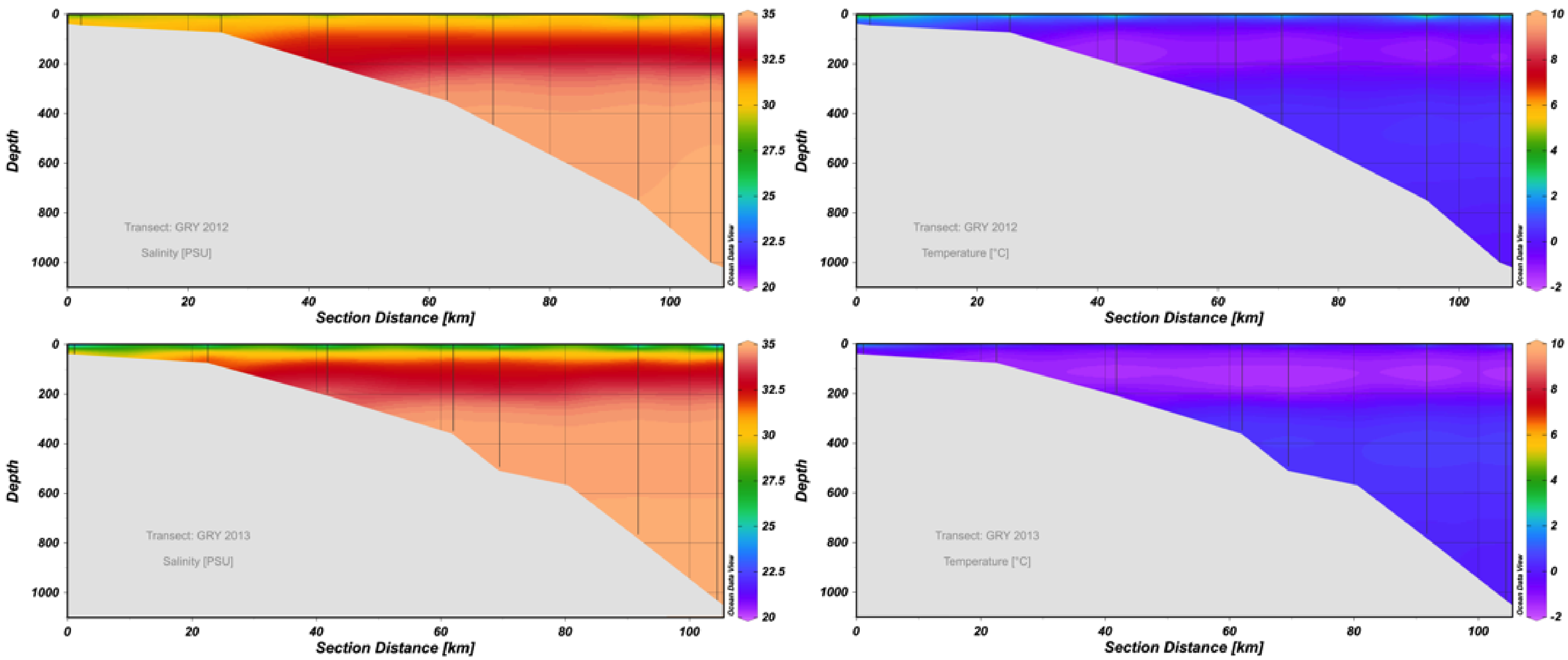


Figure 11 Comparison of salinity and temperature profiles for the GRY transect in 2012 and 2013 as an example of interannual variability.

2.1.2 Marine Primary Productivity

Water column properties and lower trophic level components make up important basic elements of fish habitat and underlying ecosystem linkages (i.e., conditions under which primary and secondary productivity are initiated). By gathering information on the biomass, distribution, and composition of lower trophic organisms, in relation to oceanographic/environmental characteristics, we can better understand the ecosystems inhabited by fish. The objectives of the marine primary productivity component of the BSMF project were to obtain:

A. Profiles of conductivity, temperature and salinity (CTD) and $\delta^{18}O$ (a measure of oxygen stable isotopes descriptive of water mass characteristics); calibrated against *in situ* measurements (salinity).
B. Discrete profiles of nutrients: $NO_3 + NO_2$, PO_4, $Si(OH)_4$.
C. Continuous measurements of downwelling solar radiation, i.e. Photosynthetically Active Radiation (PAR) present across different depths.
D. Discrete profiles of size-fractionated chlorophyll *a* (chl *a*) biomass (chl *a* total and chl *a* > 5 μm), particulate and dissolved organic carbon and nitrogen.
E. Discrete profiles of prokaryotic abundance, small (< 40 μm) autotrophic and heterotrophic eukaryote abundance, and seawater archaeal and bacterial community structure.
F. Estimates of trophic linkages using stable isotope and fatty acids methods.
G. Estimates of cell abundance and biological diversity.

Methods

Water samples at each station were collected in Niskin bottles at discrete depths from the rosette-CTD sampler (Table 4). The number of sampling depths varied among stations, increasing with the overall depth of the sampling station (Table 5). The rosette sampler was generally deployed to within 5-10 m of the bottom, where a maximum depth water sample was obtained. Targeted samples were also collected from strata/depths corresponding to 33.1 salinity and the depth of highest fluorescence signal (i.e., chlorophyll maximum, chlmax). Downwelling PAR was measured every second, with 15 min averages logged. Nutrients ($NO_3 + NO_2$, PO_4,

$Si(OH)_4$), oxygen-18 and dissolved organic carbon samples were collected directly from Niskin bottle spigots. Niskin water intended for other biological samples was transferred to carboys and taken below-deck to the F/V *Frosti* wet lab for further processing. Filtrations were conducted in the wet lab (Fig. 12) and samples were preserved (-50 ˚C) or stored in a refrigerator (4 ˚C) until analysis. Processing times was 2.5-5 h per station, plus analysis the following day for chlorophyll. Chlorophyll filters were extracted in 90% acetone for 18-24 h and then analyzed with a Turner 10AU fluorometer in the *F/V Frosti* wet lab.

Table 4 Marine primary productivity sampling summary. IOS refers to Institute of Ocean Sciences, Sidney, BC; where salinity analyses were done for 2013 and 2014.

Year	Salinity	$\delta^{18}O$[1]	Inorganic nutrients[2]	Chl *a*[3]	DOC & DN[4]	POC & PON[5]	POM $\delta^{13}C$ & $\delta^{15}N$[6]	FA POM[7]	Bacteria abundance	Protist abundance	Microbial Diversity (DNA)	Taxonomy
2012	x	x	x	x	x			x	x	x	x	x
2013	(IOS)	x	x	x	x	x	x	x	x	x	x	x
2014	(IOS)	x	x	x	x	x	x	x	x	x	x	x

[1]Oxygen isotopes
[2]Inorganic nutrients include nitrate, nitrite, phosphate, and silica C = carbon and N = nitrogen
[3]Total chlorophyll *a* and size fractionated chlorophyll *a* (>5 µm)
[4]Dissolved organic carbon (DOC) and nitrogen (DN)
[5]Particulate organic carbon (POC) nitrogen (PON)
[6]Stable isotopes ($\delta^{13}C$ & $\delta^{15}N$) of particulate organic matter (POM)
[7]Fatty acids and total lipids of particulate organic matter

Table 5 Maximum number of sampling depths per station on the shelf and slope.

Station Depth (m)	Number of Sampling Depths
40	5
75	8
200	13
275	13
300	14
500	15
1000	20

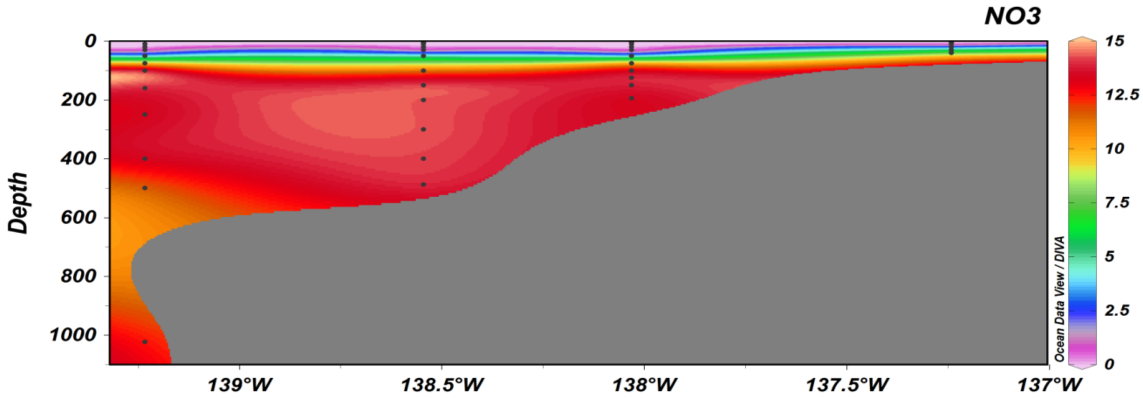
Figure 12 Marine productivity filtration laboratory aboard the F/V *Frosti*.

Results

Nutrient concentrations (NO_3 and NO_2) were much higher at depth in 2013 compared to 2012 (Fig. 13), possibly as a result of a mixing event or nutrient resupply deeper in the water column.

In both years there were very low nutrient concentrations in the surface layer, indicating an earlier bloom in the upper water column and a productive period well underway at the time of sampling. Nutrient profiles of NO_3, PO_4 and $Si(OH)_4$ showed extensive nutrient depletion at the surface and a strong nutricline (i.e., sharp transition zone in nutrient concentrations) at approximately 20 m (Fig. 14), although this varied among stations. Consistent with present knowledge of the region, the subsurface chlorophyll *a* max (both total biomass and large cells) was located at the pycnocline (i.e., the transition zone associated with salinity) (Fig. 14). In 2013, the highest concentrations of chlorophyll *a*, indicative of higher phytoplankton biomass, were found in Amundsen Gulf (Fig. 15). In addition, coastal regions of higher biomass were observed in Darnley Bay and Cape Parry. Concentrations of large cells in these areas indicated potentially efficient transfer of biomass/energy to fishes and higher trophic levels.

2012



2013

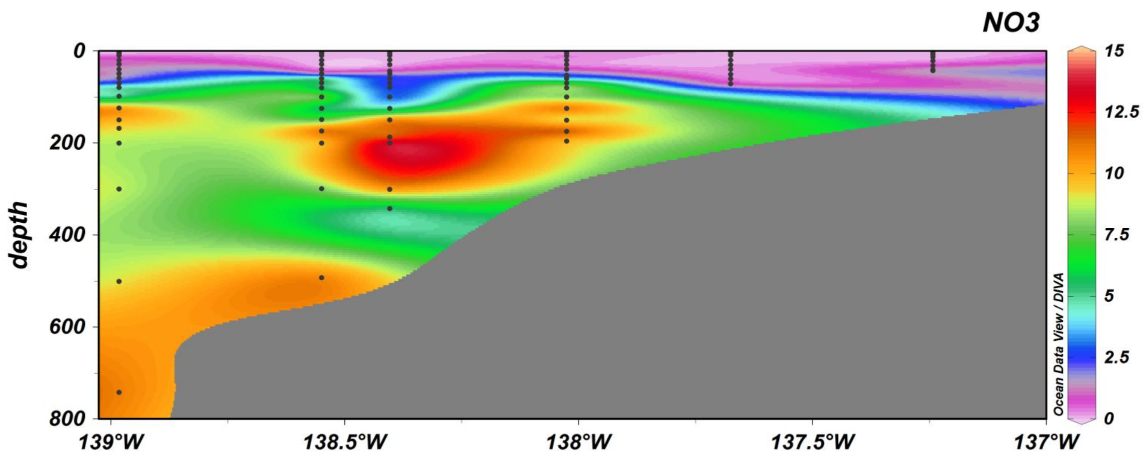


Figure 13 NO3 concentrations (μmol L^{-1}) along the GRY transect in 2012 and 2013.

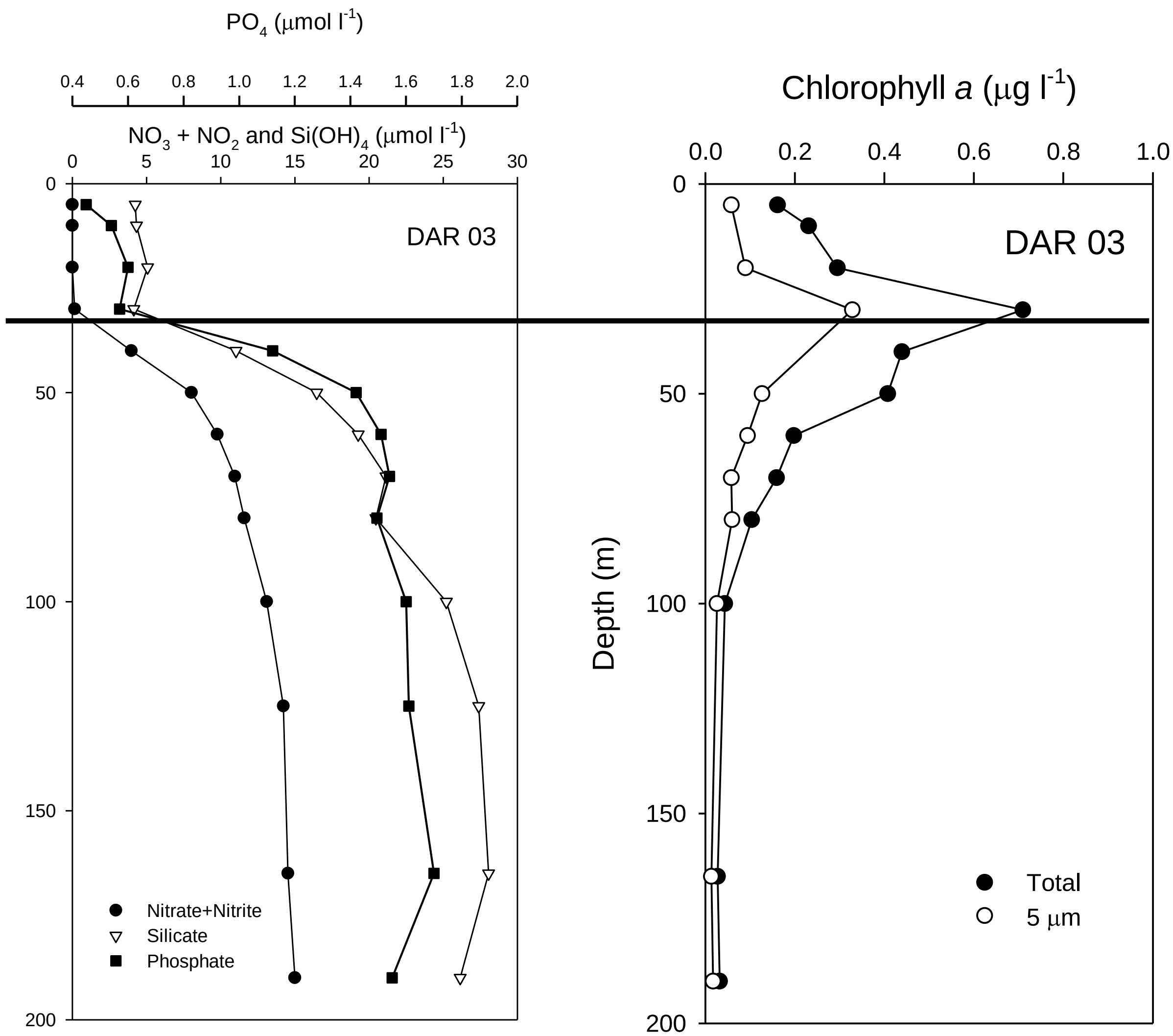


Figure 14 Nutrient (left panel) and chlorophyll *a* (right panel) profiles at DAR 03 sampling station in 2013. The dark horizontal line indicates the nutricline depth.

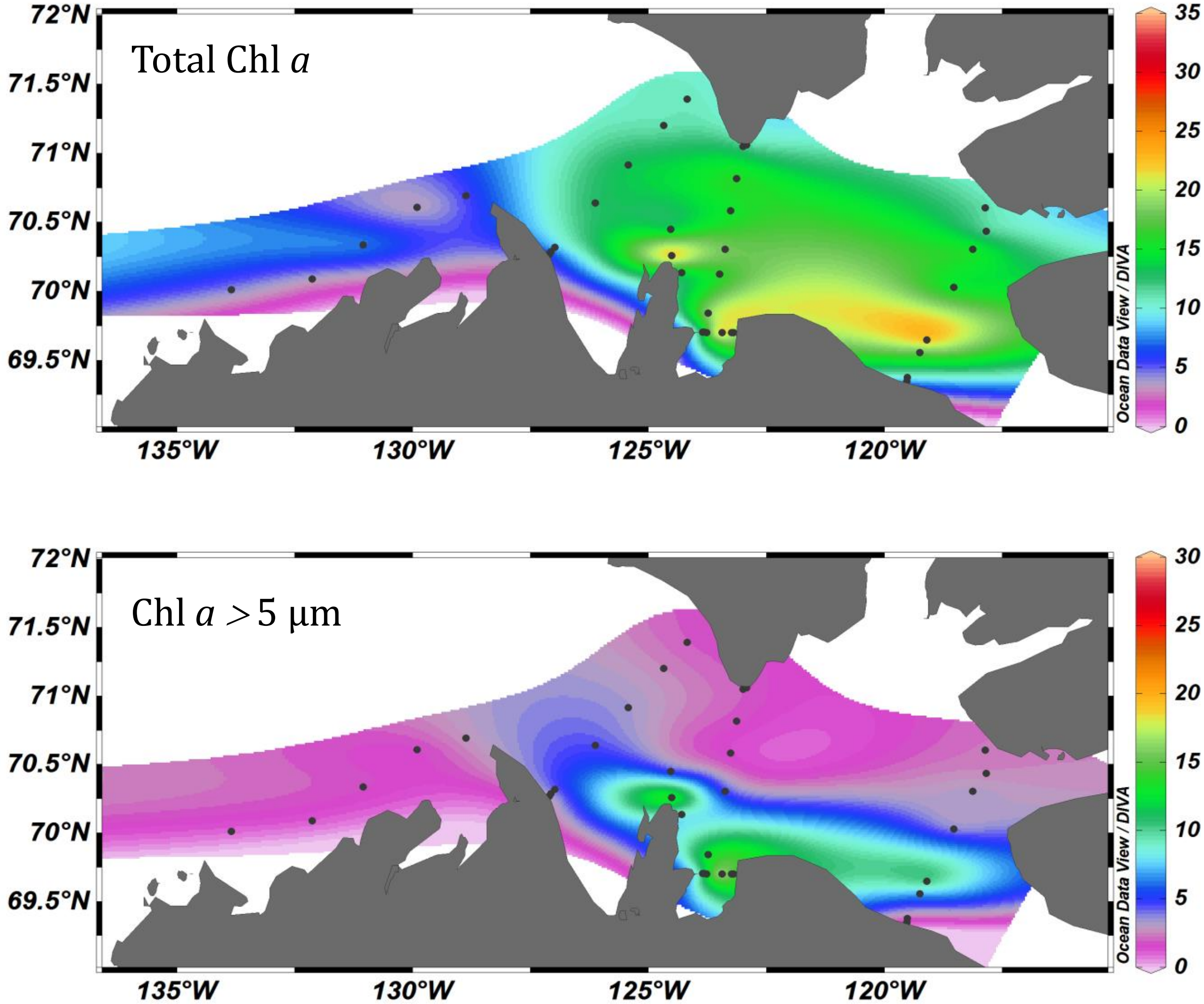


Figure 15 Integrated chlorophyll *a* concentrations (mg m^{-2}) in the Beaufort Sea in 2013.

2.2 Sediment and Infauna

The primary objectives of the BSMF project Sediment and Infauna component were to provide information about bottom composition and the availability of benthic invertebrate prey items for benthic fishes, specifically by:

A. Characterizing bottom substrate as a key habitat feature for benthic organisms based on sediment granulometry (% sand, silt, clay), percent organic carbon content and benthic chlorophyll concentration.
B. Examining spatial patterns of species-level diversity, abundance and biomass of benthic macrofauna.
C. Collecting benthic infauna to characterize trophic relationships.
D. Identifying assemblages of benthic macrofauna and establishing relationships with environmental drivers.

Methods

At a given sampling station, a 50 cm x 50 cm UNSEL box corer was lowered from the port side of the *F/V Frosti* to the bottom of the ocean to collect 1-2 cores of marine sediments (Fig. 16). A primary core (tallest, cleanest surface-water interface, flattest sediment surface with no slumping,) was divided into two sections for quantitative sampling of approximately equal area (~0.125 m^2 each). The first section was used to collect surface sediment samples for organic carbon content, granulometry, stable isotopes, contaminants, chlorophyll, prokaryotes, lipids and proteins, with remaining material sieved through a 1.0 mm stainless steel mesh to collect infauna for stable isotope analysis (SIA) (Table 6). The second half of the core was sorted quantitatively for taxonomic abundance and biomass of infauna from two depth strata from 0-5 cm and from 5 cm to clay layer (typically 20-25 cm depth). Taxonomic samples were sieved through a 0.5 mm stainless steel mesh and preserved in 10 % buffered formalin (Table 7). In addition, extra sediment was collected and frozen at every station to reserve for opportunistic post-hoc analyses.

The second core was sampled for replicates of organic carbon content, granulometry and also to collect meiofauna. Remaining sediment was processed for infauna SIA as above. Infauna collected for stable isotopes were not sorted at sea due to limited crew and laboratory capacity, but were frozen in bulk sediments for later analysis.

Table 6 Sediment sampling summary.

Year	Granulometry	Organic Matter Content	Benthic Chlorophyll	Stable Isotopes	Contaminants (Hg)	Prokaryotes	Bacteria	Total lipids	Extra sediment	Push Core 10 cm diameter	Meiofauna
2012	x	x	x	x	x	x			x	x	
2013	x	x	x	x	x	x		x	x		x
2014	x	x	x	x	x	x	x	x	x		x

Table 7 Benthic infauna sampling summary.

Year	Taxonomic Abundance	Taxonomic Biomass	Stable Isotopes
2012	x	x	x
2013	x	x	x
2014	x	x	x

Figure 16 Box-corer being deployed from the F/V *Frosti* (left), and surface of a core sample (right).

Results

Sediment composition varied across study sites (Fig. 17). For example, sediment samples collected at the shallow stations (<100 m) along the Canadian Beaufort Shelf typically consisted of a thick layer of clay with narrow bands of organic layers throughout the core. These samples generally had very little sand and gravel. Stations ranging in depth from 100-200 m were mostly composed of gravel-sized material along with a thick, hard-packed clay substrate. In contrast, the sediments collected from Amundsen Gulf and near the west shore of Banks Island (between depths of 20 and 500 m) contained a higher percentage of coarse substrate (sand, gravel, cobble) than did the stations that were sampled across the Beaufort Shelf. However, note that sediment granulometry as described here is based on a single 1 cm^3 subcore. The focus of the sediment sampling program was to characterize bottom composition for benthic fishes and invertebrates at a given sample site, rather than to describe the sediment distribution pattern at a larger spatial scale, which would require many more replicate samples.

In terms of the infauna, worms (polychaetes) were the dominant group in all habitats. Many of the shallow stations along the shelf included bryozoans, hydrozoans, sponges, and arthropods (e.g., isopods, amphipods). The deeper stations along the slope and lower-slope were dominated by polychaetes and smaller bivalves (mussels and clams). Overall, a total of 385 distinct infauna from 14 phyla were sampled from 2012-2013. The infauna was dominated by annelids (mostly polychaetes) across all habitats and geographic regions, but with phylum-level evenness of numbers of taxa increasing with depth in all geographic areas (Figs. 18-20; also shown are epifauna, see Section 2.3). In future, more in-depth, multivariate analyses using species-level distribution and abundance data will be used to distinguish unique areas based on benthic assemblages and their environmental correlates.

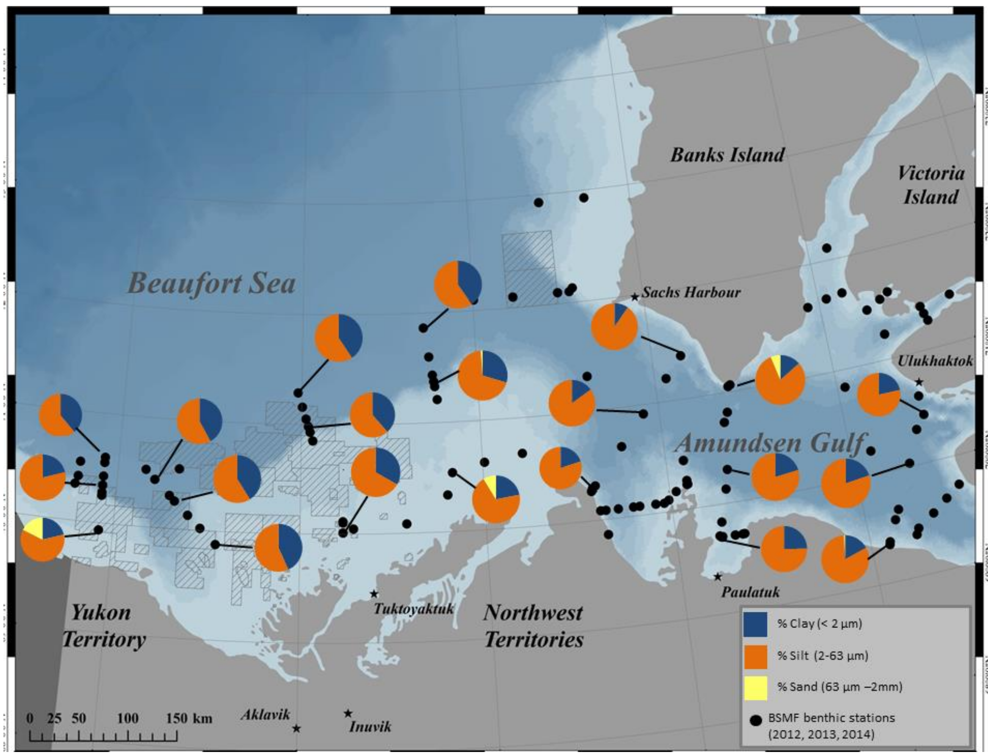


Figure 17 Percentage sand (yellow), silt (orange) and clay (blue) in surface sediments collected from the Beaufort Sea and Amundsen Gulf, 2012-2014.

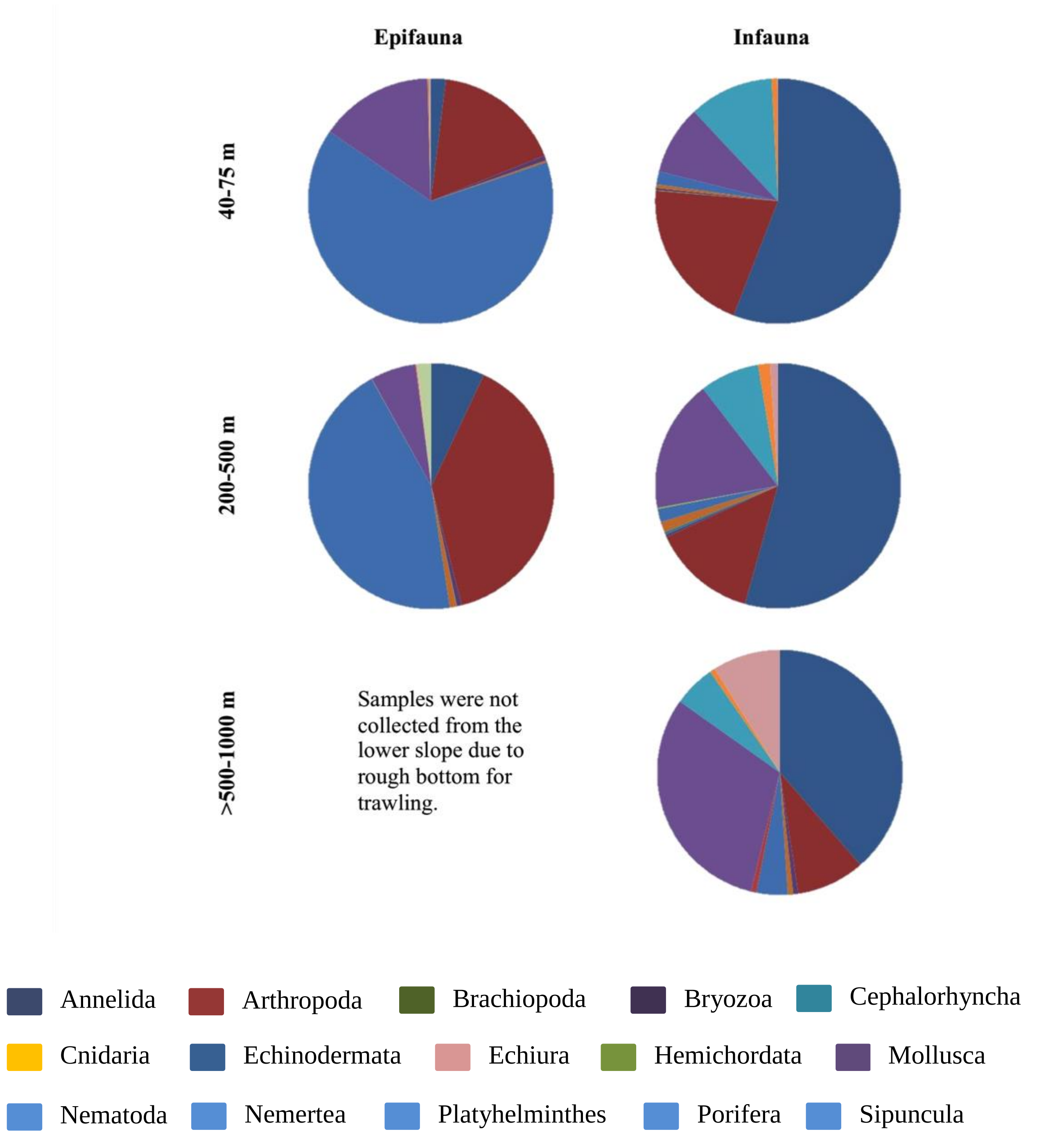


Figure 18 Relative abundance of epifauna and infauna phyla collected from the Alaskan Shelf in 2012.

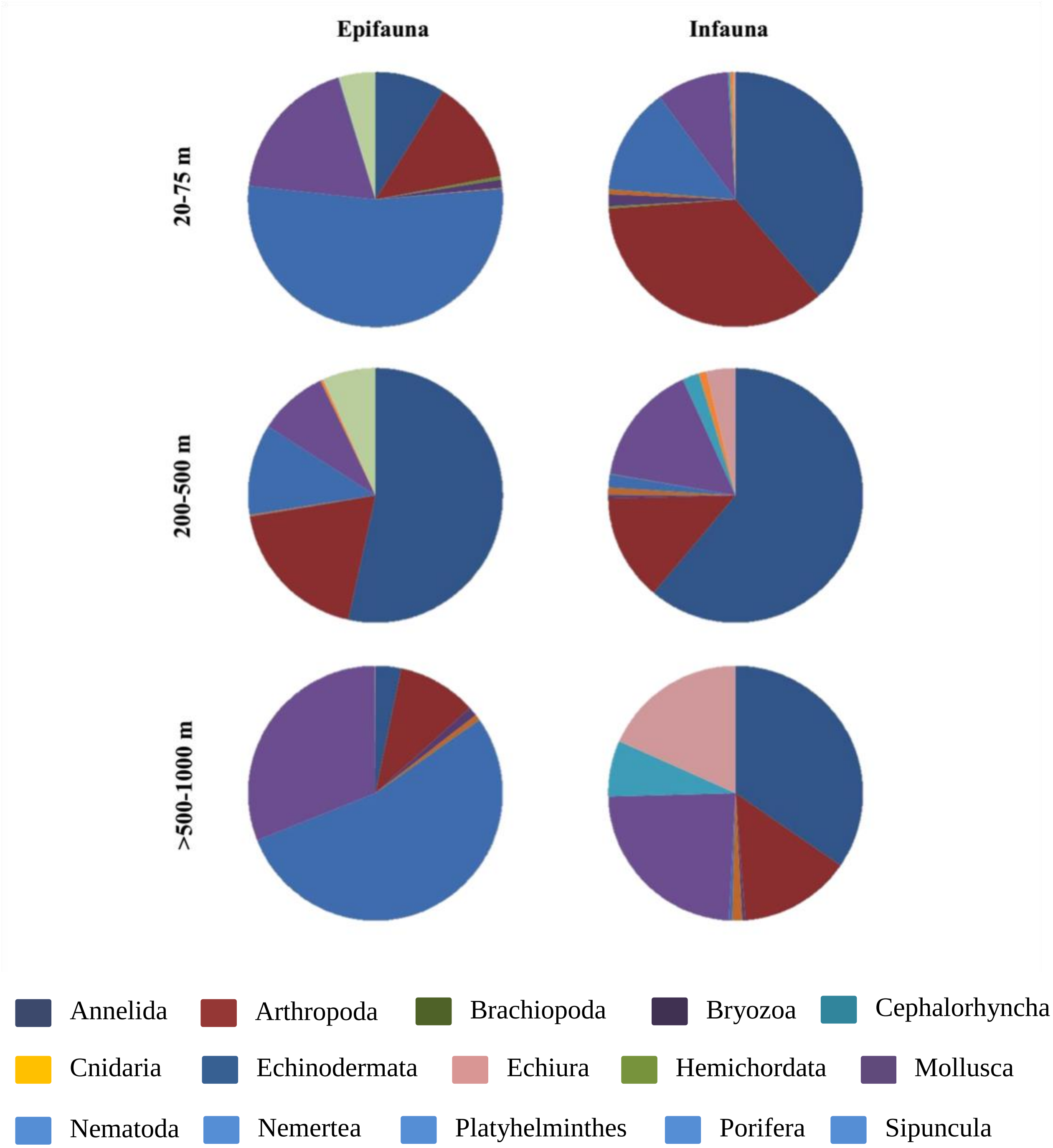


Figure 19 Relative abundance of epifauna and infauna phyla collected from the Central Beaufort Sea Shelf and Slope in 2012.

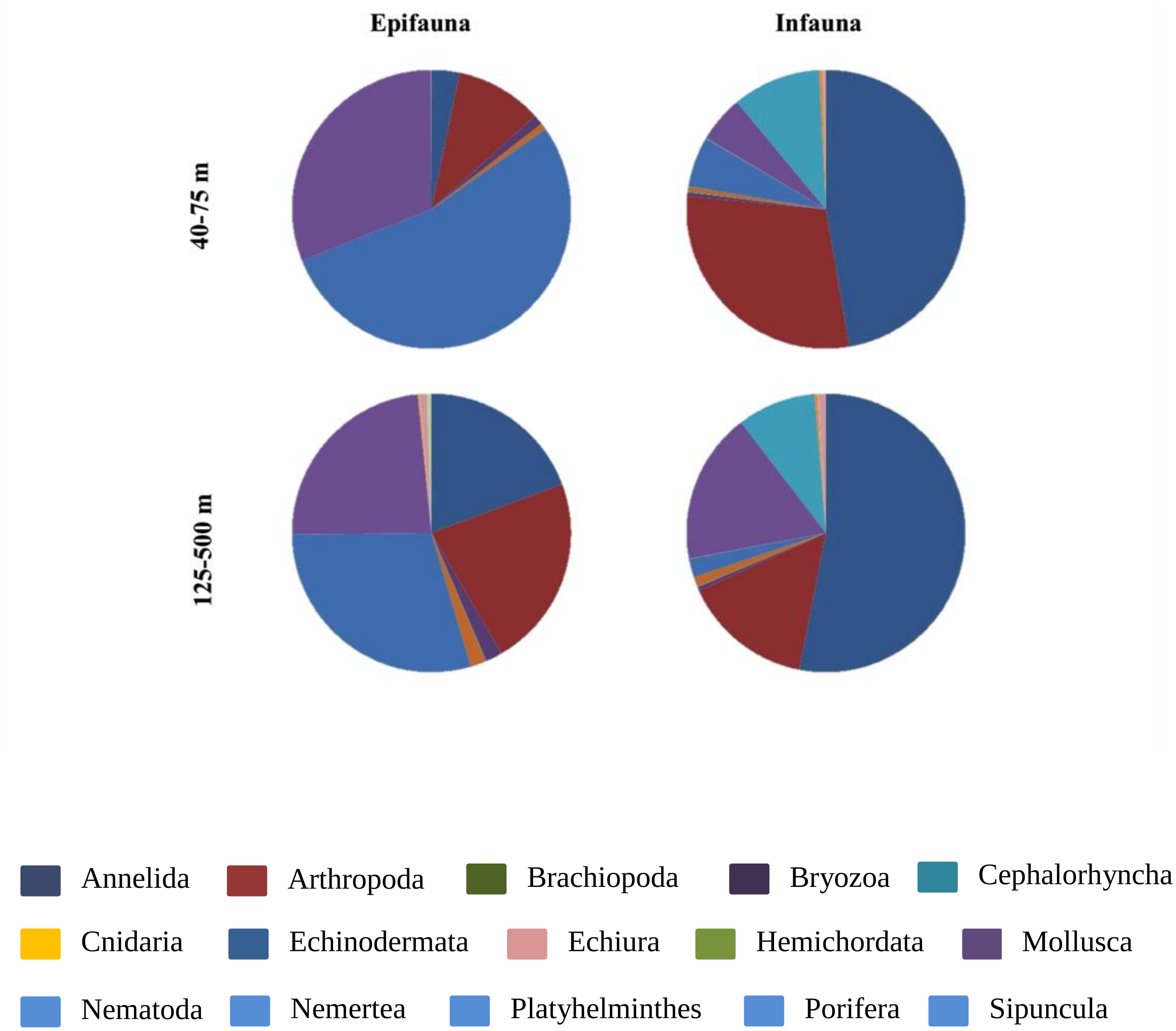


Figure 20 Relative abundance of epifauna and infauna phyla collected from Amundsen Gulf in 2013.

2.3 Epifauna

Marine invertebrates living on the sediment surface (epifauna or epibenthos) are an important part of the diets of benthic fishes. Studies of the composition of the epifauna community and the abundance and distribution of important food items are needed in order to better understand fish communities and their habitats as well as food web linkages between benthic and pelagic habitats. The BSMF project epibenthic program objectives aimed to:

A. Quantify macrobenthic organisms (abundance, biomass and diversity) along regional gradients (inshore-offshore, East-West).
B. Expand upon the limited knowledge of epibenthic biodiversity within the Beaufort Sea and Amundsen Gulf.

Methods

Samples of the epifauna were collected using a 3 m benthic beam trawl (BBT) and a modified Atlantic Western IIA otter trawl (WIIA) (Fig. 21; Table 8). The BBT was the main gear type used, but was limited to stations that were less than 500 m deep. At deep-water stations (>500 m), or at stations with rocky or hard bottom substrates, the WIIA was used exclusively. The BBT was towed across the seafloor at speeds between 1.81-2.35 knots for approximately 10 minutes whereas the WIIA was towed across the seafloor at speeds between 2.75-3.3 knots for 20 minutes. Samples were washed with seawater in a 2 mm sieve (BBT) and 4 mm sieve (WIIA), and organisms were counted and identified to the lowest taxonomical level possible. When taxonomic identification was uncertain, specimens were preserved (10 % formalin or frozen -20 ºC) for further examination in the laboratory.

Figure 21 Deployment of the 3 m benthic beam trawl (BBT), the primary gear for sampling epibenthic invertebrates.

Table 8 Epifauna sampling summary.

Year	Taxonomic Abundance	Taxonomic Biomass	Contaminants (Hg)	Stable Isotopes	Fatty Acids	Voucher specimens	Genetics*
2012	x	x	x	x	x		
2013	x	x	x	x	x		
2014	x	x	x	x	x	x	x

* only for *Astarte sp*. (bivalve)

Results

During the BSMF project at least 384 distinct epifauna taxa from 15 phyla were sampled from 2012 to 2013. Overall, diversity of epifauna was generally greatest with respect to evenness (i.e., how equal the abundances of the species were) along upper slope habitats. Most phyla occurred in all habitats, with the exception of Brachiopoda, which were only collected from the Beaufort Shelf (Figs. 18-20). Echinoderms dominated epifauna communities (Fig. 22), accounting for more than 50% of relative abundance across all habitats in each major geographic area except for the slope habitats of the Central Beaufort Sea, where annelids and arthropods dominated the upper and lower slopes, respectively.

Figure 22 Sample beam trawl catch from 2013 full of seastars and brittle stars.

2.4 Zooplankton and Ichthyoplankton

Zooplankton represent an important link in the food web because they consume biomass from primary producing phytoplankton and transfer energy to higher trophic levels including fish, seals, and whales. Ichthyoplankton are young stages of the various fish species occurring in the area; the larval stages of most fish species tend to be pelagic (i.e., found in the upper layers of the water column usually in association with various sizes of zooplankton as well as the phytoplankton, both of which serve as food for the various larval fishes). Thus, both zooplankton and ichthyoplankton are captured together using the same gear. The objectives of this component were to:

A. Characterize the taxonomic composition and vertical/horizontal distribution of zooplankton/ichthyoplankton communities in the Canadian Beaufort Sea.
B. Collect samples of zooplankton/ichthyoplankton for contaminants analysis (Hg, PAHs) and food-web/trophic and energetic studies (SIA and FA).
C. Collect samples of zooplankton/ichthyoplankton for molecular studies (genetic diversity).
D. Provide ground-truthing of hydroacoustic surveys (see below) accompanying zooplankton and fish net sampling.

Methods

Two sampling methods were used to collect zooplankton data over the duration of the BSMF project (Table 9). Information on the vertical distribution of medium size zooplankton (mesozooplankton; 0.2-20 mm) such as copepods was collected using a Hydro-Bios sampler (MultiNet) (Fig. 23). The net had a 0.25 m^2 opening and a mesh size of 150 µm and was capable of sampling up to 5 different water layers during a single deployment, which provided information on the vertical distribution of zooplankton, i.e., the depths at which particular zooplankton were found in the water column. The MultiNet proved to be reliable, durable and efficient enough for deployment in this type of Arctic sea. Another type of plankton net, the Bongo net (0.30 m^2; 500 µm mesh), was used to sample larger zooplankton (macrozooplankton; 20-200 mm) such as amphipods, krill, and larval fish (ichthyoplankton). The Bongo net consisted of two side-by-side sampling nets that were towed in an oblique pattern (diagonal) from near the bottom of the ocean (no deeper than 200 m) back up to the surface (Fig. 24). The Bongo was equipped with flow-meters to record the volume of water filtered during a sampling effort.

Figure 23 Multinet - multiple net opening/closing apparatus for stratified vertical zooplankton sampling.

Table 9 Zooplankton and Ichthyoplankton sampling summary.

Year	Taxonomic Abundance	Taxonomic Biomass	Contaminants (Hg)	Stable Isotopes	Polycyclic aromatic hydrocarbons (PAHs)	Fatty Acids	Energetics	Genetics (DNA)
2012	x	x	x	x	x	x	x	x
2013	x	x	x	x	x	x	x	x
2014	x	x	x	x	x	x	x	x

Figure 24 Bongo net for oblique sampling of plankton and larval fish.

Results

From 2012 to 2014, zooplankton samples were collected between 20-1000 m, which represents the first time zooplankton sampling covered such a large area at these depths in the Canadian Beaufort Sea. Our results showed that the 2012 and 2013 zooplankton samples consisted mostly of crustaceans. The crustacean zooplankton biomass was dominated by calanoid copepods and amphipods. From the ichthyoplankton (larval fish) samples, Arctic Cod was the most common species followed by Pricklebacks (Stichaeidae). In comparison, zooplankton samples collected in 2014 were comprised mainly of the sea butterflies (pteropods) and amphipods highlighting the inter-annual variability in the plankton community. In the 2014 samples, crustacean zooplankton were only collected at stations deeper than 80 m.

Taxonomic analysis of zooplankton from all 28 stations sampled in 2012 resulted in the identification of 104 taxa, from which 92 were identified to species, 4 to genus and the remaining to higher levels (mainly meroplankton, i.e., organisms planktonic for only a limited portion of their life history). Margalef's diversity index revealed a consistent trend towards higher diversity offshore along all transects (Fig. 25). This trend was primarily due to the fact that diversity increased vertically along with increasing depth. Margalef's index values were significantly different between the sampled water layers (50-100 m, 100-200 m, >200 m), however, there was no difference in diversity in the two shallow-most layers (0-25 m and 25-50 m). Increased diversity offshore can be attributed to the occurrence of the deep water taxa that were found beyond the shelf boundary. On the other hand, there was the opposite trend in regards to zooplankton biomass, which was higher on the shelf, particularly at the shallowest stations (Fig. 26). We expect that these findings result from a combination of local upwelling phenomena or the concentration of zooplankton advected onto the shelf with the coastal currents.

Vertical distribution of the two ecologically most important copepods - *Calanus glacialis* and *C. hyperboreus* - showed that they primarily occurred higher in the water column in summer (Figs. 27-28). The greatest biomass of both *C. glacialis* and *C. hyperboreus* was recorded on the shelf, which confirms the previously observed distributions of these two species in the region. It has been documented that the high densities of *Calanus* (Fig. 29) on the Beaufort Sea Shelf in summer provide essential energy source (lipids) for numerous bowhead whales[20]. These copepods also serve as food for juvenile and adult fishes including pivotal species such as Arctic Cod[15].

This study provides baseline information on spatial (in both vertical and horizontal dimensions) distribution of zooplankton. In-depth taxonomic analysis allows us to establish patterns for virtually all zooplankton species including analysis of assemblages in relation to geographical location and depth. Ultimately, the availability of zooplankton is a limiting factor for the success and distribution of many other species at higher trophic levels that feed upon the zooplankton, including marine fishes.

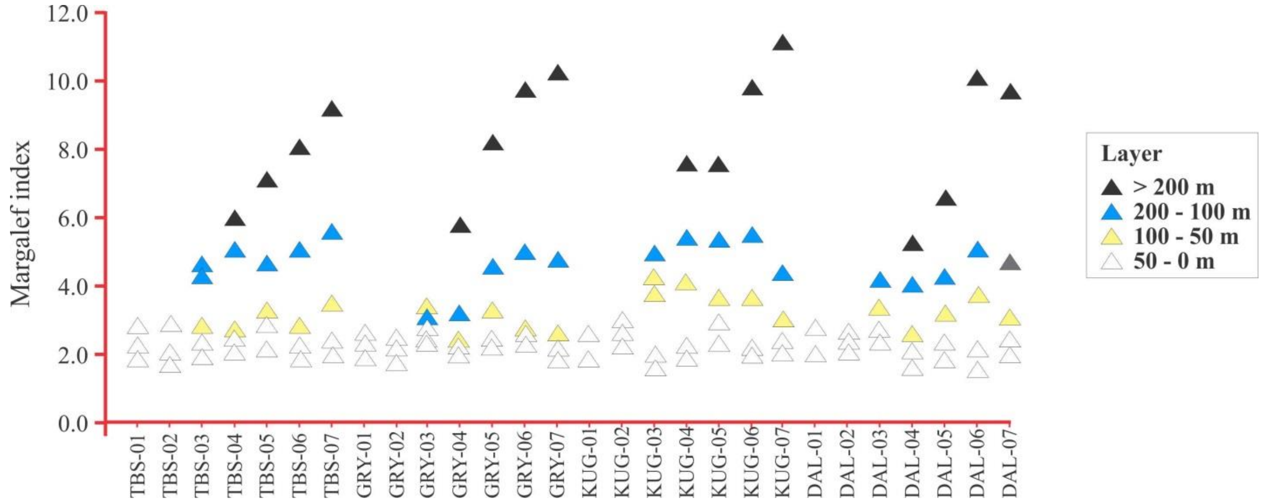


Figure 25 Biodiversity as indicated by Margalef's index for all depth layers in the Beaufort Sea.

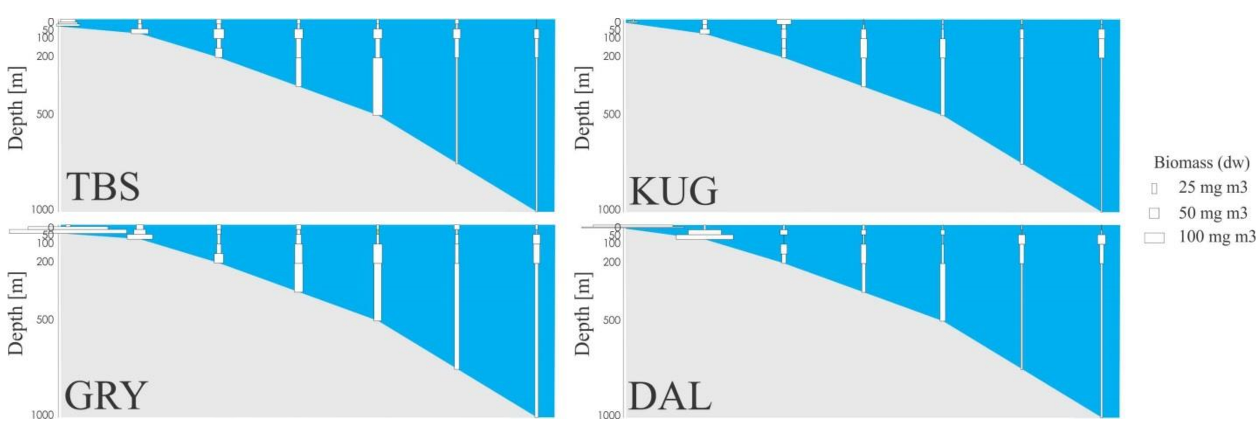


Figure 26 Total zooplankton biomass (dry weight - dw) for all transects sampled in the Beaufort Sea in 2012. The width of the vertical bars corresponds to the biomass of zooplankton found in the particular layer. Exemplary biomass values and related bar widths are provided in the figure legend.

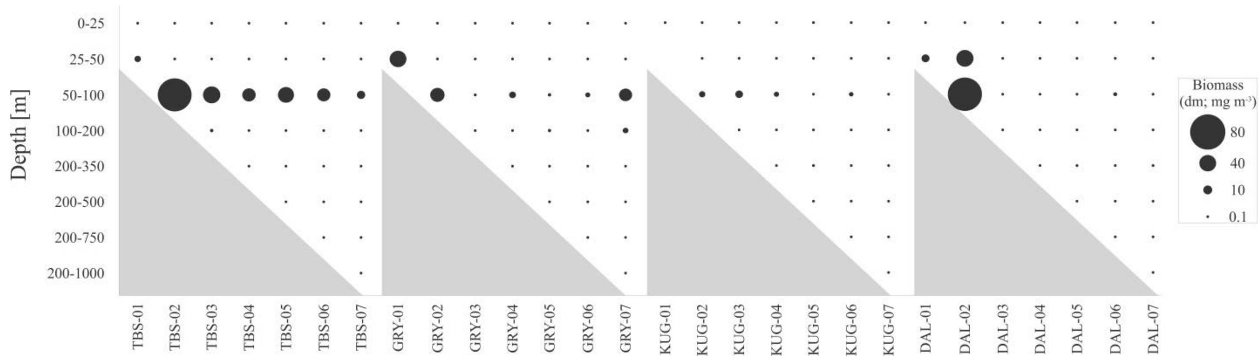


Figure 27 Cross-section diagram showing biomass (mg m^{-3}) of *Calanus glacialis* for depth classes across different transects in the Beaufort Sea.

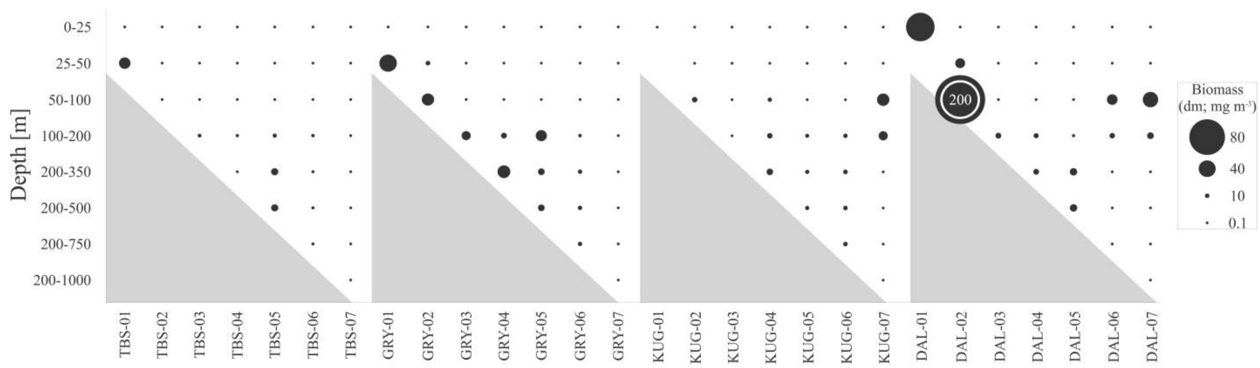


Figure 28 Cross-section diagram showing biomass (mg m^{-3}) of *Calanus hyperboreus* at different transects in the Beaufort Sea.

Figure 29 The copepod *Calanus hyperboreus* - one of the most numerous zooplankton species in the Beaufort Sea.

2.5 Fish

2.5.1 Demersal (bottom-dwelling) Fishes

Fish sampling was the primary goal of the BSMF project. The main objectives for this component were to:

A. Identify community structure and baselines for the diversity, distributions and relative abundances of offshore fishes and fish habitats on the Canadian Beaufort Shelf and Slope, and in Amundsen Gulf.
B. Increase understanding of interannual variability of fish populations and fish habitats.
C. Collect data to evaluate energetic links between the Amundsen Gulf, Canadian Beaufort Shelf, Canadian Beaufort marine ecosystem components.
D. Identify trophic patterns, food web structure, and feeding strategies among and within fish in the Canadian Beaufort Sea.
E. Collect hydroacoustic data to detect and document pelagic fish and other biota in relation to watermass characteristics, and validate hydroacoustic data with trawling efforts (see below).

Methods

Benthic fish sampling was conducted using two nets: 1) a modified Atlantic Western IIA (WIIA) benthic otter trawl (22.86 m head rope, 21.23 m footrope) with a 1.27 cm mesh cod-end and intermediate liner, paired with Thyborøn Type II, 2.72 m bottom-tending doors, and 2) a 3 m High-Rise Benthic Beam Trawl (BBT; 4.27 m headrope and footrope) with a 0.63 cm mesh codend liner (see Majewski et al. 2011[14] for full net details) (Table 10). The WIIA is a broad spectrum net suited for the capture of larger and faster fish such as Right Eye Flounders (Pleuronectidae) and Skates (Rajidae), as well as smaller-bodied bottom fishes previously documented in the Canadian Beaufort Sea. The WIIA was typically towed for 20 minutes per station at a target speed of 2.9 knots (2.7 – 3.1 acceptable range)[21].

Table 10 Fish component sampling summary.

Year	Taxonomy[1]	Contaminants (Hg)	Stable Isotopes	Fatty Acids	DNA	RNA	Gut Contents	PAHs[2]	Energetics	Biological parameters[3]	Otoliths	Voucher specimens
2012	x	x	x	x	x	x	x	x	x	x	x	x
2013	x	x	x	x	x		x			x	x	x
2014	x	x	x	x	x		x			x	x	x

[1]Abundance and biomass
[2]Polycyclic aromatic hydrocarbons
[3]Biological parameters include length, weight, sex and maturity

Net deployments were generally for 20 minutes bottom-time and were standardized to a target speed-over-ground (SOG) of 1.49 m s^{-1} (2.9 kn; 2.7 to 3.1 kn acceptable range). Trawling was typically conducted along bathymetric contours unless local currents dictated the need for adjustment to ensure acceptable trawl performance. Scanmar CGM-05/TE40-2 net mensuration equipment was used in conjunction with door spread and trawleye sensors to monitor net performance and bottom-contact. A Furuno GP31 global positioning system (GPS) was used to monitor bottom-contact and lift-off positions, and SOG. Average door spread, speed, and the bottom-time of each net deployment was recorded and used to calculate area swept. The smaller BBT was designed to target small-bodied benthic fishes such as Sculpins (Cottidae), Lumpfish (Cyclopteridae) and Snailfish (Liparidae) at stations less than 500 m deep. The BBT was towed at a target speed of 2.0 knots, and was deployed twice per station for 10 minutes to avoid clogging of the smaller meshes with mud. Bottom contact was monitored with a Scanmar trawleye sensor and the Furuno GP31 system was used to monitor position and speed. Speed and the bottom-time of each net deployment was recorded and used in conjunction with measurements of beam width to calculate area swept; see Atchison et al. (*in prep*)[22] for full deployment details and net specifications.

Once the nets from the trawls were brought onboard they were emptied and sorted. The catch was then separated into fish and invertebrates. Further processing took place on deck or below in the fish processing area. Processing onboard consisted of bulk weighing of each taxonomic family per catch, identifying each fish to the lowest taxonomic level possible, recording the length of each individual fish, and individually bagging fish and assigning a number tag. Samples were frozen and stored in the ship's hold for the remainder of the field program. New or unconfirmed species and representative examples of more common species were preserved as voucher specimens in 10% formalin for archiving purposes. Voucher specimens were collected to provide a lasting physical record of fish sampled during the BSMF project. A fin clip for DNA was taken from each voucher specimen. Further and full processing of individual fish was conducted at the Freshwater Institute in Winnipeg where a variety of aging structures (e.g., otoliths), tissues, and other important measurements from the fish were also gathered in order to understand how fish samples collected in the trawls fit into the larger population from which they originated.

Once samples arrived back in Winnipeg, the **taxonomic identification** of each fish was verified. Weights, lengths, sex and maturity of each fish were examined to provide information on the size structure and life-stages of the fishes during the summer. The stomach contents of fish were examined in order to see what food and how much food a fish was eating recently. In addition, clips of fin and muscle tissue were removed for population genetics/DNA studies. Lastly, samples of muscle tissue were also taken for food web studies (e.g., stable isotope analysis, fatty acid analysis), and to study contaminants (see below for details regarding these follow-on analyses).

Results

At least 16 new occurrences of previously undocumented marine fish species were recorded as part of this work; additionally, potential new records are possible as fish identifications are confirmed by taxonomic experts. The previous documented diversity of 52 species is thus incremented to 68 species as the total number of marine fishes now known to occur in the Canadian Beaufort Sea. The highest number of confirmed species was recorded in the central Canadian Beaufort Sea at 45, relative to 34 at stations on the Alaskan Shelf and slope and 35 in Amundsen Gulf. Within sub-regions, the highest fish diversity occurred at stations between 200 and 500 m depths. These depths coincide with the upper-slopes of the Alaskan and Canadian Beaufort continental shelves and the Pacific-Atlantic thermohalocline and upper-Atlantic water mass (see oceanography section). Fish diversity was generally lowest in areas deeper than 500 m. These results have not been corrected to account for relative sampling effort across sub-regions and depths, but are currently being investigated by Majewski et al. (2015)[21].

Percent relative catch abundances for the three field years are reported by taxonomic family for the Alaskan Shelf-slope, the Canadian Beaufort Shelf-slope and Amundsen Gulf (Figs. 30-33). Though overall family-level taxonomic composition was similar across areas and years, relative abundances were variable. The family Gadidae was primarily represented by Arctic Cod (*Boreogadus saida*), which occurred in all demersal habitats. Highest relative catch proportions of Arctic Cod generally occurred at stations depths between 200 and 500 m, though Arctic Cod were also prevalent at shallower stations within the Pacific water mass (see oceanography section). A detailed description of the distribution of Arctic Cod biomass on the Canadian

Beaufort Shelf and slope, based on these study results, can be found in Majewski et al. (2015)[21]. In general, the highest percent relative abundances of Arctic Cod were observed during 2013 across most areas and depths. Species from families Agonidae (e.g., Arctic Alligatorfish, *Aspidophoroides olrikii*) and Cottidae (e.g., Arctic Staghorn Sculpin, *Gymnocanthus tricuspis*; Twohorn Sculpin, *Icelus bicornis*) were also prevalent throughout the study area, though their proportionate abundances in the catches were highest in nearshore habitats (20-75 m). Zoarcids occurred in all demersal habitats, however, species composition changed with depth[22]. Zoarcids (e.g., Adolf's Eelpout, *Lycodes adolfi*) accounted for the majority of relative catch abundances at most lower-slope (>750 m) stations, which are associated with the lower-Atlantic water mass where Arctic Cod were less abundant (Fig. 30). Larger bodied fishes such as Greenland Halibut (Pleuronectidae; *Reinhardtius hippoglossoides*) and Arctic Skate (Rajidae; *Amblyraja hyperborea*) were also caught at deeper stations (≥350m) in association with the Atlantic water mass (see oceanography section). These two species did not account for a large proportion of relative abundances within stations but, given their relatively large sizes, were important from a biomass perspective.

Our results support recent work showing that fish in the Beaufort Sea display specific habitat associations by depth, such that fish community composition can be distinguished based on bathymetry, salinity and temperature[18,21]. Our results also indicate differences in fish community composition among the sub-regions presented here, based both on the relative abundances of species is common and also on unique fish occurrences. For example, Capelin (Osmeridae; *Mallotus villosus*) occurred only in Amundsen Gulf (Fig. 33), and primarily in Darnley Bay. Greenland Halibut were prevalent at slope stations associated with the Alaskan and Canadian Beaufort shelves, but were not abundant at similar depths in Amundsen Gulf. See Appendix 4 for draft publications that will describe marine fish community structure and habitat associations.

Basic biological and net deployment data will be published in the Canadian Data Report for Fisheries and Aquatic Science series. Detailed analyses of fish diversity, community structure, and habitat associations are ongoing and resulting manuscripts will provide an updated account of fish biodiversity in the Beaufort Sea, describe regional differences in species composition, and will examine habitat variables that influence community structure.

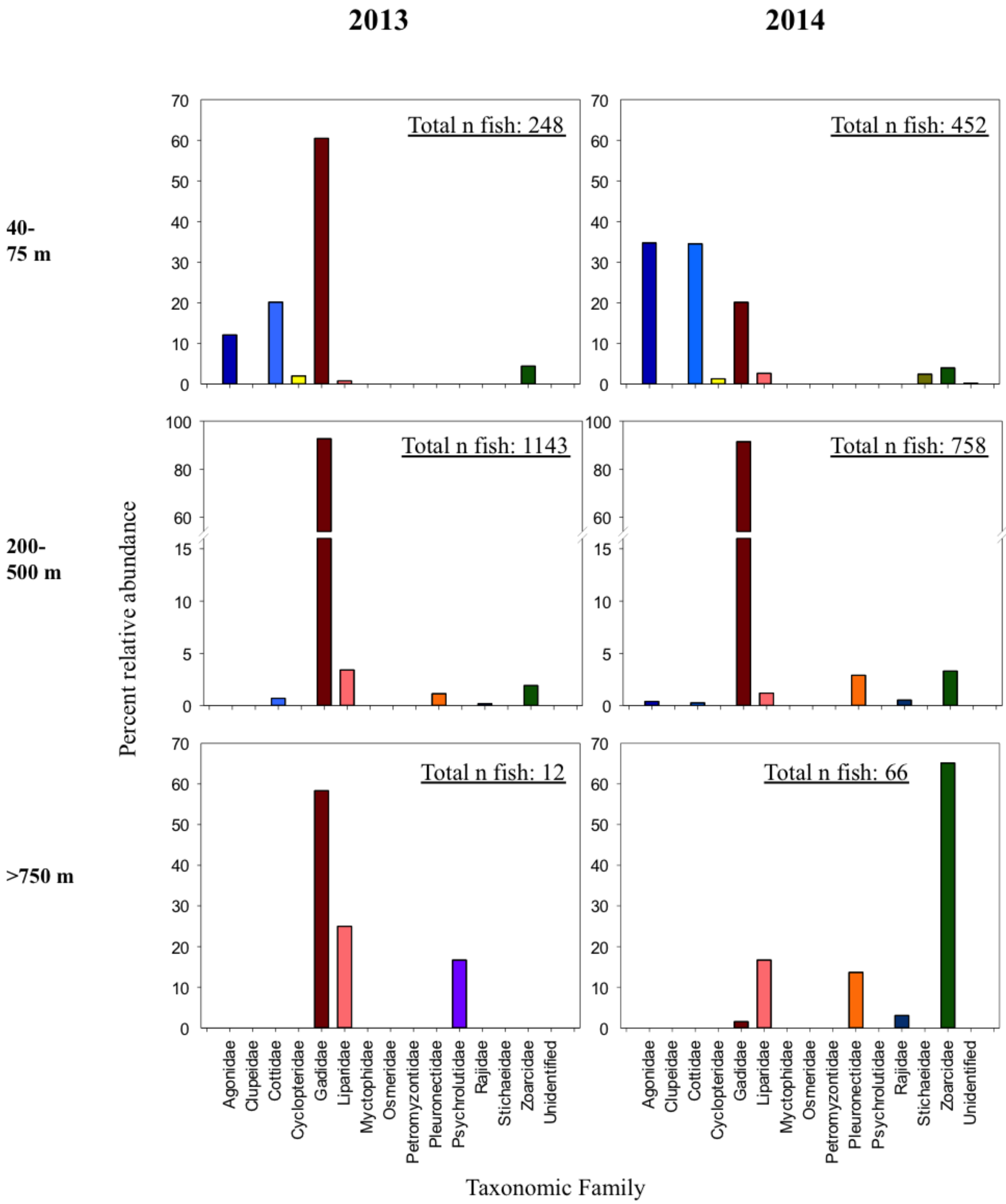


Figure 30 Percent relative abundance by taxonomic family, Alaskan Shelf.

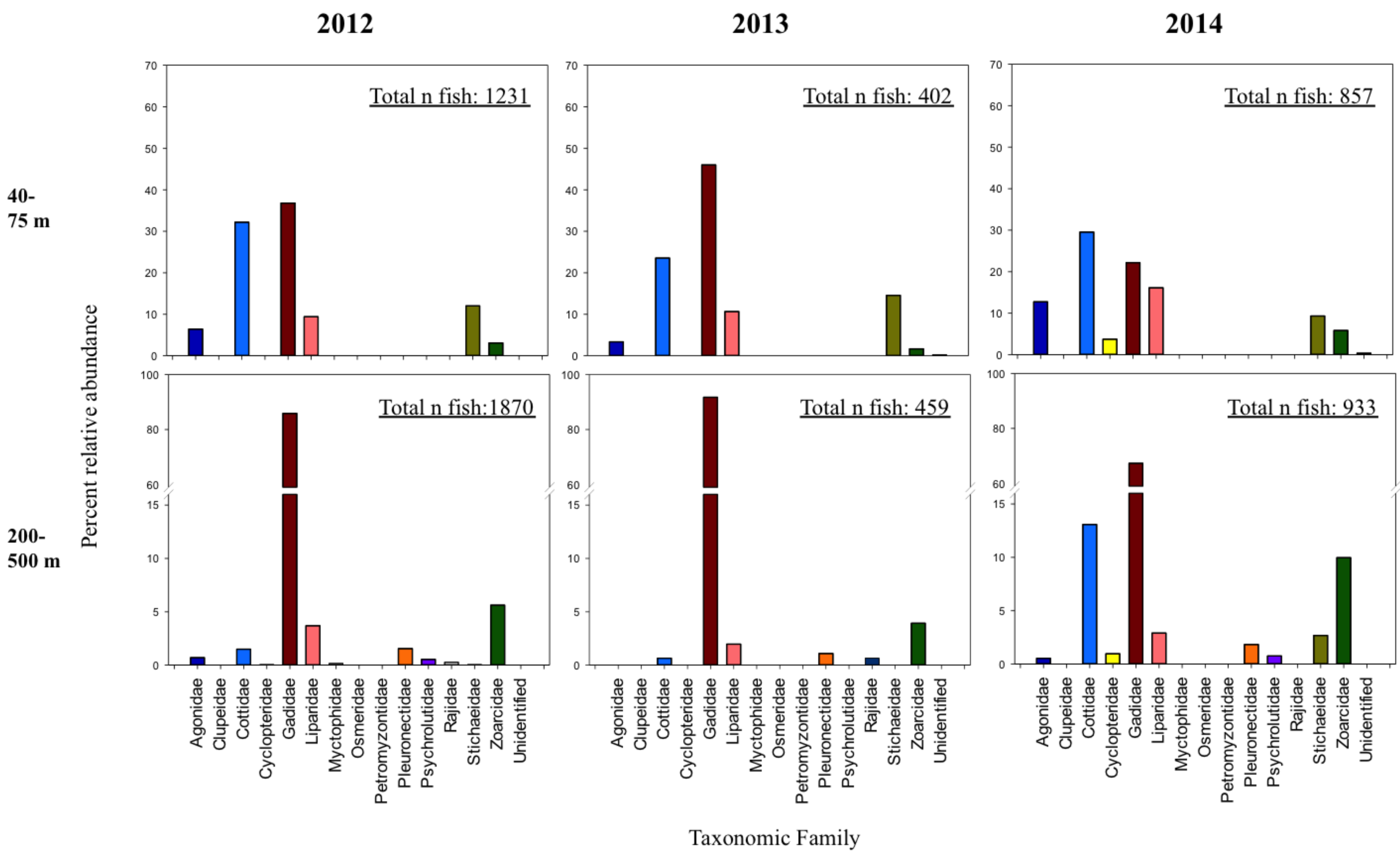


Figure 31 Percent relative abundance by taxonomic family, Central Beaufort Sea.

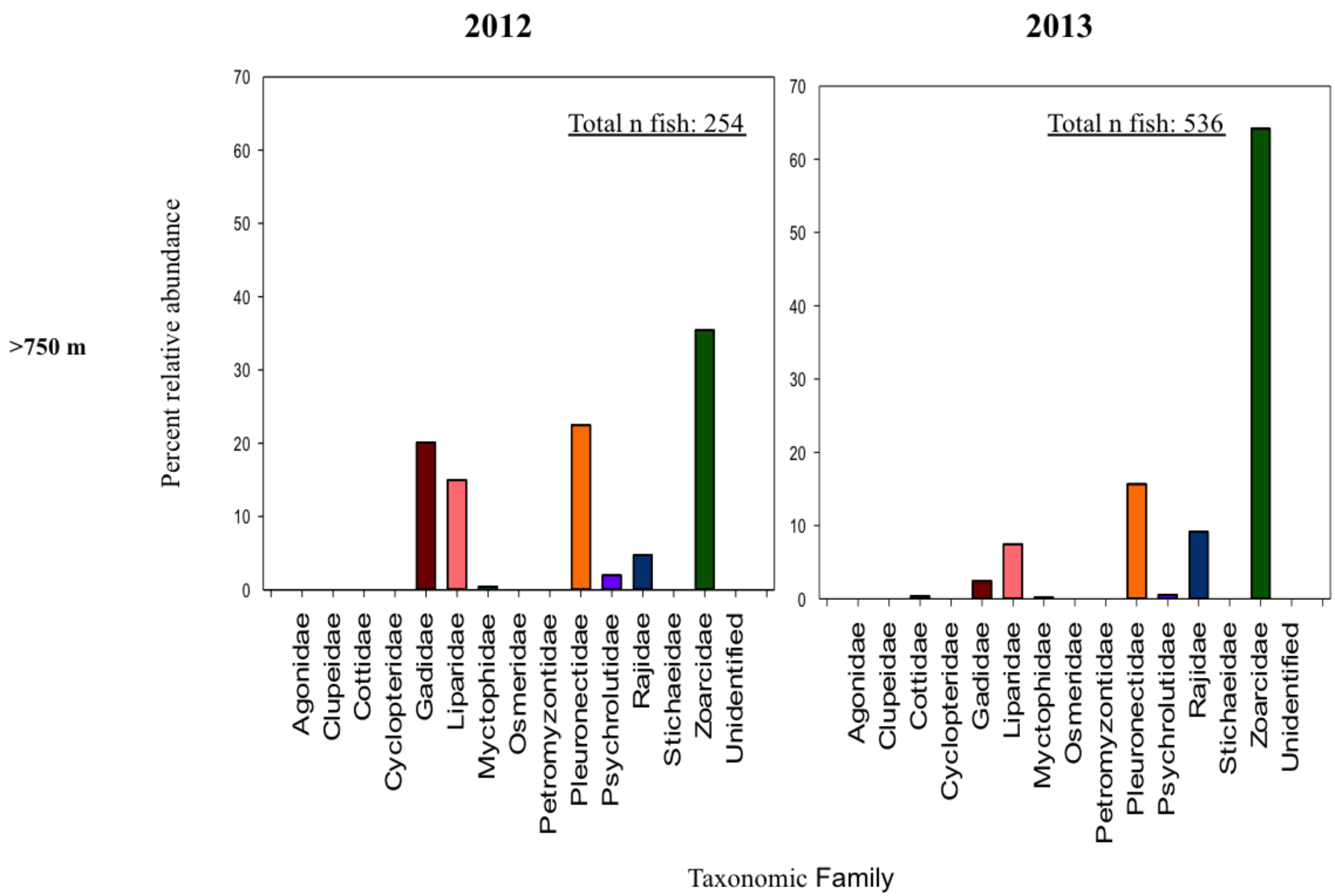


Figure 32 (cont'd) Percent relative abundance by taxonomic family, Central Beaufort Sea.

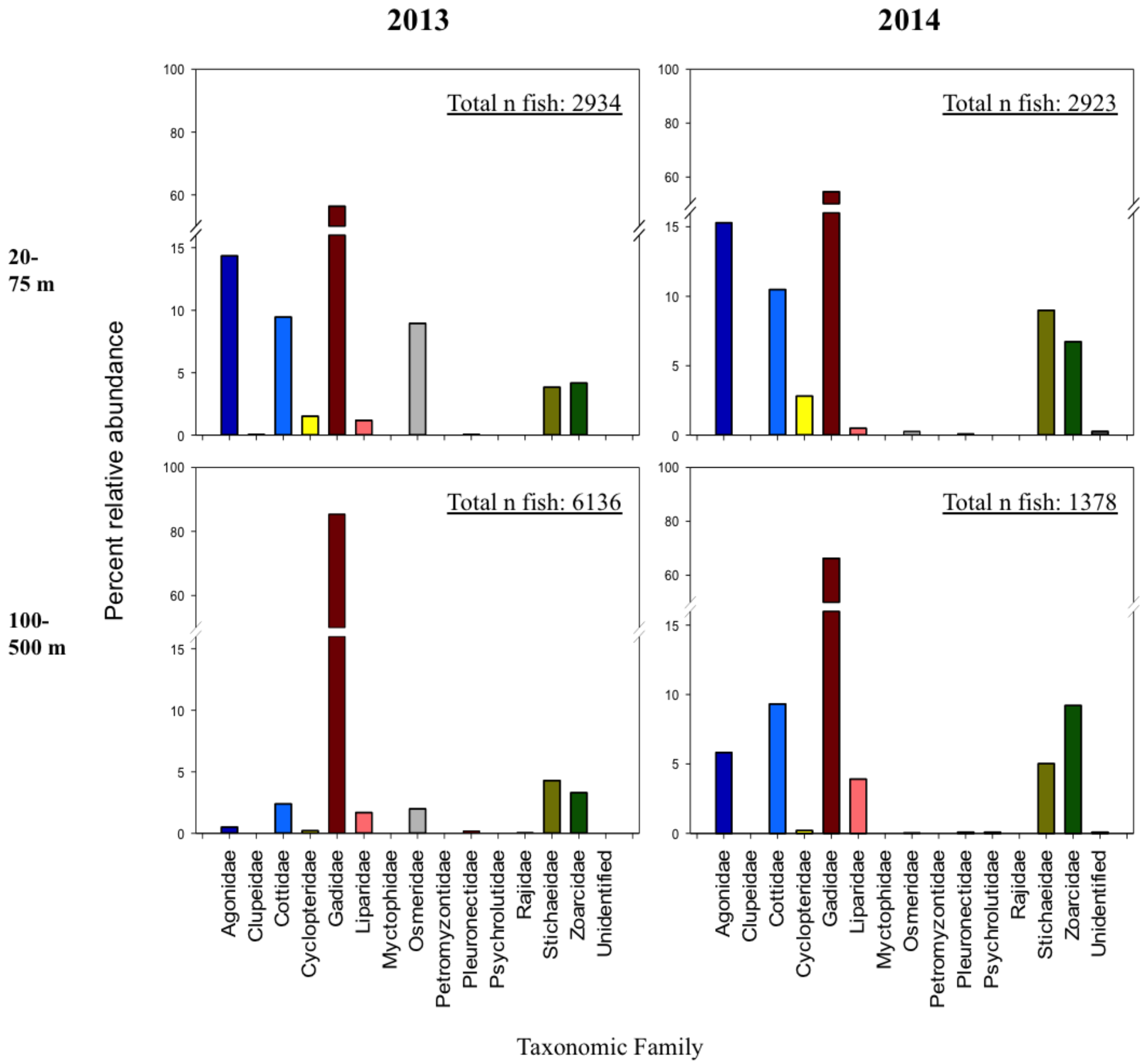


Figure 33 Percent relative abundance by taxonomic family, Amundsen Gulf.

2.5.2 Hydroacoustics and Pelagic Fish Sampling

The objectives of the hydroacoustics portion of the Fish component were to:

A. Detect pelagic organisms and document their abundance and biomass within surface and bottom aggregations, with a particular focus on Arctic Cod.
B. Document pelagic fish distributions and migrations (including diel vertical migration; DVM).
C. Verify the presence of schools of Arctic Cod in shallow areas (<50 m) and, if possible, at the Marginal Ice Zone (MIZ).
D. Validate Target-Strength to standard length relationships for Arctic Cod to allow better biomass estimates.
E. Estimate abundance of Arctic Cod stocks in the Canadian Beaufort Sea.
F. Collect hydroacoustics data for the Canadian Beaufort Sea time-series (since 2003).

Methods

Hydroacoustic work was conducted using a Simrad EK60 split-beam multi-frequency (38, 120, and 200 kHz) echosounder along the same transect lines as other sampling. Once a target of interest was identified by the hydroacoustic echogram (Fig. 34), a benthic or mid-water trawl net was deployed to validate the signal. In addition, a hydro-bios multinet (see Zooplankton section) was towed horizontally in the water column to sample zooplankton from target layers, and CTD casts were conducted to document water mass characteristics and calculate the speed of sound and absorption coefficients. In 2012 and 2013, targets were sampled using both benthic and pelagic nets. In 2014, sampling focused on the mid-water column only (i.e., pelagic net).

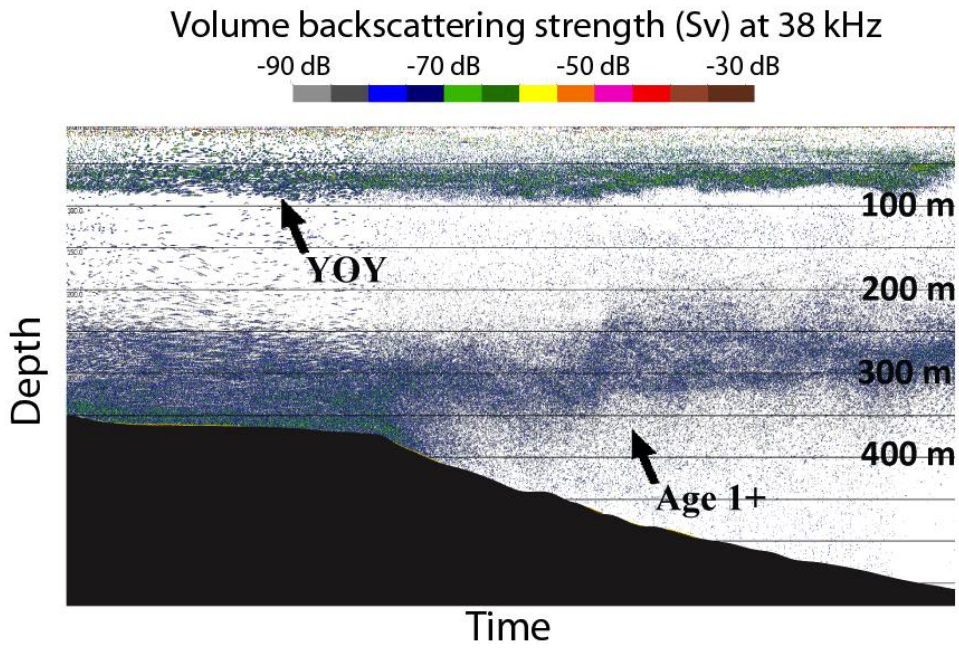


Figure 34 Echogram from 2012 showing targets of Arctic Cod at different depths in the water column. YOY are young of year fish. Age 1+ are fish that were older than one year.

Results

Hydroacoustic results showed that Arctic Cod were located in different layers of the water column depending on their age (size). Net sampling indicated that as much as 88% of the fish found in the upper 100 m of the water column (the **epipelagic** layer) were young-of-year Arctic Cod. Young-of-year Arctic Cod hatch at the surface of the water column in spring and move to deeper water when they reach a length of between 3 and 5.5 cm from July to November before the annual freeze-up[23]. Older and larger (>2.5 cm, age 1+) Arctic Cod aggregated primarily in the water column between 200-500 m (the **mesopelagic** layer), though Arctic Cod were captured with benthic nets in small numbers as deep as 1000 m (see Benthic Fish Sampling section).

Arctic Cod were numerically dominant in pelagic catches and in particular on the Alaskan and Canadian Beaufort shelves where they accounted for up to 100% of catch abundance in some areas and years (see Gadidae in Figs. 35-37). Young-of-year liparids were common to catches in all sub areas in both shallow and deep tows, as were cottids. Young-of-year stichaeids (poachers) were only common in pelagic catches in Amundsen Gulf (Fig. 37), as were cyclopterids (lumpsuckers). In general, fish diversity was lower in pelagic catches than that observed in benthic catches. Six species were collected in pelagic trawls on the Alaskan and Canadian Beaufort shelves, and eight were captured in Amundsen Gulf (Table 11).

Most of the adult fish biomass in the water-column was found at depths >200 m in association with the Pacific-Atlantic thermohalocline and the upper-Atlantic water mass. However, net-validated hydrocacoustics indicated that in 2014 the widespread aggregation of Arctic Cod was mostly absent throughout the study area, indicating substantial inter-annual variability in the distribution and/or abundance of Arctic Cod in the Canadian Beaufort Sea. In general, high survival of the young-of-year occurred in years characterized by relatively early ice break-up and warm sea-surface temperatures in spring. Environmental factors may thus play an important role in driving variability in early life survival and in subsequent abundance of Arctic cod stocks.[24]

Overall, we found average biomass was high in 2012 (1.18 $g{\cdot}m^{-2}$) and low in 2014 (0.02 $g{\cdot}m^{-2}$). In 2012 and 2013, the mesopelagic stock of Arctic Cod was sufficient to sustain the estimated energetic requirements of marine mammals, but in 2014 predators likely had to rely more heavily on demersal Arctic Cod[24]. Hydroacoustic sampling in Franklin Bay, Minto Inlet and Walker Bay indicated high biomass of young-of-year Arctic Cod in the surface waters compared to other areas of Amundsen Gulf and the Canadian Beaufort Shelf and slope. These results suggest that embayments could be important rearing habitat for Arctic Cod, thereby having important ecological significance for the ecosystem as a whole.

These findings are important because they show that young-of-year and adult Arctic Cod use different habitats, and that their distributions and total biomasses vary with the timing of the ice break-up and sea-surface temperatures, indicating that inter-annual variations are also important.

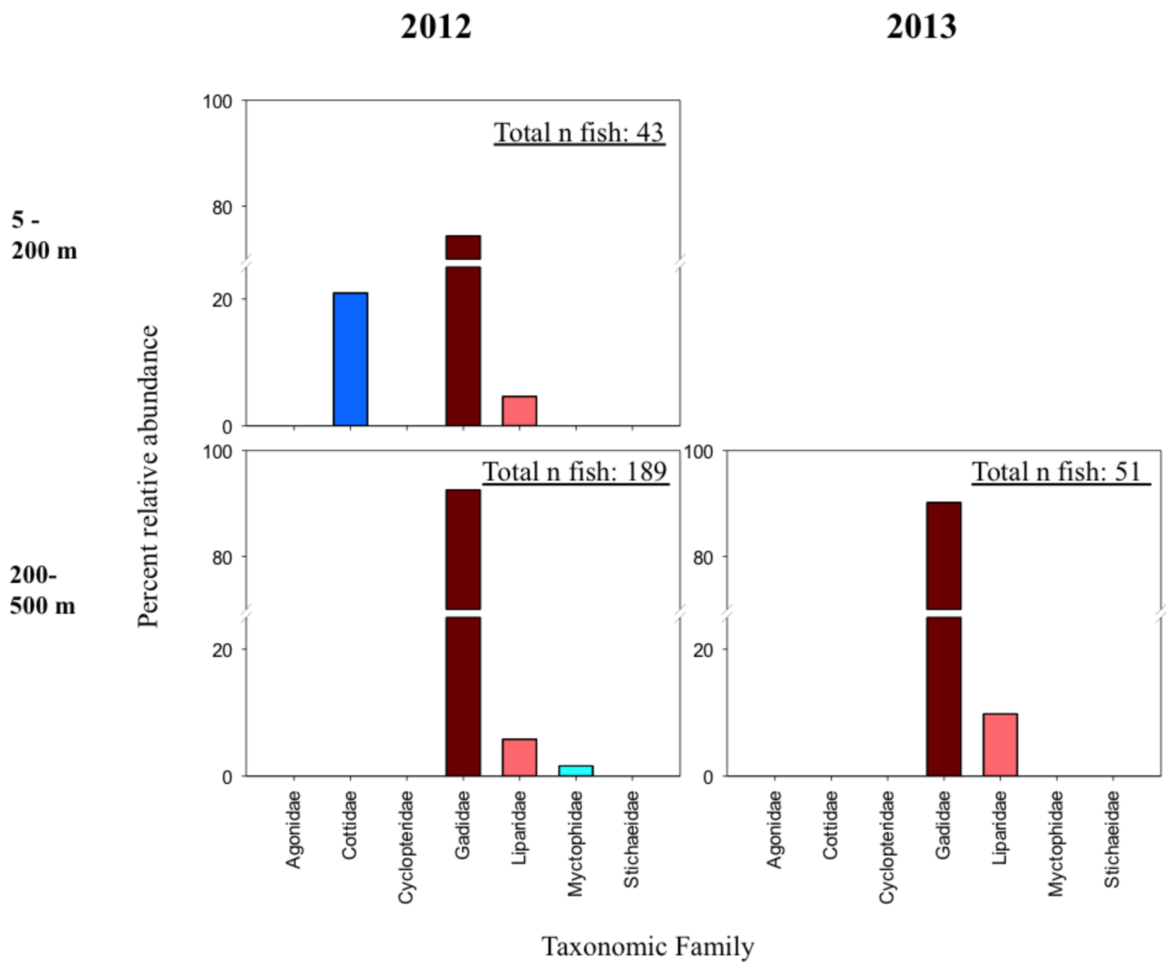


Figure 35 Percent relative abundance by taxonomic family, Pelagic habitats, Alaskan Shelf.

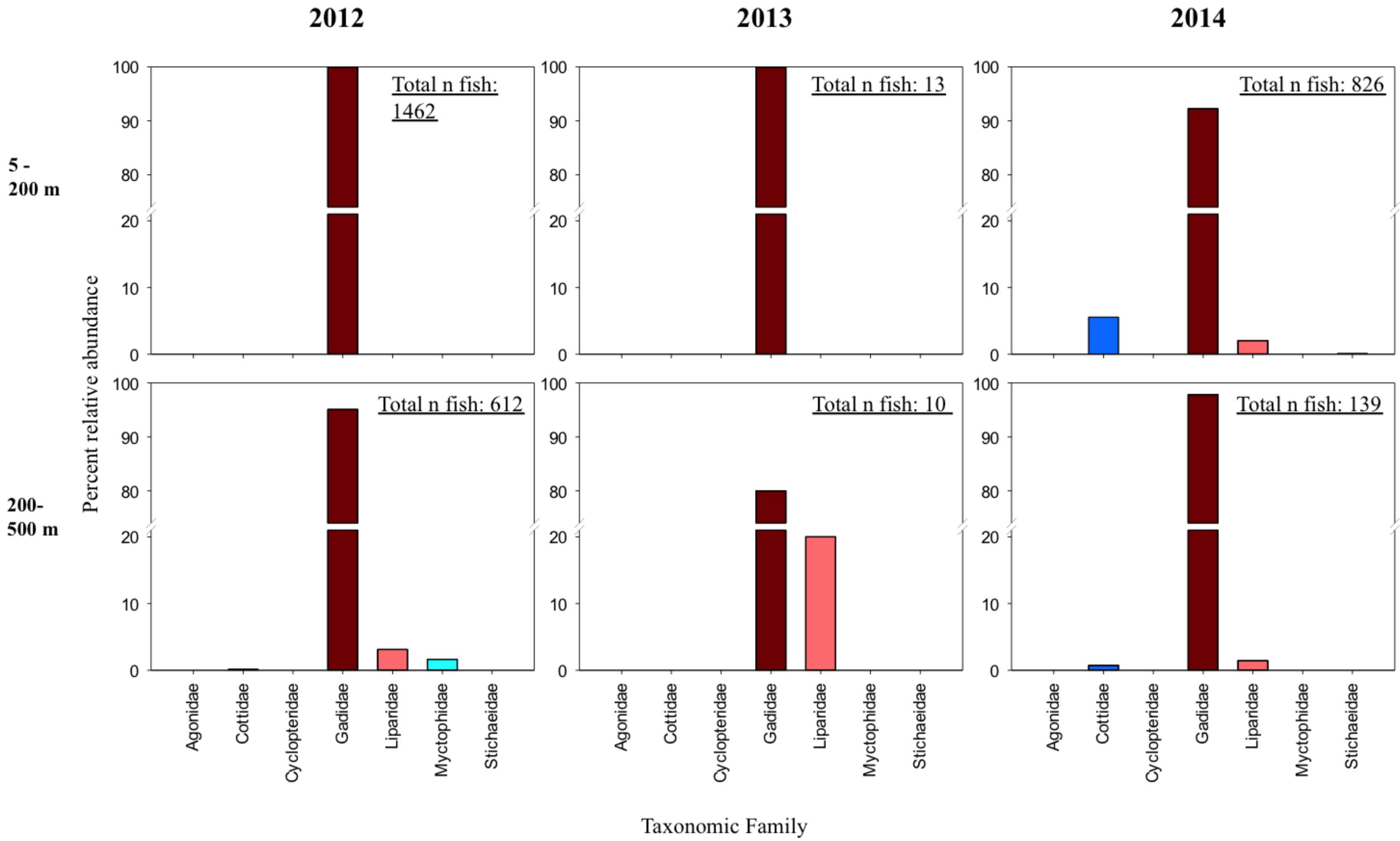


Figure 36 Percent relative abundance by taxonomic family, Pelagic habitats, Central Canadian Beaufort Sea.

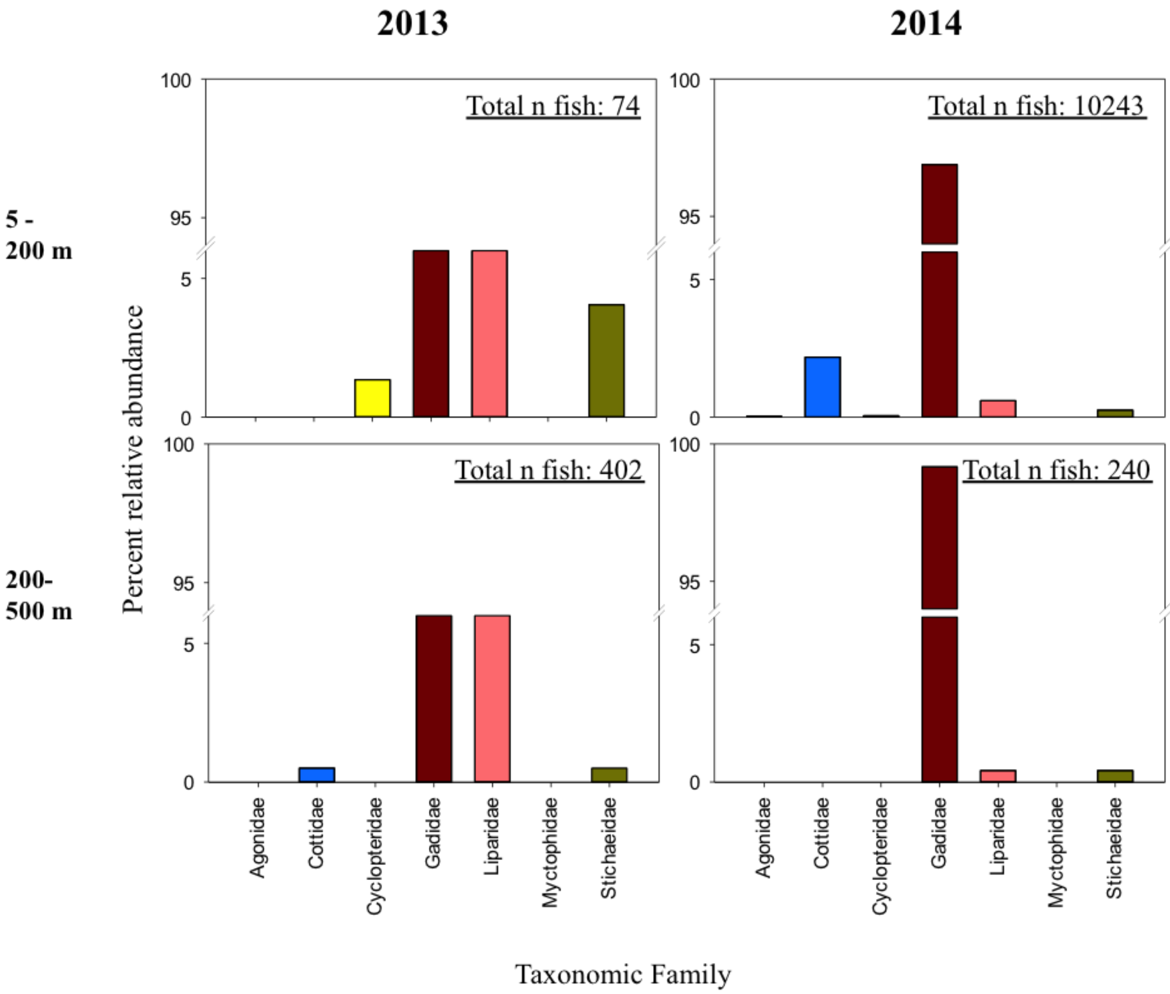


Figure 37 Percent relative abundance by taxonomic family, Pelagic habitats, Amundsen Gulf (2013-2014).

Table 11 Species composition in pelagic habitats; table entries indicate numbers of individuals found for the respective transect and depth combination.

Sum of n				**Area**					
Family	**Genus**	**Species**	**Common Name**	**AK 5-200**	**AK 200-500**	**CBS 5-200**	**CBS 200-500**	**AMN 5-200**	**AMN 200-500**
Agonidae	*Aspidophoroides*	*olrikii*	Arctic Alligatorfish					4	
Cottidae	*Gymnocanthus*	*tricuspis*	Arctic Staghorn Sculpin	8					
	Icelus	sp.	unidentified Cottidae, genus Icelus					2	
	Triglops	*pingelii*	Ribbed Sculpin	1			1	9	1
	Triglops	*nybelini*	Bigeye Sculpin				1	32	1
	Unidentified	unidentified	unidentified Cottidae			46		180	
Cyclopteridae	*Eumicrotremus*	*spinosus*	Atlantic Spiny Lumpsucker					6	
Gadidae	*Boreogadus*	*saida*	Arctic Cod	32	221	2237	726	9987	602
Liparidae	*Liparis*	sp.	unidentified Liparidae, genus Liparis			3		6	
	Liparis	*fabricii*	Gelatinous Seasnail	1	6		10	57	34
		tunicatus	Kelp Snailfish	1	10	1	13		1
	Unidentified	unidentified	unidentified Liparidae			13		5	
Myctophidae	*Benthosema*	*glaciale*	Glacier Lanternfish		3		10		
Stichaeidae	*Lumpenus*	*fabricii*	Slender Eelblenny					4	2
	Unidentified	unidentified	unidentified Stichaeidae			1		25	1

Species composition of pelagic habitats - Alaskan slope (2012-2013): 6 species, 0 unidentified/unconfirmed, Central Canadian Beaufort Sea (2012-2014): 6 species, 3 unidentified/unconfirmed, Amundsen Gulf (2013-2014): 8 species, 5 unidentified/unconfirmed

2.6 How do all of these components fit together?

All of the above components describe the habitats and the various potential food sources of marine fishes in the offshore region of the Canadian Beaufort Sea. The physical oceanography characterised water masses and oceanographic conditions that make up the water-column habitats of different organisms (invertebrates and fish). The sediments component aimed to characterize the bottom substrate, which is a key habitat feature for benthic marine fishes. Baseline information on the biomass, distribution, and interactions of lower trophic organisms, including primary producers (i.e., algae, cyanobacteria), were collected to distinguish the different water column habitats and identify the links between these habitats and the fish occupying them. Infauna, epifauna, and zooplankton are important food sources for marine fishes. As such, information on their diversity, abundances, and community structure is needed to better understand the ecology of fish communities. New information on the diversity of the biota studied during this project, the processes such as energy flow, and linkages (e.g., between nearshore and offshore communities) of the offshore marine environment support an ecosystem-based approach to management. Altogether, this information serves as a baseline of ecosystem structure and function from which researchers can assess the potential effects of industrial development (e.g., habitat alteration, contaminants) and differentiate those from other background stressors such as climate change.

3.0 Major Conclusions and Outcomes

3.1 What did this study accomplish?

A total of 184 stations were sampled from 2012-2014 as part of the Beaufort Sea Marine Fishes Project. Prior to this project, only 70 fish species (52 marine and 18 anadromous) were known to occur in the region, most of which were found on the Canadian Beaufort Shelf, whereas offshore fish habitats remained virtually unstudied. In addition, it was generally assumed that there were fewer pelagic marine fishes compared to the larger number of marine benthic fish species. Before this study took place, Arctic Cod (*Boreogadus saida*) were known to be an important species in the region, yet there was uncertainty in Arctic Cod population distribution and their preferred habitat. Based on previous shelf-based work conducted under the NCMS program, Walkusz et al. (2013)[25] demonstrated that the known biomass stock of Arctic Cod in the Canadian Beaufort Sea was insufficient to fulfil its presumed role as a primary food source for marine mammals and birds. The BSMF project expanded the geographic coverage of fish and other biological sampling in the Canadian Beaufort sea to include deepwater slope habitats and, in doing so, identified important upper-slope habitats that support both a large abundance of adult Arctic Cod as well as the highest benthic fish diversity documented within the study area.

Since the completion of the BSMF project, 16 tentative new marine fish species (12 pending expert taxonomic verification) have been recorded for the Canadian Beaufort Sea, some of which had not been previously reported in Canadian waters. This project recorded several new species occurrences in shelf and slope habitats (Fig. 38), most of which came from the deeper areas beyond the shelf-break (>200 m depth). Benthic and mid-water trawling confirmed that there was low water column diversity and high bottom diversity in marine fishes. In addition, all related pelagic and benthic habitats were described by examining physical and chemical characteristics of the water as well as the sediments at each station. Sampling of primary producers, infauna, epifauna, and zooplankton contributed to knowledge of the non-fish biota in the region and then allowed for examination of food web linkages. The ability to sample marine fishes in waters deeper than 200 m, coupled with information on water properties and different components of the food web, allowed us to determine that fish communities in the Canadian Beaufort Sea differ by habitat and by area. Community structure analyses will build on previous results for the Canadian Beaufort Shelf and slope[18] to describe fish assemblages and their habitat assemblages and their habitat associations beyond the continental shelf break to 1000 m depth. Arctic Cod was found in almost every habitat studied, but were particularly abundant in slope habitats associated with the Pacific-Atlantic thermohalocline and the upper-Atlantic water mass[21]. Follow-on work will confirm couplings between benthic and pelagic habitats, as well as between near-shore and offshore habitats through gut content, stable isotope and fatty acid analyses.

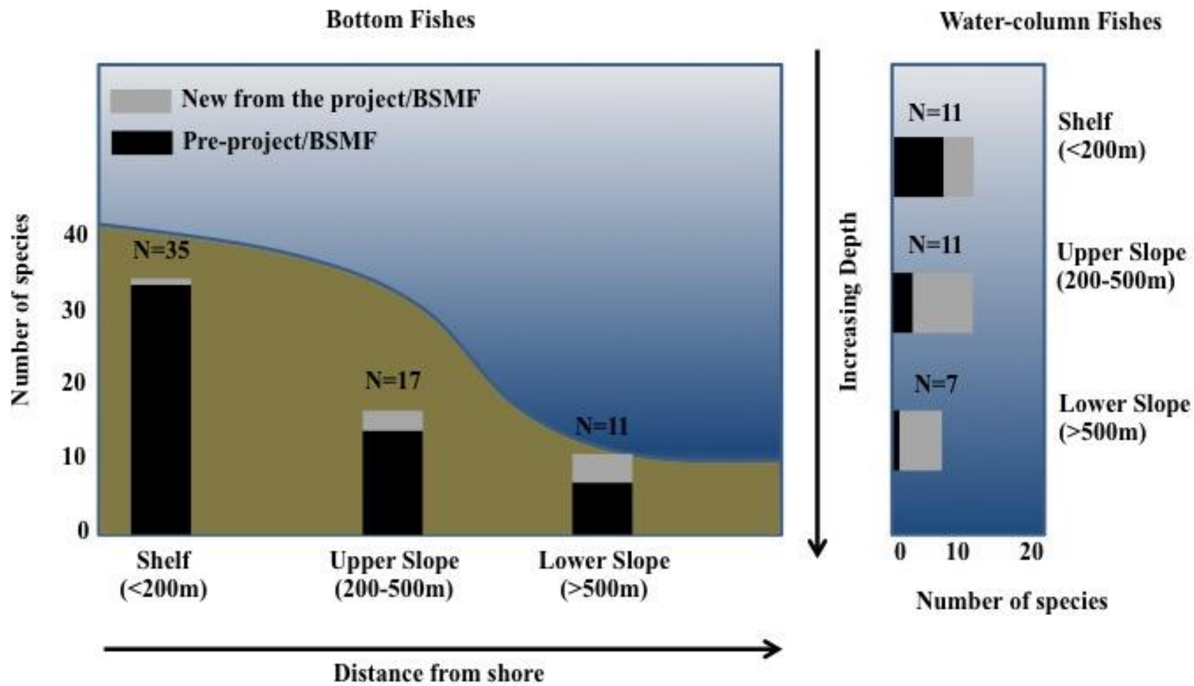


Figure 38 Marine fishes known to the Beaufort Sea before and after the BSMF project.

3.2 Information and Tools for Stakeholders

The samples, data, and knowledge gathered during the BSMF project will provide key information regarding fish community structure, habitat utilization, life history and food web linkages both within and among the deeper shelf and slope waters of the Beaufort Sea, and the embayments and straits surrounding Amundsen Gulf, which were previously unexplored in this context. The work represents a significant step toward facilitating regional levels of assessment, ocean management, and regulatory processes. New information on the diversity and productivity of all components studied during this project (e.g., fishes, invertebrates), the energy flow throughout the food web, and linkages between nearshore and offshore communities will support an ecosystem-based approach to management. This information serves as a baseline from which researchers can measure the potential effects of industrial development (e.g., habitat alteration, contaminants) and differentiate those from other background stressors such as climate change.

The use of archived data, summaries of existing knowledge and datasets will help to identify critical habitats relevant to sensitive species or key life stages of marine fishes, and relevant indicator organisms that could be used in establishing community-based and future monitoring programs. The use of archived data will also supplement any new data collected by this project, and provide longer-term context for understanding present-day Beaufort Sea ecosystem. Collection, on going processing, and analysis of BSMF project samples will benefit communities in the Inuvialuit Settlement Region (ISR) by providing region-specific baseline information on the structure, function, and key processes of ecosystem components in the LOMA. This includes information on fishes and their distributions, habitats, contaminants, and offshore food webs, as well as coastal/offshore energetic linkages between marine fishes and biota of cultural, recreational, and economic significance such as anadromous fishes and beluga.

3.3 Remaining knowledge gaps

Researchers involved in the BSMF project are continuing to integrate data, study food web structure, and identify habitat associations and key energetic linkages. Ultimately, this combined knowledge is an important step in understanding productivity in the marine ecosystem. The BSMF project examined the distributions and habitat associations of many Beaufort Sea marine fishes that were previously unstudied in this context. However, the ecological roles of many of these fishes are still poorly understood. Follow-on research should build upon the results of the BSMF project to determine which species play key roles in ecosystem structure and function, followed by targeted studies of their diet and habitat requirements across life-history stages. One of the major findings of the BSMF project was that the large aggregation of adult Arctic Cod observed in both 2012 and 2013 along the continental slope and into Amundsen Gulf, was absent in 2014. This finding highlights the need to better understand year-to-year differences in Arctic Cod and other marine fish populations with respect to the consequences of such variations to the food webs in the Beaufort Sea. Future studies should further investigate the environmental factors affecting the distributions, abundances, and life histories of key marine fishes.

Determining natural environmental variability will be key to detecting and understanding potential impacts from industrial activities in the offshore Beaufort Sea. Sampling in 2014 also highlighted the potential ecological relevance of straits and embayments to fish communities and the larger Beaufort Sea ecosystem. More work is required to understand the significance of these and other unexplored areas in the region.

As interest in hydrocarbon development, Arctic shipping, fisheries potential and tourism increases in frontier areas, and with the anticipated future effects of climate change in the Arctic, there is a need to expand the geographic scope of baseline studies to include areas of potential development, to identify key areas for implementing conservation measures, and to develop a regional context for future impact assessments. A key remaining gap that is relevant to current development scenarios, including hydrocarbon exploration, includes information on the diversity and distribution of fishes within the Canadian Exclusive Economic Zone in deep-water habitats (>1000 m depth) over the central Beaufort slope and Canada Basin (Central Arctic Ocean), and within the Canadian Arctic Archipelago, which, to-date, have not been sampled in an ecosystem context such as described here.

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Appendix 1: External Lab-based Collaborators for BSMF project (as of 2015)

In addition to the main components of the research described above, several follow-on activities (described below) were conducted using data and/or samples from the fieldwork. Note that this listing does not include the associated coastal research.

Stable Isotopes (food-web studies):
Ashley Stasko (PhD student), University of Waterloo (UofW)
Dr. M. Power, UofW
Dr. H. Swanson, UofW

Contaminants (metals – especially Hg, organic compounds):
Dr. G. Stern, University of Manitoba (UofM)
Dr. G. Tomy, UofM

Fish Identification (confirmation/voucher specimens):
Dr. P. Moller, University of Copenhagen
Dr. B. Coad, Canadian Museum of Nature

Genetics (fishes):
Dr. M. Docker, UofM (cods)
Dr. J. Nelson, University of Victoria (UVic) (Arctic Cod)
Dr. D. Roy, University of Connecticut (Greenland Halibut)

Hydroacoustics:
M. Geoffroy (PhD student), University of Laval (UL)
Dr. L. Fortier, UL
Dr. S. Gauthier, Fisheries and Oceans

Arctic Cod/Arctic Skate Energetics:
B. Lynn (MSc student), UofM
Dr. J. Treberg, UofM

Data Archival → Polar Data Catalogue

Appendix 2: Transects, station names and coordinates (decimal degrees) separated by year

Year	Transect	Station	Latitude	Longitude
2012	Dalhousie	dal_01	70.538	-130.840
		dal_02	71.209	-131.170
		dal_03	71.329	-131.228
		dal_04	71.374	-131.250
		dal_05	71.433	-131.279
		dal_06	71.599	-131.360
		dal_07	71.863	-131.489
	Garry	gry_01	69.877	-137.244
		gry_02	70.017	-137.675
		gry_03	70.131	-138.025
		gry_04	70.254	-138.402
		gry_05	70.301	-138.550
		gry_06	70.439	-138.974
		gry_07	70.524	-139.235
	Kugmallit	kug_01	70.012	-133.844
		kug_01b	70.243	-134.033
		kug_02	70.850	-134.676
		kug_03	70.930	-134.754
		kug_04	70.981	-134.805
		kug_05	71.049	-134.872
		kug_06	71.157	-134.980
		kug_07	71.285	-135.105
	Trans-boundary	tbs_01	69.933	-140.376
		tbs_02	70.252	-140.376
		tbs_03	70.279	-140.376
		tbs_04	70.346	-140.377
		tbs_05	70.428	-140.376
		tbs_06	70.553	-140.377
		tbs_07	70.601	-140.376
2013	Alaskan 1	a1_01	70.038	-141.077
		a1_02	70.337	-141.117
		a1_.03	70.369	-141.130
		a1_04	70.412	-141.057
		a1_05	70.472	-141.016
		a1_06	70.539	-141.025
		a1_07	70.606	-141.039
	Bennett Point	bpt_01	69.713	-123.849
		bpt_02	69.704	-123.778
		bpt_03	69.699	-123.438
		bpt_04	69.698	-123.241

Year	Transect	Station	Latitude	Longitude
2013		bpt_05	69.699	-123.197
	Cape Bathurst	cbh_01	70.268	-127.104
		cbh_02	70.293	-127.069
		cbh_03	70.316	-126.987
		cbh_04	70.645	-126.147
		cbh_05	70.917	-125.439
		cbh_06	71.207	-124.675
		cbh_07	71.394	-124.169
	Cape Parry	cpy_01	70.224	-124.517
		cpy_02	70.259	-124.505
		cpy_03	70.445	-124.522
	Darnley Bay	dar_01	69.703	-123.819
		dar_02	69.840	-123.728
		dar_03	70.125	-123.493
		dar_04	70.303	-123.372
		dar_05	70.583	-123.249
		dar_06	70.815	-123.130
		dar_07	71.049	-122.985
		dar_08	71.061	-122.917
	Deep-water	dwt_01	70.599	-138.329
		dwt_02	70.593	-138.080
		dwt_03	70.746	-138.128
	Escape	esc_01	70.694	-128.870
		esc_02	70.606	-129.877
		esc_03	70.335	-131.052
		esc_04	70.086	-132.166
		esc_05	70.011	-133.843
	Garry	gry_01	69.875	-137.242
		gry_02	70.001	-137.676
		gry_03	70.131	-138.032
		gry_04	70.256	-138.408
		gry_05	70.302	-138.545
		gry_06	70.442	-138.983
		gry_07	70.524	-139.235
	Trans-boundary	tbs_01	69.930	-140.377
		tbs_02	70.252	-140.376
		tbs_02b	70.262	-140.433
		tbs_03	70.281	-140.376
		tbs_04	70.346	-140.377
		tbs_05	70.413	-140.313

Year	Transect	Station	Latitude	Longitude
		tbs_06	70.553	-140.377
	Ulukhaktok	ulu_01	69.346	-119.514
		ulu_02	69.371	-119.495
		ulu_03	69.556	-119.232
		ulu_04	69.643	-119.094
		ulu_05	70.030	-118.528
		ulu_06	70.316	-118.129
		ulu_07	70.432	-117.840
		ulu_08	70.607	-117.855
2014	Amauligak	agk_01	70.103	-133.844
		agk_02	70.046	-133.558
	Alexander Milne Point	alx_01	71.619	-120.337
		alx_02	71.661	-119.766
		alx_03	71.683	-119.284
	Amundsen Gulf	amn_01	70.839	-119.783
		amn_02	70.219	-119.471
	Banks Island	bnk_01	72.130	-127.039
		bnk_02	72.100	-127.484
		bnk_03	72.095	-129.976
		bnk_04	72.097	-128.813
		bnk_05	72.928	-127.790
		bnk_06	72.929	-126.393
		bnk_07	72.099	-127.143
	Bowhead Whale*	bow_01	69.971	-126.774
	Bennett Point	bpt_01	69.704	-123.820
		bpt_02	69.700	-123.787
		bpt_03	69.700	-123.447
		bpt_04	69.698	-123.242
		bpt_05	69.700	-123.194
	Cape Parry	cpy_01	70.226	-124.497
		cpy_02	70.261	-124.508
		cpy_03	70.447	-124.521
	Dolphin Strait	dol_01	69.379	-118.769
		dol_02	69.432	-118.690

Year	Transect	Station	Latitude	Longitude
		dol_03	69.536	-118.220
		dol_04	69.639	-117.792
		dol_05	69.735	-117.386
	Escape	esc_03	70.336	-130.993
		esc_04	70.086	-132.130
	Franklin Bay	frk_01	70.083	-125.190
		frk_02	70.084	-125.420
		frk_03	70.084	-125.856
		frk_04	70.084	-126.023
		frk_05	70.084	-126.435
		frk_06	70.084	-126.770
		frk_07	70.084	-126.910
	Kugmallit	kug_01	70.115	-133.844
		kug_02	70.850	-134.676
		kug_03	70.930	-134.754
		kug_04	70.981	-134.805
		kug_05	71.049	-134.872
	Minto Inlet	mnt_01	71.229	-118.366
		mnt_02	71.257	-117.085
		mnt_03	71.326	-117.146
		mnt_04	71.394	-117.196
		mnt_05	71.435	-116.301
	Northern Transport. Co.*	ntc_01	71.317	-126.887
	Prince of Wales Strait	pws_01	72.109	-119.428
		pws_02	72.317	-118.875
	Smoking Hills*	smo_01	69.861	-126.774
	Wise Bay	wis_01	70.105	-125.062
		wis_02	70.174	-124.835
		wlk_01	71.480	-118.695
		wlk_02	71.548	-118.266
		wlk_03	71.597	-118.006

*Single station sampling point, not associated with a transect.

Appendix 3: Coordinates (decimal degrees) for break points , turn points, and underway CTD sampling points associated with hydroacoustic sampling

Year	Transect	Hydroacoustic points	Latitude	Longitude
2012	Dalhousie	dal_hc1	71.753	-131.435
		dal_hc2	71.468	-131.295
		dal_hc3	71.294	-131.211
		dal_hc4	70.414	-130.835
		dal_hc5	71.377	-131.242
	Garry	gry_hc1	70.345	-138.685
		gry_hc2	70.277	-138.474
		gry_hc3	69.799	-136.849
	Hydro-acoustic Transect	hct_hc1	71.041	-134.086
		hct_hc2	71.137	-134.176
		hct_hc3	71.206	-134.243
		hct_hc4	71.306	-134.337
	Kugmallit	kug_hc1	71.040	-134.864
		kug_hc2	70.965	-134.790
		kug_hc3	70.899	-134.724
		kug_hc4	70.872	-134.697
		kug_uctd2†	71.133	-134.958
		kug_uctd3†	71.090	-134.916
		kug_uctd4†	71.051	-134.876
		kug_uctd5†	71.024	-134.848
		kug_uctd6†	71.000	-134.822
		kug_uctd7†	70.984	-134.805
		kug_uctd8†	70.967	-134.789
		kug_uctd9†	70.947	-134.771
		kug_uctd10†	70.929	-134.757
		kug_uctd11†	70.920	-134.746
		kug_uctd12†	70.904	-134.730
		kug_uctd13†	70.871	-134.697
	Mackenzie Trough	mac_uctd1†	70.131	-138.637
		mac_uctd2†	70.131	-138.654
		mac_uctd3†	70.132	-138.752
		mac_uctd4†	70.134	-138.868
		mac_uctd5†	70.137	-138.972
		mac_uctd6†	70.140	-138.223
		mac_uctd7†	70.142	-138.377
		mac_uctd8†	70.144	-138.486
		mac_uctd9†	70.144	-138.664
		mac_uctd10†	70.123	-138.861
		mac_uctd11†	70.106	-139.013
		mac_uctd12†	70.101	-139.055
		mac_uctd13†	70.093	-139.126
		mac_uctd14†	70.079	-139.240
		mac_uctd15†	70.073	-139.297
		mac_uctd16†	70.069	-139.324
	Trans-boundary	tbs_hc1	70.428	-140.376
		tbs_hc2	70.280	-140.375
		tbs_hc3	70.113	-140.376
		tbs_hc4	69.678	-140.375
	West to East	wte_hc1*	70.408	-140.389
		wte_hc2*	70.157	-139.396
		wte_hc3*	70.286	-138.457
		wte_hc4*	70.396	-136.969
		wte_hc5*	70.460	-136.737
		wte_hc6*	70.744	-135.684
		wte_hc7*	70.931	-134.755
		wte_hc8*	71.019	-134.027
		wte_hc9*	71.407	-131.246
2013	Alaskan 1	a1_hc1	70.478	-141.046
	Cape Bathurst	cbh_hc1	71.299	-124.438
		cbh_hc2	71.059	-124.076
		cbh_hc2*	70.811	-125.704
		cbh_hc2*	70.654	-125.453
		cbh_hc2*	70.521	-125.761
		cbh_hc2*	70.441	-125.944
		cbh_hc2*	70.446	-125.990
		cbh_hc2*	70.436	-126.258
		cbh_hc2*	70.405	-126.324
		cbh_hc2*	70.396	-126.361
		cbh_hc3	70.425	-126.704
		cbh_uctd21†	70.371	-126.843
		cbh_uctd22†	70.312	-127.154
		cbh_uctd23†	70.369	-127.254
		cbh_uctd24†	70.373	-127.266
		cbh_uctd25†	70.000	-127.000
		cbh_uctd26†	70.512	-127.536
		cbh_uctd27†	70.576	-127.683
		cbh_uctd28†	70.604	-127.696
		cbh_uctd29†	70.615	-127.690

Year	Transect	Hydroacoustic points	Latitude	Longitude
		cbh_uctd30†	70.647	-127.660
		cbh_uctd31†	70.664	-127.901
		cbh_uctd32†	70.685	-128.048
		cbh_uctd33†	70.711	-128.177
		cbh_uctd34†	70.711	-128.177
		cbh_uctd35†	70.772	-128.320
		cbh_uctd36†	70.754	-128.378
	Cod	cod_hc1	70.376	-121.299
		cod_hc2	70.723	-122.162
		cod_uctd13†	70.890	-122.545
		cod_uctd14†	70.923	-123.621
		cod_uctd15†	70.794	-124.331
		cod_uctd16†	70.663	-125.014
	Deep-water	dwt_uctd51†	70.826	-136.324
		dwt_uctd52†	70.747	-136.070
		dwt_uctd53†	70.736	-136.038
		dwt_uctd54†	70.717	-135.978
		dwt_uctd55†	70.692	-135.899
		dwt_uctd56†	70.682	-135.870
		dwt_uctd57†	70.672	-135.844
		dwt_uctd58†	70.657	-135.802
		dwt_uctd59†	70.645	-135.759
		dwt_uctd60†	70.638	-135.737
		dwt_uctd61†	70.633	-135.721
		dwt_uctd62†	70.628	-135.706
		dwt_uctd63†	70.619	-135.842
		dwt_uctd64†	70.615	-135.663
		dwt_uctd65†	70.568	-135.497
		dwt_uctd66†	70.981	-134.802
		dwt_uctd67†	70.962	-134.786
		dwt_uctd68†	70.945	-134.768
		dwt_uctd69†	70.931	-134.753
		dwt_uctd70†	70.920	-134.742
		dwt_uctd71†	70.904	-134.726
	Darnley Bay	dar_uctd†	70.504	-123.300
		dar_hc1	70.885	-123.095
		dar_hc2	70.407	-123.365
		dar_hc3	70.169	-123.520
	Garry	gry_hc1	70.410	-138.886
	Trans-boundary	tbs_hc1	70.318	-140.378
		tbs_uctd437†	70.640	-140.383

Year	Transect	Hydroacoustic points	Latitude	Longitude
		tbs_uctd438†	70.565	-140.375
		tbs_uctd439†	70.468	-140.375
		tbs_uctd440†	70.372	-140.380
		tbs_uctd441†	70.348	-140.382
		tbs_uctd442†	70.309	-140.374
		tbs_uctd443†	70.318	-140.383
		tbs_uctd444†	70.298	-140.382
		tbs_uctd445†	70.287	-140.381
		tbs_uctd446†	70.273	-140.382
		tbs_uctd447†	70.263	-140.381
		tbs_uctd448†	70.254	-140.381
		tbs_uctd449†	70.095	-140.363
		tbs_uctd450†	70.004	-140.366
		tbs_uctd450b†	69.927	-140.378
	Ulukhaktok	ulu_hc1	70.413	-117.960
		ulu_hc2	69.976	-118.593
		ulu_hc3	69.649	-119.074
		ulu_hc4	69.367	-119.487
		ulu_uctd9†	69.709	-119.602
		ulu_uctd10†	69.850	-119.973
		ulu_uctd11†	70.087	-120.569
2014	Banks Island (South)	bnk_hc1	72.101	-126.814
		bnk_hc2	72.100	-127.167
		bnk_hc3	72.099	-127.832
		bnk_hc4	72.097	-128.889
	Bennett Point	bpt_hc1	69.703	-123.587
		bpt_hc2	69.693	-123.370
	Cape Parry	cpy_hc1	70.328	-124.504
		cpy_hc2	70.173	-124.835
		cpy_hc3	70.102	-125.062
	Franklin Bay	frk_hc1	70.084	-126.747
		frk_hc2	70.084	-126.178
		frk_hc3	70.084	-125.403
	Kugmallit	kug_hc1	71.065	-134.751
		kug_hc2	70.978	-134.802
		kug_hc3	70.930	-134.754
	Minto Inlet	mnt_hc1	71.436	-116.298
		mnt_hc2	71.383	-116.705
		mnt_hc3	71.280	-117.737
	Walker Bay	wlk_hc1	71.594	-118.006
		wlk_hc2	71.480	-127.850

*Turning points associated with hydroacoustic transect, no sampling was conducted at these points
†Underway CTD sampling point

Appendix 4: Publications Completed or In Progress

"Investigations into food web structure in the Beaufort Sea" Stasko, A. D. (2014). Thesis proposal submitted in partial fulfillment of the requirements for the degree of Ph.D. in Biology, Department of Biology, University of Waterloo, March 2014

"Polycyclic Aromatic Hydrocarbon Metabolites in Arctic Cod (*Boreogadus saida*) from the Beaufort Sea and Associative Health Effects" Tomy, G.T., Halldorson, T., Chernomas, G., Bestvater, L., Dangerfield, K., Ward, T., Pleskach, K., Stern, G., Atchison, S., Majewski, A., Reist, J.D., and Palace, V. P. (2015) Environmental Science & Technology, Oct 2014, 7;48(19):11629-36. (e-pub Sept 2014)

"Trophic variability of Arctic fishes in the Canadian Beaufort Sea: a fatty acids and stable isotopes approach." Giraldo, C., Stasko, A.D., Choy, E., Rosenberg, B., Majewski, A.R., Power, M., Swanson, H., Loseto, L. L., and Reist, J.D. (2015). Polar Biol. DOI 10.1007/s00300-015-1851-4

"Distribution and diet of demersal Arctic Cod, *Boreogadus saida*, in relation to habitat characteristics in the Canadian Beaufort Sea" Majewski, A. R., Walkusz, W., Lynn, B. R., Atchison, S. P., Eert, J., and Reist, J. D. (2015). Polar Biol., DOI 10.1007/s00300-015-1857-y

"Vertical segregation of age-0 and age-1+ polar cod (*Boreogadus saida*) over the annual cycle in the Canadian Beaufort Sea." Geoffroy, M., Gauthier, S., Majewski, A. R., LeBlanc, M., Walkusz, W., Reist, J. D., Fortier, L. (2015). Polar Biology. DOI 10.1007/s00300-015-1811-z

"Dietary characteristics of co-occurring polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) in the Canadian Arctic, Darnley Bay" McNicholl, D. G., Walkusz, W., Davoren, G. K., Majewski, A. R., and Reist, J. D. (2015). Polar Biol. DOI 10.1007/s00300-015-1834-5

“Spatial distribution and diet of larval snailfishes (*Liparis fabricii, Liparis gibbus, Liparis tunicatus*) in the southern Canadian Beaufort Sea.” Walkusz, W., Paulic, J.E., Wong, S., Kwasniewski, S., Papst, M. H., Reist, J. D. (2015). http://dx.doi.org/10.1016/j.oceano.2015.12.001

“Integrated Regional Impact Study (IRIS) Area 1 – Chapter 4. Arctic Change: Impacts on Marine Ecosystems and Contaminants” (2015). Fortier, L., Reist, J.D., Ferguson, S.H., Archambault, P., Matley, J., Macdonald, R.W., Robert, D., Darnis, G., Geoffroy, M., Suzuki, K., Falardeau, M., MacPhee, S.A., Majewski, A.R., Marcoux, M., Sawatzky, C.D., Atchison, S., Loseto, L.L., Grant, C., Link, H., Asselin, N.C., Harwood, L.A., Slavik, D., Letcher,R.J. (2015). Integrated Regional Impact Study (IRIS) Area 1, ArcticNet, a Network of Centres of Excellence.

“Distant drivers or local signals: where do mercury trends in western Arctic belugas originate?” Loseto, L.L., Stern, G.A., Macdonald, R.M. (2015). Science of the Total Environment, 509-510 (226-236)

“Examining the Health and Energetic Impacts of Climate-Induced Prey Shifts on Beluga Whales using Community-Based Monitoring” Choy, ES. (2014). ARCTIC 67(4):570-573

“Diet analysis of Alaska Arctic snow crabs (Chionoecetes opilio) using stomach contents and δ13C and δ15N stable isotopes” Divine, L. M., Bluhm, B. A., Mueter, F. J., and Iken, K. (2015). Deep-Sea Res. II. http://dx.doi.org/10.1016/j.dsr2.2015.11.009i

“Benthic Macrofaunal and Megafaunal Distribution on the Canadian Beaufort Shelf and Slope” Nephin, J. (2015). University of British Columbia. A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in the School of Earth and Ocean Sciences.

“Signature bioacoustique, distribution et abundance des poissons pélagiques et des mammifères marins en mer de Beaufort (Arctique canadien).” Geoffory, M. (2015). PhD thesis, Université Laval, 2015.

“Sex- and age-dependent differences and habitat influences on demersal Arctic Cod (*Boreogadus saida*, Lepechin 1774) diet and energy allocation in the Canadian Beaufort Sea.” Lynn, B. (2016). MSc thesis, University of Manitoba, Winnipeg, Manitoba.

“Assessment of stressors, impacts and Pathways of Effects for the Darnley Bay Anuniaqvia Niqiqyuam Area of Interest for Marine Protected Area designation” DFO (2014). Sci. Advis. Sec. Sci. Advis. Rep. 2014/002.

“Physical, chemical and biological oceanographic data from the Beaufort Regional Environmental Assessment: Marine Fishes Project, August-September 2012” Eert, J., Meisterhans, G., Michel, C., Niemi, A., Reist, J. D., Williams, W. J. (2015). Can. Data Rep. Hydrogr. Ocean Sci. 197: vii + 84 p.

“Physical, chemical and biological oceanographic data from the Beaufort Regional Environmental Assessment: Marine Fishes Project, August-September 2013” Niemi, A., Michel, C., Dempsey, M., Eert, J., Reist, J. D., Williams, W. J. (2015). Can. Data Rep. Hydrogr. Ocean Sci. 198: vii + 144 p.

Newsletters and Communications:

“Beaufort Sea Fisheries Studies: 2014 Field Activities Newsletter; Summer/Fall 2014” MacPhee, S.A., Atchison, S. P., McNicholl, D. G., Henry, J.C. (2015). Newsletter circulated to project collaborators, Fisheries Joint Management Committee, Inuvialuit Game Council, and distributed at the BREA final results forum, Feb 2015, Inuvik, NT

“2015-2016 Interim Research Progress Report Beaufort Sea Foodweb Studies: Stable Isotope Analyses of Infauna” MacPhee, S. A., de Montety, L., and Stasko, A. D. Prepared for the Fisheries Joint Management Committee, December 2015.

“How many living things can you see? – Primary productivity, overview and potential impacts of climate change” Niemi, A, Michel, C. (2015). Handout distributed at BREA final results forum, Feb 2015, Inuvik, NT

“Close, but no ‘cigar-fish - Visual guide on how to identify similar looking ‘cigar shaped’ forage fish.” McNicholl, D.G. (2015). Handout distributed at BREA final results forum, Feb 2015, Inuvik, NT

“BREA Fish Sampling: Understanding Techniques and Tissues Used” Henry, J.C. (2015). Handout distributed at BREA final results forum, Feb 2015, Inuvik, NT

“BREA Marine Fishes Project: Fishes in their Habitats” Atchison, S.P. (2015). Handout distributed at BREA final results forum, Feb 2015, Inuvik, NT

“BREA Marine Fishes Project: Sampling Methods aboard the F/V/ Frosti” Atchison, S.P. (2015). Handout distributed at BREA final results forum, Feb 2015, Inuvik, NT

“Arctic Cod diet in the Beaufort Sea” Walkusz, W. (2015). Handout distributed at BREA final results forum, Feb 2015, Inuvik, NT

“Why is zooplankton so important?” Walkusz, W. (2015). Handout distributed at BREA final results forum, Feb 2015, Inuvik, NT

“Beluga Bulletin fall/winter 2014-2014 issue” Loseto, L.L., Brewster, J., Ostertag, S.K., Hoover, C., Choy, E.S., Hansen-Craik, K., Snow, K., Whalen, D. (2015)

Appendix 5: Glossary

Anadromous – fish born in freshwater that migrate to the ocean as juveniles where they grow into adults before migrating back into freshwater to spawn

Bathymetry – the measurement of water depth at various places in a body of water such as the ocean

Benthic – the area at the bottom of the ocean

Benthos - the organisms living on the bottom of the ocean (in the benthic region)

Bioaccumulates – when a substance becomes concentrated inside the bodies of living things

Biomagnifies – the increased concentration of a substance (e.g., toxin) in an organism as a result of it ingesting other organisms containing lower concentrations of the substance

Biota – the organisms (animals or plants) living in a particular region

Conductivity – the measure of how well a solution conducts electricity (directly related to salinity)

Downwelling – a downward current of surface water in the ocean

Ecosystem – a community of interacting organisms and their physical environment

Epifauna – animals living on the surface of the seafloor

Epipelagic – the uppermost region of the ocean that receives enough sunlight to allow for photosynthesis

Food web – the links among species in an ecosystem showing who eats whom

Granulometry – a measurement of the size distribution in a collection of grains of sediment

Heterogeneity – being made up of diverse (different) parts

Ichthyoplankton – the eggs and larvae of fish that are found within the upper (epipelagic) region of the water column

Infauna – the animals living in the sediments of the ocean

Invertebrate – an animal lacking a backbone (e.g. clams, seastars, worms)

Macrofauna – benthic organisms that are at least 1 mm in length

Mesopelagic – the intermediate depths of the sea (~200 to 1000 m below the surface)

Oceanography – the scientific study of the physical and biological properties and phenomena of the sea

Pelagic – the upper layers of the open sea

Photosynthesis – the process by which algae use sunlight to produce food (energy) from carbon dioxide and water

Photosynthetically active radiation (PAR) – the amount of light available for photosynthesis

Phytoplankton – plankton consisting of microscopic plants

Plankton – the small and microscopic organisms drifting or floating in the ocean

Primary producers – photosynthetically active organisms that produce biomass from inorganic compounds

Salinity – the saltiness or dissolved salt content of the water

Secondary producers – herbivorous consumers that produce biomass by feeding on primary producers

Stratification – occurs when water masses with different chemical properties form layers that act as barriers to water mixing

Taxonomic identification – the classification and naming of organisms (e.g. species) in an ordered system to indicate evolutionary relationships

Topography – the detail of the surface features of land (e.g. the bottom of the ocean)

Transects – straight lines across a region of the ocean along which observations or measurements are taken

Trophic levels – the different levels in an ecosystem comprised of organisms sharing the same position in the food web

Turbidity – the cloudiness or haziness of water

Upwelling – the process by which deep water rises towards the surface of the ocean

Zooplankton – plankton consisting of small animals and the juvenile stages of larger animals