Beaufort Sea Marine Fishes Project

Update for Stakeholders

Beaufort Sea Marine Fishes Project - Update for Stakeholders.

Fisheries and Oceans Canada, 2016

Majewski AR, Atchison SP, Suchy KD, Henry J, MacPhee SA, Walkusz W, Eert J, Dempsey M, Niemi A, de Montety L, Geoffroy M, Giraldo C, Michel C, Archambault P, Williams WJ, Fortier L and JD Reist (2016). "Beaufort Sea Marine Fishes Project - Update for Stakeholders". Fisheries and Oceans Canada, Ottawa. viii+57pp.

Designed and prepared by S. Atchison, K. Suchy, and E. Worden.

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Beaufort Sea Marine Fishes Project

Update for Stakeholders

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Abstract

The Beaufort Sea Marine Fishes Project (BSMFP) 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 BSMFP 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. A total of 184 stations were sampled from 2012-2014. Sixteen new marine fish species (12 pending expert taxonomic verification) are tentatively recorded for the Canadian Beaufort Sea during the BSMFP. 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.

View from the bridge of the F/V *Frosti*,
overlooking the bow. Photo credit: S. Atchison.

Acknowledgements

The Beaufort Sea Marine Fishes Project science team and partners thank Frosti Fishing Inc. and the crew of the *F/V Frosti* for their professionalism and enthusiasm both on board the vessel and in the planning and preparation, and execution of three highly successful field seasons. Funding in part was provided by the Beaufort Regional Environmental Assessment program administered by Aboriginal Affairs and Northern Development Canada (AANDC), the Environmental Studies Research Fund and the Program for Energy Research and Development both administered by Natural Resources Canada (NRCan), Fisheries and Oceans Canada's (DFO) International Governance Strategy and National Conservation Plan as well as other DFO funds, the Joint Secretariat of the Inuvialuit Settlement Region and ArcticNet. Thanks to the late Charles Ruben, Desmond Ruben, Joseph Illasiak and Lorena Edenfield for assistance with field work. We also thank Diane Ruben, Desmond Ruben, Mykle Wolki, Frank Wolki, Ray Ruben and other members of the Paulatuk HTC who assisted with crew changes and logistics. We are grateful to the Inuvialuit Game Council and the Fisheries Joint Management Committee for supporting this project and for providing valuable input to the study design and logistics.

View of the stern of the F/V *Frosti*.
Photo credit: S. Atchison.

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Note: University and other collaborators associated with lab-based components of the work are not listed above (See Appendix 1).

2012 crew. Back row (left to right): Wojciech Walkusz, Andy Majewski, Lorena Edenfield, Guillaume Meisterhans, Laure de Montety. Front row (left to right): Sheila Atchison, Shannon MacPhee, Charlie Ruben, Jane Eert.

2013 crew. Left to right: Robert Young, Desmond Ruben, Mike Dempsey, Jane Eert, Laure de Montety, Shannon MacPhee, Ashley Stasko, Tracey Loewen, Brittany Lynn, Andrea Niemi, Akash Sastri, Sheila Atchison, Andy Majewski.

2014 Research and ship crew onboard the F/V *Frosti*. Photo by BSMFP group.

Back row (left to right): Hugh Maclean, Mykle Wolki, Desmond Ruben, Shannon MacPhee, Kelly Young, Daniel Mose, Mike Dempsey, Tony Reddick, Penny Parkinson, Ross Gordon, Carolina Giraldo, Laure de Montety, Andrea Niemi, Guillaume Meisterhans, Andy Majewski. Front row (left to right): Sheila Atchison, Joseph Illasiak, Kelly Muller, John Roach, Julie Henry, Michelle Kamula, Ashley Stasko.

Project Rationale

The Beaufort Sea Marine Fishes Project (BSMFP) was primarily designed to be 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. The overall goal of the BSMFP was to provide governments, Inuvialuit, and industry with knowledge to better prepare for oil and gas exploration and development, as well as potential effects of climate change, in the offshore region of the Beaufort Sea. The survey 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 BSMFP was not simply a fish study; rather, it was an 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

Taking pictures of a polar bear on the ice floes. Photo by A. Majewski.

areas, the latter of which are important to the Inuvialuit. Because of these connections, 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. Another consideration during this study was climate change, which is rapidly and substantially changing all ecosystems in the Arctic. Because of this, 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. As such, a multi-year project design was undertaken for the development and delivery of both the offshore research and a linked coastal program.

A snowy owl on the bow of the ship, stopping for a rest. Photo by S. Atchison.

Background Objectives and Scientific Approach

Previous Beaufort Sea Research

The ecology of marine fishes and other food web components within the Beaufort Sea are not well known. Although scientific sampling in the area has occurred for almost 100 years, it has previously been irregular, of limited duration, and has focused mostly on nearshore coastal areas. Only 52 known species of marine fishes have been reported in the region[1,2] to date. Many of these earlier projects were limited by vessel capabilities which restricted their fishing efforts to smaller fishing gear and depths shallower than 150 m. Late clearing of winter sea ice coupled with persistent and variable summer sea ice also restricted the scope and nature of research activities.

The main goal of the BSMFP was to establish baseline data for the diversity, relative numbers (abundance), and distributions of offshore marine fishes in the Canadian Canadian Beaufort Sea in association with data that will characterize their habitats.

Fish communities and habitats (i.e., the specific places in which they live) in waters deeper than 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. Hydrocarbon (oil and gas) development discussions during the 1970s to early 2000s focussed on nearshore and shelf deposits of natural gas and its transport. As a result, scientific surveys done at that time focused on that area.[3-8]

In the 1970s, the Beaufort Sea Project developed knowledge of **biota** (i.e., living organisms or biodiversity), 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 were conducted through the Northern Oil and Gas Assessment Program (NOGAP). 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].

In the early 2000s, 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 Northern Coastal Marine Studies (NCMS, 2003 - 2009) program focused on the shelf areas.[12-14] This research examined the **community structure** and distribution of the

macrofauna[15], **zooplankton**[16], larval and early juvenile fishes[17-18], and **benthic** adult fishes in relation to environmental variables.[19] Due to limitations inherent to the type of vessel used during the NCMS program, fishing was restricted to smaller gear types and shallower (i.e., less than 200 m depth) waters. In 2008, an offshore (20-500 m) fish and **invertebrate** pilot project[20] was carried out in the Alaskan Beaufort Sea. 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.

As part of the Beaufort Sea Regional Environmental Assessment (2011-2015, AANDC, www.BeaufortREA.ca), the BSMFP 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.

Study Objectives

The main goal of the BSMFP was to establish baseline data for the diversity, relative numbers (abundance), and distributions of offshore marine fishes in the Canadian Beaufort Sea in association with data that will characterize their habitats. The collection of baseline data provides a starting point from which to understand future changes in the environment. This project also aimed to determine the structure of marine fish communities and their habitats, as well as to understand linkages between marine fishes and

Close up of a shrimp's abdomen.
Photo by S. Atchison.

other components of the offshore food web. Of additional relevance are the ecosystem connections within the southern Canadian Beaufort Sea (offshore-coastal), and the connections with the Canada Basin and Canadian Archipelago. 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.

An ecosystem generally consists of the biota present, the habitats in which those organisms live, and the physical and chemical aspects of the environment.

Overview of Scientific Approach

An ecosystem generally consists of the biota present, the habitats in which those organisms live, and the physical and chemical aspects of the environment. There are also linkages among organisms *within* the ecosystem (e.g., predator/prey interactions), and linkages *between* the ecosystem and outside components. These outside components include those coming into and going out of the ecosystem (e.g., energy from the Sun, water movements by currents, nutrient inputs, migrations by biota). In order to properly understand an ecosystem, it is important to know how different organisms/species interact. The most obvious example of this interaction is the food web or trophic pattern (i.e., who eats whom, for example: seals eat fish, polar bears eat seals).

The food web includes **primary producers**, zooplankton, benthic invertebrates, fishes, marine mammals and birds (Figure 01). The primary producers in the Beaufort Sea are **phytoplankton**, ice algae, and benthic algae. These primary producers use energy from the Sun to convert carbon dioxide and water into organic matter. In the shelf region of the Beaufort Sea,

Sample catch from the benthic beam trawl net. Photo by S. Atchison.

light controls the *timing* of both under ice- and phyto-plankton production while nutrient availability controls the overall *amount* of primary production. Zooplankton (**secondary producers**), an animal group that includes small organisms such as copepods, jellyfish, and **ichthyoplankton** (i.e., fish eggs, newly hatched and larval fish), feed on the primary producers and are a food source for a range of species from small invertebrates to fishes such as Arctic Cod and Bowhead whales. Dead **plankton** also 'rains' down to the bottom, serving as food for both bottom-feeding invertebrates such as clams and seastars as well as bottom-feeding fishes (e.g., eelpouts and sculpins). Higher-level predators, including predatory fishes, beluga whales, and ringed seals, feed upon these 'mid-level' consumers. As in most other Arctic seas, Arctic Cod is a versatile fish species occupying many habitats and having a central role between lower **trophic levels** (i.e., plankton) and higher trophic levels. The relationships between organisms can be understood using **ecosystem tracers** such as **fatty acids** or **stable isotopes**.

Complex food web interactions show how all species are affected by others. Keystone species, those important to the food web such as Arctic Cod, have a disproportionately high influence on overall ecosystem health by either being widespread sources of prey, or by regulating populations with predation.

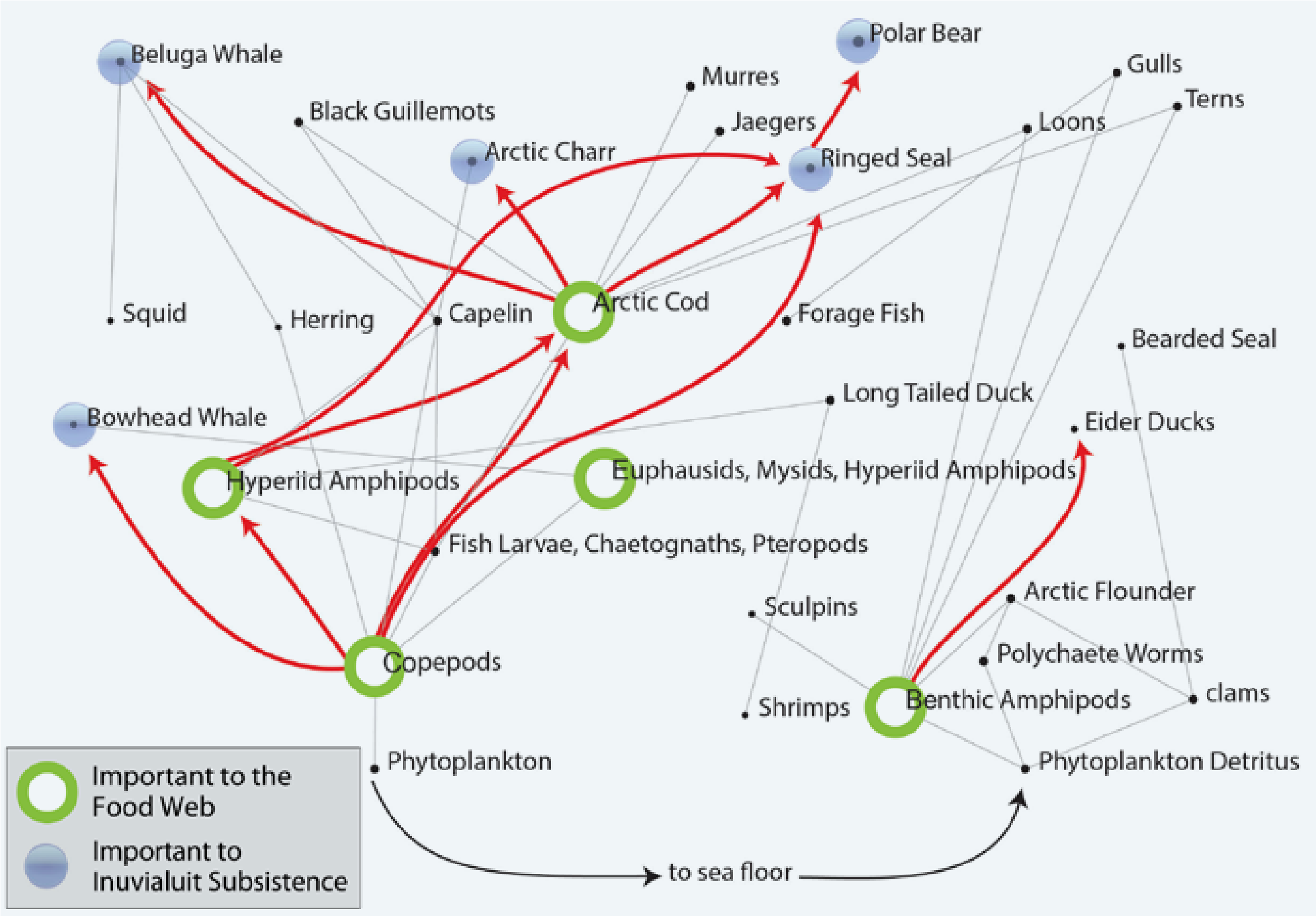


Figure 01: Example of an Arctic Food Web

Recreated, with additions, from Mathias (2013). Mathias, J. 2013. The Canadian Beaufort Sea ecosystem: A fisheries perspective. Canada/Inuvialuit Fisheries Joint Management Committee Report 2013-01: viii + 111 p.

By understanding the biodiversity of the ecosystem, the habitats where the organisms occur, and the linkages or relationships among them, the proper foundation of knowledge relevant for management, conservation, and monitoring can be developed.

The association of an organism with a particular habitat is also important when studying an ecosystem. These associations may be very specific (i.e., a species only lives in a particular habitat) or they may be more general (i.e., a species lives in many habitats). Additionally, the different stages a species goes through during its life cycle (e.g., larval to adult) may live in, or need, different habitats. Understanding these organisms' life-stage habitat associations associations is essential. Because different types of organisms live in different places in the ecosystem, collecting samples and data requires us to use different types of gear. Because of this, the BSMFP used a range of techniques during 'Field Sampling Activities' (Figure 02) to collect samples and data, each of which contributed key elements to describe fishes, their habitats, and ecosystem linkages.

Oceanographic data (e.g., temperature and **salinity**), marine productivity parameters, zooplankton, sediment, **infauna** (invertebrate animals that live in the sediments of the seafloor), **epifauna** (invertebrate animals that live on the seafloor), and fish samples were collected. They were then used to examine food web structure and ecosystem linkages within/between offshore and nearshore ecosystems. The samples collected were also used to examine topics including genetic structure of some species, species-specific ecology, and contaminants as part of the 'Follow-on Laboratory Activities' (Figure 03). By understanding the biodiversity of the ecosystem, the habitats where the organisms occur, and the linkages or relationships among them, the proper foundation of knowledge relevant for management, conservation, and monitoring can be developed.

A view of Wise Bay. Photo by S. Atchison.

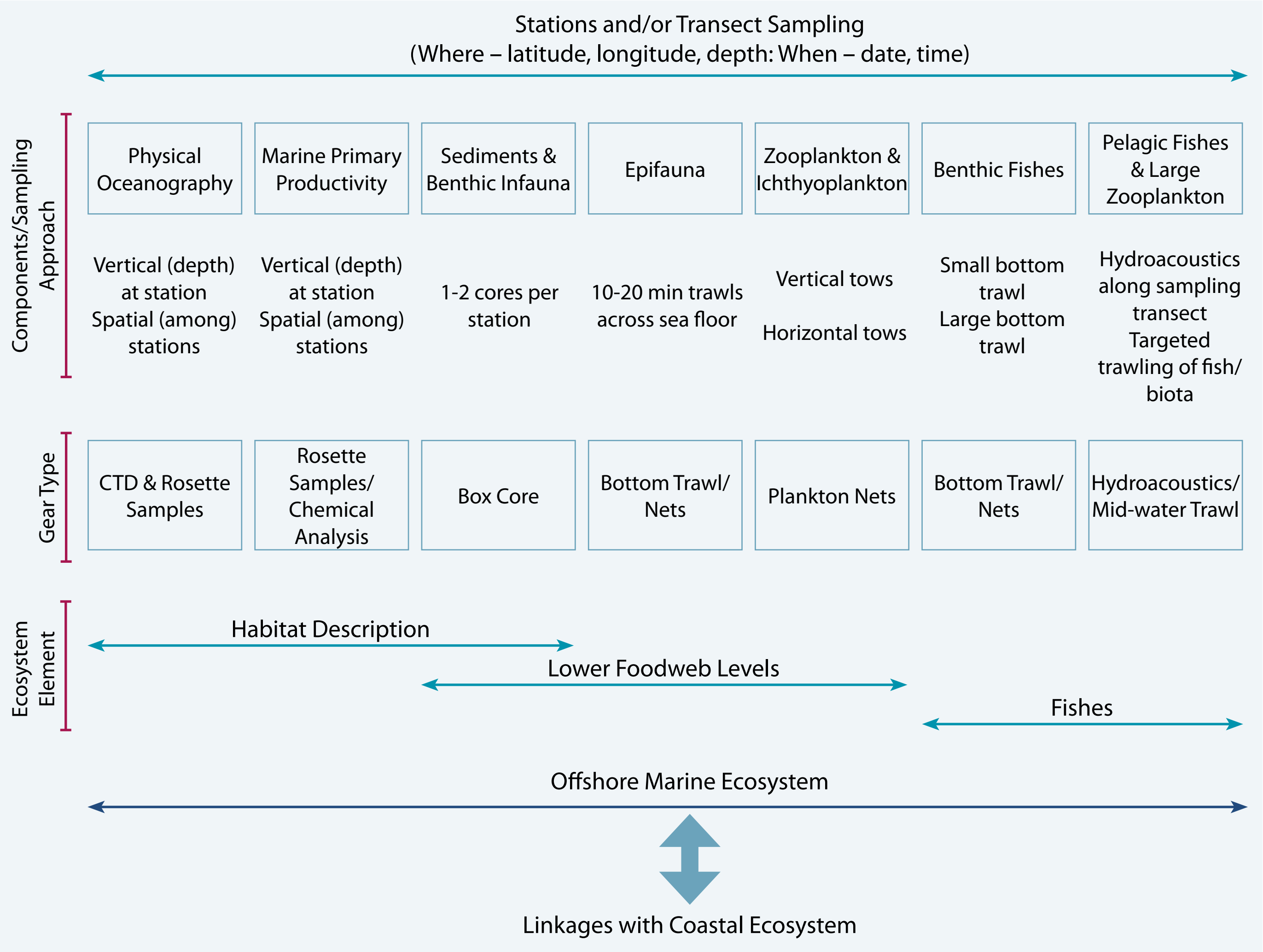


Figure 02: Field Sampling Activities

When assessing large ecosystems such as the Canadian Beaufort Sea, many factors have to be studied. This diagram shows all of the topics studied, what gear was used to gather data, and where in the ecosystem each topic fits.

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 (Figure 04). Further east, the Mackenzie River has a dominant influence by depositing large volumes of fresh water and sediments on the 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 (~500 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.

The BSMFP 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 (Figure 04). 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 study area is bounded by the Beaufort Sea Large Ocean Management Area (LOMA) of the marine portion of the Inuvialuit Settlement Region (ISR) covering approximately 1,107,694 km^2.

This table outlines the follow-on work associated with each research element for which samples were collected in the field, and the future actions that could be taken to increase knowledge on each element.

Follow-on Activities

Type of Sample	Main Analyses (see sampling)	Species Identification	Size (width, length) measures	Aging structure (otolith)	Diet (stomach)	Stable Isotopes	Fatty Acids	Genetics	Contaminants	Archived Samples (tissues, vouchers)
Water	✓	–	–	–	–	–	–	–	–	◊
Sediment	✓	–	–	–	–	–	–	–	–	◊
Infauna[1]		✓	✓	–	–	✓	✓	–	✓	✓
Epifauna[1]		✓	✓	–	–	✓	✓	–	✓	✓
Zooplankton & Ichthyoplankton		✓ ◊	✓ ◊	– –	– –	✓ ◊	✓ ◊	– –	✓ –	✓ ✓
Fishes		✓	✓	✓	✓[2]	✓	✓	✓[2]	✓[2]	✓

✓ = sample taken/work done or planned

– = no work done or planned/not relevant

◊ = no work done or planned but could be done in future

[1] Follow on analyses done by species or higher taxonomic group (e.g., family) where relevant, and/or as a sample batch

[2] Done only for some species

Figure 03: Follow-on Laboratory Activities

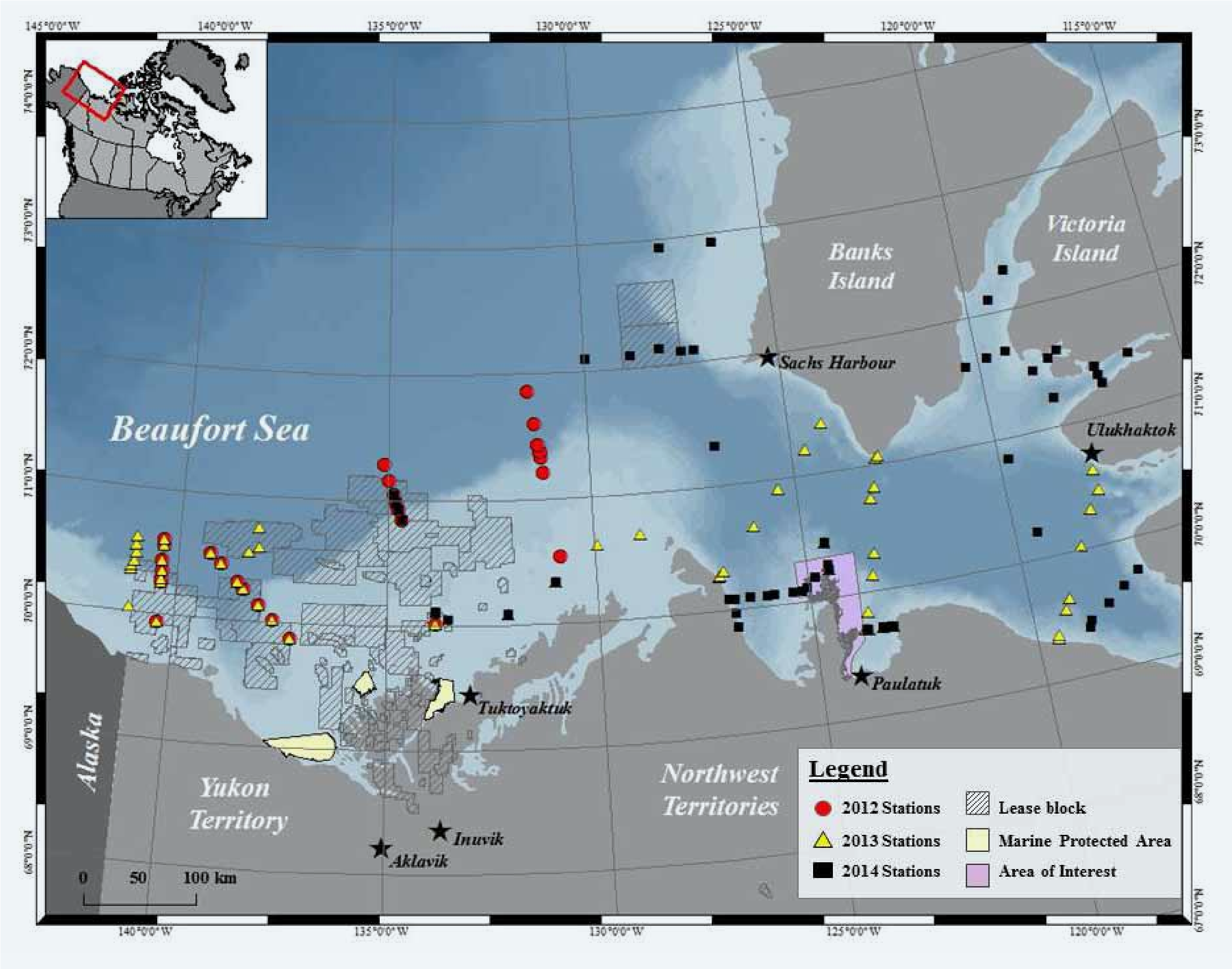


Figure 04: Sampling Coverage from 2012 to 2014

Sampling station locations followed pre-set lines called transects, which were set up according to factors such as sea floor depth and oceanography. This allowed for a regional scale assessment of the wide range of marine habitats present in the Canadian Beaufort Sea. Lease blocks (cross hatching), Marine Protected Areas (yellow), and Areas of Interest (pink) are shown. Note: map does not show hydroacoustic (pelagic) sampling points.

Habitats for Fishes

Depth Structure and Water Currents

The Canadian Beaufort Sea is made up of relatively stable, distinct layers of water known as **water masses** (Figure 05). Sea ice melt, freshwater input from the Mackenzie River, incoming surface flows along the coast from the North Pacific Ocean via Bering Strait, sub-surface polar **gyres** of water originating from the Atlantic Ocean, and deep Arctic Basin water all contribute to oceanographic conditions in the region. Temperature and salinity are two basic aspects of marine waters that result in buoyancy differences among water masses. They 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 they physically intersect the bottom (e.g., along the slope), tend to concentrate food (e.g., plankton) which results 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.

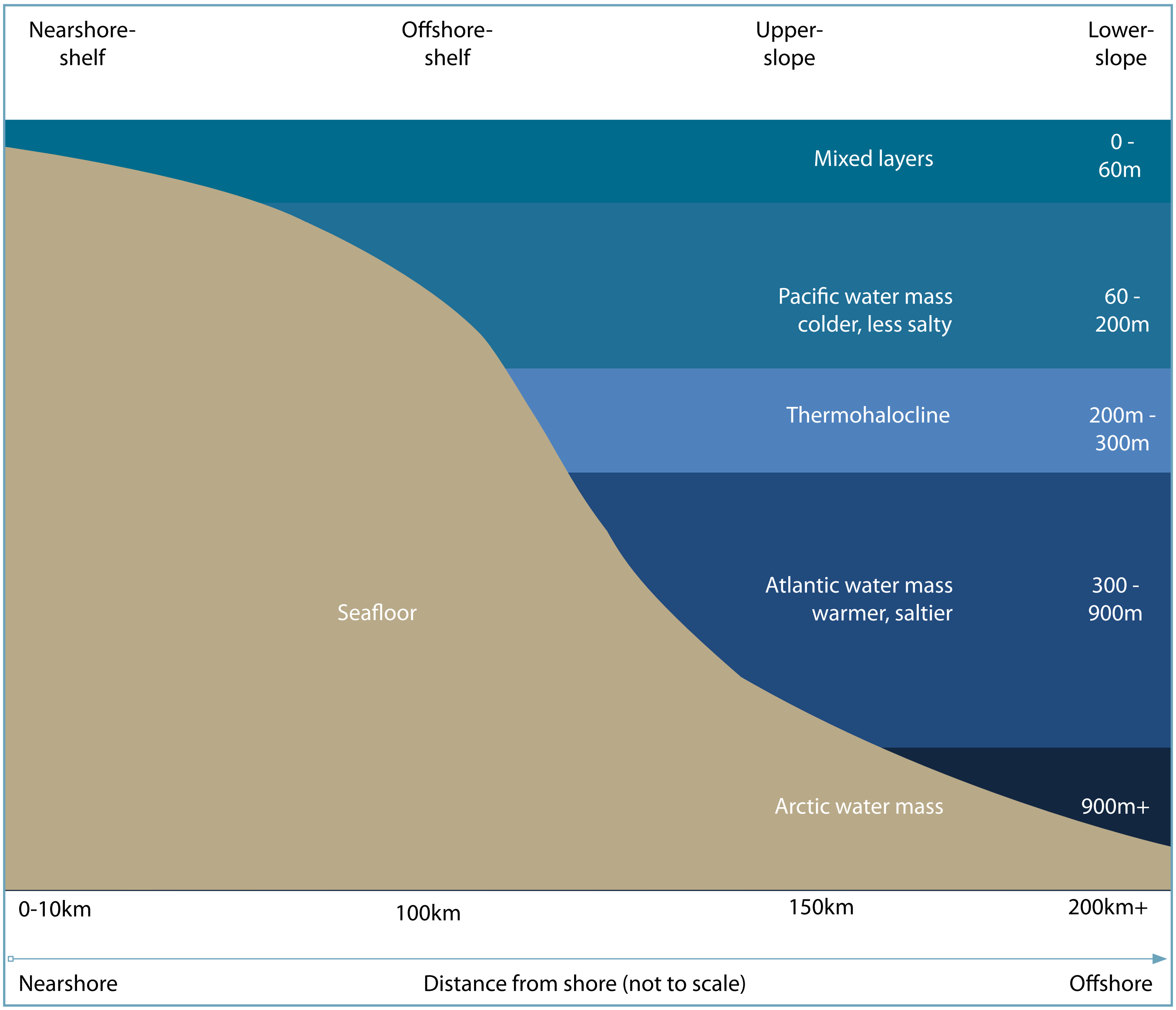


Figure 05: Simplified Vertical Water Mass Structure in the Canadian Beaufort Sea

These water layers, influenced by several factors such as sea ice melt and ocean gyres, each have different physical and chemical attributes that comprise different habitats for fishes and other marine animals.

Surface currents in the offshore zone of the Canadian Beaufort Sea are generally present as the 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 to the shelf edge then generally moves eastwards. Deeper currents originating in the Arctic Ocean (Atlantic and Pacific water) tend to move anti-clockwise and come onshore along the slope margin[23]. As these currents are 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, meaning that the sampling design for this study had to investigate as wide a range of habitats as possible.

The BSMFP was the first comprehensive examination of the offshore fishes and their ecosystems for the Canadian Beaufort Sea.

Sampling Design

The BSMFP was the first comprehensive examination of the offshore fishes and their ecosystems for the Canadian Beaufort Sea. For that reason, 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

Wojciech Walkusz sorting zooplankton. Photo by S. MacPhee.

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, made it necessary to have a multi-year sampling design that covered a wide range of depths. Moreover, some shallower sites along specific **transects** had been previously sampled during the NCMS program. Re-sampling these areas using the same fishing nets allowed for potential inter-annual assessments to be extended over a longer period of time. Given the nature of the BSMFP, the survey design focused on the 'summer' open water season when navigation was possible (as noted, ice floes and their movements affected activities in some years).

The basic design of the survey was onshore to offshore lines (transects) with stations situated at key depths to sample shelf (40-200 m), upper-slope (200-500 m), and lower-slope (500+ m) habitats, and included a target maximum depth of 1000 m where possible (Figure 04). In general, seven depth stations were sampled along these lines in the southern and western areas. Lines were modified in Amundsen Gulf and associated embayments to accommodate both **bathymetry** and particular focal areas. Sampling was not conducted on any specific lease blocks for oil development, however, many of the lease blocks in

Charlie Ruben showing the camera a sea spider. Photo by S. Atchison.

the area were sampled. Repetitive sampling of key transects (and stations in some cases) was designed to address inter-annual variation in the system.

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. In 2013, sampling took place over approximately six weeks and was divided into two legs. Leg 1 focused on transects in 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 transboundary region, and included re-sampling of key 2012 transects. Sampling in 2014 also extended over a six-week period of time with a focus on the Canadian Beaufort Shelf and slope regions, in addition to Amundsen Gulf. In all years, key transects (either from the NCMS program or the BSMFP) were resampled to assess inter-annual 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 should be kept in mind when considering overall project findings.

Finally, information on marine fishes generally remains unresolved with respect to spring (break-up), autumn (freeze-up), and winter (ice-covered) for the Beaufort Sea due to the limited operational time and the geographic scale of the survey area.

Close up of a basket star. Photo by S. Atchison.

Fishing Vessel 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 (Figure 06). The F/V *Frosti* is a Canadian owned and operated factory stern trawler based out of Nanoose Bay, British Columbia. This vessel is capable of holding up to eight science staff in addition to six crew members and was crewed sufficiently to allow for 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 setup, which allowed for 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 was 9.5 knots and the vessel could work at sea for up to 35 days without refuelling, depending upon conditions.

Crew members await the arrival of the science team and their supplies. Photo by S. Atchison.

Figure 06: F/V *Frosti*

Offshore Linkages to Other Systems

The offshore region is tightly linked to both the shelf and coastal regions of the Canadian Beaufort Sea via large-scale oceanographic processes. The shelf acts as an estuary that draws water from both the Arctic Ocean (i.e., an oceanic source)[21] and the Mackenzie River (i.e., a coastal source)[22]. When water from the Mackenzie River enters the shelf region, it is either driven offshore by a process called **upwelling** (when easterly winds cause deeper water to be brought to the surface) or the river water can remain close to the coast due to **downwelling** (when westerly winds cause the surface waters to be pushed deeper in the water column)[23]. In addition, water from the Mackenzie River stays nearshore during years when sea ice remains close to shore, whereas when the shelf is completely cleared of ice, water from the river often spreads to the edge of the shelf and beyond[24]. Therefore, both winds and the extent of ice cover influence the amount of river inflow reaching the shelf.

The larger-scale physical processes mentioned above also influence the concentration of nutrients that are present in the water column and thus have repercussions throughout the entire food web. Ice cover and river inflow vary inter-annually and the source of the water drawn to the shelf has a great significance for the biota in terms of the opportunity for growth (e.g., primary production) and as a source of "seed" populations for certain organisms[23]. The Mackenzie River acts as the main source for land-derived nutrients in the upper 5-10 m of the coastal ocean[25].

In contrast, nutrients are supplied to the upper waters (0-220 m) of the offshore region by Pacific Ocean water inflowing through the Bering Strait[25], whereas deeper waters (below ~220 m) in the offshore originate in the Atlantic Ocean and Nordic Seas[26]. As a result, upwelling events may move waters of Pacific origin from the offshore region onto the shelf, thereby having a significant effect on the nearshore ecosystem[25].

The availability of nutrients in the different regions of the Canadian Beaufort Sea determines the annual limit for primary productivity, which forms the basis of the Arctic marine food web[25]. In general, the surface waters (i.e., the top 60 m or so) are important rearing habitats for juvenile fishes both on and offshore. Although species composition differs with proximity to shore and the Mackenzie River plume (i.e., estuarine fishes are nearshore, whereas marine

The availability of nutrients in the different regions of the Canadian Beaufort Sea determines the annual limit for primary productivity, which forms the basis of the Arctic marine food web.

Increasing knowledge of this critical Arctic marine ecosystem, the fishes therein, and the structural and functional relationships between offshore and nearshore regions will build a better understanding of the entire Beaufort Sea ecosystem.

fishes are offshore), these compositional changes likely reflect differences in spawning locations and associated transport of passive-swimming larval and juvenile fishes via currents. **Aggregations** of certain species nearshore (e.g., Capelin) serve as a food source for coastal predators (Arctic Charr, sea birds, and possibly Beluga). Many of these species are key biota (e.g., marine mammals, sea birds, **anadromous** fish) harvested by Inuvialuit. Therefore, inter-annual variations may have strong impacts throughout the food web and, ultimately, on the foods harvested by people living in the coastal regions.

In order to strengthen the knowledge of linkages between coastal and offshore regions, the BSMFP was linked directly with other projects. Coastal-based sampling was conducted in Darnley Bay in July 2013 and 2014 in order to determine how nearshore and offshore ecosystems are connected. Species compositions of fishes in nearshore and offshore habitats were compared in order to determine if Capelin and Arctic Cod are competing for food and habitat resources. In addition, recent studies on the link between feeding of top predators (Beluga) on fish from the Canadian Beaufort Shelf ecosystem revealed that marine fish were an important component of the beluga diet[26-28]. Therefore, the health of Beluga, which frequent shallow estuaries during summer, may be significantly influenced by ecosystem processes both on the Canadian Beaufort shelf and in the offshore/deep waters[29]. Increasing knowledge of this critical Arctic marine ecosystem, the fishes therein, and the structural and functional relationships between offshore and nearshore regions will build a better understanding of the entire Beaufort Sea ecosystem.

Bearded seal napping on an ice floe. Photo by M. Dempsey.

Field Sampling Activities

Physical and Chemical Oceanography

Physical **oceanography** is the study of the physical conditions and processes within the ocean, including the movement of water and the physical properties of the water. Physical oceanography 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. At each station, measurements were collected using Conductivity/Temperature/Depth sensors (CTDs) equipped with Niskin bottles. These bottles were used to collect water samples needed for chemical measurements such as dissolved inorganic carbon (DIC), nutrients, bacteria, and salinity (Figure 07). The CTDs were equipped with specific sensors to capture information on the temperature, **conductivity**, pressure, **turbidity**, and oxygen concentration of the water column. An Underway CTD (UCTD) was also used to measure conductivity and temperature while the ship was underway, allowing us to collect measurements over a larger spatial area. Samples were collected by slowly lowering the CTD into the water column until it reached a depth of 5-10 m above the bottom. The CTD was then brought back up to the surface while collecting measurements and water samples at specific depths along the way.

Sheila Atchison, Andy Majewski and Brittany Lynn still grinning after cleaning up a 'mud bomb' - a net full of mud instead of fish! Photo by S. MacPhee.

The CTD rosette is a piece of equipment that samples the physical and chemical properties of sea water at several points in the water column to get an idea of its stratification, or layers. Some water properties are measured by sensors on the CTD rosette, while others are measured from water collected in the grey cylinders (Niskin bottles). Photo by M. Dempsey.

Figure 07: Conductivity/Temperature/Depth (CTD) Rosette

During all three sampling years, temperature and salinity results obtained from CTD measurements showed that the water column was divided into four different layers, confirming observation from past studies. The **stratification** of the entire water column was dominated by salinity since the temperature range in the Beaufort Sea is too small to cause stratification based on density.

In general, bottom water in this region is typically warmer than the water above it in deeper areas. Specifically, the top layer (starting at the surface and going down to ~20 m) was warm (8˚C -11˚C), well-mixed, and had a salinity lower than 30 psu (psu = practical salinity units; normal sea water is about 33 psu). Below this layer was a layer of typical Pacific winter water characterized by temperatures between -1˚C and -2˚C and salinities ranging from 32-34 psu. Under the Pacific winter layer, a layer of Pacific summer water was identified.

Under that, beginning at approximately 200-250 m depth, was another layer of (0.5°C), saltier (>34 psu) water showing Atlantic characteristics that were not observed at the shallow stations (Figure 05). In 2013, ice at the mouth of Amundsen Gulf resulted in surface waters with low salinities and below average surface temperatures, both of which indicated recent ice melt.

These results provide a better understanding of habitats available to fishes and other organisms because the different water masses result in distinct chemical and physical properties of bottom habitats for bottom-dwelling fishes. In addition, the conditions present in the surface layers can influence the phytoplankton and zooplankton. For example, upwelling areas (where warmer, nutrient-rich water from deep in the ocean is brought to the surface/nearshore) or water currents are ecologically and biologically significant to both primary and secondary producers. Therefore, these conditions may ultimately affect population dynamics of fishes by influencing the organisms on which fishes feed.

Sediment and Benthic Infauna

The main objective of studying the sediment (mud at the bottom of the ocean) and infauna (organisms living within the sediments) was to provide supporting information on the habitat and available prey of bottom-dwelling marine fishes. Samples of soft sediments were taken with box cores (Figure 08) lowered from the ship to the sea bottom to examine different characteristics of the sediment, including **granulometry** (% sand, silt, and clay) and the organic content of the sediment, which also included benthic chlorophyll (a measure of the amount of algae in the sediments). In addition, we studied the benthic infauna community, which plays an important role in Arctic marine food webs as food for benthic fishes.

At a given sampling station, a 50 cm x 50 cm box corer was lowered from the ship down to the bottom of the ocean to collect 1-2 cores/samples of marine sediments. Sediment-dwelling organisms were identified to species level to provide information on species diversity, abundance, and biomass. It should be noted that in some locations the sediment was too hard to sample, thus the information on the **benthos** in those locations is lacking.

The box corer being deployed from the F/V *Frosti* (left, Photo by S. Atchison), and Ashley Stasko taking samples from the surface of a sediment core (right, photo by T. Loewen).

Figure 08: Process of Obtaining Box Core Samples

The types of sediment varied throughout the different regions of the sampling program. For example, sediment samples collected at the shallow stations (<100 m) along the Canadian Beaufort Shelf mostly consisted of a thick layer of clay with thinner organic layers throughout the core with very little sand and gravel. Stations ranging in depth from 100-200 m were mostly made up of gravel-sized material along with a hard, thick clay-type **substrate**. In contrast, the sediments collected from Amundsen Gulf and near the west shore of Banks Island (between depths of 20 and 500 m) had a higher percentage of coarse substrate (sand, gravel, cobble) than did the stations that were sampled across the Beaufort Shelf. In terms of the benthic infauna, worms (polychaetes) were the dominant group in all habitats. Many of the shallow stations along the shelf were also made up of communities of bryozoans, hydrozoans, sponges, and arthropods (e.g., isopods, amphipods). The deeper stations along the slope and lower-slope (i.e., the ones with higher percentages of sand and clay) were dominated by polychaetes and smaller bivalves (e.g., mussels and clams) (Figure 09). Ultimately, learning about differences in types of bottom substrates provides information on the various bottom habitats available for fish and other biota on which the fishes feed.

Figure 09: Benthic Organisms

Species such as this polychaete (left), these gastropods (top right) and this annelid worm (bottom right), are examples of animals that live on the bottom of the Canadian Beaufort Sea. Photo credits: Left by L. de Montety; top right and bottom right by S. Atchison.

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 links between benthic and pelagic habitats. The goals of the epifauna component were to quantify epibenthic organisms in terms of abundance, biomass, and species diversity along regional gradients (nearshore-offshore/depth, East-West) and to expand upon the limited knowledge of epibenthic diversity within the Beaufort Sea and Amundsen Gulf. Samples of the epifauna were collected using a 3 m benthic beam trawl (BBT; Figure 10) and a modified Atlantic Western IIA otter trawl (W2A). 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 W2A was used exclusively. The BBT was towed across the seafloor at a speed of 2 knots for approximately 10 minutes whereas the W2A was towed across the seafloor at a speed of 3 knots for 20 minutes.

Deployment of the 3m benthic beam trawl, which is towed along the ocean floor, and is the primary gear for sampling epibenthic invertebrates. Photo by S. Atchison.

Figure 10: Three Meter Benthic Beam Trawl

The species composition of epifauna on the Canadian Beaufort Shelf varied spatially and also between years. The Beaufort Shelf was dominated by echinoderms (40-200 m), whereas worms were most abundant on the upper-slope (200-500 m), and arthropods were most common on the lower-slope (>500 m) (Figure 11). Unlike the Canadian Beaufort Shelf samples, 2013 samples from Amundsen Gulf showed that species composition did not vary between transects or depth in this region. One major difference between these regions was that larger shrimp species were more common in Amundsen Gulf than in the Canadian Beaufort Shelf. In terms of inter-annual differences, stations on the shelf had a high number of crinoids (sea lilies) in 2013 compared to 2012. During Leg 2 in 2013, BBT catches on the shelf were small and the trawls collected mostly planktonic organisms (jellyfish, copepods). It should be noted that BBT sampling in 2014 appeared to be more efficient (collected more fish and invertebrates) than in 2013 due to differences in gear performance. The variability in species composition across different depths and regions may be associated with sediment type, food availability, or other environmental variables. Therefore, results obtained by collecting epifauna samples can provide information about differences in food available to benthic fishes in different regions of the Beaufort Sea.

Figure 11: Sample Beam Trawl Catch

Sample beam trawl catch from 2013 full of seastars, brittle stars and a few crabs. Photo by L. de Montety.

Marine Primary Productivity

Marine primary productivity is the rate at which phytoplankton (algae) convert energy (sunlight) to organic substances via **photosynthesis**. Water column properties and lower trophic level (e.g., phytoplankton) components make up important elements of fish habitat and underlying ecosystem linkages. By gathering information on the biomass, distribution, and composition (type, diversity) of lower trophic organisms, in relation to oceanographic/environmental characteristics, we can better understand the ecosystems inhabited by fish. As part of this component, specific nutrients that phytoplankton require for growth such as nitrate (NO_3), nitrite (NO_2), phosphate (PO_4), and silicate ($Si(OH)_4$) were measured throughout the water column. In addition, there was a continuous measurement of solar radiation available to phytoplankton (i.e., **Photosynthetically Active Radiation,** PAR) in the water column. Water samples were taken at specific depths throughout the water column. Measurements were taken from these samples to collect information on **size-fractionated chlorophyll *a*** (an indicator of phytoplankton biomass), particulate and dissolved organic carbon and nitrogen, as well as phytoplankton cell abundance and diversity (Figure 12). All of these samples were obtained from the water collected in Niskin bottles on the same rosette sampler as the CTD (see Physical Oceanography). The number of depths sampled varied among stations, and increased with the overall depth of the sampling station.

Water samples collected from the Canadian Beaufort Sea were quickly processed in the onboard laboratory of the F/V *Frosti* to obtain the most immediate and accurate results. Photo of Andrea Niemi taken by L. de Montety.

Figure 12: Marine Productivity Filtrations

Results from the marine primary productivity component showed distinct variations in the phytoplankton community between sampling years. For example, low chlorophyll *a* and low nutrient concentrations in samples collected in 2012 and 2013 suggested that our sampling took place after the primary algal bloom on the Canadian Beaufort Shelf and slope. During these years, phytoplankton in these habitats consisted mainly of small (< 5 µm) cells.

Closer to shore, coastal transects in 2013 had a high algal biomass of large phytoplankton cells (> 5 µm). In contrast, 2014 sampling took place during an active bloom period as suggested by significant phytoplankton concentrations (e.g., > 5 µg l^{-1}) consisting of large cells. Due to the fact that phytoplankton is the main food source for zooplankton, information on the base of the food web provides an indication of the productivity of the system. For example, high productivity is usually associated with larger cells, which support the growth of larger zooplankton species. The amount of food available to zooplankton is an important factor in the success and distribution of many other species at higher trophic levels, including marine fishes and other organisms that feed upon them.

Zooplankton and Ichthyoplankton

Zooplankton are small, often microscopic, animals that live in the water column. They are important because they consume energy and biomass from primary producing phytoplankton and transfer it to higher trophic levels including fish, seals, and whales (i.e., zooplankton are in turn eaten by these animals). The amount of zooplankton in a given region (abundance) can have a direct influence on organisms that rely on them as a food source, which highlights the need for studying both vertical (i.e., by depth) and spatial variations in zooplankton communities over time. Ichthyoplankton is a special sub-component of zooplankton that is composed of the larval or early life stages of many of the fish species present in the area. Adult fish lay their eggs in the water in association with ice, or perhaps on the bottom substrate. Once the eggs hatch as larval fish, these usually become part of the plankton present in the upper levels of the water column for the early portions of their life history. Here they consume other plankton (either zooplankton or phytoplankton) and, in turn, may be consumed by larger organisms. As the larval fish grow and develop, they usually leave the upper water column and relocate to different habitats as juvenile or adult fish.

Once the eggs hatch as larval fish, these usually become part of the plankton present in the upper levels of the water column for the early portions of their life history. Here they consume other plankton (either zooplankton or phytoplankton) and, in turn, may be consumed by larger organisms.

The objectives of this component were to determine which species make up the zooplankton/ichthyoplankton communities in the Canadian Beaufort Sea. In addition, we wanted to determine the patterns of their location within the water column (i.e., depths) and/or in different habitats spatially. Extra zooplankton samples were also collected for contaminants analysis, food-web/trophic and energetic studies (see Follow-on Activities), and for possible molecular studies (genetics).

Medium size (0.2-20 mm) zooplankton (meso-zooplankton) such as copepods were collected using a Hydro-Bios sampler (MultiNet) (Figure 13). The net had a 0.25 m² opening and a mesh size of 150 µm and was capable of sampling up to 5 different water layers during a single deployment, which gave us information on the vertical distribution of zooplankton, i.e., the depths at which particular zooplankton were found in the water column. Another type of plankton net, the Bongo net (0.30 m²; 500 µm mesh), was used to sample larger zooplankton (macro-zooplankton; 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 (Figure14).

Made of multiple nets that open and close at specific points in the water column, the MultiNet allows for sampling of zooplankton from different water layers. Photo by K. Young.

Figure 13: MultiNet Being Readied for Deployment

Figure 14: Bongo Net for Horizontal Sampling

The Bongo net is towed diagonally from a depth of no more than 200m to the water's surface, with the goal of capturing larger zooplankton such as fish larvae. Photos by S. Atchison.

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 (Figure 15). From the ichthyoplankton (larval fish) samples, Arctic Cod was the most common species, followed by Pricklebacks (Stichaeidae family). In comparison, zooplankton samples collected in 2014 were comprised mainly of sea butterflies (pteropods) and amphipods (which were found in a matrix of jelly-like organisms or 'goo') highlighting the inter-annual variability in the plankton community. In the 2014 samples, crustacean zooplankton were only collected at stations deeper than 80 m. Ultimately, the availability of zooplankton is a limiting factor for the success and distribution of many other species at higher trophic levels, including marine fishes.

This copepod is one of the most numerous zooplankton species in the Canadian Beaufort Sea. Photo by W. Walkusz.

Figure 15: The Copepod *Calanus hyperboreus*

Fish

Fish sampling was the primary goal of the BSMFP. The main objectives for this component were to identify the community structure and **relative abundances** of offshore fishes on the Canadian Beaufort Sea habitats (i.e., shelf, slope and deep waters) and in Amundsen Gulf. Our goal was to improve the knowledge base of year-to-year changes in fish populations and fish habitats. Benthic fish sampling was conducted using two nets: a Modified Atlantic Western IIA (W2A) Benthic Otter Trawl and a 3 m High-Rise Benthic Beam Trawl (BBT) (see Epifauna section). The W2A was typically towed at the bottom of the ocean for 20 minutes per station and up to 60 minutes at deep-water stations (>1000m). The smaller BBT, on the other hand, was designed to catch small-bodied fish living near the ocean bottom at stations less than 500 m deep. The BBT was towed two separate times for 10 minutes to avoid clogging of the smaller mesh with mud.

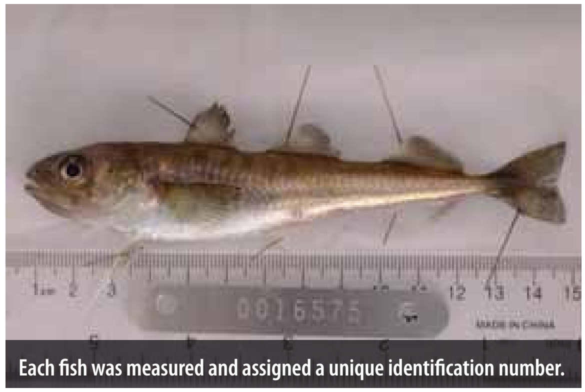
In total, the BSMFP documented 16 occurrences of new species in the region (pending expert verification). Most of the species collected throughout the sampling program were small individuals. In 2012, 9,500 fishes from

Juvenile eelpout


Each specimen was photographed from different angles for ease of identification.


Lumpsuckers are an unusual family of fish that stick to surfaces with small suction pads on their undersides.

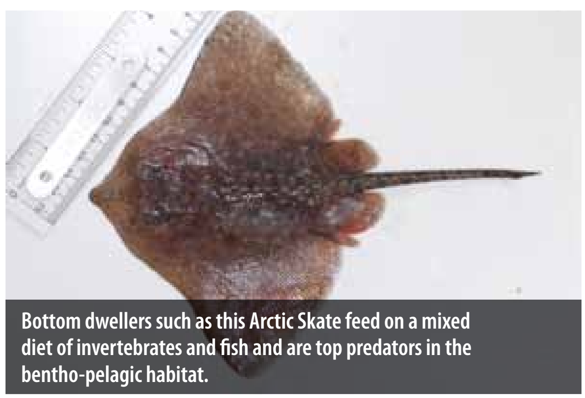

Arctic cod are the most numerically abundant species of fish in the Canadian Beaufort Sea.



Each fish was measured and assigned a unique identification number.


Greenland Halibut


Sculpin


Bottom dwellers such as this Arctic Skate feed on a mixed diet of invertebrates and fish and are top predators in the bentho-pelagic habitat.


Fish in the Canadian Beaufort Sea come in a wide variety of colours, textures, and shapes.


Lumpsucker


Arctic cod at different life stages play different roles in the ecosystem, both as prey and predators.


Arctic Cod


Juvenile flatfish.

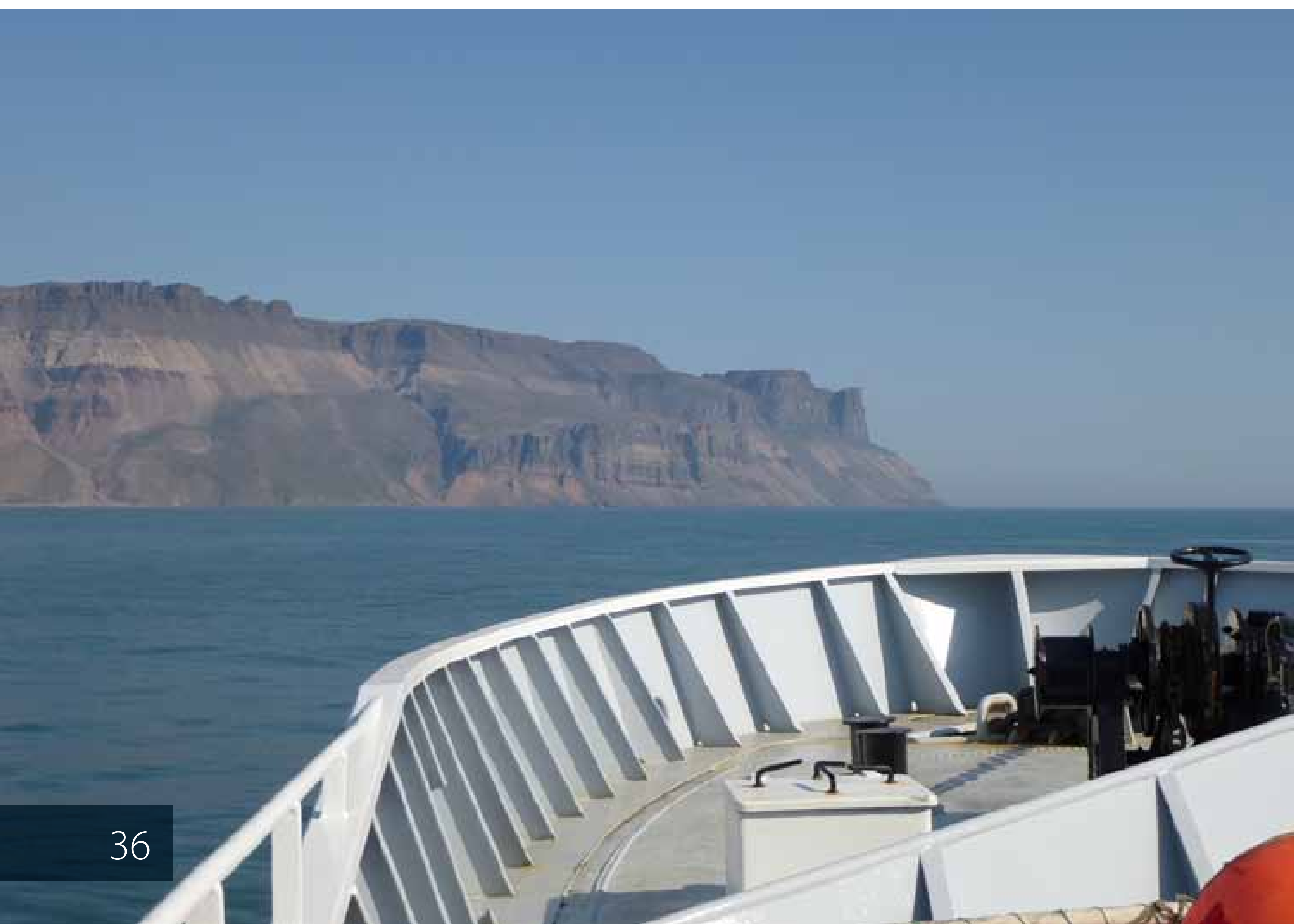

Threadfin Seasnail, a new occurrence in the Canadian Beaufort Sea.


Sculpin

11 different **taxonomic** families were sampled. In 2013, 13,350 fishes from 13 taxonomic families were sampled. In 2014, a total of 17,536 fish from 13 taxonomic families were sampled. Four distinct groups of bottom fishes were found to occupy different habitats on the shelf and slope. Small-bodied bottom fishes and a low number of Arctic Cod (*Boreogadus saida*) were found in nearshore shelf habitats (20-75 m). Offshore shelf habitats (75-200 m) also had small-bodied fishes, but the species were different and more Arctic Cod were present. The highest diversity of bottom fish occurred in upper slope habitats shallower than 500 m. Within these habitats, we observed the largest numbers of Arctic Cod, along with the presence of larger-bodied fishes. The lowest diversity fishes and lowest number of Arctic Cod occurred on the lower-slope (500-1000 m) where catches mainly consisted of larger bodied species (e.g., Greenland Halibut and Arctic Skate).

Despite these differences in diversity of bottom fishes in relation to habitat, Arctic Cod were the most abundant fish sampled in bottom habitats signifying their importance as a **keystone species** in the Canadian Beaufort Sea. During the open water seasons of 2012 and 2013, large aggregations of adult Arctic Cod were sampled at approximately 200-400 m depths (near the bottom)

Banks Island, August 10 2013.
Photo credit: M. Dempsey.



across a broad geographic range. In contrast to 2012, in 2013 there was a noticeable decrease in the relative abundance of Arctic Cod observed at all stations deeper than 500 m. Relatively few adult Arctic Cod were sampled at sites deeper than 200 m in 2014, whereas high abundances of young-of-year Arctic Cod were found in the surface waters of bays within Amundsen Gulf. These results clearly demonstrate the association of Arctic Cod with particular bottom habitats and depths, and also highlight inter-annual variability in the distribution of Arctic Cod biomass; thus emphasizing the need to continue surveys in the future.

Hydroacoustics

Hydroacoustics is the study of sound waves in water and is used for detecting physical and biological (e.g., fish, zooplankton) objects underwater. Hydroacoustics were monitored along the same transect lines as the other sampling. The goal was to document the location and biomass of pelagic fishes in relation to water mass characteristics, with a particular focus on Arctic Cod. Hydroacoustic work was done using an instrument called a Simrad EK60 split-beam multi-frequency (38, 120, and 200 kHz) echosounder. Echosounders record activity underwater and produce an echogram (Figure 16), which indicates whether or not objects have been detected. Dots (i.e., echo returns) on the echogram represent an object in the water column, which can be identified as a particular fish species (or other organism) through appropriate follow-on net sampling. Once a target of interest was identified by the hydroacoustic echogram, a 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 the suspected fish-target layers and a CTD cast was done in order to document water mass characteristics.

Echosounders record activity underwater and produce an echogram (Figure 16), which indicates whether or not objects have been detected. Dots (i.e., echo returns) on the echogram represent an object in the water column, which can be identified as a particular fish species (or other organism) through appropriate follow-on net sampling.

This hydroacoustic echogram shows that the distribution of Arctic Cod in the water column is largely based on their age, with larval (young-of-year) fish mostly near the surface, and adult cod moving deeper into the water column. Each dot represents an echo return, signifying an individual cod fish.

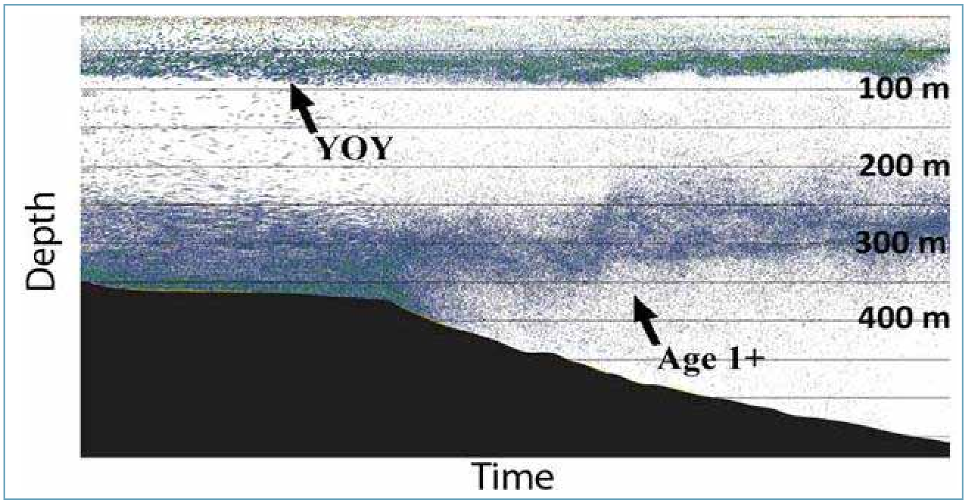


Figure 16: Echogram Showing Arctic Cod at Different Depths

Hydroacoustic results showed that Arctic Cod were located in different layers of the water column depending on their age. 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, or fish hatched within the last year. Slightly larger, older (>2.5 cm, age 1+) Arctic Cod were found lower in the water column between 200-400 m (the **mesopelagic** layer). Fish larger than 10 cm (adults) and most of the fish biomass were found over the slope region at depths greater than 200 m. These results match the findings of the benthic net sampling program described in the Fish section. Young-of-year Arctic Cod hatch at the surface of the water column 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. Overall, we found average biomass was high in 2012 and low in 2014. These results were important because they showed that young-of-year and adult Arctic Cod use different habitats, and their distributions and total biomasses were variable across years.

How do all of these components fit together?

All of the above components describe the habitats and the various 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), was 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 and 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, and the processes (e.g., energy flow) and linkages (e.g., between nearshore and offshore communities) of the offshore environment support an ecosystem-based approach to management. Altogether, this information serves as a baseline of ecosystem structure and function 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.

Sheila Atchison displaying an enormous eelpout. Photo by J. Eert.

Follow-On Laboratory Activities

Full laboratory processing of individual fish was conducted at the Freshwater Institute Science Laboratory in Winnipeg, where the taxonomic identification (i.e., the species name) of each fish was verified.

Basic Biological Processing

The information provided above is primarily focused on the field activities on the ship, and initial sampling and data collection. Once samples were returned to the laboratory in Winnipeg, a range of follow-on processing and sampling work was conducted. For example, **taxonomic identification** of zooplankton and epi/infauna is performed in labs where proper microscopes, lighting, taxonomic keys, and other resources are more accessible than those on a research vessel where space, equipment, and time are limited.

Fish

Once the nets from the trawls were brought onboard, they were emptied and sorted into fish and invertebrates. Further processing took place on deck or below in the fish processing area. Fish were identified to the lowest taxonomic level possible and the length of each fish was recorded. 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 BSMFP.

Full laboratory processing of individual fish was conducted at the Freshwater Institute Science Laboratory in Winnipeg, where the taxonomic identification (i.e., the species name) of each fish was verified. In some cases, special expertise was needed to identify fishes, and those fish were sent away to researchers with specialized knowledge. Weights, lengths and the sex and maturity of each fish were examined. This information provides insight into the size structure and life-stages of the fishes during the summer. A variety of aging structures (e.g., otoliths), tissues, and other important measurements from the fish were also gathered in order to understand how the fish collected in the trawls fit into the larger population from which they came.

The stomach contents of fish were examined in order to see what and how much food a fish was eating recently. This type of stomach content information helps us to better understand a fish's role in an ecosystem. For

A sea spider, with a hand for perspective.

Epimeria loricata, a species of amphipod.

Amphipod, Ampelisca sp.

A tiny species of bivalve that lives in the sediment of the ocean floor.

Sea urchins.

Seastar with eleven arms!

Several shrimp.

Laure de Montety displaying a large crab.

Sorting through a big catch of shrimp and other invertebrates.

The vivid blue eye of an octopus.

example, both the amount and the quality of food found in the stomach of a fish can tell us if the fish and its environment are healthy, and can indicate changes in an ecosystem over time. In addition, clips of fin and muscle tissue were removed for genetics/DNA studies. These studies allow us to determine how different fish populations are related to one another and/or from where the fish originated. 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). Altogether, this information can be used to examine fish populations over time to better manage a fishery and understand an ecosystem.

Zooplankton

The bongo nets used to collect zooplankton provided two replicate samples. Organisms collected in the first bongo sample were preserved in a 10% buffered formalin solution for later taxonomic analysis in the lab. The second bongo sample was used entirely for collecting organisms for follow-on analyses such as stable isotopes, fatty acids and contaminants (see sections below). Onboard, sub-samples of zooplankton were sorted by species and then frozen and stored until they could be moved to the lab. Zooplankton collected from the MultiNet were also sorted live, recorded, and frozen for follow-on analyses. All of the organisms identified and frozen onboard were used by researchers working on ecosystem tracers. Ecosystem tracers are tools (e.g., stable isotopes, fatty acids) that allow us to examine the movement of energy, nutrients, or contaminants throughout a food web. Therefore, by examining these ecosystem tracers in many different groups of organisms, we can better understand how variations in lower trophic levels (e.g., phytoplankton) can influence higher trophic levels including fish populations.

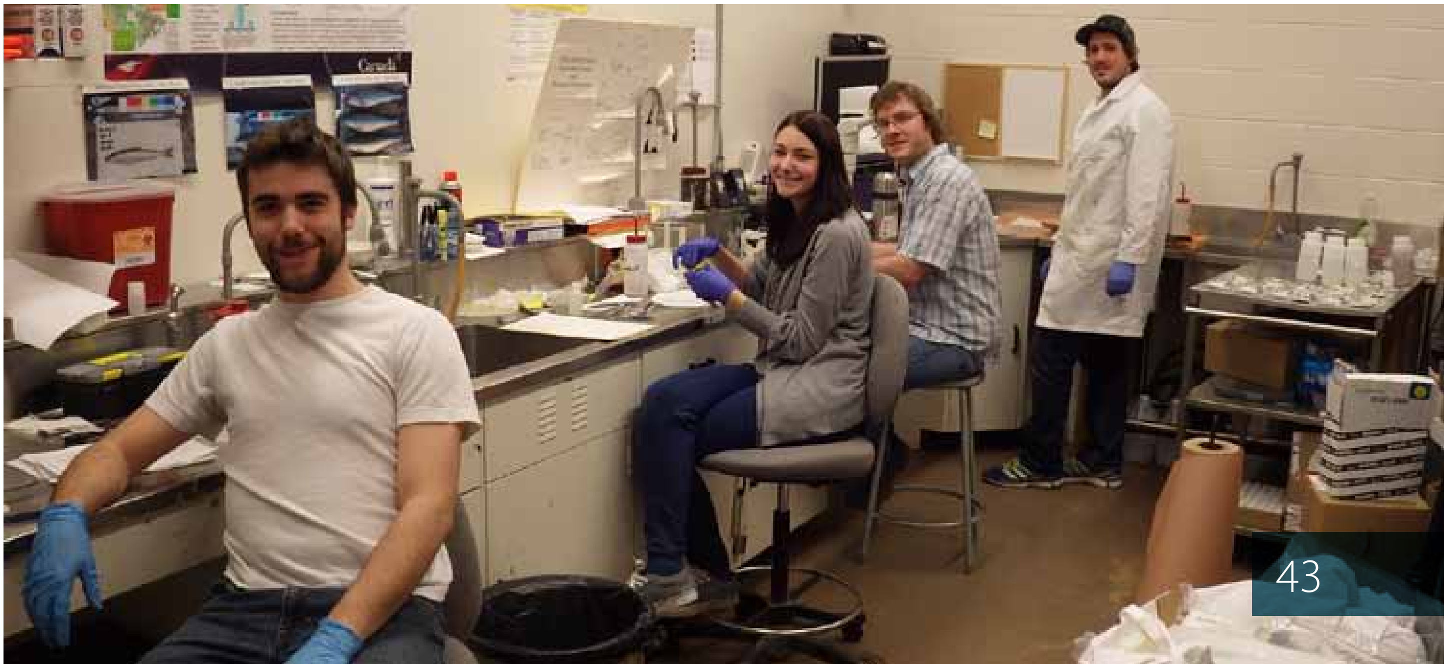
Sediments and Infauna

Sediment cores were divided in half, with one portion being used to collect surface samples of the sediment in order to examine organic content, granulometry (grain or particle size), stable isotopes, surface contaminants, chlorophyll, and prokaryotic community structure. These data provide information on the habitat/environments of where fish are living. The second half of the core was sampled for infauna at two depth layers in the sediment core: one from 0 to 5 cm deep and another from 5 to 25 cm deep in order to compare the taxonomic composition of animals living on the sediment surface with those living within the sediments. Extra sediment was also collected and frozen at every station to reserve for future ecosystem tracer studies. Combined with ecosystem tracer data from fish samples, we can gain a better understanding of what benthic organisms are eating, in addition to how "healthy" they are as food items for benthic fishes.

Lab Activities

Fatty Acid Analysis

Fatty acids are the essential building blocks of fat in an organism and in the food that they eat. Organisms contain certain types of fatty acids depending on what they eat, and when/where they eat it. Each prey type has a unique fatty acid signature that is integrated into the fatty acid signature of predators that eat them. By analyzing the fatty acids of predators, we can determine what types of prey they have been eating. Polar organisms are particularly rich in **lipids** (fatty acid), which they must store as energy reserves in order to survive for long periods of time (e.g., during ice cover) when food is hard to find (less abundant). Invertebrates do not make many of their own fatty acids, instead their fatty acid content depends on their diet during the few weeks before sampling. Additional phytoplankton, invertebrate (infauna, epifauna, zooplankton) and fish samples were all collected in order to analyze the lipid content of these different ecosystem components. In order to determine the fatty acid content of invertebrates, individuals (or groups of individuals if they are small) were homogenized (crushed together) and the lipids were collected. The fatty acids were then analyzed using a technique called gas chromatography with flame ionization detection (GC-FID).



Lab workers at the Freshwater Institute in Winnipeg analyzing the fish caught onboard the F/V *Frosti*. Photo credit: M. Lowdon.

The collection of fatty acid data from different organisms provides a tool through which ecological relationships can be determined. For example, muscle samples from fish, blubber samples from Beluga sampled during coastal research programs, or tissues from other predators can also be analyzed to determine their fatty acid composition, and thus their place or role in the food web.

Stable Isotope Analysis

The higher up an organism is in the food web, the higher the concentration of 15N. Knowing this, we can determine the position, or trophic level, at which an individual in the food web feeds.

Stable isotopes are another tool used to understand food web structure (i.e., as an ecosystem tracer) and can help to link together different components of a food web. Stable isotopes are forms of a specific chemical element such as nitrogen (N) or carbon (C) that can be traced through a food web. By looking at the different forms of "light" and "heavy" stable isotopes we can piece together information on where certain animals fit in the food web and what they are feeding on. Small samples of tissue (usually the muscle of fish or the whole body of invertebrates) are analyzed to determine the ratio of heavy to light isotopes (called delta15N or delta13C).

Organisms living on the bottom of the ocean accumulate more of the heavy ^{13}C isotope relative to the light one (^{12}C), while those feeding in the water column have less of the heavy one (^{13}C). By examining the ratio of heavy to light stable isotopes, we can better understand the source of an animal's food and where it came from in the water column. Heavy ^{15}N, on the other hand, accumulates in tissues of consumers that feed on other organisms. The higher up an organism is in the food web, the higher the concentration of ^{15}N. Knowing this, we can determine the position, or trophic level, at which an individual in the food web feeds. In other words, the combination of carbon and nitrogen stable isotopes provides information on 'who eats whom' within a given food web.

Stable isotopes were analyzed using an instrument called a continuous-flow isotope ratio mass spectrometer (CF-IR-MS) at the University of Waterloo.

Other Lab Analyses

Mercury (Hg) exists in a range of chemical forms as it cycles through the Arctic environment. Methyl mercury **bioaccumulates** and **biomagnifies** (i.e., the concentration of methyl mercury is higher in a predator organism compared to its prey) within ecosystems. To date, only limited information is available on the accumulation of mercury in fishes from the offshore Beaufort Sea. Knowledge of mercury concentrations in a given ecosystem is useful as an environmental tracer and also has serious health implications for humans who consume organisms with high mercury concentrations. Similarly, Polycyclic Aromatic Hydrocarbons (PAHs) and their metabolites (a substance produced during metabolism) in fish have yet to be studied in offshore waters of the Beaufort Sea. PAHs can be readily metabolized by many fish species and their resulting metabolites pose a threat to the health of fish. Sediments, invertebrate samples, and muscle tissues of fish will be examined for both contaminants found in the marine environments. Results will provide a key baseline of mercury values for comparison with future studies. Background values of PAHs will be established as a baseline for future indicators of fish health (e.g., thyroid hormone levels, levels of oxidative stress).

Students visit the DFO lab through the Ikaarvik project with the Winnipeg Zoo/ Vancouver Aquarium. Photo credit Shelly Elverum.

Archives and data

All samples of fish and invertebrates are archived in long-term storage prior to their distribution to the project collaborators, or in case the samples are needed for future reference. Complete sets of voucher specimens of each fish species, along with aging structures (otoliths) and frozen fish (lab processing remains and intact fish) have been stored with Fisheries and Oceans Canada (DFO) in Winnipeg. Additional sets of voucher specimens are stored in the Canadian Museum of Nature in Ottawa and with DFO in Inuvik. These voucher specimens will be used for public education events (e.g., school visits, symposia) and as museum specimens. In addition to the sample archives, all **metadata** related to the BSMFP are stored in digital format on the Polar Data Catalogue (PDC). This includes information on the activities of the collaborators using project samples as a part of larger overall projects. Raw data will also be archived on the PDC two years after it is generated (for federal scientists and academics) or following publication of thesis-related data (for graduate students). These raw data include basic biological data (species identifications, abundance, biomass, length information) and data generated from follow-on activities (fatty acids, stable isotopes, contaminants, energetics, genetics, etc.). Basic data will also be developed into various DFO Data Reports and will be published accordingly. These reports will contain data specific to particular components or aspects of the overall project and thus will both support individual scientific publications and be topic-specific.

Lab work being done at DFO Winnipeg. Photo credit: S. Atchison.

Fish being processed. Photo credit: Mark Lowdon.

Major Conclusions and Outcomes

The overarching accomplishments of the BSMFP were twofold: 1) the establishment of associations between marine fish communities and their habitats, enabling the prediction of which fishes will likely occur in a given area and thereby facilitating planning, management, and mitigation efforts and allowing for the effective evaluation of potential impacts of habitat disturbance; and 2) the development of regional baselines for multiple ecosystem components (e.g., presence/absence of species, physical and chemical properties of habitats) which provides context from which to identify unique areas, and from which to gauge impacts from stressors linked to industrial development (e.g., oil and gas) and climate change at both local and regional scales.

What did this study accomplish?

A total of 184 stations were sampled from 2012-2014 as part of the BSMFP. 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. In addition, it was generally assumed that there were fewer marine fishes present in the water column compared to deeper waters near the bottom of the ocean. Before this study took place, Arctic Cod were known to be an important species in the region, yet there was uncertainty about the Arctic Cod population distribution and their preferred habitats.

Since the completion of the BSMFP, 16 new marine fish species have been tentatively identified for the Canadian Beaufort Sea, some of which had not been previously reported in Canada. This project recorded several new species occurrences to the shelf and slope habitats (Figure 17), most of which came from the deeper areas beyond the shelf-break (>200 m depth) which had not previously been comprehensively sampled. Benthic and pelagic trawling confirmed that there was low water column diversity and high bottom diversity in marine fishes. In addition, all related water column and bottom habitats were determined 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. 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. Arctic Cod was found in almost every habitat that we studied[29], but were particularly abundant in slope habitats. Follow-on work will confirm linkages between benthic and pelagic habitats, as well as between near-shore and offshore habitats through gut content, stable isotope and fatty acid analyses.

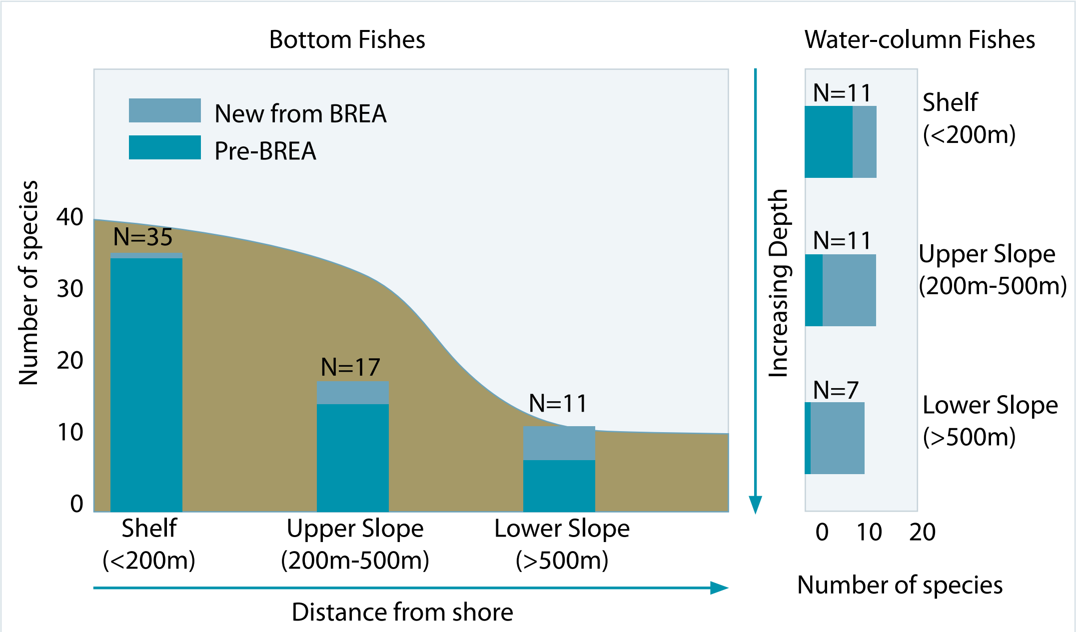


Figure 17: Marine Fishes Known to the Beaufort Sea Before and After the BSMFP

Since the BSMFP was completed, 16 new marine fish species have been recorded for the Canadian Beaufort Sea (pending expert verification). Most of the new species live in environments deeper than 200m, which is due to the fact that scientific sampling had not previously occurred at that depth and the benthic ecosystem was largely unknown.

Information and Tools for Stakeholders

The samples, data, and knowledge gathered during the BSMFP 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. These regions 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. Altogether, 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 effects 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 the present-day Beaufort Sea ecosystem. Collection, on-going processing, and analysis of BSMFP 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 Beaufort Sea Large Ocean Management Area (LOMA), which covers the marine portion of the ISR. This includes information on fishes and 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.

Remaining Knowledge Gaps

Researchers involved in the BSMFP are continuing to integrate data, study food web structure, and identify key energetic links. Ultimately, this combined knowledge is an important step in understanding productivity in the marine ecosystem. One of the major findings of the BSMFP was that the large aggregations of adult Arctic Cod observed in both 2012 and 2013 along the Beaufort Sea slope and extending farther offshore and into Amundsen Gulf, were absent in 2014. This finding highlights the need to better understand year-to-year differences in Arctic Cod and other fish communities with respect to the consequences of such variations to the food webs in the Beaufort Sea. Future studies are also needed to further investigate the factors affecting the distribution, abundance, and life history of Arctic Cod, a critical link in the transfer of energy in the offshore marine food web. 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 embayments to fish communities and the larger Beaufort Sea ecosystem. More work is needed to understand the significance of these and other unstudied areas in the region. Lastly, although a better understanding of many Beaufort Sea marine fish species (e.g., Arctic Cod, Greenland Halibut, Arctic Skate) resulted from this research, the ecological roles of most species remain poorly studied, thus highlighting the need for future research.

As interest in hydrocarbon development into Arctic areas increases, and with the anticipated future effects of Arctic climate change, there is a need to expand the geographic scope of baseline studies to include areas of potential lease development, to identify key areas for implementing conservation measures, and to develop a regional context for future impact assessments. A key remaining gap includes information on the diversity and distribution of fishes within the Canadian Exclusive Economic Zone in deep-water habitats (>1000m 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.

Sunset with Banks Island. Photo credit: S. Atchison.

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Appendix 1: External Lab-based Collaborators for BSMFP (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 (U of W)

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. Rask Møller, University of Copenhagen

Dr. B. Coad, Canadian Museum of Nature

Genetics (fishes)

Dr. M. Docker, UofM (cods)

Dr. J. Nelson, University of Victoria (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: Glossary

Aggregations – Large groups or clusters of biota

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

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 feeding on other organisms containing lower concentrations of the substance

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

Community structure – the composition of species present

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

Ecosystem tracers – a traceable element whose pathway through an ecosystem tell us about its structure and function

Epifauna – animals living on the surface of the seafloor

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

Fatty acids – the essential building blocks of fat (energy storage) in an organism

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

Gyres – large surface currents in the ocean that slowly rotate in a circular motion

Heterogeneity – being made up of diverse (different) parts

Hydroacoustics – The study of sound waves in water and is used for detecting physical and biological objects underwater, similar to a fish finder

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)

Keystone species – A species that has a disproportionately high influence on overall ecosystem health and function. If a keystone species were to disappear, the entire structure of its ecosystem would change dramatically

Lipids – a type of fat that does not dissolve in water, is stored in bodies, and is one of the main parts of living cells (i.e., oil, wax, fatty acids)

Linkages – ecological connections between different ecosystem components

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

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

Metadata – Information about how data and samples were collected

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 –microscopic plants making up the bottom of the food web

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

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

Relative abundance – an indication of how common or rare a species is in relation to other species in the same ecosystem, or how the abundance of a species differs in space and/or time

Salinity – the saltiness or dissolved salt content of the water

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

Size-fractionated chlorophyll a – a way to measure the composition of the phytoplankton community by separating cells into small and large sizes

Stable isotopes - forms of a specific element such as nitrogen (N) or carbon (C) that can be used to understand a food web

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

Substrate – the environment in which an organism lives, e.g. the sediment and organic material making up the ocean floor

Taxonomic – the identification, 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 made up 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

Water masses – water that originates from a distinct source (e.g., the Atlantic Ocean) and is different from other water masses around it

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

Appendix 3: Abbreviations

µg – microgram – one one-thousandths of a milligram

m – meter – 100 cm or approximately 3.3 feet

µm – micrometer or micron – one one-thousandths of a millimeter

Canada

Fisheries and Oceans Canada / Pêches et Océans Canada

Aboriginal Affairs and Northern Development Canada / Affaires autochtones et Développement du Nord Canada

Natural Resources Canada / Ressources naturelles Canada

ArcticNet
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