Marine Fish Habitat Associations and Ecosystem Roles on the Canadian Beaufort Shelf and Slope

Project Leader: Andrew Majewski, Department of Fisheries and Oceans (DFO)

Project team: Jim Reist, DFO
Andrea Niemi, DFO
Sheila Atchison, DFO
Ashley Ehrman, DFO
Carolina Giraldo, Institut français de recherche pour l'exploitation de la mer
Shannon MacPhee, DFO
Bill Williams, DFO
Jane Eert, DFO
Christine Michel, DFO
Philippe Archambault, Université Laval
Maxime Geoffroy, Memorial University of Newfoundland

Research Project Overview

Marine fishes in the Canadian Beaufort Sea have complex interactions with habitats and prey, and occupy a pivotal position in the food web by transferring energy between lower-and upper-trophic levels, and also within and among habitats (McNicholl et al. 2015; Stasko et al. 2016, 2018; Giraldo et al. 2015, 2018; Brewster et al. 2018). Until recently, summer sea-ice extent and lack of suitable research platforms have precluded collection of comprehensive baseline data to characterize the ecosystems relevant to offshore fishes and their habitats. The Department of Fisheries and Oceans (DFO) conducted a baseline survey of biological communities and habitat parameters in the offshore Canadian Beaufort Sea between 2012 and 2014, as part of the federally administered Beaufort Regional Environmental Assessment (BREA). The BREA-Marine Fishes Project (BREA-MFP) was the first comprehensive baseline study of offshore marine fish diversity and associated habitats in the Canadian Beaufort Sea.

The Canadian Beaufort Sea – Marine Ecosystem Assessment (CBS-MEA, 2017) is building on biological baselines and ecological knowledge derived from the BREA-MFP to develop a comprehensive research and monitoring approach for the offshore Canadian Beaufort Sea. This approach will enable us to better understand the relationship between oceanographic drivers and ecosystem responses.

Project Purpose and Goals

The main goal of the BREA-MFP was to carry out a baseline exploration of fish diversity and distributions; however, it additionally aimed to understand complex ecological linkages between fish, the physical habitat, and other components of the biological community (e.g., invertebrates, plankton, and primary producers). The field sampling campaign was the first of its kind to span the region from the shelf (~20m) to deep offshore (~1500m) with the objectives of establishing:

- Measures of biological productivity and diversity, relative abundances, and distributions of marine life,

- The community structure and habitat associations of marine fishes,
- Baselines of the physical, biological and chemical characteristics of the water column and seafloor habitat, and
- Ecosystem and trophic (i.e., food web) linkages of marine fishes, and energy pathways within and amongst habitats.

The ongoing CBS-MEA focuses on integrating oceanography, food web linkages, physical-biological couplings, and spatial and inter-annual variabilities, while also expanding upon baseline coverage of species diversity, abundances, and habitat associations to areas of the Beaufort Sea and Canadian Archipelago that are previously unstudied in this context. Current research objectives include:

- Establishing baselines for diversity, distributions, and abundance of biological communities and associated physical and chemical habitat parameters i.e., understand the current structure of the marine ecosystem;
- Assessing ecological linkages amongst biological communities and to the physical environment i.e., develop knowledge to support predictions of in-situ and down-stream effects of environmental stressors (e.g., oil spill) through understanding of biological-physical linkages and interactions;
- Researching the nature and effects of stressors (e.g., ocean acidification, microplastics, climate variabilities) on the structure (e.g., biodiversity) and function (e.g., trophic shifts, 'health' of key biota) of the ecosystem.

Approach

The BREA-MFP team developed a multidisciplinary approach with experts from federal, university and local Inuvialuit communities. Exploratory off-shore field programs occurred in the summers of 2012, 2013 and 2014 using a 39 m science-capable, ice-strengthened fishing trawler, the F/V *Frosti*. The program was unique in its capacity to conduct full-scale biodiversity surveys of nearshore and deep-water offshore fish and invertebrate communities in addition to collecting relevant environmental and habitat data.

The BREA-MFP sampling design was based on shallow-to-deep water transect lines consisting of multiple stations (20-1500m depths) spanning the southern Canadian Beaufort Sea, from the Alaskan border eastwards into the Amundsen Gulf, and offshore of southwestern Banks Island to the limits of summer sea-ice. Additional sites were surveyed in coastal embayments, upwelling sites, southern Prince of Wales Strait, and along the slope drop-off. Sea-state permitting, sampling activities at stations typically included:

  - demersal trawling for fishes and epifaunal macroinvertebrates
  - sediment box-coring for infaunal invertebrates and characterisation of bottom habitat
  - plankton sampling (e.g., zooplankton, ichthyoplankton) using both water-column integrated and depth-stratified approaches, and
  - physical, chemical, and biological oceanographic sampling (e.g., CTD casts, bio-chemical water analyses) for characterisation of the water column habitat.

Hydroacoustic survey data of fish and zooplankton aggregations was collected continuously during ship operations. Whenever possible, transects would be retraced after sampling was completed to provide continuous hydracoustic profiles. Targeted hydroacoustic transects also occurred, with midwater trawl and zooplankton net deployments coordinated to provide ground-truthing of hydroacoustic detections.

A total of 184 stations were sampled between 2012 and 2014, during August and September of each year. See Majewski et al. (2017) for a comprehensive overview of the sampling program, station coordinates, and preliminary data summaries.

Use of Traditional Knowledge

The program was enriched by support from the Inuvialuit Game Council, Inuvialuit Hunters and Trappers Committees, and the Fisheries Joint Management Committee, including: regular consultation on the project priorities, design, logistics, and scope; regular project updates; and the direct participation of Inuvialuit community members as part of the scientific sampling crew.

In collaboration with the Arctic Salmon Project (lead: K. Dunmall, DFO), the Inuvialuit Game Council, and local Hunters and Trappers Committees, the CBS-MEA program participated in a series of local and traditional knowledge interviews in each ISR community between 2017 and 2019. The study gathered knowledge and observations on the marine environment near communities and in traditional fishing and hunting areas. Interviews included questions about the ocean environment, weather, and sea ice, and also captured perspectives on changes in coastal marine areas and the animals that use them. The knowledge gathered will be synthesized in a graduate thesis, grey literature report(s), and community focused products (presentations and handouts). Local and traditional knowledge on marine fishes and their habitats will provide complimentary perspective and longer-term context for the analysis and interpretation of results from the BREA-MFP and CBS-MEA.

Summary of Results/Outcomes

<u>Results of BREA</u>

- Species occurrences
  Benthic trawl surveys conducted between 18-1001 m depths on the Canadian Beaufort Shelf and slope collected 34 species, accounting for approximately 44% (34/77) of the marine and anadromous fish species present in the ISR. The majority of species caught during the BREA-Marine Fishes Project (BREA-MFP) were relatively rare, with only eight contributing >1% to the total abundance-based catch-per-unit-effort. The BREA-MFP recorded 16 new marine fish species for the Canadian Beaufort Sea (pending expert verification), most from environments deeper than 200 m (Majewski et al. 2016), and contributed to taxonomic studies for some difficult groups (e.g., zoarcids).

- Habitat associations
  Marine fish community structure was most strongly correlated with depth, and assemblages were generally delineated into the following depth ranges coinciding with distinct water mass habitats: a) Nearshore-shelf: <50 m depth, b) Offshore-shelf: >50 and ≤200 m depths, c) Upper-slope: ≥200 and ≤500 m depths, and d) Lower-slope: ≥500m depths (figure 2). The species composition of the assemblages is described in Majewski et al. (2017). Water mass habitats, delineated in association with biological sampling, are presented in Eert et al. (2015) and Niemi et al. (2015) (see example in figure 3). The benthic community was similarly depth-structured,

with distinct delineations in both macro- and megafauna communities for shelf, shelf-break, and slope habitats (Nephin 2015). Preliminary analyses of zooplankton community structure also indicate depth structuring across shelf and slope habitats (Walkusz, unpublished data), and support results reported for linked research in the Canada-US transboundary region (Smoot and Hopcroft 2017).

- Food web dynamics

  Food web dynamics of offshore communities were studied to identify key forage and predator species, and to understand their roles in the ecosystem. Previous studies identified Arctic Cod (*Boreogadus saida*) as a keystone species in the structure (i.e., trophic pathways) and function (i.e., energy transfers) of Arctic marine ecosystems. The BREA-MFP determined the habitat associations and diet of Arctic Cod in areas relevant to existing lease development. Acoustic and net-based surveys identified the upper-continental slope, and associated upper-Atlantic water mass, as primary habitat for adult Arctic Cod (Geoffroy et al. 2015; Majewski et al. 2015). Diet analysis identified four primary prey species for Arctic Cod and revealed depth- and size-related diet shifts, coinciding with habitat association across different life-history stages (Majewski et al. 2015). Arctic Cod was also an important prey item for Greenland Halibut (*Reinhardtius hippoglossoides*) (Giraldo et al. 2018), which is a top predator and for which there are commercially harvested stocks in the eastern Canadian Arctic. Giraldo et al. (2018) provided the first description the trophic patterns of this important bottom-associated predator species, and determined that much of its energy is derived from pelagic, rather than benthic, resources. In particular, the fatty acid signature of Greenland Halibut indicates that *Calanus* copepods are an important aspect of their diet. The authors determined that much of the *Calanus*-derived signature results indirectly from consumption of Arctic Cod, a major forager on *Calanus* species. Previous work by Giraldo et al. (2015) examined the feeding ecology of seven of the most abundant benthic fish species in BREA-MFP catches on the Canadian Beaufort Shelf and slope, and determined that *Calanus* species were evident to varying degrees in the fatty acids signature of each species, suggesting a strong contribution of pelagic-derived diet input into benthic fish communities. Incorporation of this signal in the benthos may result from either direct consumption of deep overwintering copepods (i.e., off-bottom feeding) or through detrital accumulation in benthic invertebrate prey. These results illustrate the importance of considering dependencies across habitats (e.g., benthic and pelagic), when considering effects of development scenarios on a species or community.

  Stasko et al. (2018) published the first description of the fish and invertebrate food web for habitats deeper than 200 m in the Canadian Beaufort Sea, based on BREA-MFP samples, and confirmed that benthic-pelagic trophic coupling is widely important for energy transfer in the Canadian Beaufort Sea. Data suggested that benthic−pelagic coupling was strongest west of Mackenzie Trough where sinking particulate organic matter (i.e., flux) is relatively high, intermediate in the central Canadian Beaufort Shelf and slope which is dominated by riverine inputs of terrestrial organic matter, and weakest in Amundsen Gulf where strong pelagic grazing is known to limit sinking flux.

Anticipated results for CBS-MEA

Through the ongoing Canadian Beaufort Sea – Marine Ecosystem Assessment (CBS-MEA, 2017-present), DFO is extending the ecosystem-based science approach into Amundsen Gulf, to include potential shipping routes, equipment staging locations, and areas that play important supporting roles to the ecosystem. Continuation of sampling selected key transects, and establishment of a network of biological moorings, has facilitated the establishment of first-time baselines to assess variabilities of biological communities and marine habitats in the offshore Beaufort Sea, which are essential for detecting and gauging impacts and change in the ecosystem.

Links to BRSEA

The BREA-MFP delivered baselines for the diversity, distributions, and relative abundances of marine fishes on the Mackenzie Shelf and slope where oil and gas leases are most concentrated (figure 1). The structure of the marine fish community was strongly correlated to depth and associated water mass structure (figures 2 and 3), facilitating prediction of the fish community that would be encountered in a given area of interest. Food web linkages and core habitats of key marine fish species (e.g., Arctic Cod, Greenland Halibut) were identified, and should be considered in planning, and the development of mitigation strategies, for potential offshore development. In particular, the upper-continental slope was home to the highest diversity of marine fishes (figure 2), and is also core habitat for the keystone species Arctic Cod, which supports culturally important subsistence animals including beluga, Arctic Char, and seals, and also marine birds and larger offshore fish species (e.g., Greenland Halibut). Enhanced baseline information, including assessments of spatial and temporal variability, will provide context to detect and gauge future effects of both individual and multiple stressors. Future surveys will focus on studying the ecological relevance of unique and sensitive habitats identified during the BREA-MFP (e.g., embayments, upwelling areas), and will aim to extend baseline sampling coverage to new areas that have not been explored in this context (e.g., west Banks Island, deepwater slope, M'Clure Strait). Regional stressors such as ocean acidification and climate variabilities (e.g., changing sea-ice conditions) will likely have direct consequences on the marine food web, including subsistence species, and thus understanding these is an important factor when considering cumulative effects and to underpin all management actions.

References

Brewster, J.D., Giraldo, C.,Choy, E.S., MacPhee, S.A., Hoover, C., Lynn, B., McNicholl, D.G., Majewski, A., Rosenberg, B., Power, M., Reist, J.D., Loseto, L.L. (2018). A comparison of the trophic ecology of the Beaufort Sea Gadidae using fatty acids and stable isotopes. Polar Biol. 41(1): 149-162. DOI: 10.1007/s00300-017-2178-0

Eert, J., Meisterhans, G., Michel, C., Niemi, A., Reist, J., Williams, W.J., (2015). Physical, chemical and biological oceanographic data from the Beaufort Regional Environmental Assessment: Marine Fishes Project, August-September 2012. Can. Data Rep. Hydro. Ocean Sci. 197:vi + 83 p.

Geoffroy, M., Majewski, A., LeBlanc, M., Gauthier, S., Walkusz, W., Reist, J.D., Fortier, L. (2015). Vertical segregation of age-0 and age-1+ polar cod (*Boreogadus saida*) over the annual cycle in the Canadian Beaufort Sea. Polar Biol. 39: 1023-1037. DOI: 10.1007/s00300-015-1811-z

Giraldo, C., Stasko, A.D., Choy, E.S., Rosenberg, B., Majewski, A.R., Power, M, Swanson, H. K., Loseto, L.L., Reist, J.D. (2015). Trophic variability of Arctic fishes in the Canadian Beaufort Sea: A fatty acids and stable isotopes approach. Polar Biol. 39: 1267-1282. DOI: 10.1007/s00300-015-1851-4

Giraldo, C., Stasko, A., Walkusz, W., Majewski, A., Rosenberg, B., Power, M., Swanson, H., Reist, J.D. (2018). Feeding of Greenland halibut (*Reinhardtius hippoglossoides*) in the Canadian Beaufort Sea. J. Mar. Syst. 183: 32-41.

Majewski, A.R., Walkusz, W., Lynn, B.R., Atchison, S., Eert, J., Reist, J.D. (2015). Distribution and diet of demersal Arctic Cod, (*Boreogadus saida*), in relation to habitat characteristics in the Canadian Beaufort Sea. Polar Biol. 39: 1087-1098. DOI: 10.1007/s00300-015-1857-y

Majewski, A.R., Atchison, S.P., Suchy, K.D., Henry, J., MacPhee, S.A., Walkusz, W., Eert, J., Dempsey, M., Neimi, A., de Montety, L., Giraldo, C., Michel, C., Archambault, P., Williams W.J., Fortier, L., Reist, J.D. (2016). Beaufort Sea Marine Fishes Project: Update for Stakeholders. Fisheries and Oceans Canada, Ottawa, viii + 57pp.

Majewski, A.R., Atchison, S., MacPhee, S., Eert, J., Niemi, A., Michel, C., Reist, J.D. (2017). Marine fish community structure and habitat associations on the Canadian Beaufort shelf and slope. Deep-Sea Res. I: 121: 169-182. DOI: 10.1016/j.dsr.2017.01.009

McNicholl, D.G., Walkusz, W., Davoren, G.K., Majewski, A.R., Reist, J.D. (2015). Dietary characteristics of co-occurring polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) in the Canadian Arctic, Darnley Bay. Polar Biol. 39: 1099-1108. DOI: 10.1007/s00300-015-1834-5

Nephin, J. (2015). Benthic macrofaunal and megafaunal distribution on the Canadian Beaufort shelf and slope. MSc thesis. University of British Columbia. http://dspace.library.uvic.ca

Niemi, A., Ferguson, S., Hedges, K., Melling, H., Michel, C., Ayles, B., Azetsu-Scott, K., Coupel, P., Deslauriers, D., Devred, E., Doniol-Valcroze, T., Dunmall, K., Eert, J., Galbraith, P., Geoffroy, M., Gilchrist, G., Hennin, H., Howland, K., Kendall, M., Kohlbach, D., Lea, E., Loseto, L., Majewski, A., Marcoux, M., Matthews, C., McNicholl, D., Mosnier, A., Mundy, C.J., Ogloff, W., Perrie, W., Richards, C., Richardson, E., Reist, R., Roy, V., Sawatzky, C., Scharffenberg, K., Tallman, R.,

Tremblay, J-É., Tufts, T., Watt, C., Williams, W., Worden, E., Yurkowski, D., Zimmerman, S. 2019. State of Canada's Arctic Seas. Can. Tech. Rep. Fish. Aquat. Sci. 3344: xv + xxx p.

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

Smoot, C.A., Hopcroft, R.R. (2017). Depth-stratified community structure of Beaufort Sea slope zooplankton and its relations to water masses. J Plankton Res.39 (1): 79–91. DOI: 10.1093/plankt/fbw087

Stasko, A.D., Swanson, H., Majewski, A., Atchison, S., Reist, J., Power, M. (2016). Influences of depth and pelagic subsidies on the size-based trophic structure of Beaufort Sea fish communities. Mar. Ecol. Prog. Ser. 549: 153-166. DOI: 10.3354/meps11709

Stasko, A., Bluhm, B., Michel, C., Archambault, P., Majewski, A., Reist, J.D., Swanson, H., Power, M. (2018). Benthic-pelagic trophic coupling in an Arctic marine food web along vertical mass and organic matter gradients. Mar. Ecol. Prog. Ser. 594: 1-19. DOI: 103354/meps12582

Figures

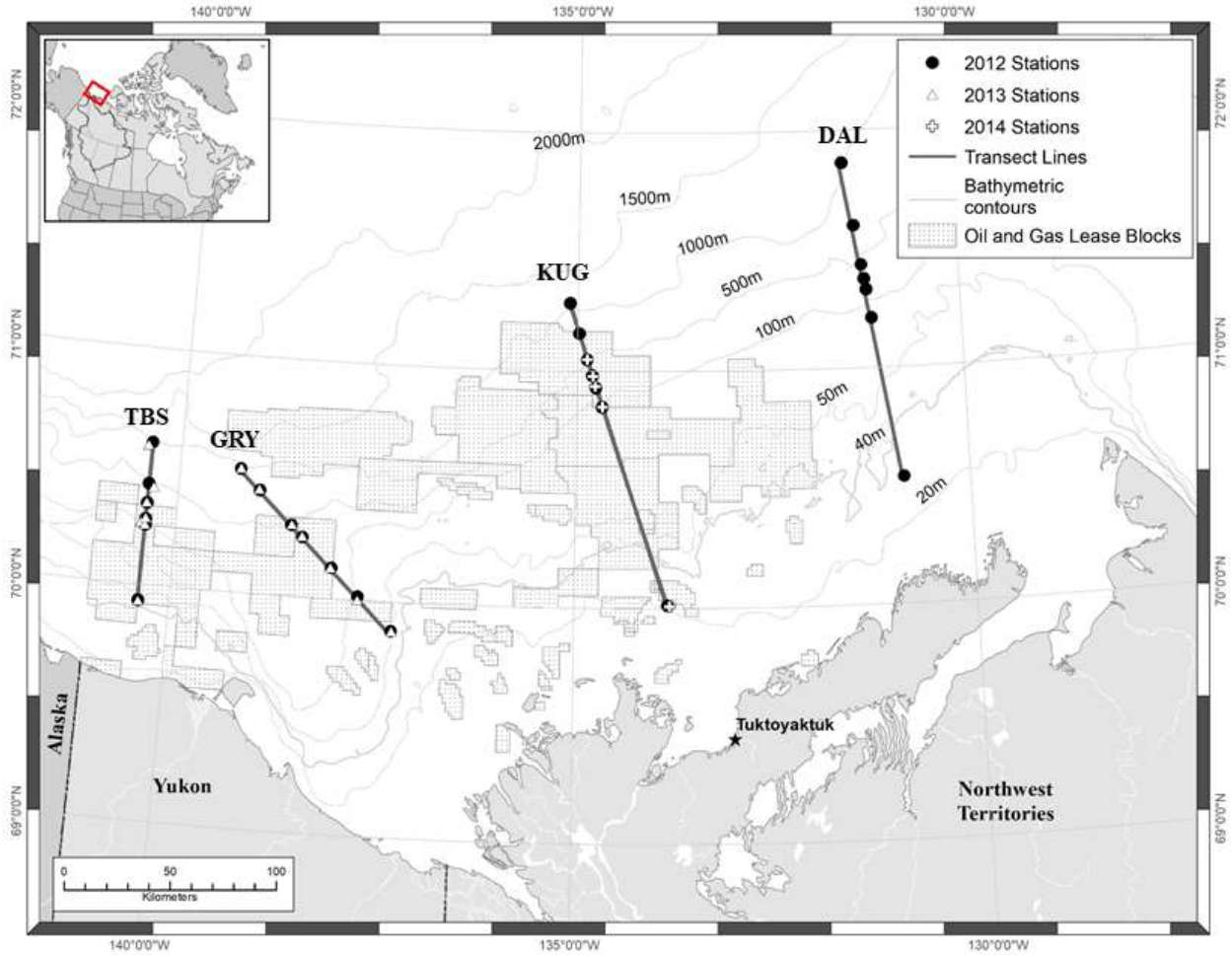

Figure 1. Location of stations and transects sampled on the Canadian Beaufort Shelf and slope during the BREA-MFP between 2012 and 2014.

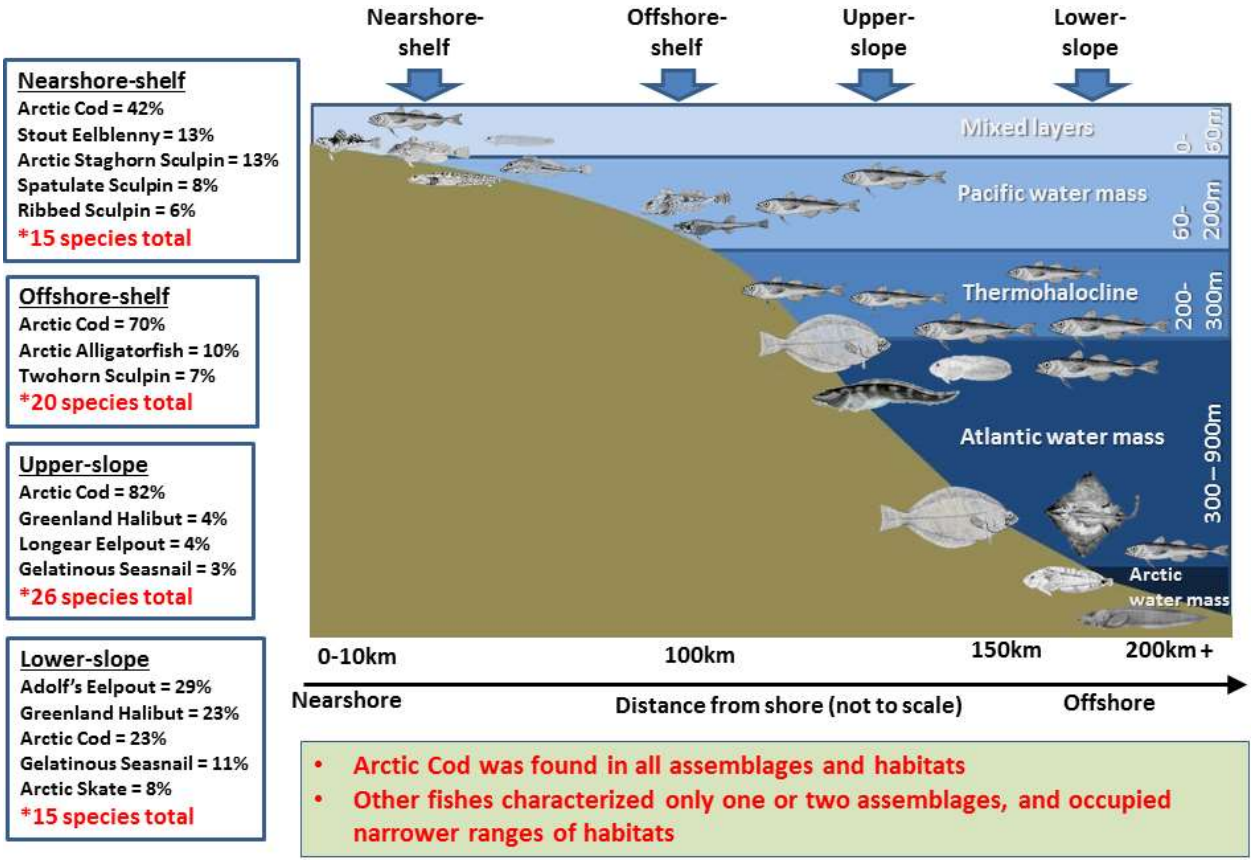

Figure 2. Marine fish assemblages and associated water mass habitats on the Canadian Beaufort Shelf and slope. Percent similarity values indicate the relative importance of each species in characterizing an assemblage (figure sourced from Niemi et al. 2019).

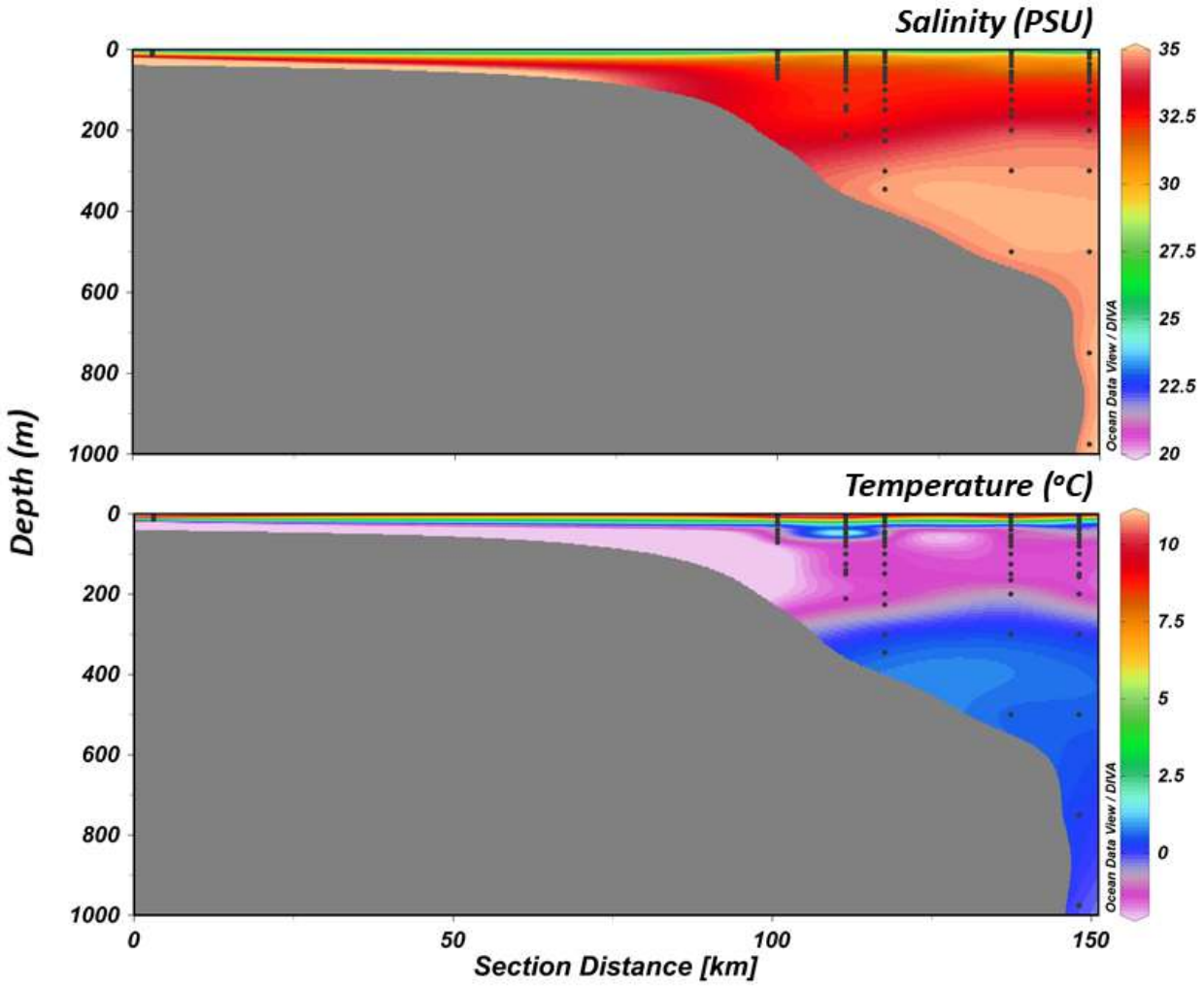

Figure 3. Salinity and temperature profiles along the KUG transect on the central Canadian Beaufort Shelf and slope in 2012. Dotted lines indicate oceanographic sampling profiles.