A Deep Life: Using Stable Isotopes to Understand Deep-Sea Food Web Metrics from the Poles to the Tropics

by Laurissa Christie

INTRODUCTION

The deep-sea is defined as the area 200 m below the surface (Priede, 2017), forming the world's largest environment (Norse et al., 2012). This highly understudied biome is facing increasing chemical and physical stressors (Thresher et al., 2015). Within the Arctic deep-sea, it is predicted that temperatures will increase 0.1˚C – 3.7˚C by 2100, which will have negative physical and biological consequences for deep-sea species that are adapted to relatively stable conditions (Sweetman et al., 2017). In this study, niche is one tool that will be used to understand temporal and spatial variation in the Arctic deep-sea food web and provide insight into how species may respond to environmental changes. Niche has been used to describe the role that species play in an ecosystem and how ecological resources are used since the early- to mid-1900s (Grinnell, 1917; Elton, 1927; Hutchinson, 1957; Bearhop et al., 2004; Colwell and Rangel, 2009).

Stable isotopes and highly branched isoprenoid (HBI) biomarkers are two chemical tracers that aid in the characterization of niche. For a full description of the background information and methods for this project, please refer to Christie (2018).

OBJECTIVES

This project has five main objectives:

1) Review and synthesize the literature that has used stable isotope (δ^{15}N and δ^{13}C) to understand the structure and function of global deep-sea food webs.
2) Quantify niche using stable isotopes (δ^{15}N and δ^{13}C) for deep-sea species with different foraging strategies in relation to temporal variation (seasonal and inter-annual) and spatial variation (geographically distinct sites that experience different sea ice conditions) across a latitudinal gradient in the Canadian Arctic.
3) Examine surface to deep-sea energy connectivity by quantifying sympagic (sea ice) versus pelagic carbon sources using HBI biomarkers.
4) Quantify environmental conditions including sea ice concentration, sea surface temperature, and chlorophyll-a that may be driving spatial differences in food webs in the Arctic.
5) Compare the Arctic deep-sea food web to findings from the global literature review.

METHODS

Literature Review

A literature search was performed in Web of Science using the search terms: "deep-water food webs" or "deep-sea food webs" and "stable isotopes." A total of 54 papers were identified and sorted into categories: food web structure, feeding behaviour, trophic position, trophic interactions, niche, energy pathway coupling, nutrient variability, spatial variation, temporal variation, ontogenetic variation, inter-specific and intra-specific variability, and isotopic methods and approaches.

Data Collection

Fishes and invertebrates were collected by otter trawl (Fig. 1) and longline surveys in Nunavut at Scott Inlet

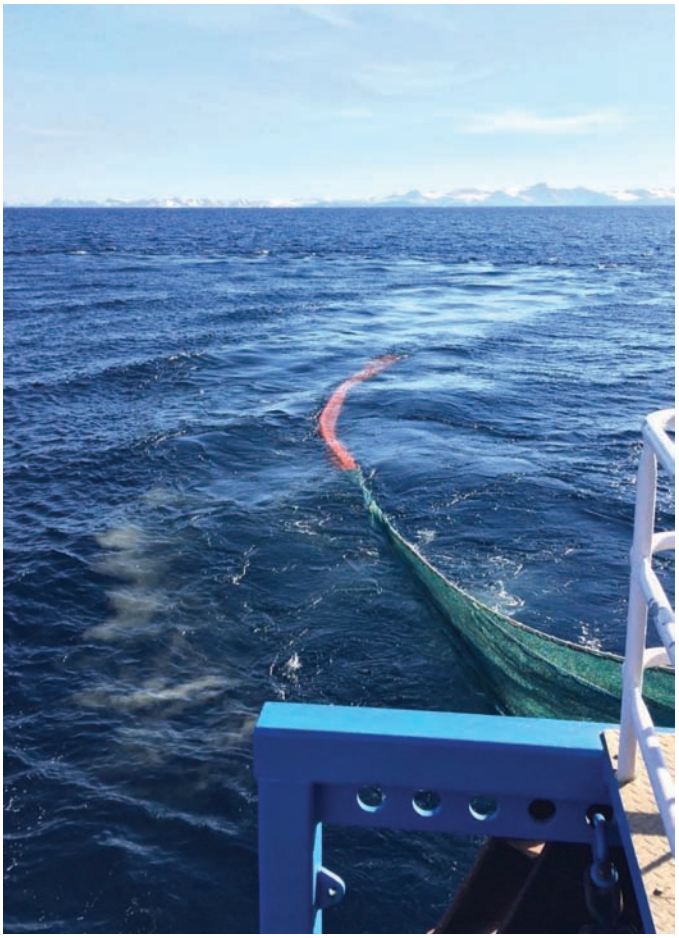

FIG. 1. Otter trawl being deployed on the MV Nuliajuk.

FIG. 2. The MV Nuliajuk used for deep-sea food web sampling.

(2013), Qikiqtarjuaq (2017, 2018), and Pond Inlet (2017, 2018) (Christie 2018) using the MV *Nuliajuk* (Fig. 2). Five fish and two shrimp species were identified as target species based on foraging characteristics, abundance, and economic importance (Table 1). Samples were dissected to obtain tissues with different metabolic turnover rates (fast versus slow, liver versus muscle) (Boecklen et al., 2011; Heady and Moore, 2012; Trueman et al., 2012; Vander Zanden et al., 2015). Muscle was obtained from both shrimp and fishes, and liver was sampled from fishes. Additionally, morphometric characteristics (e.g., body length, body mass, liver mass, and eye diameter) were recorded for comparison with niche, stable isotopes, and HBIs (Fig. 3).

Chemical Tracers

Liver and muscle samples were analyzed for stable isotopes (δ^{13}C and δ^{15}N) and HBI biomarkers. Stable isotopes are often used to make inferences about species niche (Newsome et al., 2007), average diet history (Post, 2002), trophic position (Turner et al., 2010; Zimmo et al., 2012), and habitat use (Peterson and Fry, 1987; Inger and Bearhop, 2008; Layman et al., 2012). These tracers can be analyzed inexpensively (Newton, 2010) to answer ecosystem level questions.

HBI biomarkers form an index known as H-Print, which is used to quantify the amount of pelagic- and sympagic-derived carbon in food webs (Brown and Belt, 2017). H-Print was used to understand the importance and transfer rate of surface inputs (e.g., sea ice) and water column (e.g., pelagic) derived carbon to deep-sea ecosystems (Brown and Belt, 2017).

Environmental Data

Sea ice concentration was obtained from the University of Bremen and analyzed for average concentration using the python interface in Arc GIS. Sea surface temperature will be obtained from Environment Canada and chlorophyll-a production will be obtained from Aqua/MODIS, from NASA.

FIG. 3. Teaching a member of the crew, Linda Kanayuk, how to measure morphometric characteristics and take tissue samples from an Arctic skate (Amblyraja hyperborea).

PRIMARY RESULTS

Arctic cod (*Boreogadus saida*), Atlantic poacher (*Leptagonus decagonus*), gelatinous snailfish (*Liparis fabricii*), and bigeye sculpin (*Triglops nybelini*) specimens were all relatively small-bodied with a length range of 6.8 cm to 28.3 cm and a mass range of 1.8 g to 68.7 g. Greenland halibut (*Reinhardtius hippoglossoides*) were larger, with fork length ranging from 30 cm to 58 cm and mass from 175 g to 1910 g.

In Scott Inlet, the muscle tissue δ^{15}N range of the examined deep-sea species was larger compared to the liver tissue δ^{15}N range. This indicated greater trophic diversity over a longer time period (muscle) compared to a shorter and more recent time period (liver). The opposite trend was observed for the range of δ^{13}C; liver had a higher δ^{13}C range compared to muscle. The larger range of δ^{13}C in liver could be due to greater resource availability at the base of the food web for fish in Scott Inlet during the ice-free summer months. Preliminary isotopic niche analysis of both muscle and liver tissue for fish species within Scott Inlet indicates niche overlap for all fishes except Atlantic poacher.

FUTURE WORK

Analysis of stable isotope and H-Print data is currently underway for Qikiqtarjuaq and Pond Inlet samples to quantify food web dynamics across a latitudinal gradient. Undertaking Arctic research can be quite challenging because of the remoteness, difficult working conditions, and high associated costs. As such, there are no further field collections planned at this stage. Several fishes, including eelpouts (*Lycodes mcallisteri*, *L. rossi*, *L. eudipleurostictus*), sea tadpoles (*Careproctus reinhardti*), and American plaice (*Hippoglossoides platessoides*), and

TABLE 1. Characteristics of deep-sea Arctic species collected in Scott Inlet (2013), Qikiqtarjuaq (2017, 2018), and Pond Inlet (2017, 2018).

Name	Depth range (m)	Maximum recorded length	Common prey	Economic significance	References
Arctic cod, *Boreogadus saida*	surface – 1390 m, pelagic	40 cm	plankton, benthic crustaceans, chaetongnaths, gastropods, polychaetes, squid	Yes	1
Greenland halibut, *Reinhardtius hippoglossoides*	14 – 2000 m, benthopelagic	130 cm	fish, crustaceans, squids, bottom invertebrates, shrimp	Yes	1, 6
Bigeye sculpin, *Triglops nybelini*	135 – 1279 m, baythal, demersal; juveniles can be found over 37 m deep	17 cm	crustaceans: amphipids, mysids, planktons	No	1, 4
Atlantic poacher, *Leptagonus decagonus*	2 – 968 m, benthic-bathypelagic, demersal	25 cm	pelagic and benthic organisms (e.g., crustaceans, molluscs, amphipods, polychaete worms), copepods	No	1, 7
Gelatinous snailfish, *Liparis fabricii*	6–1880 m, southeastern Baffin Island depth is 146 – 409 m, bathydemersal	19.4 cm	Overall they consume crustaceans (pelagic hyperiid amphipods, mysids, euphausiids, gammarids, gastropods, polychaete worms, calanoid and copepods)	No	1, 3, 5
Northern shrimp, *Pandalus borealis*	20 – 1330 m, bottom clay and mud	16.5 cm	zooplankton, detritus, phytoplankton, euphausiids, chaetognaths, amphipods, mysids, jellyfish, copepods, tunicates, ichthyoplankton	Yes	2, 8, 9
Warrior shrimp, *Sclerocrangon ferox*	90 – 1000 m	Carapace length: 31 mm	phytobenthos, amphipods, polychaetes, ophiuroids, gastropods, bivalves, sponge spinicles	No	8, 10

References: [1]Coad and Reist, 2017; [2]Fisheries and Oceans Canada, 2003; [3]Froese and Pauly, 2019a; [4]Froese and Pauly, 2019b; [5]Froese and Pauly, 2019c; [6]Froese and Pauly, 2019d; [7]Heggland et al., 2015; [8]McLeod et al., 2009; [9]Savenkoff et al., 2006; [10]Squires, 1965, 1990, 1996.

invertebrates (e.g., *Eualus gaimardii*) were collected from all three locations. Future work may involve completing H-Print and stable isotope analyses on these additional species to gain a more complete understanding of the deep-sea environment in the Arctic.

PROJECT SIGNIFICANCE

This project will play a key role in advancing the understanding of deep-sea environments, both globally and in the Arctic. Concerns over increasing chemical, physical, and biological changes in the deep-sea include changes to nutrient recycling (Levin and Le Bris, 2015), food availability, ocean acidification, increased water temperatures, increased species' metabolic rates (Sweetman et al., 2017), and invasive species (Smith et al., 2012; Sweetman et al., 2017). Arctic deep-sea species are especially vulnerable to changes in food web dynamics through increased predation pressure, competition, and habitat displacement due to invading species and changes in diet (e.g., native Arctic versus Atlantic zooplankton have different energy compositions) (Fossheim et al., 2015).

Greenland halibut, Arctic cod, and northern shrimp are all economically important species in the North. Other species that are being studied, including bigeye sculpin, gelatinous snailfish, Atlantic poacher, and warrior shrimp

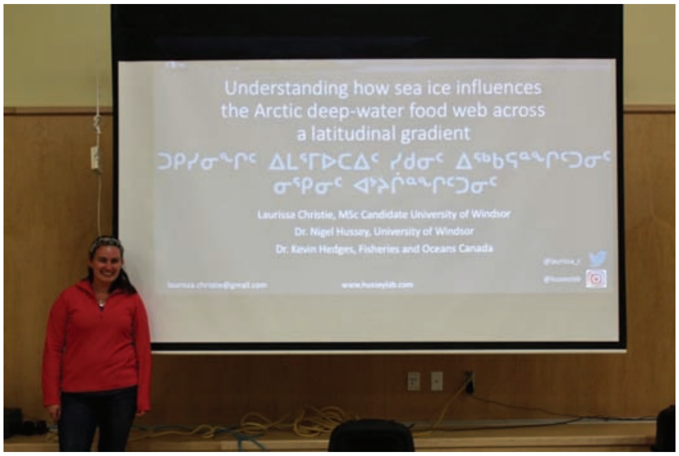

FIG. 4. Presenting my research project to the community of Qikiqtarjuaq, Nunavut, during a public presentation in September 2018.

are indirectly important because they are a key part of the food web by supporting economically important fishery species. Species selected include a top predator (Greenland halibut), a keystone species (Arctic cod), as well as lower trophic level species (Atlantic poacher, gelatinous snailfish, bigeye sculpin, northern shrimp, and warrior shrimp).

The global review of deep-sea food webs will identify knowledge gaps and key research questions to address how the Arctic and the deep-sea may respond to environmental perturbations. The review will also play a key role in determining whether deep-sea food webs in the Arctic follow the same trends as elsewhere in the world. This will be vital for understanding spatiotemporal variation given increasing exploitation pressures (e.g., mining, fishing) in the deep-sea. In addition, research has examined the importance of sea ice to shallow water food webs (e.g., polar bears, seals), but little is understood regarding connectivity among food webs from the surface to the deep-sea.

Results from this study will benefit northern communities by aiding in sustainable fishery development and bringing economic growth, employment, and food security to the North (Christie, 2018). Findings will be shared with northern communities in reports, public presentations (Fig. 4), and with the local hunters and trappers organizations.

ACKNOWLEDGEMENTS

I am honoured to be the recipient of the 2019 Lorraine Allison Scholarship and express my gratitude to the Arctic Institute of North America and the selection committee for this award. Thank you to my supervisor Dr. Nigel Hussey, from the University of Windsor, my co-supervisor Dr. Kevin Hedges, from Fisheries and Oceans Canada, and Dr. Harri Pettitt-Wade, a postdoctoral fellow at the University of Windsor, for their guidance and encouragement. In addition, I would like to thank the Hussey Lab graduate students, staff, and volunteers, particularly Dr. Mallory Wiper and Monica Sokolowski for their assistance with dissections. Furthermore, the support of the hunters and trappers organizations of Pond Inlet, Clyde River, and Qikiqtarjuaq, and the dedication of the crew of the MV *Nuliajuk*, particularly science crew members from each community, were essential for the successful and safe completion of the field program.

Funding and support for this project has come from the National Sciences and Engineering Research Council of Canada, Fisheries and Oceans Canada, the Garfield Weston Foundation, Northern Studies Training Program, Marine Stewardship Council, the Ontario Graduate Student Scholarship, Canadian Northern Economic Development Agency, the Association of Canadian Universities for Northern Studies, and the Government of Nunavut.

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