ARTICLE IN PRESS

Deep-Sea Research II ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Diet compositions and trophic guild structure of the eastern Chukchi Sea demersal fish community

George A. Whitehouse [a,*], Troy W. Buckley [b], Seth L. Danielson [c]

[a] University of Washington, Joint Institute for the Study of the Atmosphere and Ocean, Box 354925, Seattle, WA 98195, USA
[b] NOAA, National Marine Fisheries Service, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, USA
[c] School of Fisheries and Ocean Science, Institute of Marine Science, University of Alaska Fairbanks, P.O. Box 757220, Fairbanks, AK 99775-7220, USA

ARTICLE INFO

Keywords:
Chukchi Sea
Arctic fish
Food habits
Trophic guild
Cluster analysis
Constrained analysis of principal coordinates

ABSTRACT

Fishes are an important link in Arctic marine food webs, connecting production of lower trophic levels to apex predators. We analyzed 1773 stomach samples from 39 fish species collected during a bottom trawl survey of the eastern Chukchi Sea in the summer of 2012. We used hierarchical cluster analysis of diet dissimilarities on 21 of the most well sampled species to identify four distinct trophic guilds: gammarid amphipod consumers, benthic invertebrate generalists, fish and shrimp consumers, and zooplankton consumers. The trophic guilds reflect dominant prey types in predator diets. We used constrained analysis of principal coordinates (CAP) to determine if variation within the composite guild diets could be explained by a suite of non-diet variables. All CAP models explained a significant proportion of the variance in the diet matrices, ranging from 7% to 25% of the total variation. Explanatory variables tested included latitude, longitude, predator length, depth, and water mass. These results indicate a trophic guild structure is present amongst the demersal fish community during summer in the eastern Chukchi Sea. Regular monitoring of the food habits of the demersal fish community will be required to improve our understanding of the spatial, temporal, and interannual variation in diet composition, and to improve our ability to identify and predict the impacts of climate change and commercial development on the structure and functioning of the Chukchi Sea ecosystem.

1. Introduction

Evidence of contemporary climate change in the Arctic has been accumulating over recent decades (Wassmann et al., 2011); the most visible change has been the reduction in sea ice cover, with the nine lowest annual sea ice minima over the satellite record (1979–present) occurring in the last 9 years, 2007–2015 (Stroeve et al., 2012, http://nsidc.org). Reductions in sea ice coverage already allow greater access to the Arctic for increased commercial development including energy extraction (Shell Gulf of Mexico Inc., 2015), shipping (Smith and Stephenson, 2013), tourism (Williams, 2014), and possibly even fisheries (Zeller et al., 2011). The effects of climate change and reduced sea ice coverage may also affect the structure and function of Arctic marine food webs and alter trophic relationships. On shallow Arctic continental shelves characterized by strong pelagic–benthic coupling, much of the primary production is not utilized in the water column and ultimately settles to the seafloor to support an abundant benthic food web (Grebmeier et al., 2006a). With reduced sea ice coverage becoming common in the Arctic (Jeffries et al., 2013; Wood et al., 2015), it is hypothesized that more of the primary production will occur later in the growing season during open water blooms in relatively warmer water, rather than earlier and in relation to sea ice, allowing for more of the primary production to be consumed by grazers in the pelagic realm, leaving less of the primary production to be exported to the benthos (Carroll and Carroll, 2003; Piepenburg, 2005; Bluhm and Gradinger, 2008; Wassmann and Reigstad, 2011; Grebmeier et al., 2015; Moore and Stabeno, 2015). As a result these marine ecosystems may switch from having a benthic-dominated food web to a pelagic-dominated food web with changed species compositions and altered trophic relationships (Grebmeier et al., 2006b; Wassmann et al., 2011; Doney et al., 2012; Grebmeier, 2012). In consideration of the increasing commercial interests and the potential effects of climate change on the Arctic ecosystem, there is a growing need to provide stakeholders, resource managers, and decision makers with sufficient information to support an ecosystem-based approach to managing Arctic resources (Clement et al., 2013).

Information on trophic relationships is an essential part to incorporating ecosystem considerations into the management of

* Corresponding author. Tel.: +1 206 526 4312.
E-mail address: gaw@uw.edu (G.A. Whitehouse).

http://dx.doi.org/10.1016/j.dsr2.2016.03.010
0967-0645/

living marine resources (Hilborn, 2011; Link and Browman, 2014; Travis et al., 2014). Fishes form an important link in Arctic marine food webs, connecting production on lower trophic levels to upper level predators (Welch et al., 1992; Whitehouse et al., 2014) including people. In the Alaskan Arctic, fishes prey on a variety of pelagic and benthic invertebrates and other fishes (Coyle et al., 1997; Cui et al., 2012), and are themselves an important prey for seasonally abundant and resident marine mammals (Lowry et al., 1980; Seaman et al., 1982; Dehn et al., 2007) and seabirds (Springer et al., 1984; Divoky et al., 2015). Additionally, fishes, seabirds, and marine mammals are important subsistence resources for Arctic residents (Hovelsrud et al., 2008; Zeller et al., 2011). Because of the central role fishes play in Arctic marine food webs, the increasing commercial activity in the Alaska Arctic, the effects of climate change, and the subsistence needs and cultural traditions of Arctic communities (Hovelsrud et al., 2011), it has become increasingly important to improve our knowledge of the trophic relationships among fishes and their prey to better understand the potential impacts these stressors may have on the Arctic marine ecosystem.

There have been only a limited number of studies on the food habits of demersal fishes in the Alaska Arctic and most of these studies have been qualitative in nature or focused on a limited number of species. Frost and Lowry (1983) described the stomach contents of nine demersal fish species collected across the northeastern Chukchi Sea and western Beaufort Sea. Craig (1984) provided general diet descriptions for six fish species found in the coastal waters of the Alaskan Beaufort Sea. Coyle et al. (1997) described the relative importance of different prey groups to four common demersal fish species collected in the northeastern Chukchi Sea. Recently, Cui et al. (2012) has provided quantitative diet descriptions for six of the most abundant demersal fishes in the northern Bering Sea. The diets of demersal fishes in the Alaska Arctic are primarily composed of benthic-oriented prey, such as polychaetes, amphipods, decapods, and mollusk siphons. Gray et al. (this issue) examined regional and size-based variation in the diet of two abundant sculpin (Cottidae) species found in the western Beaufort Sea and northeastern Chukchi Sea. The diet of the semi-pelagic species, Arctic cod (*Boreogadus saida*), consists of calanoid copepods, euphausiids, and hyperiid amphipods, but they are flexible predators and have been found to consume fish and benthic invertebrates (Lowry and Frost, 1981; Craig et al., 1982; Coyle et al., 1997; Gallaway and Norcross, 2011; Cui et al., 2012; Rand et al., 2013; Gray et al., 2015). As an alternative to analysis of stomach contents, Marsh et al. (this issue) examined the trophic role of several demersal fish species in the eastern Chukchi Sea with stable isotope analyses and found trophic level and diet to vary with predator size and by water mass.

Quantifying diet composition and the sources of diet variation among a large number of species individually can be impractical. A convenient method for summarizing food habits data for a large group of species is through the use of guilds; i.e., non-taxonomic groups of species which exploit the same resource(s) (Root, 1967). Trophic guilds are aggregations of species with similar diet compositions and may provide valuable guidance in the development of functional groups for use in ecosystem and network models (Yodzis and Winemiller, 1999). Trophic aggregation has the advantage of simplifying an otherwise complex web of interactions between numerous species to a much more manageable food web of discrete trophic guilds, without incurring marked change to salient food web properties (Sugihara et al., 1989, 1997; Gauzens et al., 2013). Trophic guild analysis has previously been applied to numerous marine ecosystems in a range of habitats to explore the trophic structure among fishes (e.g., Garrison and Link, 2000; Bulman et al., 2001; Luczkovich et al., 2002; Marancik and Hare, 2007; Reum and Essington, 2008; Abdurahiman et al., 2010; Kellnreitner et al., 2012; Varghese et al., 2014), including a deep-sea benthic fish community in Davis Strait in the Canadian Arctic (Chambers and Dick, 2005).

This study addresses a portion of the knowledge gap on fish food habits in the Alaska Arctic. The objectives of this study are to provide quantitative information on the trophic ecology of the demersal fish community in the eastern Chukchi Sea, to use this information to describe trophic guilds within the community, and to determine potentially important non-diet drivers of guild structure. We analyzed the stomach contents from 39 demersal fish species encountered in the eastern Chukchi Sea during the summer of 2012. We used multivariate statistical techniques to identify distinct trophic guilds and to describe differences and similarities in the trophic guild diet compositions at the regional scale. Additionally, we use constrained ordination to determine whether any of the variation present in the diets of the trophic guilds can be explained by a collection of non-diet variables including, predator size, location, depth, and water mass. This study provides a current quantitative baseline for trophic interactions among the demersal fish community in advance of hypothesized climate-related changes to the structure and function of the Arctic marine food web.

2. Methods

2.1. Study area

Our study area was the US territorial waters of the eastern Chukchi Sea between the Bering Strait in the south and Pt. Barrow in the north (Fig. 1). The Chukchi Sea is a marginal Arctic Sea with a broad and shallow continental shelf, with most depths less than 60 m (Jakobsson, 2002). The Chukchi shelf, being an inflow conduit from the Bering Sea, provides the only oceanic connection between the Pacific and Arctic Oceans (Coachman et al., 1975; Carmack and Wassmann, 2006). Waters of Pacific origin flow into the Chukchi Sea through the Bering Strait with an annual mean transport of 0.8 Sv ($1\ \text{Sv} = 10^6\ \text{m}^3\ \text{s}^{-1}$) (Woodgate et al., 2005) and on average maintain a net northward flow across the Chukchi Sea continental shelf (Weingartner et al., 2005), although synoptic, seasonal, and inter-annual variations impart considerable temporal variability to the through-flow, including reversals of more than a week in duration (Coachman and Aagaard, 1981; Woodgate et al., 2005, 2012; Danielson et al., 2014).

There are two principle water masses contained in the volume flux that passes through Bering Strait into the Chukchi Sea; Bering Sea Water (BSW) and Alaska Coastal Water (ACW) (Coachman et al., 1975). BSW has origins on the Bering Shelf and the Gulf of Anadyr, and is characterized by moderate or relatively high salinity and can be rich with nutrients (Sambrotto et al., 1984). Alaska Coastal Water (ACW) has lower salinity, fewer nutrients and is warmer than BSW in summer months (Coachman et al., 1975; Springer and McRoy, 1993; Weingartner, 1997; Danielson et al., 2011). These water masses are reflected in spatial variations in macronutrients, phytoplankton standing crop, productivity, zooplankton, and fish communities (Walsh et al., 1989; Lee et al., 2007; Norcross et al., 2010). For example, higher primary production and an abundance of large oceanic zooplankton (e.g., *Calanus* spp., *Neocalanus* spp., euphausiids) are associated with BSW, while lower primary production and an abundance of smaller zooplankton taxa (e.g., *Pseudocalanus* spp., *Oithona similis*, meroplankton) are associated with ACW (Springer et al., 1989; Springer and McRoy, 1993; Hopcroft et al., 2010; Matsuno et al., 2011; Eisner et al., 2013). Small demersal fish assemblages in the Chukchi Sea are structured by variation in bottom sediments and