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THE CHUKCHI SEA FOOD WEB

Prepared by Andy Whitehouse
for the Pew Environment Group

NOVEMBER 2012

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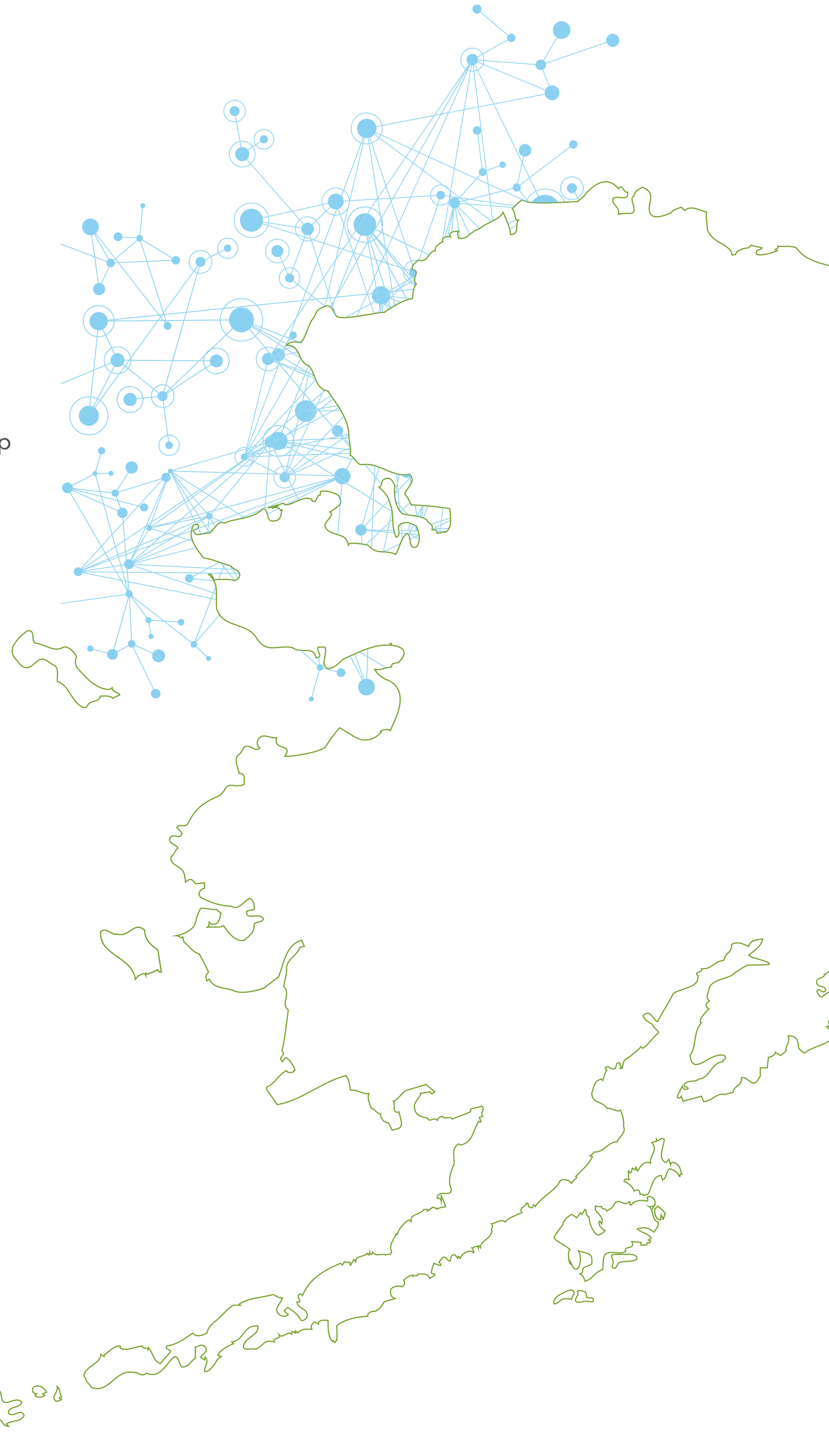

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U.S. Arctic Program
www.OceansNorth.us

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INTRODUCTION

The Chukchi is a seasonally ice-covered, peripheral sea of the western Arctic Ocean. It lies off the northwestern coast of Alaska and extends from the Bering Strait in the south to the edge of the continental shelf (200-meter isobath) in the north, and from east to west from Point Barrow, Alaska, to Wrangel Island off the coast of Russia (Figure 1). The Chukchi is a broad and shallow continental shelf sea, with most depths less than 60 meters and a total area of about 565,000 square kilometers (Jakobsson 2002). Ice covers the Chukchi Sea for about six to eight months a year, with ice cover advancing southward beginning in October and retreating northward starting in June. The Chukchi Sea is an inflow shelf to the Arctic (Carmack and Wassmann 2006). At its southern margin, a net northward flow brings cold, nutrient-enriched water of Pacific Ocean origin (Woodgate et al. 2005; Grebmeier et al. 2006). The combination of seasonal ice coverage, shallow depths, and the advection of cold Pacific waters helps to shape the structure and function of the Chukchi Sea food web.

FOOD WEB ORGANIZATION

The base of the Chukchi Sea food web is supported by primary production from two main sources: ice algae, which grow on the underside of and within the sea ice; and phytoplankton, found in the water column and near the ice edge. Primary production is substantially diminished in winter due to low light conditions, and annual primary production is affected by the extent and timing of the retreat of ice cover (Hunt et al. 2002; Wang et al. 2005). An ice algae bloom begins in late winter with the return of daylight and continues until the bloom is terminated with the onset of ice melt (Cota and Smith 1991). During this period, food may be limited, and the ice algal bloom provides early season forage for a community of invertebrates living in association with the underside of the sea ice (Bradstreet and Cross 1982). These ice-associated invertebrates are preyed on by fish, including Arctic cod, which themselves may become prey for seabirds, beluga whales, and seals, which may in turn be preyed on by polar bears (Bradstreet and Cross 1982; Legendre et al. 1992; Gradinger and Bluhm 2004). The seasonal melting and breakup of ice strengthens water column stratification and sets the stage for an ice-edge phytoplankton bloom that follows the retreating ice edge northward (Sakshaug 2004). This pulse of production in the cold water at the ice edge can account for as

> The base of the Chukchi food web is supported by two main sources: ice algae and phytoplankton.

much as 50 percent of the total annual primary production in some areas of Arctic continental shelves (Sakshaug 2004). As the summer progresses, primary production is focused in the vicinity of the northward retreating ice edge and in the southern Chukchi Sea, where open-water production is maintained by a stream of nutrient-rich Pacific-origin water from the Bering Sea (Springer and McRoy 1993; Wang et al. 2005). Maximum estimates of primary production in the southern Chukchi Sea are among the highest in the global ocean (Springer and McRoy 1993; Sakshaug 2004; Grebmeier et al. 2006).

Several ecological studies conducted over recent decades have documented an abundant and diverse community of benthic invertebrates in the Chukchi Sea (Sparks and Pereyra 1966; Feder and Jewett 1978; Feder et al. 1994; Grebmeier et al. 2006; Bluhm et al. 2009). This abundant seafloor community is in part supported by the delivery of phytoplankton sinking out of the water column. The grazing pressure exerted on phytoplankton by zooplankton is low in the cold waters of the Chukchi Sea (Coyle and Pinchuk 2002; Campbell et al. 2009; Sherr et al. 2009). The combination of high levels of primary production, low grazing by zooplankton, and the relatively shallow depths of the Chukchi continental shelf allow much of the primary production to eventually sink out of the water column and settle to the seafloor, where it becomes available to support the abundant and characteristic benthic community (Dunton et al. 2005; Grebmeier et al. 2006). Benthic invertebrates, such as clams, amphipods, marine worms, and snow crabs dominate the Chukchi Sea food web in terms of biomass. This benthic community forms an important prey resource for several benthic foraging specialists, including gray whales, Pacific walrus, bearded seals, and spectacled eiders.

> In terms of biomass, benthic invertebrates such as clams and snow crabs dominate.

Fishes have not been abundant in previous studies of the Chukchi Sea, and fish sizes are generally small. But when present, fishes have been dominated by gadids, including Arctic cod and saffron cod (Wolotira et al. 1977; Barber et al. 1997; Norcross et al. 2010). The low temperatures of the Chukchi Sea exclude many of the larger subarctic populations of groundfish that are common in the adjacent Bering Sea, such as walleye pollock and Pacific cod (Mueter and Litzow 2008; Stevenson and Lauth 2012). Though fish are not a substantial portion of the biomass, they are important prey for piscivorous predators including belugas, seals, and seabirds.

Humans also participate in the Chukchi Sea food web through the harvest of marine mammals and fishes (Hovelsrud et al. 2008; Fall et al. 2011). Marine mammals and fishes are important subsistence resources and traditionally have been used for food, boat covers, clothing, cultural crafts, tools, and other implements. The subsistence harvests of marine mammals make humans the top predators in the Chukchi Sea food web (Figure 2).

FOOD WEB MODELS

To gain an improved understanding of how marine food webs are structured and function, mass-balance food web models provide a convenient means to describe key structural and functional components of an ecosystem by synthesizing existing ecological knowledge and quantifying the various linkages between predator and prey groups. Additionally, food web models can be used to calculate a number of system metrics and indicators, such as total biomass and production, which can be useful in characterizing ecosystem status and trends.

Interest in the Chukchi Sea is growing because it possesses large petroleum reserves (Gautier et al. 2009). In addition, species of commercial importance (e.g., snow crabs) in the adjacent Bering Sea are also found in the Chukchi. A mass-balance model describing the food web of the eastern Chukchi Sea within U.S. territorial waters has recently been developed by Whitehouse (2011). Benthic invertebrates were the dominant structural component of this food web, accounting for 81 percent of the total biomass density in this ecosystem (Figures 2 and 3). In terms of ecosystem function, Whitehouse (2011) examined the relative strength of benthic and pelagic trophic pathways by evaluating the mass flow among compartments of the food web. Consistent with most marine ecosystems, these mass flows were dominated by groups at the bottom of the food web, such as phytoplankton and microbes. When these groups are excluded, benthic invertebrates account for more than 90 percent of the total mass flow, while pelagic groups, such as zooplankton, account for less than 5 percent of the total mass flow. This result highlights the importance of the benthic pathway in energy processing and emphasizes the extent of benthic dominance in the eastern Chukchi Sea.

Interest in the Chukchi Sea is growing due to its petroleum reserves.

For a broader perspective on the eastern Chukchi Sea food web, Whitehouse (2011) made comparisons using the same food web modeling framework with existing food web models of other subarctic ecosystems, the eastern Bering Sea and Gulf of Alaska (Aydin et al. 2007), and a more distant Arctic system, the Barents Sea (Blanchard et al. 2002). Then total biomass density (t km-2) was examined in each system, and the eastern Bering Sea had the highest biomass density, which was nearly equaled by the eastern Chukchi Sea (Figure 4). The nextlowest biomass density belonged to the Gulf of Alaska, followed by the Barents Sea. Finally, the sum of production (t km-2 yr-1) in each system was calculated, and again the eastern Bering Sea was the most productive, followed by the Gulf of Alaska, the eastern Chukchi Sea, and finally the Barents Sea (Figure 4).

The Chukchi Sea is not expected to be as resilient to fishing or an oil spill.

The higher levels of production in the subarctic systems are largely due to higher levels of primary production, but are also augmented by higher production from zooplankton, fish, and shrimp groups, while production in the eastern Chukchi Sea is slowed by the less productive and dominant benthos. In practical terms, this characteristic implies that the eastern Chukchi Sea is fundamentally different from the adjacent eastern Bering Sea—they have roughly comparable total biomass density, but the total production of the Chukchi Sea is 45 percent that of the eastern Bering Sea. Thus, the standing biomass in the Chukchi Sea is not expected to be as resilient as the eastern Bering Sea to fishing or other high-mortality events such as that which might be expected after a large-scale oil spill.

CONCLUSIONS AND FUTURE WORK

The Chukchi Sea is a shallow, seasonally ice-covered Arctic continental shelf system. The dynamics of primary production are influenced by the seasonal advance and retreat of sea ice and the advection of nutrient-rich water from the Bering Sea to the south. The high levels of primary production and shallow depths combine to facilitate the deposition of phytoplankton to the seafloor, where it becomes available to support the abundant and characteristic community of benthic invertebrates. This abundant seafloor food web forms an important prey base for benthic foraging marine mammals and seabirds, which in turn support human communities practicing a subsistence way of life.

The abundant seafloor food web supports human communities.

Food web modeling has highlighted the dominant role of the benthos in food web structure and function, and its effect on total system production. Compared with the eastern Bering Sea, the eastern Chukchi Sea has low productivity in relation to total biomass. This suggests that the eastern Chukchi Sea is vulnerable to extractive activities (fishing) and may be slow to recover from other disturbances, such as an oil spill reaching the benthos. These results have raised new questions about the resilience of the eastern Chukchi Sea food web and its vulnerability to human activities. Future modeling studies can help address these questions by assessing the sensitivity of the food web to individual stressors, such as fishing, vessel traffic, oil and gas exploration and development, and other anthropogenic activities, including climate change, by looking at the cumulative impacts of stressors over time and by examining the interactive effects of multiple stressors occurring simultaneously.

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FIGURES

Figure 1: Chukchi Sea

The Chukchi Sea, showing the U.S.-Russia maritime boundary and the U.S. exclusive economic zone (200-mile limit). The blue line indicates the 200-meter isobath.

Figure 2: Food Web Diagram

Food web diagram of the eastern Chukchi Sea. The boxes are arranged vertically by the approximate trophic level of each group. The size of the box is roughly proportional to the log biomass of each group. Additionally, the boxes are arranged left to right by their association with the benthic or pelagic portion of the food web, with benthic-oriented groups highlighted in red and pelagic groups in blue, with varying shades in between.

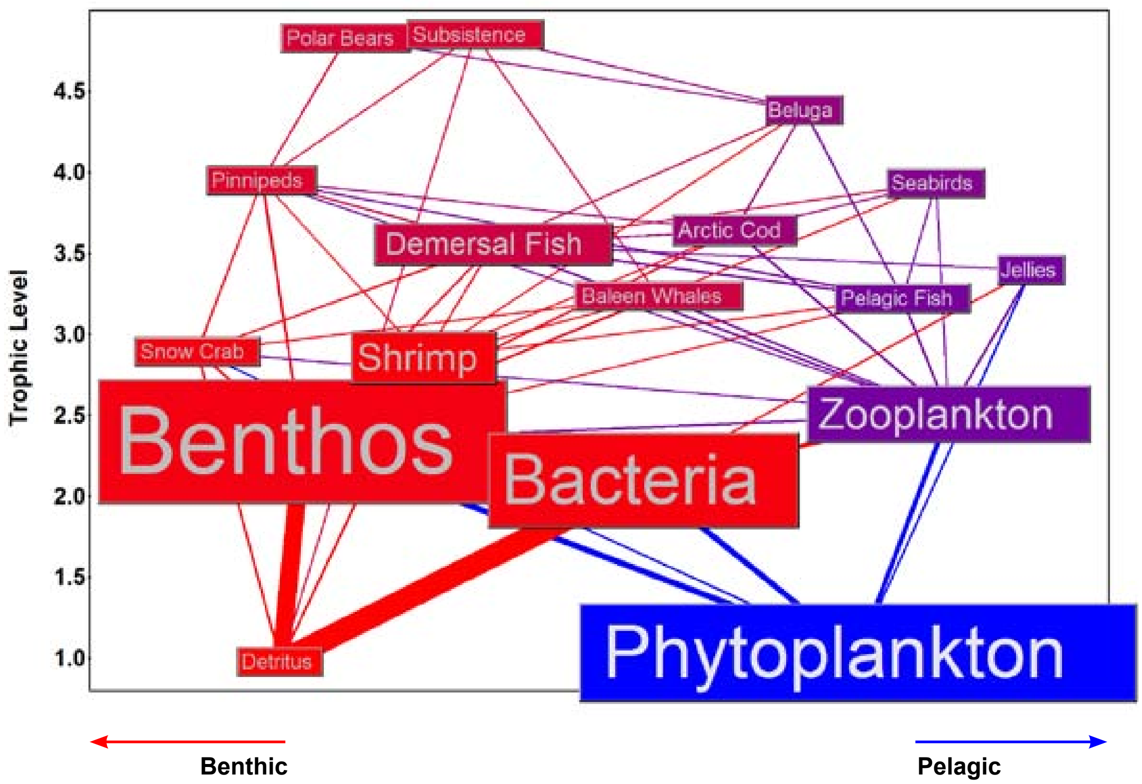


Figure 3: Chukchi Sea Biomass Density

The biomass density (t km-2) of all living functional groups in the eastern Chukchi Sea food web model (data from Whitehouse 2011).

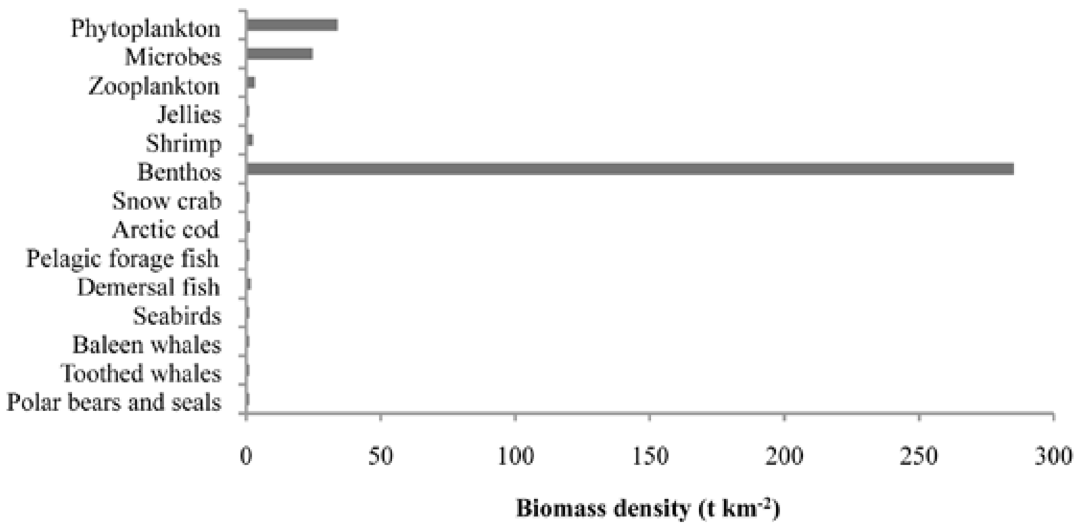
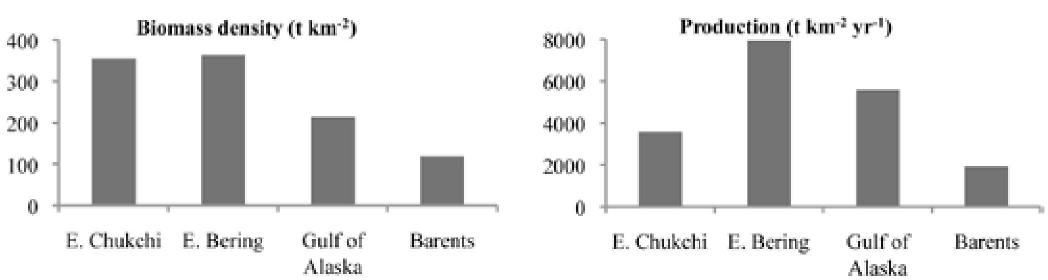


Figure 4: Total Biomass Density of Four Ecosystems

The total biomass density (t km-2) and sum of all production (t km-2 yr-1) for the four ecosystems compared by Whitehouse (2011) using the Ecopath with Ecosim software (Christensen et al. 2005).



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