Progress in Oceanography 136 (2015) 175–200

Contents lists available at ScienceDirect

Progress in Oceanography

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

Seasonal spatial patterns in seabird and marine mammal distribution in the eastern Chukchi and western Beaufort seas: Identifying biologically important pelagic areas

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ARTICLE INFO

Article history:
Available online 27 May 2015

ABSTRACT

The Chukchi and Beaufort seas are undergoing rapid climate change and increased human activity. Conservation efforts for upper trophic level predators such as seabirds and marine mammals require information on species' distributions and identification of important marine areas. Here we describe broad-scale distributions of seabirds and marine mammals. We examined spatial patterns of relative abundance of seabirds and marine mammals in the eastern Chukchi and western Beaufort seas during summer (15 June–31 August) and fall (1 September–20 November) from 2007 to 2012. We summarized 49,206 km of shipboard surveys for seabirds and 183,157 km of aerial surveys for marine mammals into a grid of 40-km × 40-km cells. We used Getis-Ord Gi^* hotspot analysis to test for cells with higher relative abundance than expected when compared to all cells within the study area. We identified cells representing single species and taxonomic group hotspots, cells representing hotspots for multiple species, and cells representing hotspots for both seabirds and marine mammals. The locations of hotspots varied among species but often were located near underwater canyons or over continental shelf features and slopes. Hotspots for seabirds, walrus, and gray whales occurred primarily in the Chukchi Sea. Hotspots for bowhead whales and other pinnipeds (i.e., seals) occurred near Barrow Canyon and along the Beaufort Sea shelf and slope. Hotspots for belugas occurred in both the Chukchi and Beaufort seas. There were three hotspots shared by both seabirds and marine mammals in summer: off Wainwright in the eastern Chukchi Sea, south of Hanna Shoal, and at the mouth of Barrow Canyon. In fall, the only identified shared hotspot occurred at the mouth of Barrow Canyon. Shared hotspots are characterized by strong fronts caused by upwelling and currents, and these areas can have high densities of euphausiids in summer and fall. Due to the high relative abundance of animals and diversity of taxa, these sites are clearly important areas of congregation for seabirds and marine mammals that should be prioritized in the development of management and conservation plans.

1. Introduction

The Pacific Arctic Ocean, encompassing the Chukchi Sea, western Beaufort Sea, and the Arctic Ocean adjoining those seas, is exhibiting changes in its physical and biological characteristics faster than subarctic or temperate regions (Grebmeier et al., 2010; Serreze and Francis, 2006; Wassmann et al., 2011). The consensus of global circulation models indicates that continued warming will lead to ice free summers in the Arctic within the next 30 years (e.g., Wang and Overland, 2009). The reduced extent and persistence of sea ice will facilitate shipping opportunities (Reeves et al., 2012), oil and gas exploration, and coastal development through arctic regions of northern Alaska, Canada, and Russia. As a result, seabirds and marine mammals will experience new influences from increased human presence associated with development (Humphries and Huettmann, 2014; Reeves et al., 2013), while facing changes to their natural world at a rapid and accelerating pace (Gradinger, 1995; Fischbach et al., 2007; Grebmeier et al., 2010; Jay et al., 2011; Wassmann et al., 2011). To address these changes, conservation efforts for large upper trophic level predators such as marine birds (hereafter, seabirds) and marine

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http://dx.doi.org/10.1016/j.pocean.2015.05.012
0079-6611/Published by Elsevier Ltd.

mammals will require basic information on the distribution and abundance of species, and the identification of important marine areas. Seabirds and marine mammals depend on the marine environment for their food and spend most (seabirds and pinnipeds) or all (cetaceans) of their lives at sea. Their distribution patterns can serve as indicators of changes in marine ecosystems over seasonal, interannual, or even longer time scales (Moore and Huntington, 2008; Piatt et al., 2007). Species-specific diets and foraging behaviors of these predators provide tractable links to physical and biological oceanography (Bluhm and Gradinger, 2008; González-Solís and Shaffer, 2009). Numerous studies have linked physical oceanography with the distribution and abundance of cetaceans (e.g., Stabeno et al., 2012; Stafford et al., 2013) and seabirds (e.g., Piatt and Springer, 2003; Gall et al., 2013b). Both seabirds and marine mammals rely on physical properties that concentrate prey or, for many seabird species, make prey more accessible near the surface (Bost et al., 2009; Moore et al., 2000; Russell et al., 1999). Therefore, we expected that species of both taxa would overlap spatially and perhaps temporally, especially when they share a common prey such as euphausiids (Euphausiidae spp.). Seabirds and marine mammals have been observed foraging symbiotically (Au and Pitman, 1986; Obst and Hunt, 1990; Anderson and Lovvorn, 2008). However, few studies have integrated data on the distribution and abundance of both seabirds and marine mammals into an analysis of mesoscale patterns over a large region (but see Santora and Veit, 2013), and none have done so in the eastern Chukchi and western Beaufort seas. Our study combines several sources of survey data to identify at-sea aggregations of seabirds and marine mammals in the eastern Chukchi and western Beaufort seas.

The distribution and abundance of seabirds and marine mammals is heavily influenced by the presence or absence of sea ice. Because ice coverage and oceanography change between summer and fall, and because animals have seasonal patterns in foraging and migratory behavior, we compared summer and fall distributions for selected species and foraging guilds.

Our objective was to identify areas of aggregation (hereafter, hotspots) of seabirds and marine mammals using densities (seabirds) and encounter rates (marine mammals) derived from vessel and aerial survey data, respectively. From the results of the hotspot analysis, we suggested what factors might influence the location of aggregations and how the factors might vary based on foraging strategy or prey species. We also identified "shared" hotspots used by both seabirds and marine mammals, to focus on areas that are associated with these taxonomically diverse upper trophic level predators in the eastern Chukchi and western Beaufort seas. These hotspots are ecologically important, as evident from the relatively high densities of animals; therefore, they should be considered important marine areas in a management context.

2. Methods

2.1. Study area

Our study area (Fig. 1) encompassed Pacific Arctic marine waters from Bering Strait (65.8°N), north across the eastern Chukchi Sea shelf and slope (73°N), west to Wrangel Island (180°W) and east across the Beaufort Sea shelf and slope to the Mackenzie River Delta (135°W), with the majority of survey effort occurring in US waters. Our study area is composed primarily of continental shelf habitat, including the wide, shallow (primarily 20–50 m deep) shelf of the eastern Chukchi Sea and the narrow (~20–100 km wide), deeper (0–200 m deep) shelf of the western Beaufort Sea, which parallels the coastlines of Alaska and Canada (Fig. 1). There are several important features that incise the shelves, influencing water flow and prey aggregation. Hope Basin (50–100 m deep) is a major submarine feature located north of Bering Strait. Barrow Canyon is a submarine feature that parallels shore in the northeastern Chukchi, extending from near Wainwright to the mouth that empties into the Arctic Ocean north of Point Barrow. The study area also includes Mackenzie Canyon, a large submarine feature extending northwest from the Mackenzie River Delta into the Arctic Ocean.

2.1.1. Oceanography

The eastern Chukchi Sea is strongly influenced by two water masses flowing north from the Bering Strait: (1) the cold (3–6 °C), high salinity oceanic Bering Sea Water; and (2) the warmer, low salinity Alaskan Coastal Water (Coachman et al., 1975; Woodgate et al., 2005). Bering Sea Water bifurcates in the Hope Basin (Fig. 1), flowing northward around two shallow areas, Herald Shoal and Hanna Shoal (defined by the 40-m isobath), which are separated by the Central Channel (Coachman et al., 1975; Day et al., 2013b). Hanna Shoal is almost entirely in our study area (Fig. 2). Although the main Hanna Shoal plateau is much smaller than that of Herald Shoal, a large area of shallows extend southwest of the Hanna Shoal plateau, between the Central Channel and Icy Cape (Fig. 1); we refer to this large shallow (<40 m deep) area as the "greater Hanna Shoal" area.

Currents flowing clockwise around Herald and Hanna shoals supply nutrients to support areas of high primary productivity of variable spatial extent in the northeastern Chukchi Sea (Hill et al., 2005). The currents themselves are formed by water funneling through Herald Canyon in the northwestern Chukchi Sea, the Central Channel in the central Chukchi Sea, and Barrow Canyon in the northeastern Chukchi Sea (Weingartner et al., 2005; Pickart and Stossmeister, 2008; Pickart et al., 2010). Most of the Alaskan Coastal Water continues northeast along bathymetric contours near the Alaska coast, forming a boundary current of varying strength, depending on wind strength (Weingartner et al., 2005). These northward-flowing water masses encounter cold, hyper-saline bottom water and fresh meltwater from arctic pack ice, which can strongly influence water column stratification (Weingartner et al., 2013) and the formation of thermohaline fronts that facilitate prey aggregation (Hunt et al., 1990; Piatt and Springer, 2003; Ainley et al., 2005). Other regional currents include the Siberian Coastal Current, which carries water from the northern coast of Siberia southeast along the Russian coast; subsurface Atlantic Water, which runs eastward along the Chukchi and Beaufort slopes; and the Beaufort Gyre, which runs westward in the Arctic Basin (Fig. 1).

2.1.2. Ice cover

Sea ice cover in the Arctic advances and retreats seasonally, which has implications for seabird and marine mammal distributions. During the winter, the offshore regions of the Chukchi and Beaufort seas are completely covered by ice except for occasional open water polynyas; maximal annual sea ice extent reaches southward into the Bering Sea in March. This ice cover generally retreats north of Bering Strait by June and continues to retreat northward in the Chukchi Sea while, concurrently, sea ice retreats westward from the Mackenzie River Delta as a result of warm freshwater runoff (Carmack and MacDonald, 2002; Nghiem et al., 2014; Wood et al., 2015). The Chukchi and Beaufort ice-free areas thus expand toward each other in July–August, with the last remaining ice cover often lingering over Hanna Shoal. During the years of this study, sea ice retreated entirely from the continental shelf by early September (Wood et al., 2015). Sea ice cover and the timing of its retreat in the spring influences primary productivity in the region (e.g., Gradinger, 1995; Arrigo et al., 2008; Arrigo and van Dijken, 2015) and, along with wind direction and strength,