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Gray whale distribution relative to benthic invertebrate biomass and abundance: Northeastern Chukchi Sea 2009–2012

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ABSTRACT

The shallow continental shelf waters of the Bering and Chukchi seas are the northernmost foraging grounds of North Pacific gray whales (*Eschrichtius robustus*). Benthic amphipods are considered the primary prey of gray whales in these waters, although no comprehensive quantitative analysis has been performed to support this assumption. Gray whale relative abundance, distribution, and behavior in the northeastern Chukchi Sea (69°–72°N, 155°–169°W) were documented during aerial surveys in June-October 2009–2012. Concurrently, vessel-based benthic infaunal sampling was conducted in the area in July-August 2009–10, September 2011, and August 2012. Gray whales were seen in the study area each month that surveys were conducted, with the majority of whales feeding. Statistical analyses confirm that the highest densities of feeding gray whales were associated with high benthic amphipod abundance, primarily within 70 km of shore from Point Barrow to Icy Cape, in water < 50 m deep. Conversely, gray whales were not seen in 40-km × 40-km cells containing benthic sampling stations with 85 m^{-2} or fewer amphipods. Continuing broad-scale aerial surveys in the Chukchi Sea and prey sampling near feeding gray whales will be an important means to monitor and document ongoing and predicted ecosystem changes.

1. Introduction

The gray whale (*Eschrichtius robustus*) is a large baleen whale that occurs in the North Pacific and Arctic oceans. The majority of gray whales belong to the eastern North Pacific (ENP) stock, which migrates seasonally along the western coast of North America between summer foraging grounds in the northern Bering and Chukchi seas and calving and wintering grounds in the lagoons of Baja California, Mexico. Records of gray whales in the northeastern Chukchi Sea date back to 1925 (Marquette and Braham, 1982) and can be used to document shifts in their distribution, relative abundance, and foraging, likely in response to changing ecological conditions and the density and distribution of prey. Comparing these changes over time, while taking into account gray whale population size, may provide insight into predator-prey relationships and spatio-temporal patterns in oceanic production (Moore, 2008).

The shallow continental shelves of the northern Bering and Chukchi seas are considered the primary northern foraging grounds of gray whales. High concentrations of gray whales have been documented in the northeastern Chukchi Sea (Clarke et al., 1989, 2013; Miller et al., 1986), along the Chukotka coast (Berzin, 1984; Heide-Jørgensen et al., 2012), in the south-central Chukchi Sea (Bakhmutov et al., 2009; Berzin, 1984; Bluhm et al., 2007; Clarke and Moore, 2002; Moore et al., 2003; Wilke and Fiscus, 1961), in the Chirikov Basin in the northern Bering Sea (Berzin, 1984; Clarke and Moore, 2002; Moore et al., 2000), and near St. Lawrence Island in the Bering Sea (Braham, 1984; Moore et al., 2003; Wilke and Fiscus, 1961). These areas are benthic-dominated ecosystems with high primary and secondary production resulting in high benthic prey densities (Coyle, 1981; Feder et al., 1994; Grebmeier et al., 1989, 2006; Highsmith and Coyle, 1990; Stoker, 1978). When gray whales feed on benthic organisms, they suction the organisms out of the sediment and strain the mud through their baleen, resulting in mud plumes that are visible at the surface of the water and detectable during aerial and shipboard

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surveys. Pelagic feeding by gray whales is much harder to detect during aerial and vessel surveys than benthic feeding; thus, pelagic prey may be underrepresented in diet data, particularly if samples are collected only from areas where gray whales are observed near visible mud plumes.

Range-wide, gray whales have been documented feeding on a variety of benthic epifaunal and infaunal invertebrates, including amphipods (Blanchard and Feder, 2014; Coyle, 1981; Darling et al., 1998; Dunham and Duffus, 2001, 2002; Feder et al., 1994; Heide-Jørgensen et al., 2012; Nerini, 1984; Oliver et al. 1984; Stoker, 1978; Yablokov and Bogoslovskaya, 1984), cumaceans (Coyle, 1981; Moore et al., 2007), mysids (Darling et al., 1998; Dunham and Duffus, 2001, 2002; Newell and Cowles, 2006), and ghost shrimp (Darling et al., 1998; Dunham and Duffus, 2001, 2002), and pelagic organisms, including euphausiids (Benson et al., 2002; Bluhm et al., 2007), porcelain crab larvae (Darling et al., 1998; Dunham and Duffus, 2001, 2002; Newell and Cowles, 2006), and herring eggs and larvae (Darling et al., 1998). Nerini (1984) lists 90 different genera of prey found in the stomachs of hunted or stranded gray whales.

In the Bering and Chukchi seas, few studies of gray whale foraging, particularly sampling near feeding gray whales or collection of stomach samples, have been conducted due to the regions' remote location and harsh weather conditions. Foraging gray whales in the Bering and Chukchi seas are distributed in areas of dense benthic amphipod communities, particularly ampeliscid amphipods, and it has been assumed gray whales associated with mud plumes in these areas are feeding on benthic prey (Blanchard and Feder, 2014; Coyle, 1981; Feder et al., 1994; Heide-Jørgensen et al., 2012; Nerini, 1984; Stoker, 1978). Stomach samples from >300 animals taken by Soviet whalers in the Bering Sea (Nerini, 1984; Yablokov and Bogoslovskaya, 1984) and sampling of gray whale mud plumes in the Bering Sea (Grebmeier and Harrison, 1992) have confirmed ampeliscid amphipods are the dominant prey of gray whales there. It is suspected that gray whales in the south-central Chukchi Sea may have a more varied diet (Bluhm et al., 2007). In the northeastern Chukchi Sea, qualitative analyses have been performed linking gray whales and their benthic amphipod prey from data collected via broad-scale aerial surveys for marine mammals (Clarke et al., 1989, 2011a, 2011b, 2011c, 2012, 2013; Moore and Clarke, 1992; Moore et al., 1986), side-scan sonar of gray whale feeding pits in the seafloor (Nelson et al., 1994), and benthic infaunal sampling (Feder et al., 1994; Grebmeier et al., 2006; Blanchard et al., 2013; Schonberg et al., 2014). Previous benthic analyses have been constrained either temporally (data that are decades old: Feder et al., 1994) or spatially (sampling that did not overlap well with feeding gray whale distribution: Blanchard et al., 2013; Schonberg et al., 2014). In this paper, we build on previous studies and perform a quantitative analysis of contemporary gray whale and benthic infaunal data that overlap temporally and spatially to statistically determine the relationship between gray whale relative abundance and distribution and amphipod abundance and biomass. To do this, we used broad-scale marine mammal aerial survey data (Clarke et al., 2011a, 2011b, 2011c, 2012, 2013) and infaunal sampling conducted offshore (predominantly >70 km from shore) (Schonberg et al., 2014, Schonberg et al., Hanna Shoal Ecosystem Study, http://arcticstudies.org/hannashoal/index.html) and near the coast (predominantly <70 km from shore) (Lovvorn et al., 2015; Dasher et al., 2015a, 2015b; Alaska Monitoring and Assessment Program) on the northeastern Chukchi Sea shelf, 2009–2012.

2. Methods

2.1. Aerial survey study area and survey design

Aerial line transect surveys were conducted by the Marine Mammal Laboratory (formerly the National Marine Mammal Laboratory) of the Alaska Fisheries Science Center and the Bureau of Ocean Energy Management (BOEM) in the northeastern Chukchi Sea as part of the Aerial Surveys of Arctic Marine Mammals (ASAMM) project. The gray whale analysis area addressed herein, extending 69°–72°N and 156°–169°W, comprised 48% (~110,000 km^2) of the entire ASAMM study area. This area was chosen because it is where gray whales were most consistently observed (Fig. 1). The analysis area included Barrow Canyon and continental shelf waters <200 m deep. Survey effort was designated as on effort (transect lines and circling from transect) or off effort (search effort and associated circling, which were not on transect lines). Survey protocols were identical during on- and off-effort periods. Circling was designated when the aircraft occasionally made brief (<10 min) diversions from transect or search effort to circle sightings to verify species, group size, or presence or absence of calves. Surveys were flown every day, weather permitting. When cloud ceilings were <305 m or Beaufort wind force was >5, survey flights were redirected to transect lines with better conditions. The survey was aborted when conditions consistently did not meet these minimum altitude or wind force requirements.

Surveys were flown in high-wing, twin-engine turbo aircraft (DeHavilland Twin Otter or Turbo Commander) at altitudes of 305–460 m and speeds of 210–220 km/h. Visual surveys were conducted by two primary observers, one on each side of the plane, looking out of bubble windows and reporting environmental conditions and all marine mammal sighting data to a data recorder. The majority of ASAMM observers returned from previous survey seasons; observers new to ASAMM were paired with experienced observers. All observers received the same training, and observer performance was evaluated with observer sighting histograms and by confirming species ID and sighting location during circling effort. The data recorder used a laptop computer, connected to a global positioning system (GPS), to log species, group size and composition (number of calves), plane position, altitude, declination angle to sighting (via clinometer), behavior, percent ice cover (estimated as a percentage of the visible sea surface), and visibility. Custom software used the declination angle, altitude, aircraft heading, and side of plane to automatically calculate each sighting's geographic position. When a declination angle was not available for a sighting, the aircraft's position at the time of sighting was the geographic position used for analysis. While circling, due to the pitch and roll of the aircraft, declination angles to sightings were not recorded. A continuously updated map display enabled the data recorder to track all sightings and assist in the identification of duplicate sightings within any one survey. Additional survey design methods can be found in Clarke et al. (2013).

2.2. Gray whale relative abundance, distribution, and behavior

Analyses were limited to 2009–2012 when aerial survey data were consistently collected from mid-June or early July through October to facilitate comparisons of gray whale sighting rates across months and years, and to complement the benthic data. The analysis area was divided into a 40-km × 40-km grid to compare sighting rates across the resulting 94 cells in the study area. The total area of any cell at least partially overlapping the analysis area was incorporated into the analysis (Fig. 1); all further reference to the analysis area includes the total area of all cells. Distance on effort (km) per cell was calculated using R version 3.3.0 (R Core Team, 2015) using packages sp (Pebesma and Bivand, 2005; Bivand et al., 2013), maptools (Bivand and Lewin-Koh, 2015), rgeos (Bivand and Rundel, 2015), and rgdal (Bivand et al., 2015). Analyses were limited to cells with ≥100 km of on-effort flightlines, pooled across all months and years, to minimize potential bias due to low survey effort unrepresentative of the entire cell.

All on-effort gray whale sightings were included in the analysis regardless of the Beaufort wind force or visibility conditions at the sighting time. Beaufort wind force was not found to affect gray whale sightability on ASAMM surveys during conditions of Beaufort wind force 0–5 (Ferguson and Clarke, 2013). To compute gray whale relative