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Seasonal presence and potential influence of humpback whales on wintering Pacific herring populations in the Gulf of Alaska

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ABSTRACT

This study addressed the lack of recovery of Pacific herring (*Clupea pallasii*) in Prince William Sound, Alaska, in relation to humpback whale (*Megaptera novaeangliae*) predation. As humpback whales rebound from commercial whaling, their ability to influence their prey through top-down forcing increases. We compared the potential influence of foraging humpback whales on three herring populations in the coastal Gulf of Alaska: Prince William Sound, Lynn Canal, and Sitka Sound (133–147°W; 57–61°N) from 2007 to 2009. Information on whale distribution, abundance, diet and the availability of herring as potential prey were used to correlate populations of overwintering herring and humpback whales. In Prince William Sound, the presence of whales coincided with the peak of herring abundance, allowing whales to maximize the consumption of overwintering herring prior to their southern migration. In Lynn Canal and Sitka Sound peak attendance of whales occurred earlier, in the fall, before the herring had completely moved into the areas, hence, there was less opportunity for predation to influence herring populations. North Pacific humpback whales in the Gulf of Alaska may be experiencing nutritional stress from reaching or exceeding carrying capacity, or oceanic conditions may have changed sufficiently to alter the prey base. Intraspecific competition for food may make it harder for humpback whales to meet their annual energetic needs. To meet their energetic demands whales may need to lengthen their time feeding in the northern latitudes or by skipping the annual migration altogether. If humpback whales extended their time feeding in Alaskan waters during the winter months, the result would likely be an increase in herring predation.

1. Introduction

The number of North Pacific humpback whales (*Megaptera novaeangliae*) has increased in the past four decades to over 21,800 whales in 2006 (Barlow et al., 2011) with an annual population growth rate of 4–7% (Calambokidis et al., 2008). Most humpback whales within the Alaskan population are seasonal migrants, moving from high latitude feeding areas to low latitudes for breeding. While on the feeding areas, humpbacks form discrete maternally-directed and genetically-distinct feeding aggregations (Baker et al., 1985, 1986). This means that calves will return as juveniles and adults to the same feeding area where their mothers introduced them. In the Gulf of Alaska (GOA), two feeding aggregations of humpback whales have been documented: Southeast Alaska/Northern British Columbia (in this paper shortened to Southeast Alaska) and the Northern GOA.

The prey base for humpback whales in the North Pacific is diverse, ranging from large zooplankton to schooling fish and varies by location, season and possibly individual preference (Witteveen et al., 2011). Well-documented North Pacific humpback whale prey include: Pacific herring (Boswell et al., 2016; Krieger and Wing, 1986), multiple species of krill *Thysanoessa* spp., *Euphausia pacifica* (Burrows et al., 2016; Krieger and Wing, 1986; Nemoto, 1957; Szabo, 2015), juvenile salmon *Oncorhynchus* spp. (Chenoweth et al., 2017), capelin *Mallotus villosus*, Pacific sandlance *Ammodytes hexapterus*, juvenile walleye pollock *Theragra chalcogramma*, (Krieger and Wing, 1986; Witteveen et al., 2008; Rice et al., 2011), eulachon *Thaleichthys pacificus*, Pacific sandfish *Trichodon trichodon*, surf smelt *Hypomesus pretious* (Witteveen et al., 2008) and myctophids *Stenobrachius leucopsarus* (Neilson et al., 2015).

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While the increase in humpback whale numbers in the North Pacific is a success story (Barlow et al., 2011), it may be having an effect on its prey populations. Furthermore, as humpback whales continue to recover globally, perhaps to above pre-whaling levels (Ivashchenko et al., 2016), their ecological impact increases (Baker and Clapham, 2004; Ripple et al., 2014). The ability for these large predators to influence their prey through top-down forcing (Baum and Worm, 2009; Bowen, 1997) might become a significant concern for management agencies, especially considering commercial fisheries interests target the same species. In the GOA, some Pacific herring stocks have remained depressed long after commercial fishing stopped (Rice et al., 2011). The hypothesis that predation by humpbacks might be impeding a rebound of herring makes sense for areas where humpback whale populations have significantly rebounded. Thus, linkages between humpback whales and fisheries in the GOA have frequently focused on direct competition for herring (Boswell et al., 2016; Heintz et al., 2010; Liddle, 2015; Teerlink, 2011).

The general behavior of herring is to gather in fall, after the water column becomes mixed and then overwinter deep in the bays and channels often near their spawning areas (Brown et al., 2002; Boswell et al., 2016; Hay, 1985). The maturing adults gradually enter bays and deep channels, forming 1arge, deep aggregations that remain as loosely aggregated schools for several weeks to months before spawning (Barnhart, 1988). Consequently, herring become vulnerable to whale predation when both overlap temporally and spatially. In Alaskan waters, the overlap begins during the fall, when herring begin to move to deeper water for the purposes of winter foraging. Some humpbacks follow the herring and others begin their migration to the southern breeding areas. By winter, all herring have moved into deeper water for overwintering (Boswell et al., 2016; Sigler and Csepp, 2007; Sigler et al., 2017) and a few whales may continue to forage. In early spring, herring become active, moving to shallower depths, in preparation for spawning, and whales begin returning from breeding areas.

In our study, three areas (Fig. 1) have in common humpback whales that forage upon shoals of Pacific herring during the fall and winter, however, the extent of prior knowledge about whales and herring in the fall and winter varied across each area. In Prince William Sound (PWS), within the northern GOA, there was little information available on the overlap of humpback whales and herring during the fall and winter (Day and Prichard, 2004; Hall, 1979). Interviews with fishermen and others with local knowledge documented herring presence in fall and winter (Brown et al., 2002). During 1994–1996, herring surveys reported humpback whales and herring were together during the fall and winter (from Matkin and Hobbs as reported in Okey and Pauly, 1999). However, the number of whales, geographic distribution, and seasonal trends were unknown in PWS, which provided impetus for this present study.

The relationships between humpback whales and herring were better understood in Southeast Alaska, where humpbacks were observed foraging on densely-aggregated herring during several winters (Straley et al., 1994). In Sitka Sound (SS), year-round studies on humpback whales to assess the relationship between humpbacks and potential prey (herein for our purposes "prey") have been conducted since the early 1980s (Liddle, 2015; Straley, 1990; Straley et al., 1994). Those studies documented the number of humpbacks foraging on both herring and euphausiids (termed krill for this study) during the fall and winter (Straley, 1990; Straley et al., 1994), but the proportion of herring and krill in the diet remained unknown. In Lynn Canal (LC), humpback presence has been documented year-round from shore-based observations (T. Quinn, University of Alaska Fairbanks, unpublished data), but the numbers of whales using this entire area during the fall and winter, and the target prey were unknown.

In this paper, we report on humpback whales in the three areas: PWS, LC, and SS. Specifically, we identified and counted humpback whales in each area during the fall and winter, observed and characterized their feeding behavior, and applied isotopic analyses to corroborate diet (Witteveen et al., 2009). We documented temporal and spatial patterns of humpback whales and herring to assess how the predator-prey relationship varied demographically.

2. Materials and methods

2.1. Study areas

Located along the perimeter of the GOA, Prince William Sound, Lynn Cana, and Sitka Sound are distinct geographically (Fig. 1) and oceanographically. PWS, the most northern study site (60.5°N 147.0°W), has relatively protected waters characterized by a complex coastline of glacial fjords and islands, with an area of approximately 4500 km^2. The other study areas are located in Southeast Alaska, which is a mosaic of islands adjacent to the mainland of Canada, deeply incised with glacial fjords, many passageways, and bays. SS is situated mid-way along the outer coast of Baranof Island (57.0°N 135.5°W), encompassing approximately 450 km^2 and is directly exposed to the elements of the GOA. LC (58.4°N 134.8°W), is a long north-south oriented deep trench located to the north and east of SS in the inside waters of Southeast Alaska. The LC study area encompasses approximately 500 km^2 and includes the waters of southern LC and the adjacent waters of northern Stephens Passage.

Adult herring typically congregate near the spawning grounds several weeks to months before spawning (Barnhart, 1988; Boswell et al., 2016; Sigler and Csepp, 2007). Spawning occurs in SS in mid-March to early April (Thynes et al., 2016), in LC in April (Thynes et al., 2016) and PWS in late March to May (Norcross et al., 2001).

In our study areas, herring populations are now and historically have been managed as an important target of commercial fishing (Carlson, 1980). Sizes of each herring population were available from the spring spawning biomass estimates conducted by the state of Alaska (Gordon et al., 2009) and winter biomass estimates from independent researchers (Boswell et al., 2016). For example, in 2009, in PWS, herring spring spawning biomass was estimated at 19,500 t (Steve Moffit, Alaska Department of Fish and Game, pers. comm.). The two study areas in Southeast Alaska, SS and LC, had spawning biomass estimates of 68,511 and 453 t, respectively (Gordon et al., 2009). However, in LC in February 2009 the overwintering herring biomass estimate was 32,295 ($\pm$ 3020 SE) tonnes (Boswell et al., 2016), a substantial increase from the spawning biomass, indicating this area supported many spawning aggregations of herring that dispersed prior to spawning in LC. In SS, the overwintering biomass in February 2009 was estimated to be 82,970 ($\pm$ 12,960 SE) tonnes (Rice et al., 2007). Only SS has sustained a herring fishery in recent years, including the years of our study. Prince William Sound and LC had not recovered from low biomass levels (Rice et al., 2007) and did not meet minimum biomass levels to sustain a commercial fishery.

2.2. Whale survey effort

In PWS, eight surveys were conducted aboard the 18-m vessel M/V *Auklet*, starting and ending in Cordova, circumnavigating PWS for a total survey distance total of 4587 km (Table 1a). Each survey lasted five to six days covering roughly the same route with at least two trained observers aboard. One observer, at a minimum, was present in the wheelhouse along with skipper looking for signs of whale activity during all daylight hours. Total distance traveled each day was recorded on a handheld Garmin72 GPS and tallied for the entire survey. In Sitka Sound and LC, 46 and 25 surveys, respectively, were conducted during day trips from small boats (< 10 m) with two observers aboard. A GPS recorded the track line for a total survey distance of 2282 km for LC and 1110 km for SS. When daylight and weather conditions limited surveys, effort was focused on areas with higher concentrations of whales (Table 1b and c). Although as effort increases, the number of whales identified reaches an asymptote (the actual number of whales in