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Seasonal abundance and distribution of pelagic and demersal fishes in southeastern Alaska

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ABSTRACT

We quantified seasonal and interannual variability of pelagic and demersal fishes available to marine predators in southeastern Alaska focusing on prey of the Steller sea lion (*Eumetopias jubatus*). Estimates of abundance were determined from echo integration mid-water trawl and demersal longline surveys. The dominant species were walleye pollock (*Theragra chalcogramma*) (average biomass 9057 t), Pacific hake (*Merluccius productus*) (1715 t), Pacific herring (*Clupea pallasii*) (1176 t), Pacific halibut (*Hippoglossus stenolepis*) (average catch rate 524 kg per 1000 hooks), Pacific cod (*Gadus macrocephalus*) (177 kg per 1000 hooks), sablefish (*Anoplopoma fimbria*) (120 kg per 1000 hooks), and sandpaper skate (*Bathyraja interrupta*) (26 kg per 1000 hooks). Of these species, seasonal differences in species abundance were detected for walleye pollock ($p = 0.03$), Pacific cod ($p = 0.001$) and sablefish ($p < 0.001$) with walleye pollock the most abundant and widespread species year-round. Herring, hake, and juvenile (120–350 mm) and adult (>350 mm) pollock are pelagic species. Adult and juvenile pollock and hake were found in open water, while herring, young-of-the-year (<120 mm) and the smallest juvenile pollock were found in bays. Herring of all ages concentrate in dense schools. Pollock and hake form scattered layers throughout open water with juvenile pollock shallower than adult pollock and adult pollock shallower than hake. Halibut, sablefish, skates, Pacific cod and arrowtooth flounder are demersal species; sablefish were deeper than the other demersal species. These seasonal and annual changes in prey availability affected prey selection of sea lions which shifted their diet in response.

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1. Introduction

Organisms in high latitude oceans with short productive seasons rely on seasonal pulses in energy availability (Odum et al., 1995). Annual migrations and aggregations of prey species, such as young-of-the-year (age-0) walleye pollock (*Theragra chalcogramma*) (Carlson, 1995; Johnson et al., 2005), winter aggregations of Pacific herring (*Clupea pallasii*) (Carlson, 1980; Gende and Sigler, 2006; Sigler and Csepp, 2007), spawning Pacific herring (Carlson, 1980), eulachon (*Thaleichthys pacificus*) (Marston et al., 2000; Sigler et al., 2004) and Pacific salmon (*Oncorhynchus* spp.) (Willson and Halupka, 1995) provide such energy pulses. These predictable energy resources occur at critical periods relative to winter conditions of prey scarcity, and are important for many marine predators including mammals, sea birds, and fish.

The goal of this study was to improve our understanding of seasonal predator–prey relationships for major forage species in the North Pacific Ocean. Predator–prey relationships involving forage species are poorly described in the North Pacific Ocean, especially in seasons other than summer. Few studies have quantified seasonality of prey species for marine predators despite evidence that foraging pinnipeds (Sinclair and Zeppelin, 2002; Womble et al., 2005; Willson and Womble, 2006; Womble and Sigler, 2006) and odontocetes (Similä et al., 1996) take advantage of seasonally concentrated prey. Here we quantified the seasonal and interannual variation in abundance of pelagic and demersal prey species available to Steller sea lions (*Eumetopias jubatus*) over 3 years in Stephens Passage and Frederick Sound, southeastern Alaska. Our objectives were to measure the abundance of potential prey species available to marine predators and to determine whether these abundances changed between seasons and years.

2. Materials and methods

2.1. Study area

Twelve echo integration-trawl surveys were conducted over 2700 km^2 in Stephens Passage, Frederick Sound, and associated bays in southeastern Alaska approximately every 3 months between June 2001 and May 2004 (Fig. 1). Three longline surveys

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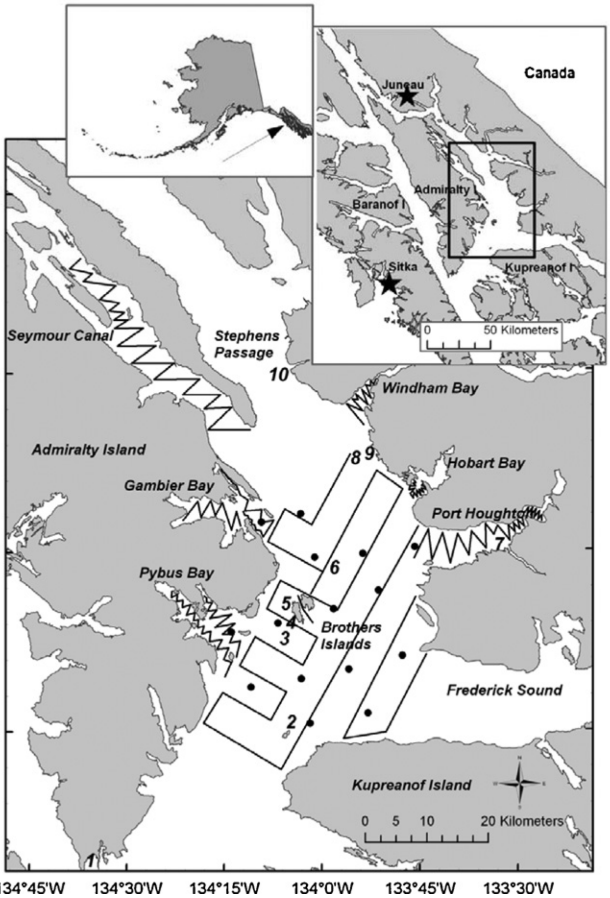

Fig. 1. Survey area with acoustic transects (—), longline sets (●), and Steller sea lion haulouts: 1, Yasha I; 2, Turnabout I; 3, Round Rock; 4, Southwest Brothers I; 5, West Brother I; 6, Sail I; 7, Walter I; 8, Sunset I; 9, Sunset Point; 10, Point League.

were conducted in the same area from September 2003 to May 2004. The study area was chosen because of the high density of Steller sea lions, with seasonal abundances ranging between 920 and 2860 animals on 10 haulouts located within this area (Womble et al., 2009). These haulouts account for approximately 5–14% of the Steller sea lion population in southeastern Alaska, depending on season (Pitcher et al., 2007; Womble et al., 2009). Sea lions in the study region are part of the eastern population, which is growing (Pitcher et al., 2005), unlike the declining western population (Loughlin et al., 1992; Trites and Larkin, 1996; Sease et al., 2001). Additionally, the inside waters of southeastern Alaska were chosen because they are relatively sheltered, facilitating year-round surveys using small, cost-effective vessels. The study area encompassed an open sound (Frederick Sound and Stephens Passage) and adjacent bays (e.g. Port Houghton) with a mean bottom depth of 210 m and depths as great as 630 m. For our analysis, we stratified the data into open water (one stratum for the open sound) and individual bays (one stratum for each bay) because abundance, fish sizes and species composition often differed among these geographic locations.

2.2. Echo integration-trawl surveys

To estimate pelagic fish species biomass, we used a portable Simrad 38 kHz split beam scientific echo sounder with a 12° beam angle transducer towed beside a vessel at 11 km h^{-1}, or a 7° beam angle transducer attached to the hull of a vessel traveling at 15 km h^{-1}. Acoustic data were georeferenced using a Garmin global positioning system with an accuracy of 10 m and collected using Simrad software. In the open water of Stephens Passage and Frederick Sound, the cruise track was a standard box (rectangular grid) configuration (Fig. 1). In bays, the cruise track followed a zigzag pattern due to limited vessel maneuverability in these generally narrow fjords. Surveys began in the morning 30 min after sunrise and concluded 30 min before sunset. In 2001 and 2002, additional surveys were conducted after sunset to document possible diurnal changes in fish abundance. Pacific herring undergo diurnal migrations (Huse and Korneliussen, 2000) along with many other prey species found in the study area, including crustaceans (Ouellet and Lefaivre, 1994; Shumway et al., 1985), juvenile gadids (Krutzikowsky and Emmett, 2004; Miyashita et al., 2004; Schabetsberger et al., 2000), and myctophids (Watanabe et al., 1999). Another purpose of night surveys was to acquire single targets for *in situ* target strengths (TSs). However, fish density never decreased enough to resolve single targets, so all acoustic sampling after December 2002 was limited to daylight hours.

A general-purpose transceiver produced and collected the sound from the transducer, recording and integrating the returning echoes from fish passing beneath the vessel. The instrument was calibrated seasonally using Simrad protocol and post-processing software. Calibration values and raw acoustic data were integrated using echo-integration and manipulation software (SonarData Echoview) to estimate biomass using a nautical area scattering coefficient (NASC in m^2 nmi^{-2}). NASC is the acoustic scattering output and is proportional to fish density (MacLennan and Simmonds, 1992). The acoustic data were classified by species, and integrated for 0.9 km length intervals (transect) and 10 m depth intervals. To convert NASC to fish density in numbers per square meter, estimates of acoustic reflectivity for single fish are needed for each species. Target strength (TS in dB re 1 m^{-1}) refers to the acoustic reflectivity of a single fish and depends on length (L in cm), where $TS = 20 \log_{10} L + b$ (MacLennan and Simmonds, 1992). For walleye pollock we used $b = -66$ dB, and for Pacific hake we used $b = -68$ dB (Traynor, 1996). For herring we used the value for Atlantic herring (*Clupea harengus*), $b = -65.4$ dB (Ona, 2003), which is intermediate to values reported for Pacific herring in two recent studies: −66 dB (Thomas et al., 2002), and −65.1 dB (Gauthier and Horne, 2004). In addition, NASC and TS values for Pacific herring were adjusted for depth compression of the air bladder (Ona, 2003) and acoustic shadowing (Zhao and Ona, 2003) by methods described in Sigler and Csepp (2007). Gonad size of Pacific herring also may influence target strength, but Ona (2003) recommended ignoring this effect. Target strength is transformed to backscattering cross-section (σ_{bs} in m^2), where $\sigma_{bs} = 4\pi 10^{TS/10}$. Fish density in numbers per square meter was computed by dividing NASC by σ_{bs} and then converted to kg km^{-2} by multiplying by average weight. Species identification, length and weight data are essential components for acoustic surveys and necessary for converting acoustic data into biomass. Species composition, length, and weight data were collected quarterly with midwater trawls deployed from the 18 m F/V *Solstice* (September 2001 to March 2002), the 31 m F/V *Viking Storm* (May 2002 to September 2003), and the 37 m R/V *Medeia* (January 2004 to March 2004). Two midwater trawls were used: a 164 Nordic rope trawl with an opening 7.7 m high by 17.5 m wide, a 19 mm mesh codend liner and 1.5 m^2 alloy doors, and a mesh wing 25/21/64 trawl with an opening 11 m high by 29 m wide, a 32 mm mesh codend liner and 3.0 m^2 alloy doors. The larger midwater trawl was used with the larger vessels, which we used 2/3 of the time, to match their larger trawl-handling equipment. The codend mesh sizes were similar for both nets so that size selection of all but the smallest organisms should be similar for both nets. The tow duration was adjusted as necessary to ensure adequate catches for species identification and length frequency samples.

Adult Pacific hake and adult walleye pollock were usually found in distinct layers but occasionally intermingled with each other