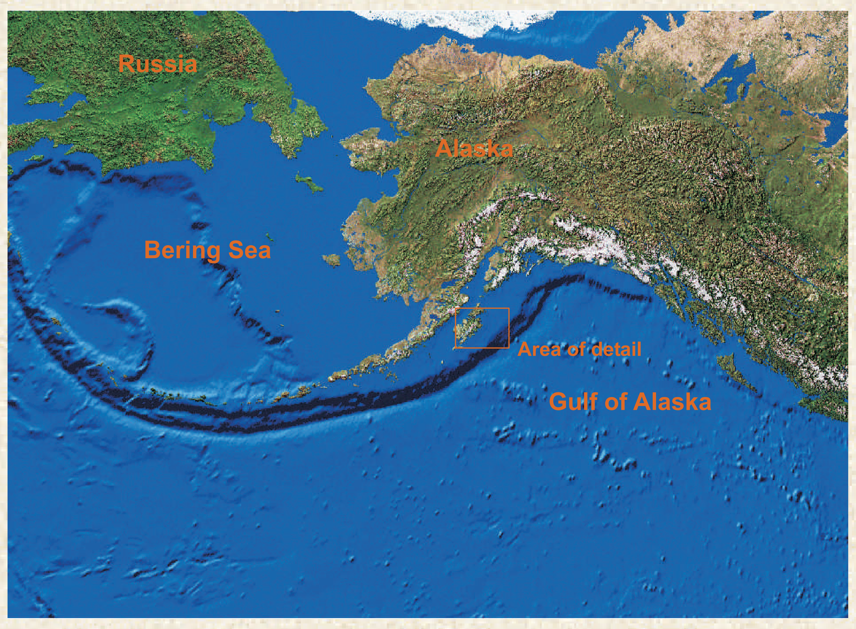

A model exploring changes in the small-scale distribution of fish due to environmental variability and the presence of a fishery, and consequent effects on predator foraging efficiency

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Introduction

Acoustic survey data provide details about fish distribution that are rarely found by other methods. The data allow mapping of fish geographically as well as vertically in the water column, so that the distribution can be viewed in a three-dimensional space. Acoustics are particularly good for assessing pelagic species as well as those that exhibit diel migrations. This study focuses on 2 fish species; walleye pollock (Theragra chalcogramma), a pelagic species and capelin (Mallotus villosus), a small forage fish that exhibits diel migration. An acoustic survey was conducted to investigate whether commercial fishing activity has an effect on the distribution and abundance of walleye pollock (hereafter called pollock). Details about the survey can be found in Wilson et al. (this symposium). During the survey time period, a storm event occurred that resulted in cooler surface waters due to wind mixing. The potential effects of changes in surface water temperatures on fish distribution have been investigated by Hollowed et al. (in review). Here we report on how the fishery and storm event affected the vertical distribution of fish and how this might affect the foraging efficiency of a top predator, the Steller sea lion (Eumetopias jubatus).

Methods

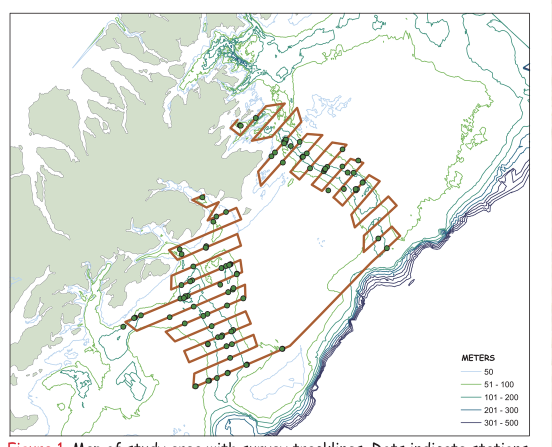

Figure 1. Map of study area with survey tracklines. Dots indicate stations where oceanographic measurements were taken.

The data used here were collected on an echo-integration trawl survey that was conducted between 9-31 August 2001, off the east coast of Kodiak Island, in the Gulf of Alaska (Fig. 1). The study area consisted of two adjacent troughs, Chiniak and Barnabas, that were used as treatment and control sites; fishing was prohibited in Chiniak but allowed in Barnabas. The fishery occurred from 22 August to 10 September 2001, and the majority of the effort was confined to the northern half of Barnabas.

The survey consisted of a series of uniformly-spaced (3 nmi) parallel transects (Fig. 1). One complete run through the transects took 2 days in Chiniak and 3 days in Barnabas trough. Two complete runs through the transects were conducted in each trough before the fishery and storm event. One complete run was conducted in each trough after the events. Reciprocal transects were run during the non-daylight hours to determine whether the survey could be conducted around the clock.

Oceanographic data were collected using a combination of moorings, satellite-tracked drifters, CTDs, and trawl-mounted temperature probes. Sea surface temperature was continuously measured using a flow-through ship intake sampling system. 5 moorings and 7 drifters were deployed in our study site and 46 CTD profiles were taken (Fig. 1).

Acoustic data were collected with a calibrated Simrad EK 500 echosounder operating at 38 kHz. The data were binned into cells with a horizontal resolution of 0.1 nmi (185 m) and a vertical resolution of 5 m. After initial analysis at this resolution, the data were collapsed into 50 m vertical bins for use in a model that explored sea lion foraging efficiency. The vertical distribution is represented as distance from the surface as this is the parameter most likely to affect the foraging efficiency of a diving sea lion.

Steller sea lion data were collected by the National Marine Mammal Laboratory. Dive depth (Table 1) and duration were captured using satellite-linked time depth recorders. Most of the data collected thus far are from juvenile sea lions that most likely have a different foraging pattern than adults. For the sea lion foraging efficiency model, the total daily energetic requirements of a sea lion were calculated using values and equations from the literature (Winship et al. 2002). The model was used to explore how a sea lion might proportion its dives per day into different depths, each with a different probability of prey occurrence, in order to reach its daily 'quota'. Foraging efficiency was calculated for the different prey distributions in the study area.

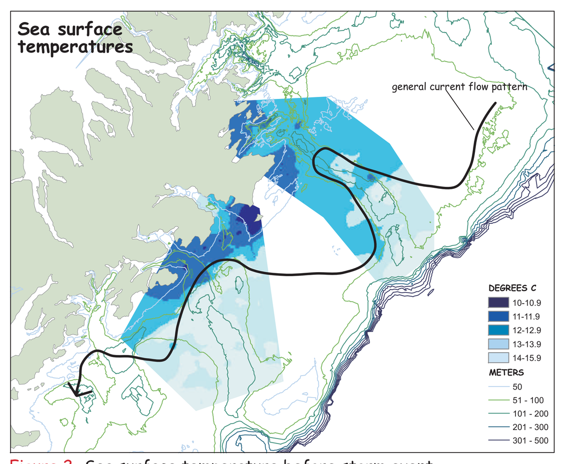

Figure 2. Sea surface temperature before storm event

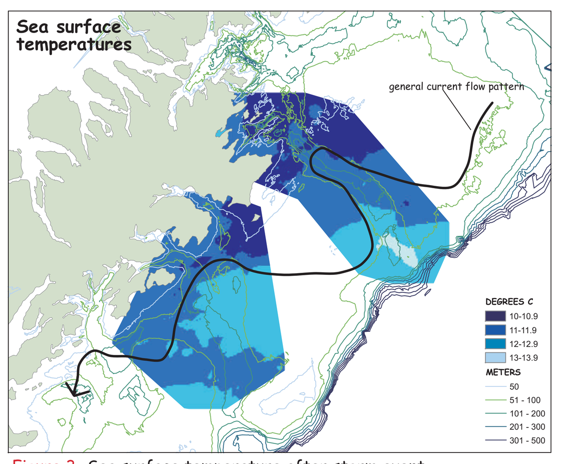

Figure 3. Sea surface temperature after storm event

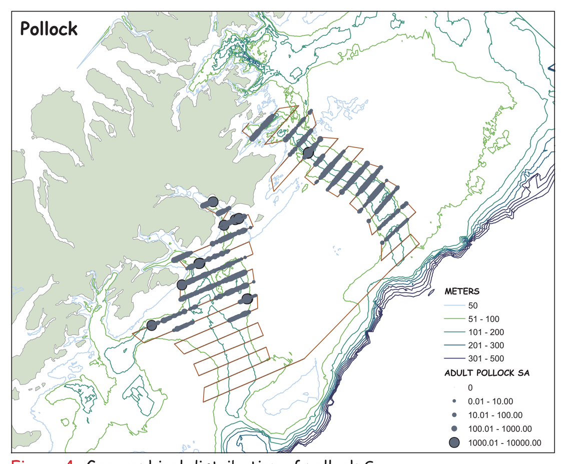

Figure 4. Geographical distribution of pollock S_A

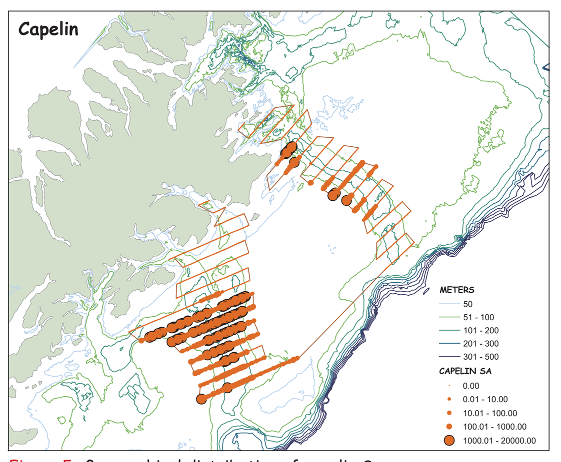

Figure 5. Geographical distribution of capelin S_A

Vertical distribution of pollock in Chiniak and Barnabas troughs

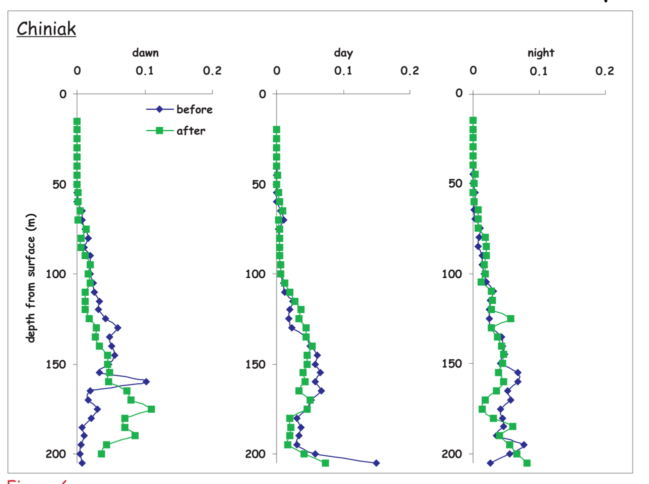

Figure 6a.

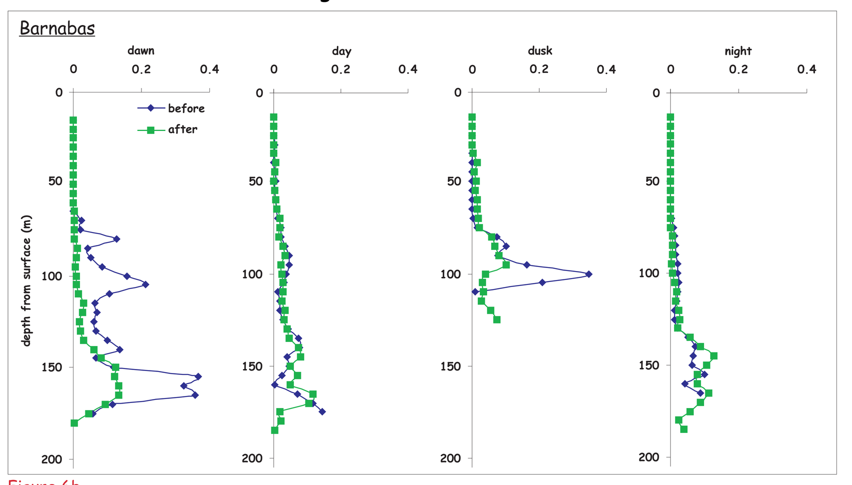

Figure 6b.

Vertical distribution of capelin in Chiniak and Barnabas troughs

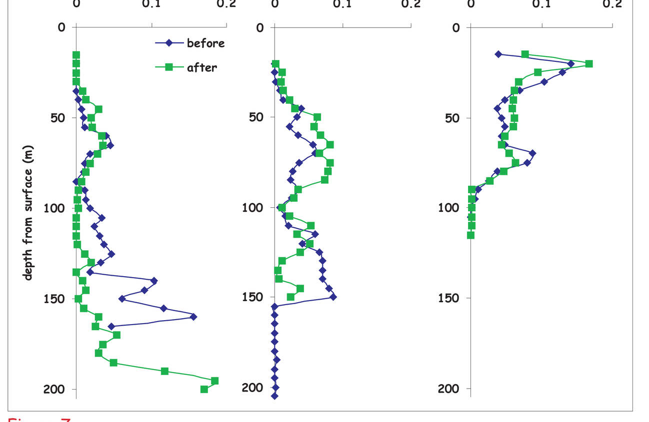

Figure 7a.

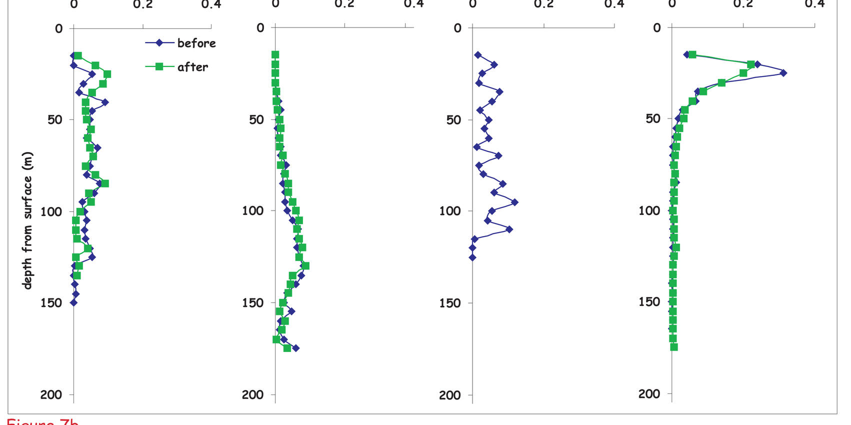

Figure 7b.

Table 1. **Steller sea lion dive data**

Average number of dives

Day	Night
122	280

Dive probability distribution

	Day	Night
0-50 m	0.38	0.99
51-100 m	0.06	0.01
101-150 m	0.56	0.00
151-200 m	0.00	0.00
>201 m	0.00	0.00

Table 2. **Steller sea lion foraging efficiency**

Chiniak	
Mixed-inner trough	0.01
Mixed-outer trough	0.14
Barnabas	
Pollock only-inner trough	1.00
Mixed-middle trough	0.26
Capelin only-outer trough	0.35

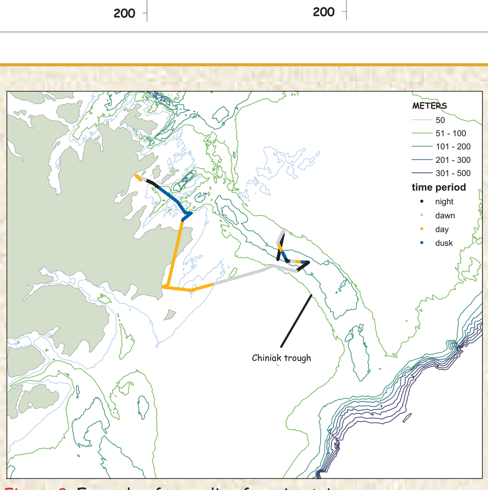

Figure 8. Example of a sea lion foraging trip

A representative trackline for a sea lion foraging trip is shown in Fig. 8. Examination of the sea lion dive data revealed that a juvenile sea lion will proportion its dive depths differently depending on whether it is in shallow, nearshore water or deeper trough water. The fish distribution was therefore also divided accordingly into shallow and deep waters. This division suggested that adult pollock in Chiniak were more evenly distributed in the water column in deeper water as opposed to shallower water where they were more concentrated at depth. In Barnabas trough the difference between shallow and deep water was more a shift in the mode. No capelin were recorded in shallower water. The sea lion will dive mostly at night in both shallow and deep waters except during the day in deeper waters when it will dive to 100-150 m.

Preliminary results from the model suggest that sea lion foraging efficiency is more dependent on their ability to capture capelin rather than pollock. In both shallow and deep water, increasing the number of dives during the night brings the greatest net benefits. This assumes that there are 10 capelin caught for every one pollock caught. Relative foraging efficiency, in terms of food consumed versus metabolic energy expended, was calculated for different fish distributions in the deeper trough waters of Chiniak and Barnabas (Table 2). These calculations revealed that areas where pollock were abundant had the highest relative foraging efficiency. Values were higher in Barnabas than Chiniak.

In the nearshore waters of Chiniak, the observed dive pattern was most similar to values obtained assuming a diet comprised of 80% pollock and 20% capelin. In the deeper Chiniak and Barnabas trough water, the observed dive pattern best matched a diet of 60% pollock and 40% capelin. Data were not available for nearshore Barnabas waters.

Results

Surface water temperature records indicate that there is a shelf-break front in Chiniak trough, while in Barnabas, the front is located closer to the head of the trough. The difference in the locations of the fronts may well be explained by the observed general current flow (Figs. 2 and 3). Changes in surface water temperature were more pronounced in Barnabas trough (temperatures differences of 2-5 °C) than Chiniak (1-2 °C). The storm event did not appear to affect temperatures at depth (data not shown).

4 sign types were seen during the survey: adult pollock, age-1 pollock, capelin, and other fishes. Initial analysis presented here will focus on adult pollock and capelin. Due to the coincident timing of the storm and the start of the commercial fishery effort, changes in fish distribution are evaluated before and after the combined event. No significant geographical movement was seen in adult pollock before and after the storm/fishery (Wilson et al., this symposium). Adult pollock were present throughout Chiniak trough but were more concentrated towards the northern half of Barnabas trough (Fig. 4). Geographical distribution of capelin did not differ significantly before and after the storm/fishery event either (Fig. 5; Wilson et al., this symposium). Capelin tended to be found along the shallow edges of Chiniak trough and towards the southern half of Barnabas trough in deeper water.

Adult pollock tended to form layers close to the bottom and exhibited minimal dispersal at night with slight movement off bottom in both Chiniak and Barnabas (Figs. 6a and 6b). There were no diel differences in distribution before and after the storm/fishery. Capelin were aggregated into dense balls during the day but widely dispersed throughout the upper water column at night. Differences in vertical distribution between the troughs were evident during the dawn and day time periods (Figs. 7a and 7b). During dawn, capelin were higher in the water column in Barnabas while during the day, capelin were higher in Chiniak than Barnabas. Differences between before and after the storm/fishery were not evident during the night but during the day, there was an upward shift after the events.

Discussion

The storm only changed sea surface temperatures which would suggest that capelin that migrate towards the surface at night would be affected but not the adult pollock that remain close to the bottom during the day and night. However, capelin vertical distributions did not differ before and after the event. Adult pollock were observed close to the bottom and were not affected by changes in temperature. However, the geographical distribution of pollock suggests that pollock were affected by the frontal system set up in the northern half of Barnabas by the general current flow pattern and further emphasized by the storm event. It is hypothesized that the pollock are attracted to the nutrient-rich frontal waters (Hollowed et al., in review). The commercial fishery also took advantage of this concentration of fish by only fishing in this area, within our study site, at depths of 100-150 m. No change in adult pollock distribution can currently be attributed to fishing effort during our survey time period (Fig 8.; Wilson et al., this symposium).

The sea lion dive data suggest that they dive progressively deeper from night through dawn to day (Table 1). This would suggest that most of the shallow diving at night is for capelin while the deeper day dives target both capelin and pollock. However, many of the night dives are quite shallow which might indicate that the sea lions are not foraging but surfing near the surface. Since the acoustic data are only available from 14 m below the surface, it is difficult to assess the availability of prey near the surface.

The model results suggest that the sea lions do not have any problems capturing pollock and can forage efficiently where pollock are available. Areas where there is an increased dependence on capelin, like the outer Barnabas trough area, decrease sea lion foraging efficiency. This may explain why there are more sea lions present near Chiniak than Barnabas. It is worth mentioning here that there may be a seasonal component to these results as the energetic return from prey likely varies throughout the year. During August, the average energetic density of pollock (5.1 kJ/gram) is slightly greater than capelin (4 kJ/gram). Therefore the energy gained from one 1-2 kg adult pollock is much greater than ten 8-10 g capelin. It would be advantageous for the sea lion to target adult pollock when possible and the increase in pollock dependence in shallow water is consistent with this hypothesis. Since deeper dives translate into shorter search time available, prey at depth should be reliably present and/or easily captured. During the day, adult pollock at depth are usually aggregated into layers compared to capelin that are in patchy, tight schools that may be hard to find for a sea lion.

Future work will involve analysis of the dive pattern of older sea lions to see how different sea lion age classes may partition the prey field in both shallow and deep water. Effects of commercial fishing effort will continue to be monitored. The survey may be expanded to different seasons and areas.

Acknowledgements

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