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ABSTRACT: Results from the first two years of a multiyear fishery interaction study near Kodiak Island in the Gulf of Alaska are presented. Findings from acoustic surveys, which were conducted in August 2000 and 2001, provide important information that begins to address the question of whether the abundance and spatial patterns of various species, including walleye pollock *Theragra chalcogramma* are impacted by commercial fishing activities over short spatio-temporal scales. The biomass and distribution of walleye pollock were stable over periods of days to weeks although during the second year an unusual, extremely dense, small-scale walleye pollock aggregation was detected during one of several survey passes. Several morphological descriptors of the walleye pollock echosign layers were evaluated to better understand whether differences at the scale of the fish aggregations occurred in response to fishing. Variography was also used to quantify walleye pollock spatial patterns. Results from the second year, when the commercial fishery took place within the study area, do not suggest a significant link between fishing activities and changes in estimates of juvenile and adult walleye pollock geographical distribution, biomass, or vertical distribution. It will be important, however, to evaluate whether these trends persist during subsequent years.

INTRODUCTION

A multiyear field experiment was initiated in August 2000 near Kodiak Island in the Gulf of Alaska. The aim of this research was to characterize the effects of commercial fishing activity on the distribution and abundance of walleye pollock *Theragra chalcogramma* over short temporal scales of days to weeks. The work forms part of a larger research effort designed to determine whether commercial fishing activities impact the prey availability of walleye pollock and other forage fish species (e.g., capelin *Mallotus villosus*) to endangered Steller sea lions *Eumetopias jubatus* (Fadely et al. 2003).

The impetus for this work was the need to understand mechanisms that contributed to the precipitous decline in the western stock of Steller sea lions which began in the 1970s (Loughlin 1998). One of several explanations that have been offered to account for this decline is that large-scale commercial fisheries, such as those for walleye pollock and Atka mackerel *Pleurogrammus monopterygius*, compete with Steller sea lion populations by reducing the availability of potential prey in localized areas (Loughlin and Merrick 1989; Merrick et al. 1987). The home range of a foraging Steller sea lion could be considered a localized area. A reduction in prey availability may result from a reduction in prey abundance and/or a disruption in the spatial patterns of the Steller sea lion prey. The spatio-temporal extent of the perturbation to the prey field could determine the impact on the foraging success of the Steller sea lion predator. For example, fishing removals may cause a decline in the abundance of a prey species within a localized area, but recovery to pre-fishery levels may be so quick that impacts to predator foraging success would be negligible. Alternatively, disturbances from fishing operations may elicit longer-term behavioral responses by prey species that might affect spatial patterns and impact Steller sea lion foraging behaviors. Disturbed fish might move deeper in the water column to form smaller, denser aggregations, which may adversely impact the foraging behavior of Steller sea lions. Unfortunately, no data exist to answer two important questions regarding interactions among commercial fishing, Steller sea lions, and their prey. Firstly, do commercial fishing activities affect the distribution and abundance of Steller sea lion

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prey species significantly? And secondly, if the fishery induces perturbations in prey spatial patterns and/or abundance, how do these perturbations impact Steller sea lion foraging success?

The primary goal of this study was to investigate whether measurable changes in spatial patterns (i.e., vertical distribution, fish school characteristics) and abundance occurred in walleye pollock at scales relevant to Steller sea lion foraging (Merrick and Loughlin 1997). This paper reports results from the first two years of the field study to examine the spatiotemporal characteristics of walleye pollock before and during a commercial fishing season. Although results for capelin are briefly discussed, complete results for this species will be reported elsewhere. Future directions for this type of fishery-interaction research are also discussed.

METHODS

Study Area and Season

The east side of Kodiak Island in the Gulf of Alaska was chosen as the study area for the fishery interaction work for several reasons (Figure 1). Two adjacent submarine troughs with similar topographical features characterized the area. Barnabas Trough served as a treatment site where commercial fishing was allowed and Chiniak Trough served as a control site where fishing was prohibited. The proximity of the two troughs minimized vessel travel time and enabled a more synoptic sampling schedule. Additionally, a commercial trawl fishery for walleye pollock occurs within the area so that implementation of an experimental fishery perturbation was relatively easy. Although not a requirement for the experiment, the area along the east side of Kodiak Island is also characterized by at least six haulout sites for Steller seal lions where 508 animals were counted in June–July 2002 (Sease and Gudmundson 2002; Figure 1). Thus, other closely associated research efforts have been initiated in the area, which focus directly on the behavior of the Steller sea lions in relation to their prey distributions (Fadely et al. 2003; Shima et al. 2003).

Surveys for the fishery interaction experiment occurred in August when recently weaned Steller sea lion juveniles (1-year-olds) were considered vulnerable to nutritional stress due to their high caloric needs per unit body weight and inexperience at capturing prey (Winship et al. 2002; Loughlin et al. *In press*). A commercial walleye pollock fishery was also scheduled to open in the area during August. The study was designed to extend over several years because natural shifts in ocean conditions and/or variations in the age composition of the walleye pollock stock might influence responses to fishing activities.

Field Methods

Multiple surveys of the control and treatment troughs were conducted during daylight hours (about 15 hours/day) over several weeks in August 2000 and August 2001 using acoustic survey methods routinely employed by Alaska Fisheries Science Center scientists (Karp and Walters 1994; Traynor 1997). The surveys consisted of a series of uniformly-spaced (3 nmi) parallel transects (Figure 1). A complete sampling of all transects within a trough was considered a survey pass.

The work during the first year was completed in the absence of the August fishery and during the second year was conducted before and during the fishery. The work during the first year served two purposes. First, the area had not been previously surveyed with acoustic methods during summer, so it was important to evaluate the feasibility of this approach in the study location in August. Second, it was important to characterize the natural variability in the temporal and spatial patterns of the walleye pollock distribution and abundance over the 2–4 week field season. Two survey passes were conducted within each trough in August 2000. During the second year of the study, two survey passes were conducted within each trough before the fishery commenced in Barnabas Trough. These were followed by one pass in Chiniak Trough and two passes in Barnabas Trough *during* the fishery in Barnabas Trough to investigate whether fishery-induced changes occurred in the fish distribution. The fourth, partial pass in Barnabas Trough was only conducted over the area where walleye pollock had been encountered during earlier passes. Thus, no commercial fishing was allowed in either Barnabas or Chiniak Troughs during survey passes 1–2 in either year, and commercial fishing operations occurred in Barnabas Trough during passes 3–4 in 2001. A similar number of days elapsed between repeated surveys in each trough during both years (Table 1).

The acoustic data for this study were collected with a calibrated Simrad[1] EK 500 echosounder operating at 38 kHz. The nominal pulse length was 1 ms, beam width was 6.9°, and ping rate was 1 s^{-1}. Echo-integration data from the sounder were initially logged

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[1] Reference to product names does not imply endorsement by the National Marine Fisheries Service, NOAA.

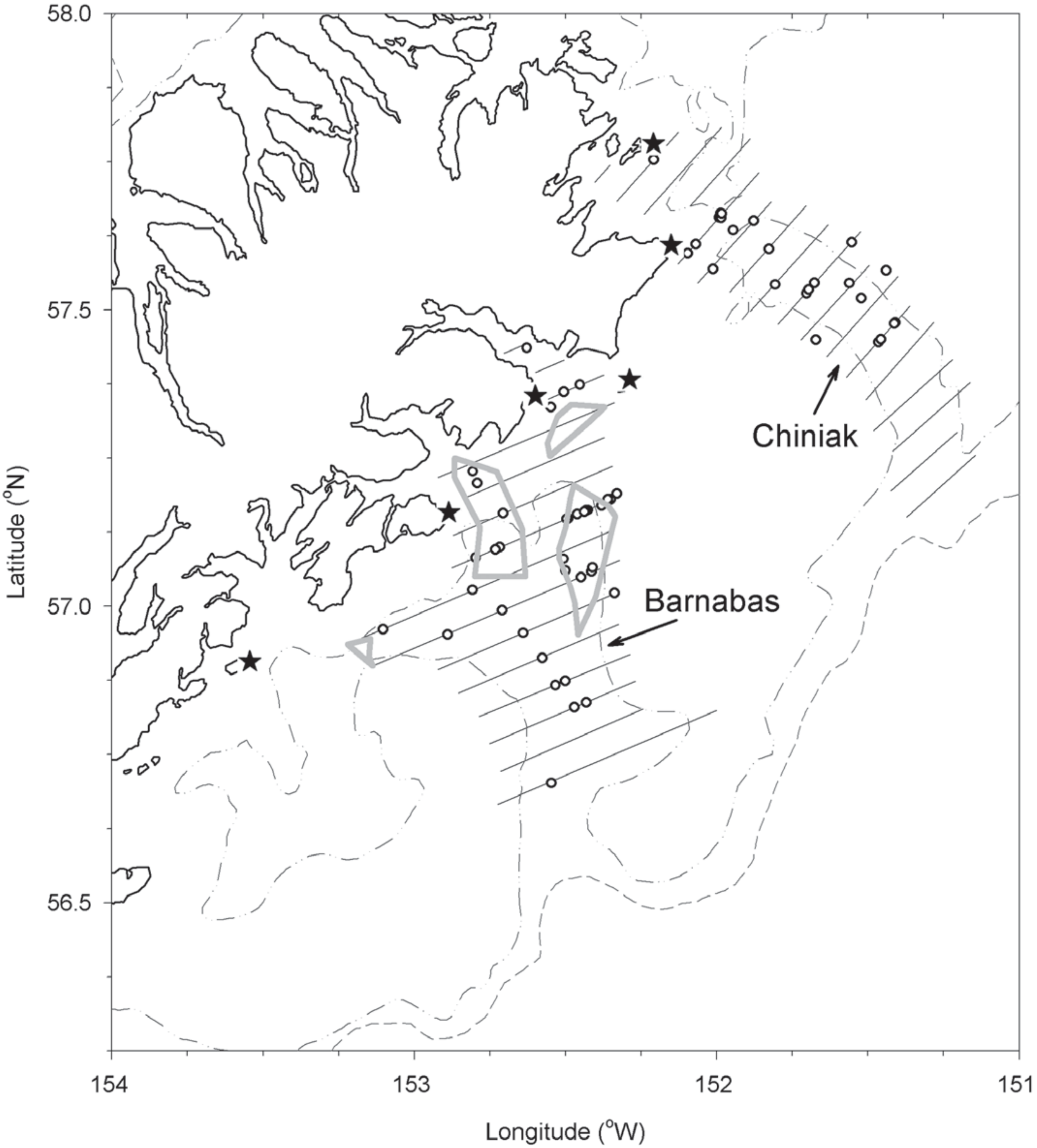

Figure 1. Fishery interaction study area off the east side of Kodiak Island showing survey transects used for all passes during August 2000 and 2001, and survey trawl locations (open circles) for August 2001. Similar numbers of trawl hauls were conducted during August 2000. Polygons (gray lines) in Barnabas Trough represent areas where commercial trawl hauls were made in August 2001. Stars represent locations of six Steller sea lion haulout sites.

Table 1. Walleye pollock biomass estimates (thousands of t) for Barnabas and Chiniak Troughs from the fishery interaction study off the east side of Kodiak Island. Error bounds are shown in parentheses (see text for explanation). Whether a survey pass was conducted prior to or during the August commercial fishery is indicated.

	Chiniak Trough			Barnabas Trough		
Survey Pass	Date	Adult	Juvenile	Date	Adult	Juvenile
Study year 2000						
1 (pre-fishery)	8–11 Aug	6.7 (5.9, 7.5)	5.9 (4.3, 7.5)	11–14 Aug	13.1 (10.7, 15.5)	0
2 (pre-fishery)	14–17 Aug	6.2 (5.4, 7.0)	8.0 (5.8, 10.2)	17–19 Aug	10.8 (8.2, 13.4)	0
Study year 2001						
1 (pre-fishery)	9–11Aug	3.5 (2.9, 4.0)	17.2 (14.5, 20.0)	11–14 Aug	12.7 (9.7, 15.8)	7.8 (4.9, 10.6)
2 (pre-fishery)	14–16 Aug	2.9 (2.3, 3.5)	19.7 (16.2, 23. 2)	16–19 Aug	4.8 (4.1, 5.5)	9.3 (8.2, 10.4)
3 (fishery)	23–26 Aug	3.7 (3.2, 4.1)	18.7 (14.8, 22.6)	26–29 Aug	7.6 (5.9, 9.2)	10.7 (9.1, 12.2)
4 (fishery)				29–30 Aug	4.6 (3.7, 5.5)	10.9 (8.0, 13.8)

with a horizontal resolution of about 5–6 m (dependent on vessel speed which averaged 5–6 m s^{-1}) and a vertical resolution of 0.1–0.5 m. These data were processed with the Echoview software (SonarData 2002) for the echo trace classification analysis. The Simrad BI500 software (Knudsen 1990) was used to log the data and to classify the echosign into different groups based on taxonomic or size-group considerations (see below and Results). The classified data were binned into cells with a vertical resolution of 5 m and horizontal resolution of 185 m (0.1 nmi) for subsequent analyses.

Biological samples were collected with trawls during all surveys to identify the species and size compositions of selected echosign and to collect other information needed to estimate abundance and distribution patterns (Wilson and Guttormsen 1997). A large midwater Aleutian wing trawl and smaller midwater Marinovich trawl were used to target midwater echosign, and a poly Nor'eastern bottom trawl (poly Nor'eastern) was used to target near-bottom echosign. The codends of the Aleutian wing trawl and poly Nor'eastern were fitted with 32 mm (1 1/4 in) mesh codend liners and the Marinovich trawl with a 3.2 mm (1/8 in) mesh liner except in August 2001, when a 9.5 mm (3/8 in) mesh liner was used in the Aleutian wing trawl. The smaller liner was used the second year to improve the retention of smaller capelin. Walleye pollock were sampled to determine sex, fork length (to nearest cm), body weight (to nearest 2 g), age, maturity, and ovary weight of selected females.

Walleye pollock biomass estimates were derived by partitioning the echogram and catch data into geographic areas within each trough so that the areas were characterized by similar walleye pollock echo signatures and fish length distributions. An estimate of the acoustic backscattering or nautical area scattering coefficient (s_A; defined in MacLennan et al. 2002) attributed to walleye pollock was calculated for each geographic area based on the average of all s_A values from within that area. The s_A estimate for each geographic area was then scaled to length-specific fish numbers and biomass using walleye pollock length distributions, a length-weight relationship derived from trawl catches, and a standard target strength to walleye pollock length relationship (Traynor 1996). Estimates of length-specific biomass were then summed across fish lengths and geographic strata to provide total estimates for each trough. Because the acoustic data were only collected from a nominal depth of 14 m to within about 0.5 m of the bottom echo, the resulting biomass estimates may not represent the total biomass within the troughs.

Data Analysis

To evaluate whether significant large-scale differences existed between the walleye pollock geographical distributions between the pre-fishing and fishing periods, a statistical test was used which is based on a modified Cramer-von Mises (CvM) statistic (Syrjala 1996). This test is dependent on the spatial scale selected. This procedure calculates a test statistic as the sum of the squares of the differences between the cumulative distribution functions of walleye pollock density (i.e., s_A) from the two samples. Observations were normalized to remove the effect of differing population sizes between passes. Significance of the test statistic was determined with a randomization test. To test for differences between the pre-fishing and fishing periods in the treatment and control troughs, the acoustic data were initially block-averaged into 3 nmi sections (i.e., distance equal to transect spacing) along transects for each survey pass. Because differences between passes were slight within the pre-fishing or fishing periods for either trough, means at each 3 nmi location were calculated using the block-averaged passes within each period when multiple passes were conducted within the period (i.e., both Chiniak and Barnabas Troughs for pre-fishery, Barnabas Trough for fishery period). For the fishery period in Barnabas Trough, observations at similar locations during pass 3 and the partial pass 4 were averaged and inserted into the pass 3 data set. These means of the block-averaged data were tested for differences using the modified CvM test.

To determine whether differences occurred between estimates of walleye pollock abundance for each period, relative estimation errors were generated using a model-based one-dimensional geostatistical procedure (Petitgas 1993a; Williamson and Traynor 1996). The estimation variance obtained from geostatistical analysis is an indicator of the precision of the biomass estimate (Rivoirard et al. 2000). Error bounds or intervals were constructed by adding or subtracting twice the relative estimation error from the mean. In this study, mean estimates of biomass were considered significantly different when intervals constructed in this way did not overlap.

To evaluate whether the walleye pollock changed position in the water column between the pre-fishing and fishing periods, estimates were calculated of the mean fish depth and the mean fish depth above the bottom. Ninety-five percent confidence intervals were generated using bootstrapping methods (Mooney and Duval 1993), and estimates were compared with a z-test (Zar 1984).

Two analytical procedures were used to describe the structure of the walleye pollock distribution in August 2001 at different spatial scales, and to evaluate whether the scale of patchiness changed between the pre-fishery and fishery periods. These included an echo trace classification (Reid 2000) and variographic analysis (Petitgas 2001) of the walleye pollock echosign, which are described below.

Walleye pollock echo traces were classified using the Echoview software (SonarData 2002), which included school or patch recognition algorithms, and also generated estimates of various descriptive parameters of the aggregations. Most of the walleye pollock echosign was distributed in pelagic and demersal layers (Reid 2000; Swartzman et al. 1994) rather than aggregations more typically chararcterized as schools (Partridge et al. 1980). For the purposes of this study, these finite walleye pollock layers are referred to as aggregations or patches. Several mean volume backscattering strength (S_v) thresholds (-70 to -60 dB) and a range of values for other criteria used to define an aggregation were evaluated before the final values were chosen. An S_v threshold of -70 dB in conjunction with other criteria values (i.e., minimum school length (40 m), minimum height (5 m), minimum connected length (5 m), minimum connected height (2 m), maximum vertical linking distance (5 m), maximum horizontal linking distance (20 m)) provided the best definition of the walleye pollock aggregations when compared to the original echograms. These final values were used in the analysis of all survey passes. As emphasized by Reid (2000) and Freon et al. (1996), the criterion values will likely contain substantial and unknown biases in defining aggregations, but if kept constant (as in the present study), they should provide useful information about the variability of the aggregation structure. Caution is needed, however, in making inferences about the exact dimensions of fish aggregations with these types of data (Reid 2000). A few areas were excluded from the present analysis, where substantial backscattering from unidentified organisms overlapped with that from walleye pollock.

Several of the aggregation-size and -shape descriptors generated by the Echoview software (SonarData 2002) were used to evaluate whether differences existed in the walleye pollock aggregations between the pre-fishery and fishery periods during the second year. Descriptors used in this analysis, which are defined in Nero and Magnuson (1989), included aggregation height, length, area, perimeter, and mean volume backscattering coefficient (S_v). Fractal dimensions of the aggregations, which relate school perimeter to school area, were also generated (Nero and Magnuson 1989; Barange 1994). An increase in the fractal value, which indicates a more complex aggregation shape, may be indicative of a redistribution process of the fish aggregation (e.g., potential indicator of disruption of walleye pollock layer into smaller groups). Where various descriptors were highly correlated (i.e., length, area, perimeter), a representative morphological variable is presented (i.e., length). Statistical significance among the descriptor estimates was based on analysis of variance results and the Student's t statistic with Bonferroni adjustment (Zar 1984). A log transform of some of the variables was needed to stabilize the variance. Statistical test results were considered significant at $P < 0.05$. Ninety-five percent confidence intervals were based on traditional sample-based methods.

Variography was used to examine the spatial structure of walleye pollock distributions. Experimental semi-variograms were constructed for the adult and juvenile walleye pollock for each pass and trough using the 0.1 nmi echo integration data (i.e., s_A). A 2-parameter (range and nugget) spherical model was fitted to each semi-variogram using a weighted least squares algorithm (Johnston et al. 2001). The range corresponds to the distance at which the semi-variogram reaches its asymptote. The sill defines the asymptotic height of the variogram (i.e., the maximum variability in the data). The two components of the sill are the nugget and partial sill. The nugget is the fitted semi-variance at a lag of zero. It is composed of measurement error and variation at scales smaller than the lag size (about 1 km in the present study). The partial sill is the difference between the sill and the nugget and is the part of the semi-variance due to autocorrelation. Model estimates for the range, nugget, and partial sill are reported to characterize walleye pollock spatial structure between the pre-fishery and fishery periods. Isotropy was assumed because data were not available to evaluate differences in the spatial structure as a function of direction at scales smaller than the inter-transect distance (3 nmi).

RESULTS

The survey for the first year of the study was conducted between 8–20 August 2000. Two survey passes were completed within each trough, along with 35 hauls conducted with the Aleutian wing trawl, 5 hauls with the poly Nor'eastern, and 5 hauls with the Marinovich trawl. The echo integration-trawl survey for the second year of the study was conducted between 9–31 August 2001. Multiple survey passes were completed within each trough prior to the fishery along with 41 hauls conducted with the Aleutian wing trawl and 16 hauls with the poly Nor'eastern.

Acoustic backscattering attributed to walleye pollock and capelin was easily recognized from other backscattering in Barnabas and Chiniak Troughs each year (Figure 2). Most of the backscattering was assigned to 4 types of fish echosign: 1) adult walleye pollock, 2) juvenile (mostly age-1) walleye pollock, 3)

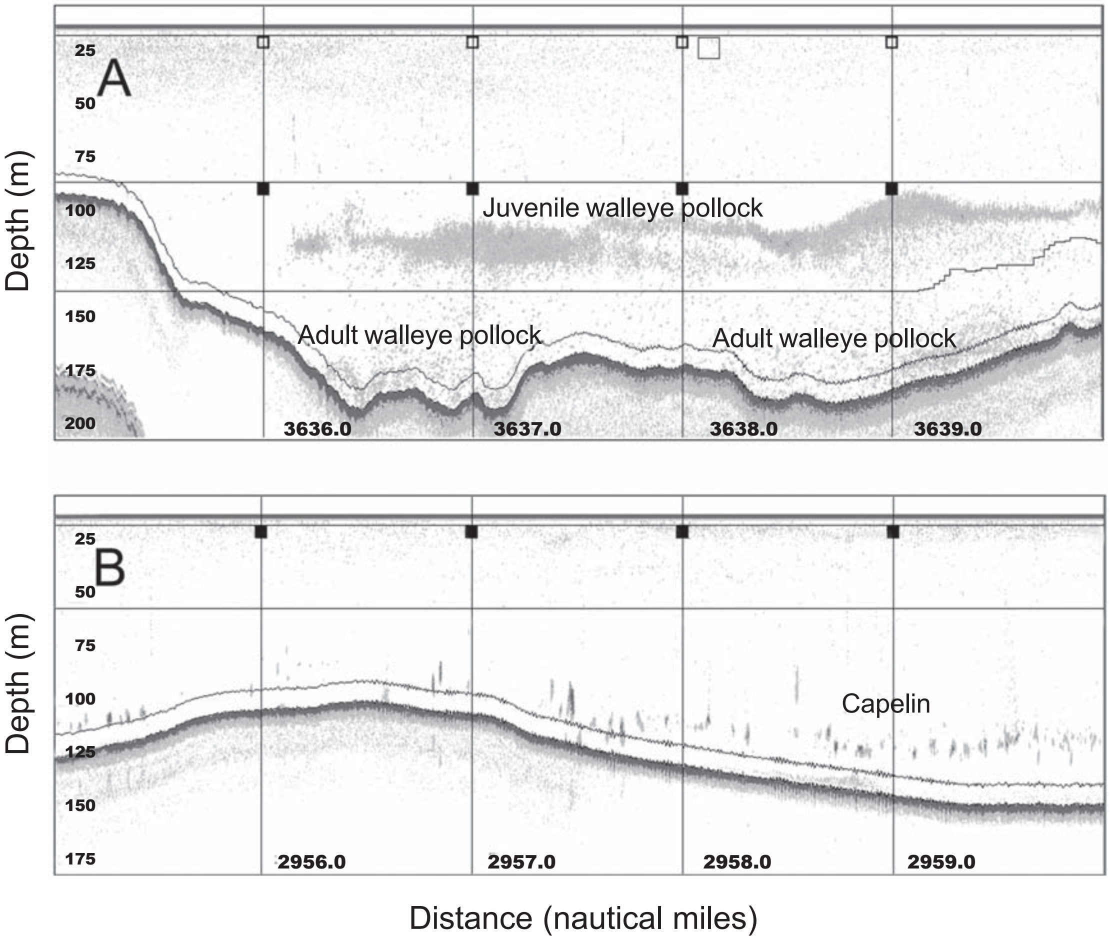

Figure 2. Example echograms illustrating echosign layers attributed to walleye pollock (A) and capelin (B) during August 2001. Distance refers to cumulative distance traveled by the vessel during the survey.

a mixture of capelin/age-0 walleye pollock in August 2000 or capelin in August 2001, and 4) other fishes.

The size composition of adult walleye pollock was similar between years and troughs whereas the juvenile walleye pollock were largely absent in Barnabas Trough during the first year (Figure 3). Juveniles were present in both troughs during the second year, although the size composition indicated that some age-2 fish (about 30 cm modal fork length) were present in Chiniak Trough but not Barnabas Trough.

August 2001 Fishery

Catch data have been compiled for 27 of 28 vessels that were fishing in Barnabas Trough during the experiment in August 2001 (Figure 1). These data account for about 99% of the total catch removed from this trough based on the National Marine Fisheries Service logbook data and shoreside database (NMFS, Alaska Region, P.O. Box 21668, Juneau AK 99802-1668). The 27 vessels spent 1,074 hours fishing to complete 167 hauls during 22–31 August (i.e., during Chiniak Trough survey pass 3 (23–26 August) and Barnabas Trough passes 3 (26–29 August) and 4 (29–30 August)). Vessel deliveries during this period indicated 2,850 t of walleye pollock were removed from Barnabas Trough. Based on historical fishing trends, this did not appear to be an unusual level of effort.

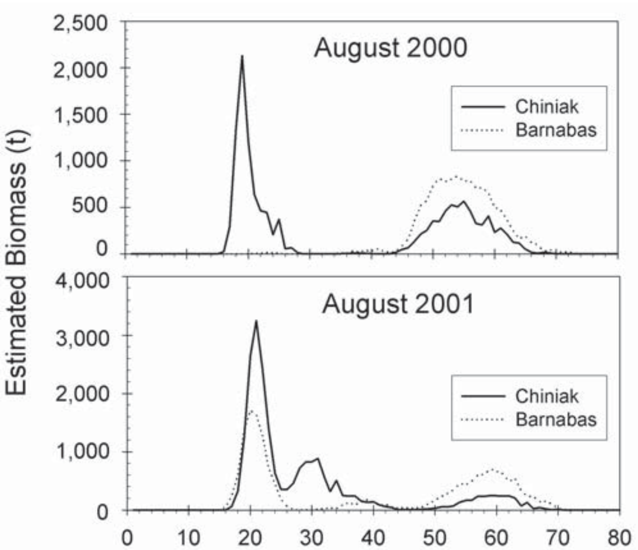

Figure 3. Walleye pollock size composition estimates for Chiniak and Barnabas Troughs during August 2000 and August 2001.

Geographical Distribution

The geographical distribution of walleye pollock and capelin within each trough exhibited similarities between years although some notable differences existed for juvenile walleye pollock. Adult walleye pollock were distributed throughout Chiniak Trough, and in Barnabas Trough they tended to concentrate more towards the northern half of the trough during both years (Figure 4). Juvenile walleye pollock were broadly distributed in Chiniak Trough but virtually absent in Barnabas Trough during the first year; they occurred in both troughs during the second year, with distributions similar to the adults (Figure 5). The mixture of age-0 walleye pollock and capelin was broadly distributed in both troughs during the August 2000 survey. The following year, age-0 walleye pollock were only detected at the east end of one transect in Chiniak Trough during the second survey pass. Capelin were often present over the shallower edges of Chiniak Trough, but were concentrated in the deeper waters within the southern half of Barnabas Trough during the second year. These basic geographical patterns for each group occurred during each pass each year. Thus, although the distributional patterns between the two troughs exhibited some intra- and interannual differences, they were similar enough to justify their use as treatment and control sites.

During the second year no significant difference was detected in the geographical distributions between the pre-fishery and fishery periods for juvenile walleye pollock in Barnabas Trough (CvM test, $P = 0.453$), although the difference was marginally significant for juveniles in Chiniak Trough ($P = 0.049$). Because no fishing was allowed in the control site, this difference suggested that the temporal variability in the juvenile distribution patterns differed between the troughs. No difference was detected between the periods for adults in Chiniak Trough ($P = 0.362$). Although a significant difference was detected between periods for adults in Barnabas Trough ($P = 0.017$), this result was due to the presence of a small, but extremely dense aggregation of adults that was only observed during one of the two pre-fishery passes (pass 1) along the east end of transects 6 and 7 (Figure 4). This dense adult aggregation also complicated biomass estimates (see below). However, when the single extreme observation along transect 6 was replaced with the pass 2 (pre-fishery) observation from the same location, no significant difference was detected between the pre-fishery and fishery periods for adults ($P = 0.108$). This illustrates that the statistical significance of the CvM test is sensitive to single large values. Thus, the statistical significance may not indicate that a fundamental difference exists in the underlying population represented in the pre-fishing and fishing periods.

Abundance

Biomass estimates for August 2000 indicated that adults were about twice as abundant in Barnabas Trough as Chiniak Trough (Table 1). Juvenile walleye pollock were scarce in Barnabas Trough but present in quantities similar to adults in Chiniak Trough. Differences in estimates between passes ranged between 7% and 36%. The results suggest that the biomass of adult walleye pollock was relatively stable over a period of 1–2 weeks in both troughs and offers support for using the two troughs as treatment and control sites.

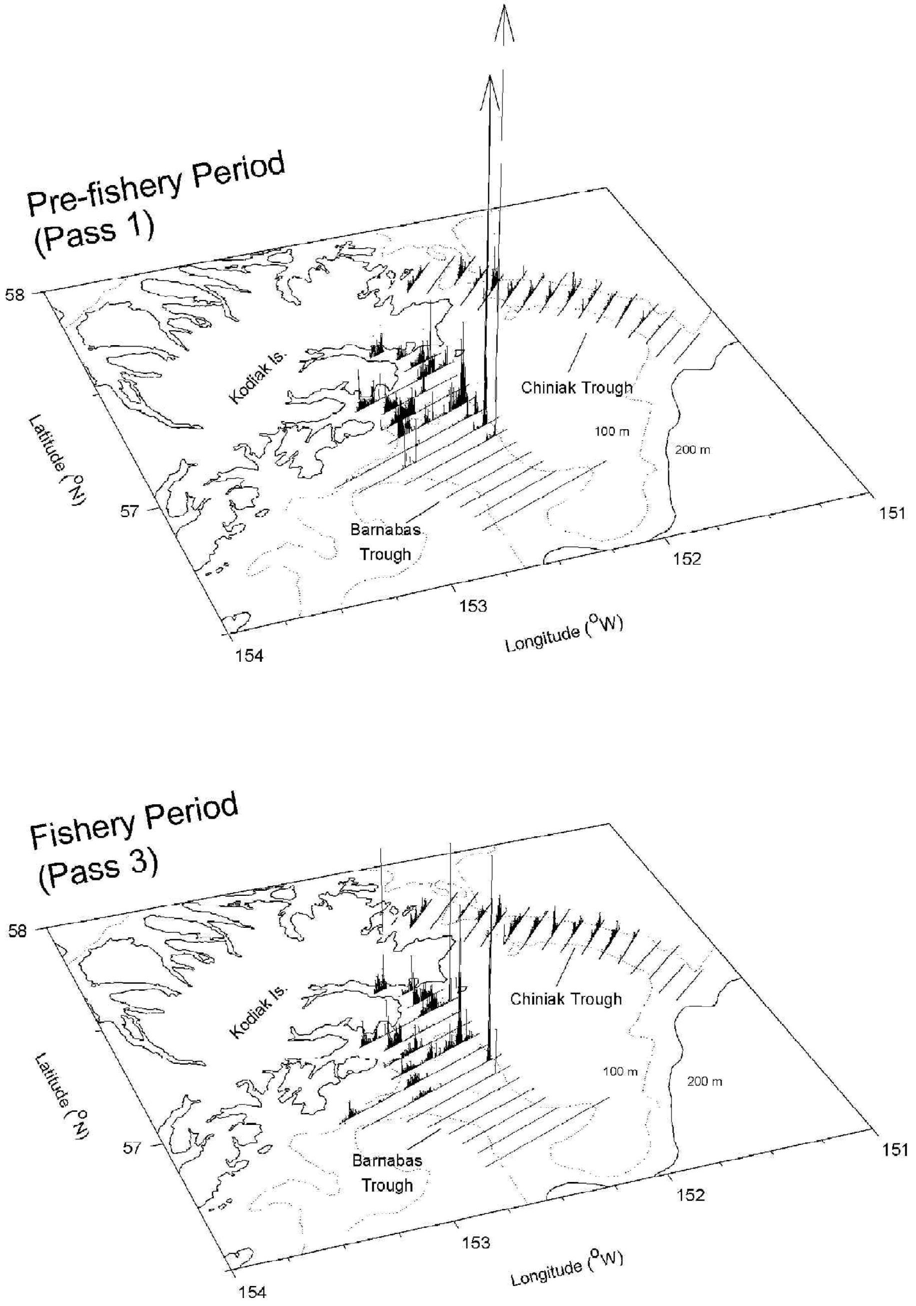

Figure 4. Acoustic backscatter attributed to adult walleye pollock along transects during a typical pass from the pre-fishery and fishery periods in August 2001. See text for explanation. Vertical (z -axis) scale is 0 to 12,000 m^2 nmi^{-2}.

During the second year, this trend was corroborated for juvenile walleye pollock although results were mixed for the adults (see below).

Although walleye pollock were present in the study area during both years, the pre-fishery estimates of walleye pollock biomass for the August 2001 field season decreased for adults and increased for juveniles when compared to the previous year (Table 1). Similar pre-fishery biomass estimates were generated within each trough with differences between passes ranging from 14% to 20%, except for the adults in Barnabas Trough (Figure 6). For these adults, the pass 1 estimate (12,733 t) was over 2.5 times greater than the estimate for pass 2 (4,829 t). This large difference occurred because of the aforementioned dense but relatively small aggregation of adult walleye pollock

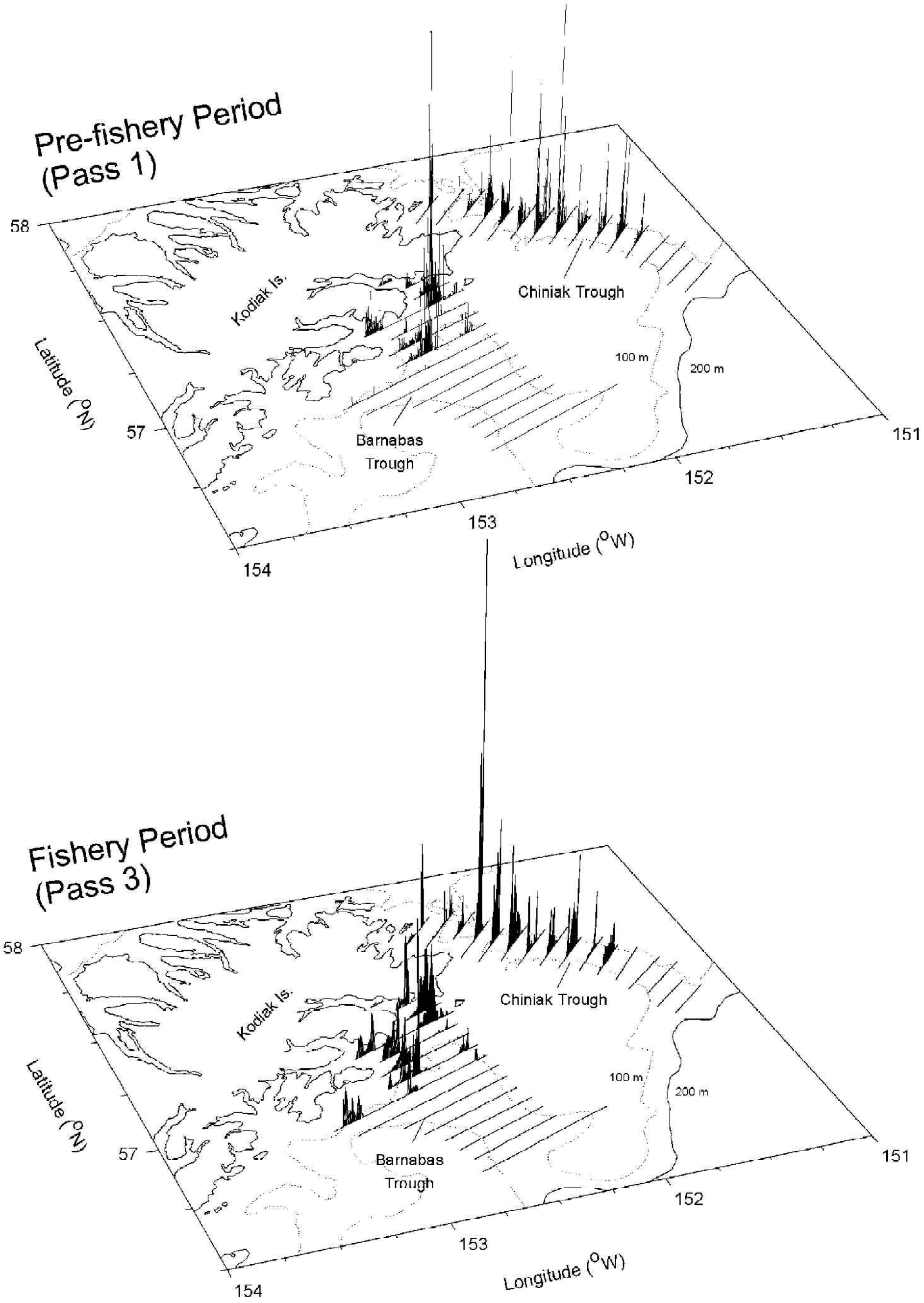

Figure 5. Acoustic backscatter mainly attributed to juvenile walleye pollock along transects during a representative pass from the pre-fishery and fishery periods in August 2001. See text for explanation. Vertical (z-axis) scale is 0 to 35,000 m^2 nmi^{-2}.

which accounted for about 40% of the total biomass estimate during pass 1 (the aggregation along transect 6 contributed 25% of total biomass over 0.1 nmi and along transect 7 contributed 16% of total biomass over 0.4 nmi).

Significant differences among either the juvenile or adult walleye pollock biomass estimates in response to commercial fishing activities were not detected (Table 1, Figure 6). For example, error bounds for juvenile estimates overlapped for all passes before (passes 1–2) and during fishing (passes 3–4). The adult estimates during the fishery period fell within the range of the two estimates during the pre-fishery period. Adult biomass estimates showed greater variability among passes than those for juveniles. For example, error bounds did not overlap between the two adult estimates during the pre-fishery period (passes 1–2) or between the two during the fishery period (passes 3–4). Further, adult estimates from the latter three passes (pre-fishery and fishery) were less than half the value of the first pass (pre-fishery). Note that large differences did not occur between adult estimates in Chiniak Trough during year 2 or either trough during the first year.

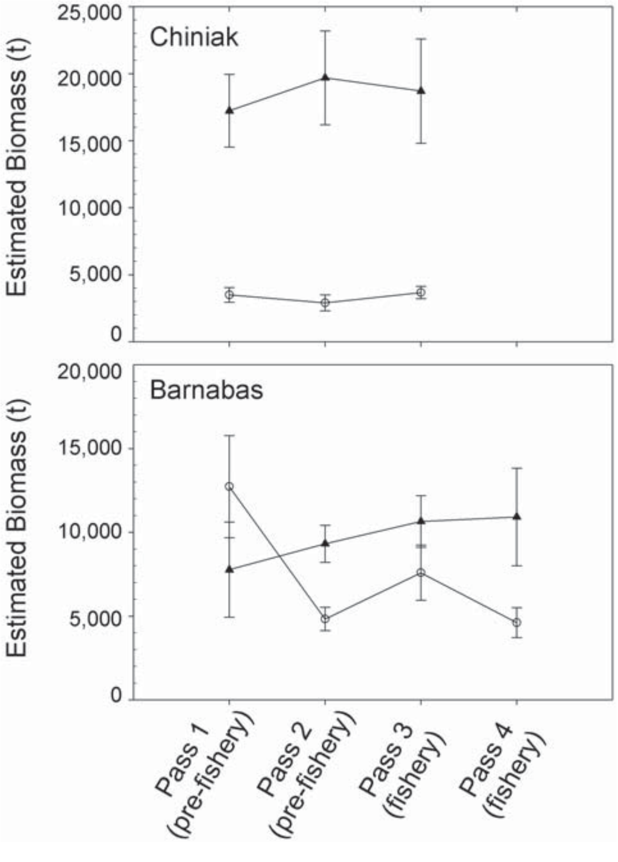

Figure 6. Biomass estimates and 95% confidence intervals for juvenile (triangles) and adult (circles) walleye pollock in Barnabas and Chiniak Troughs during August 2001.

If there were no immigration or emigration of walleye pollock in each trough for the duration of the experiment, then a decline in abundance due to fishing would have been expected. The high degree of variability between passes precluded detection of a fishing effect. Nevertheless, when the biomass estimates were averaged before and during the fishery, there appeared to be a decline that would be consistent with observed fishery removals. However, as mentioned earlier, the influence of the dense fish aggregation on the pass 1 estimate may have confounded the precision and accuracy of this estimate such that the agreement between the fishing removals and trend in biomass may have been purely coincidental.

Vertical Distribution

Several diel comparisons were made to assess whether there was a possibility of conducting the survey 24 hours per day. Adult walleye pollock exhibited relatively little dispersion and typically did not rise in the water column, remaining within about 30 m of the bottom at night. In 2001, however, the adult walleye pollock layers were sometimes difficult to distinguish from the juvenile walleye pollock layers. Echosign attributed to juvenile walleye pollock or capelin typically dispersed from aggregated daytime layers and rose in the water column during darkness. It was usually not possible to distinguish these layers from one another during the night due to the high degree of dispersal and mixing. On occasions when these layers were recognizable at night, however, the capelin generally rose to within about 20 m of the surface and the juvenile walleye pollock moved to depths immediately below the capelin layers. Small amounts of near-surface plankton echosign, which were visible during the day, were also often indistinguishable from other echosign during the night. These results suggest that the echo integration-trawl surveys should be conducted only during daylight hours during subsequent years.

The daytime vertical distribution patterns of walleye pollock and capelin were remarkably similar between years in the treatment and control troughs. Adult walleye pollock generally formed loose, near-bottom aggregations whereas the juvenile walleye pollock and capelin formed more discrete aggregations, higher in the water column. Adult walleye pollock were slightly deeper in the water column yet further off the bottom in Chiniak Trough than in Barnabas Trough (Figure 7). Juveniles were at similar depths in both troughs although those in Chiniak Trough were further off the bottom. No differences were detected in mean depths of either adult or juvenile walleye pollock when pre-fishing estimates were compared with the fishing estimates ($P \leq 0.05$).

Echo Trace Classification

Results from the echo trace classification (ETC) analysis of adult and juvenile walleye pollock from 2001 suggest pass- and trough-level variability, which could not be attributed to the fishery (Figure 8). Greater numbers of both adult and juvenile walleye pollock aggregations were identified in Chiniak Trough compared to Barnabas Trough on all passes. This was intriguing with regard to the adults because the adult biomass was generally less in Chiniak Trough yet these fish were distributed over a greater portion of the trough than in Barnabas Trough. Estimates of mean aggregation lengths for adults exhibited significant differences between troughs ($P = 0.014$). School descriptors for adults in the control trough exhibited little variability among passes or between the pre-fishery and fishery periods ($P > 0.05$). Estimates for adults in the treatment trough exhibited relatively greater variability among passes due primarily to the pass 1 values (Figure 8). For example, the pass 1 mean aggregation length differed significantly from the pass 4 estimate ($P = 0.013$), and the pass 1 fractal estimate differed significantly from passes 2–4 ($P < 0.001$). No clear reason exists at this time to explain the unique pass 1 estimate. The estimate is virtually unaffected by removal of the extremely dense, but small walleye pollock aggregation that was detected during pass 1. No significant differences in any of these descriptors were detected between the pre-fishery and fishery period for the adults ($P > 0.05$).

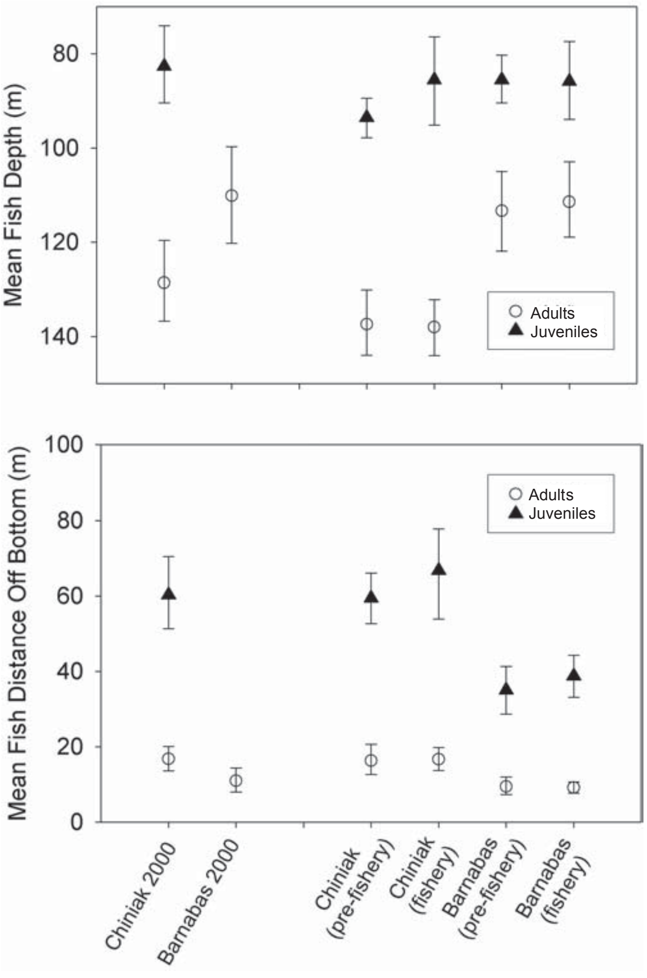

Figure 7. Weighted mean fish depth (upper) and mean distance off bottom (lower) estimates for walleye pollock in Barnabas and Chiniak Troughs during August 2000 and for passes combined into pre-fishery and fishery periods during August 2001. Ninety-five percent confidence intervals are shown.

Unlike adults, the greatest difference in juvenile ETC estimates often occurred between the pre-fishery (passes 1–2) and fishery (passes 3–4) periods for both the treatment and control troughs (Figure 8). For example, estimates of mean fractal dimension exhibited a significant effect between the pre-fishery and fishery period (i.e., temporal effect; $P = 0.037$), which was the same for both troughs ($P = 0.833$). Estimates of mean aggregation height also exhibited comparable effects (i.e., temporal effect $P = 0.035$, temporal-trough interaction $P = 0.897$). Similar, though nonsignificant differences existed for aggregation estimates of mean length and S_v between the pre-fishery and fishery periods. Because these trends for all descriptors also existed in the control trough where fishing was prohibited, differences that occurred between the pre-fishery and fishery periods must have been caused by factors unrelated to the fishery. An intense storm that followed completion of the final pre-fishery pass (pass 2) and prior to the start of the fishery survey passes (passes 3–4) may have caused some of these differences.

Variography

The walleye pollock geostatistical structures differed between Barnabas and Chiniak Troughs, particularly when comparing results from the pre-fishery passes (Table 2; Figure 9). In the control trough, the variograms for all three passes were similar, characterized by a nugget of about 25% of the sill and a range (related to patch size) of about 8 km (Figure 9a). In the treatment trough, however, the first two (pre-fishery) passes showed almost no spatial autocorrelation at scales greater than 1 km (Figure 9b). Thus, nearly all the variance was attributed to the nugget, and little information on the fish aggregation size could be inferred from the estimation of range. For the last two (fishery) passes in Barnabas Trough, only about half the variance was attributed to the nugget, and the range estimates included both the minimum and maximum values observed in the entire data set. In summary, the adult distribution in Barnabas Trough showed more structure (reduction in percent nugget) after fishing began. These fish also showed more variation in geostatistical structure, with large changes between passes in comparison with either the juveniles in both troughs (Figure 9c,d) or the adults in Chiniak Trough.

DISCUSSION

Work to characterize the interactions between commercial fishing activities and potential Steller sea lion prey

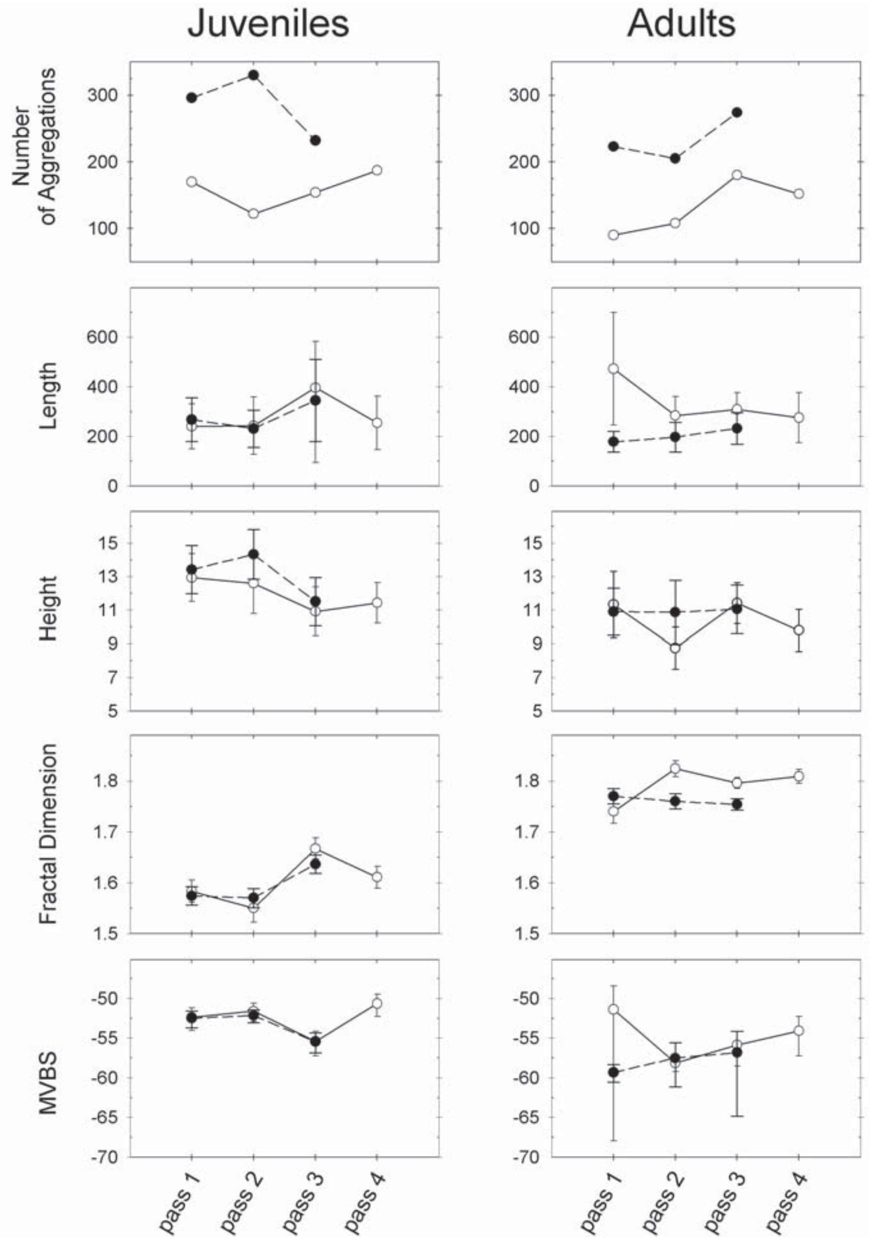

Figure 8. Mean estimates of walleye pollock aggregation descriptors, and 95% confidence intervals, for adult and juvenile walleye pollock in Chiniak (filled circles) and Barnabas (open circles) Troughs during August 2001. MVBS is mean volume backscattering (dB); other descriptor units are in meters. See text for fractal dimension definition.

has just begun. Other studies have addressed questions on the interactions between fish and commercial fishing vessels (Potier et al. 1997), and from the point of view of the fisher (Dorn 1997). Similarly, numerous studies have investigated fish avoidance responses to survey vessels and trawls (Mitson 1995 for review; Freon and Misund 1999). Most fish avoidance work has been conducted over small time and space scales, however, where the focus has been to understand the potential avoidance response to a single vessel or trawl and the impact of the behavior on the acoustic data collection by the vessel, or catchability of the gear during the trawling operation. The present work differs from these types of studies in terms of scale. This study focused on a fish avoidance response, which might be characterized by disruption of the fish distribution pat-

Table 2. Variogram models for walleye pollock distribution in Barnabas and Chiniak Troughs in August 2001.

Location	Maturity	Pass	Partial Sill	Nugget	Sill	% Nugget	Range (km)	Lag size (km)
Chiniak	Adult	1	1.1E4	3.3E3	1.4E4	23	6.8	1.2
	Adult	2	1.0E4	4.6E3	1.5E4	32	8.5	0.9
	Adult	3	1.1E4	2.5E3	1.4E4	19	8.2	1.6
Barnabas	Adult	1	0.0E0	1.8E6	1.8E6	100	–	1.0
	Adult	2	1.0E3	1.6E4	1.7E4	94	2.2	1.2
	Adult	3	3.3E4	3.9E4	7.2E4	54	2.1	1.0
	Adult	4	1.8E4	1.1E4	2.9E4	39	11.8	1.0
Chiniak	Juvenile	1	1.3E6	8.9E5	2.2E6	41	4.2	0.9
	Juvenile	2	2.5E6	1.6E6	4.1E6	39	9.3	1.0
	Juvenile	3	3.0E6	1.7E6	4.7E6	36	5.2	1.0
Barnabas	Juvenile	1	3.9E5	2.3E5	6.2E5	37	5.4	1.0
	Juvenile	2	3.0E5	4.5E5	7.5E5	60	5.4	1.0
	Juvenile	3	3.7E5	1.1E5	4.8E5	23	3.2	1.0
	Juvenile	4	1.8E6	1.5E6	3.3E6	45	5.8	0.7

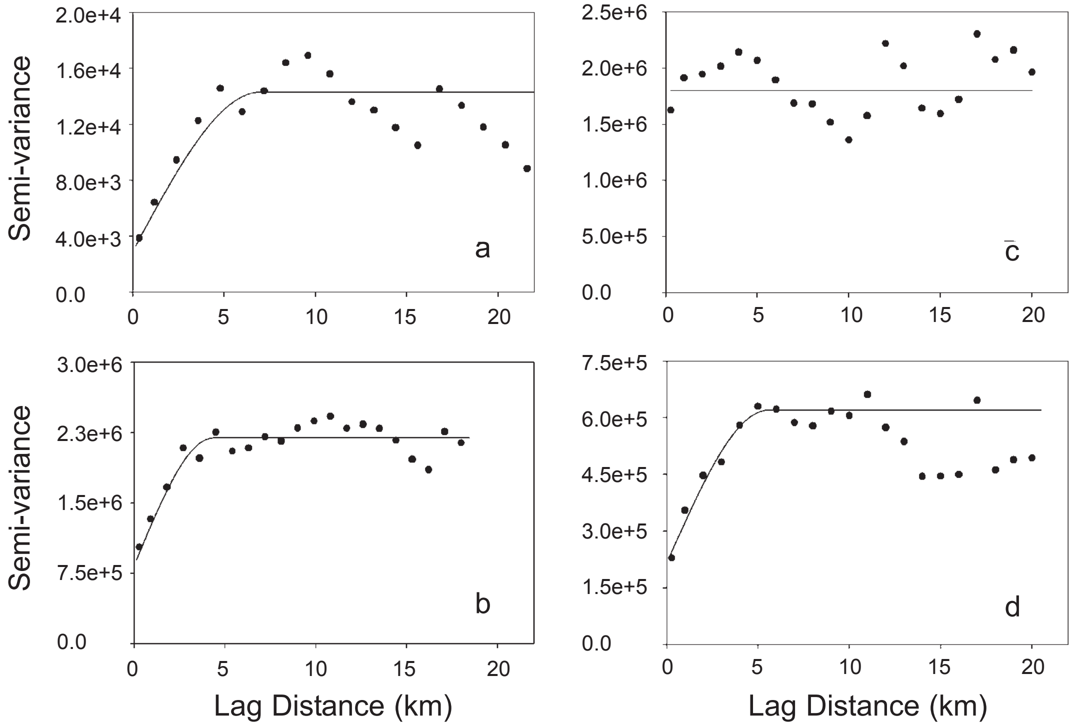

Figure 9. Variograms from pass 1 for adult walleye pollock in Chiniak (a) and Barnabas (b) Troughs and juvenile walleye pollock in Chiniak (c) and Barnabas (d) Troughs. Lag intervals were about 1 km (see Table 2). All variograms were computed for 20 lags, resulting in a maximum lag distance of about 20 km.

terns over a longer time scale (days) and space scale (area of commercial fishing operations). Efforts were made in designing the present work to incorporate a control area (Chiniak Trough) into the study to facilitate interpretation of the results. Replicate control and treatment areas are desirable for this type of field experiment (Lindegarth et al. 2000), but are difficult, and sometimes not possible to attain without a prohibitive cost to the work. Results from the first two years of the program are encouraging.

Barnabas and Chiniak Troughs appear to be suitable as treatment and control sites even though some differences were detected between the two areas. The size composition of adult walleye pollock was similar between the two sites. Likewise, the vertical distribution of the juvenile and adults were remarkably similar between troughs for both years. However, juvenile walleye pollock were not detected in Barnabas Trough during the first year of the study. The walleye pollock geographical distribution patterns were quite stable in both troughs, at least during the several week study period. Furthermore, both geostatistical and ETC analyses suggested that juvenile spatial patterns were similar between troughs. Geostatistical results indicated that differences existed between troughs for the adults, whose aggregation sizes were generally greater in Chiniak Trough. Differences in the mean aggregation lengths for adults were also detected based on the ETC, but in this case, Chiniak Trough aggregation lengths were smaller, not greater, than those in Barnabas Trough. However, the variographic analysis used a lag size of about 1 km (Table 2), so aggregation sizes less than this would not have been detected. The relationship between aggregation size and trough is dependent on the spatial scale considered. Thus, at scales less than 1 km (i.e., ETC analysis) adult mean aggregation lengths in Barnabas Trough exceed those in Chiniak Trough, whereas at scales greater than 1 km (variography), the inverse relationship exists. Others have reported complex relationships between spatial scale and patch size and shape-related variables (Nero and Magnuson 1992). Alternatively, the ETC analysis, conducted with Echoview (SonarData 2002) used somewhat arbitrary criteria in defining aggregations. Therefore, comparison of the estimated walleye pollock shape-related and other aggregation characteristics derived from the two different analytical tools (ETC and variography) with their different inherent biases may be unwise (Reid 2000). More work is planned to determine under what conditions (i.e., post-processing criteria) results from these two analytical approaches might be comparable.

Although firm conclusions regarding the response of walleye pollock to commercial fishing activities will not be made until completion of this 4-year study, results from the second year, when the commercial fishery took place within the study area, do not suggest a significant link between fishing activities and changes in estimates of juvenile and adult walleye pollock geographical distribution, biomass, and vertical distribution. No broad scale change in fish distribution occurred in response to the fishery. That is, walleye pollock were distributed in the northern portion of Barnabas Trough prior to the fishery and were not displaced from this area (e.g., into the southern portion of the trough) in response to the fishery (Figures 1, 4, and 5). Likewise, over smaller scales (3 nmi block averages) no differences were detected or similar differences occurred in both troughs, based on ETC and variographic analyses. Because the geostatistical structure for the adult pre-fishery passes differed between the control and treatment troughs, it is uncertain whether the change in the adult geostatistical structure between the pre-fishery and fishery passes in Barnabas Trough was actually due to the fishery.

Acoustic data were not collected within about 0.5 m of the bottom echo, and thus the distribution and abundance estimates for walleye pollock did not include fish within this near-bottom zone. This limitation in the acoustic data arises from characteristics of the transmitted acoustic pulse and its interaction with the seafloor to produce an acoustic deadzone (Ona and Mitson 1996). Estimates for the juvenile walleye pollock were generally unaffected by the acoustic deadzone since these fish were typically found well above the sea floor (Figure 7). Because the adult fish were often closely associated with the bottom (Figure 7), abundance values reported for this group underestimated the total absolute biomass for each trough. Nevertheless, there was no evidence to suggest that greater numbers of adult walleye pollock moved closer to the bottom, and possibly into the acoustic deadzone, during the fishery period in either trough (Figure 7). Thus the presence of the acoustic deadzone did not affect interpretation of the results. However, the adult walleye pollock biomass estimates reported in this paper should not be used to estimate a fishery exploitation rate for Barnabas Trough since the latter would be biased high.

The extremely dense walleye pollock aggregation that was only observed in August 2001 during the first survey pass in Barnabas Trough raises questions regarding the ability to discern the effects of fishing (i.e., removal of about 3,000 t) on adult walleye pollock biomass using the current experimental design, or, perhaps suggests the need to reconsider survey design parameters in future years. The dense aggregation was not detected during the second pre-fishery pass, so it was not simply removed or dispersed by the fishery. Thus, it will be difficult to conclude that changes in biomass are the result of commercial fishing activity unless differences in estimates between the pre-fishery and fishery periods are quite dramatic (e.g., > 65% reduction) given the large natural variability observed in the pre-fishery estimates (Table 1). The potential increase in patchiness characterized by this dense aggregation needs to be considered for the fieldwork planned for subsequent years. Because no other passes from Barnabas Trough (2001, *n* = 2 passes; 2002, *n* = 4) or Chiniak Trough (2001, *n* = 2, 2002, *n* = 3) produced such an extreme value, it was considered premature to assume that the high level of patchiness detected at one location in Barnabas Trough during pass 1 was representative of the walleye pollock distributional patterns within the study area in general. For this reason, a reduction in the transect spacing, with the corresponding increase in time needed to complete each pass will not be considered unless similar, high levels of patchiness are observed again.

Results from variography suggest that walleye pollock distributions east of Kodiak Island appear just as variable as other fish populations, but the variability is often at smaller scales. The support (i.e., lag size and number of lags) chosen will affect range estimation (Rivoirard et al. 2000). When the data were averaged over longer distances than 1 km (the distance used in this study), the structures observed rapidly disappeared and were subsumed into a larger nugget. For comparison, Simard et al. (1993) observed a range for small pelagic fish in the Gulf of St. Lawrence on the order of 10 km, which was unaffected by lag size from 60 to 1,920 m. These lag sizes were still considerably smaller than the range. The 11 km range computed for pre-spawning walleye pollock in Shelikof Strait (Sullivan 1991) was close to the largest range seen in this study (11.8 km). Large structures with ranges on the order of 50 nmi, such as those reported for North Sea herring *Clupea harengus* (Fernandes and Rivoirard 1999) could not be observed for walleye pollock in these two troughs because of their small geographic size. Most previous variographic analyses of acoustic data used larger sampling units, restricting the minimum size of structures that could be described (for example, Petitgas 1993b: 1 nmi; Maravelias et al. 1996: 2.5 nmi; Porteiro et al. 1996: 1 nmi; Fernandes and Simmonds 1997: 2.5 nmi).

The level of disturbance from the commercial fleet during August 2001 may not be sufficient to result in a detectable shift in local abundance, vertical distribution, or geographic distribution of walleye pollock on the eastside of Kodiak Island. This suggests that at the current level of exploitation, local walleye pollock distributions are primarily influenced by ocean conditions and ontogenetic behavior patterns (e.g., vertical separation between juvenile and adult walleye pollock). Other studies (Swartzman et al. 1994; Strickland and Sibley 1989) have reported on biophysical factors influencing walleye pollock distribution patterns. The geographic distribution of walleye pollock relative to oceanographic features was consistent in 2000 and 2001 (A.B. Hollowed, unpublished data). Likewise, vertical distributions of juvenile and adult walleye pollock were similar between years. These findings underscore the evolutionary importance of maintaining aggregations in pelagic fish populations (Bakun and Cury 1999) and the importance of affinities for a particular geographic location or structure (Bakun 2001). It may be that greater levels of exploitation are needed before detectable differences are found in response to the fishery using the methods employed in this work.

Additional fieldwork is needed to define the limits in any potential interactions that may exist between the east Kodiak Island fishery and potential Steller sea lion prey species. The presence of juveniles in Barnabas Trough during the second year and not the first highlights the value of a multiyear research effort. The incoming strong year class of walleye pollock observed in 2001 (Figure 3) will provide an important opportunity during the next two years of the study to investigate whether variations in the walleye pollock age composition influence responses to fishing activities. If significant responses by walleye pollock or other species are detected, additional survey passes will be conducted following completion of the fishery to document the duration of the perturbation. Other developing technologies will be used in future field efforts to improve the species identification of scattering layers. These include the addition of an open/closing codend for the research trawls and the use of multiple acoustic frequencies. Additional bottom trawling efforts may be included to provide abundance estimates for demersal (i.e., within about 0.5 m of bottom) walleye pollock, which are unavailable to the acoustic survey method (Ona and Mitson 1996). Because estimates of the abundance and distribution patterns for walleye pollock were not identical between the treatment and control troughs, it may be valuable to switch the control site to Barnabas Trough in subsequent years. Of course, this would require an increase in walleye pollock biomass in Chiniak Trough from the current low levels reported by this work to levels that would attract commercial fishing activities to this trough. Finally, as resources become available, efforts will be made to expand the east Kodiak Island fieldwork to other seasons and then to design similar experiments in other areas and seasons to evaluate whether regional differences exist.

LITERATURE CITED

Bakun, A. 2001. 'School-mix feedback': a different way to think about low frequency variability in large mobile fish populations. Progress in Oceanography 49:485–511.

Bakun, A., and P. Cury. 1999. The 'school trap': a mechanism for promoting large-amplitude out-of-phase population oscillations of small pelagic fish species. Ecology Letters 2:349–351.

Barange, M. 1994. Acoustic identification, classification and structure of biological patchiness on the edge of the Agulhus Bank and its relation to frontal features. South African Journal of Marine Science 14:333–347.

Dorn, M. W. 1997. Mesoscale fishing patterns of factory trawlers in the Pacific hake (*Merluccius productus*) fishery. California Cooperative Oceanic Fisheries Investigations Reports 38:77–89.

Fadely, B., R. Foy, K. Call, K. Wynne, A. Greig, and J. Sterling. 2003. Behavior of juvenile Steller sea lions in relation to available prey distribution in eastern Kodiak Island waters *in* L. Fritz, editor. Joint Scientific Symposium on Marine Science in the Northeast Pacific: Steller sea lion investigations, January 13–17, 2003, Anchorage, Alaska. Abstract only.

Fernandes, P. G., and J. Rivoirard. 1999. A geostatistical analysis of the spatial distribution and abundance of cod, haddock and whiting in north Scotland. Quantitative Geology and Geostatistics 10:201–212.

Fernandes, P. G., and E. J. Simmonds. 1997. Variographic refinement of North Sea herring acoustic survey data. Quantitative Geology and Geostatistics 9:451–462.

Freon, P., and O. A. Misund. 1999. Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment. Fishing News Books, London.

Freon, P., F. Gerlotto, and M. Soria. 1996. Diel variability of school structure with special reference to transition periods. ICES Journal of Marine Science 53:459–464.

Johnston, K., J. M. Ver Hoef, K. Krivoruchko, and N. Lucas. 2001. Using ArcGIS Geostatistical Analyst. Environmental Systems Research Institute, Inc., Redlands, California.

Karp, W. A., and G. E. Walters. 1994. Survey assessment of semi-pelagic gadoids: the example of walleye pollock, *Theragra chalcogramma*, in the eastern Bering Sea. Marine Fisheries Review 56:8–22.

Knudsen, H. P. 1990. The Bergen echo integrator: an introduction. ICES Journal of Marine Science 47:167–174.

Lindegarth, M., D. Valentinsson, M. Hansson, and M. Ulmestrand. 2000. Interpreting large-scale experiments on effects of trawling on benthic fauna: an empirical test of the potential effects of spatial confounding in experiments without replicated control and trawled areas. Journal of Experimental Marine Biology and Ecology 245:155–169.

Loughlin, T. R. 1998. The Steller sea lion: a declining species. Biosphere Conservation 1:91–98.

Loughlin, T. R., and R. L. Merrick. 1989. Comparison of commercial harvests of walleye pollock and northern sea lion abundance in the Bering Sea and Gulf of Alaska. Pages 679–700 *in* Proceedings of the international symposium on the biology and management of walleye pollock. Alaska Sea Grant Report 89–01, University of Alaska, Fairbanks.

Loughlin, T. R., J. T. Sterling, R. L. Merrick, J. L. Sease, and A. E. York. *In press*. Immature Steller sea lion diving behavior. Fishery Bulletin.

MacLennan, D. N., P. G. Fernandes, and J. Dalen. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science 59:365–369.

Maravelias, C., D. G. Reid, E. J. Simmonds, and J. Haralabous. 1996. Spatial analysis and mapping of acoustic survey data in the presence of high local variability: geostatistical application to North Sea herring (*Clupea harengus*). Canadian Journal of Fisheries and Aquatic Science 53:1497–1505.

Merrick, R. L., and T. R. Loughlin. 1997. Foraging behavior of adult female and young-of-the-year Steller sea lions in Alaskan waters. Canadian Journal of Zoology 75:776–786.

Merrick, R. L., T. R. Loughlin, and D. G. Calkins. 1987. Decline in abundance of the northern sea lion, *Eumetopias jubatus*, in Alaska, 1956–86. Fishery Bulletin 85:351–365.

Mitson, R. B. 1995. Underwater noise of research vessels: review and recommendations. ICES Cooperative Research Report 209. Denmark.

Mooney, C. Z., and R. D. Duval. 1993. Bootstrapping a nonprametric approach to statistical inference. Sage Publications, Thousand Oaks, California

Nero, R. W., and J. J. Magnuson. 1989. Characterization of patches along transects using high-resolution 70-kHz integrated acoustic data. Canadian Journal of Fisheries and Aquatic Science 46:2056–2064.

Nero, R. W., and J. J. Magnuson. 1992. Effects of changing spatial scale on acoustic observations of patchiness in the Gulf Stream. Landscape Ecology 6:279–291.

Ona, E., and R. B. Mitson. 1996. Acoustic sampling and signal processing near the seabed: the deadzone revisited. ICES Journal of Marine Science 53:677–690.

Partridge, B. L., T. Pitcher, J. M. Cullen, and J. Wilson. 1980. The three-dimensional structure of fish schools. Behavioral Ecology and Sociobiology 6:277–288.

Petitgas, P. 1993a. Geostatistics for fish stock assessments: a review and an acoustic application. ICES Journal of Marine Science 50:285–298.

Petitgas, P. 1993b. Use of a disjunctive kriging to model areas of high pelagic fish density in acoustic fisheries surveys. Aquatic Living Resources 6:201–209.

Petitgas, P. 2001. Geostatistics in fisheries survey design and stock assessment: models, variances and applications. Fish and Fisheries 2:231–249.

Porteiro, C., P. Carrera, and J. Miquel. 1996. Analysis of Spanish acoustic surveys for sardine, 1991–1993: abundance estimates and inter-annual variability. ICES Journal of Marine Science 53:429–433.

Potier, M., P. Petitgas, and D. Petit. 1997. Interaction between fish and fishing vessels in the Javanese purse seine fishery. Aquatic Living Resources 10:149–156.

Reid, D. G. 2000. Report on echo trace classification. ICES Cooperative Research Report 238, Denmark.

Rivoirard, J., J. Simmonds, K. G. Foote, P. Fernandes, and N. Bez. 2000. Geostatistics for estimating fish abundance. Blackwell, Oxford.

Sease, J. L., and C. J. Gudmundson. 2002. Aerial and land-based surveys of Steller sea lions *Eumetopias jubatus* from the western stock in Alaska, June and July 2001 and 2002. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-131.

Shima, M., A. Hollowed, B. Fadely, C. Wilson, J. Sterling, and K. Call. 2003. Comparison of Steller sea lion diving behavior relative to spatial distributions of walleye pollock and capelin *in* L. Fritz (editor). Joint Scientific Symposium on Marine Science in the Northeast Pacific: Steller sea lion investigations, January 13–17, 2003, Anchorage, Alaska. Abstract only.

Simard, Y., D. Marcotte, and G. Bourgault. 1993. Exploration of geostatistical methods for mapping and estimating acoustic biomass of pelagic fish in the Gulf of St. Lawrence: size of echo-integration unit and auxiliary environmental variables. Aquatic Living Resources 6:185–199.

SonarData. 2002. Echoview. Version 2.25.109. <http://www.verdant.com.au/sonardata/>. Tasmania, Australia. Accessed April 24, 2003.

Strickland, R. M., and T. H. Sibley. 1989. Potential effects of water transport on the walleye pollock (*Theragra chalcogramma* Pallas) fishery in the Gulf of Alaska. Reviews in Aquatic Sciences 1:281–293.

Sullivan, P. J. 1991. Stock abundance estimation using depth-dependent trends and spatially correlated variation. Canadian Journal of Fisheries and Aquatic Science 48:1691–1703.

Swarztman, G., W. Stuetzle, K. Kulman, and M. Powojowski. 1994. Relating the distribution of pollock schools in the Bering Sea to environmental factors. ICES Journal of Marine Science 51:481–492.

Syrjala, S. E. 1996. A statistical test for a difference between the spatial distributions of two populations. Ecology 77:75–80.

Traynor, J. J. 1996. Target strength measurements of walleye pollock *Theragra chalcogramma* and Pacific whiting *Merluccius productus*. ICES Journal of Marine Science 53:253–258.

Traynor, J. J. 1997. Midwater fish surveys at AFSC. Pages 1–9 *in* Alaska Fisheries Science Center Quarterly (January, February, March) Report, National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle.

Williamson, N. J., and J. J. Traynor. 1996. Application of a one-dimensional geostatistical procedure to fisheries acoustic surveys of Alaskan pollock. ICES Journal of Marine Science 53:423–428.

Wilson, C. D., and M. A. Guttormsen. 1997. Echo integration-trawl survey of Pacific whiting, *Merluccius productus*, off the west coasts of the United States and Canada during July-September 1995. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-74.

Winship, A. J., A. W. Trites, and D. A. S. Rosen. 2002. A bioenergetic model for estimating the food requirements of Steller sea lions *Eumetopas jubatus* in Alaska, USA. Marine Ecology Progress Series 229:291–312.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Inc., New Jersey, USA. (Footnotes)