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

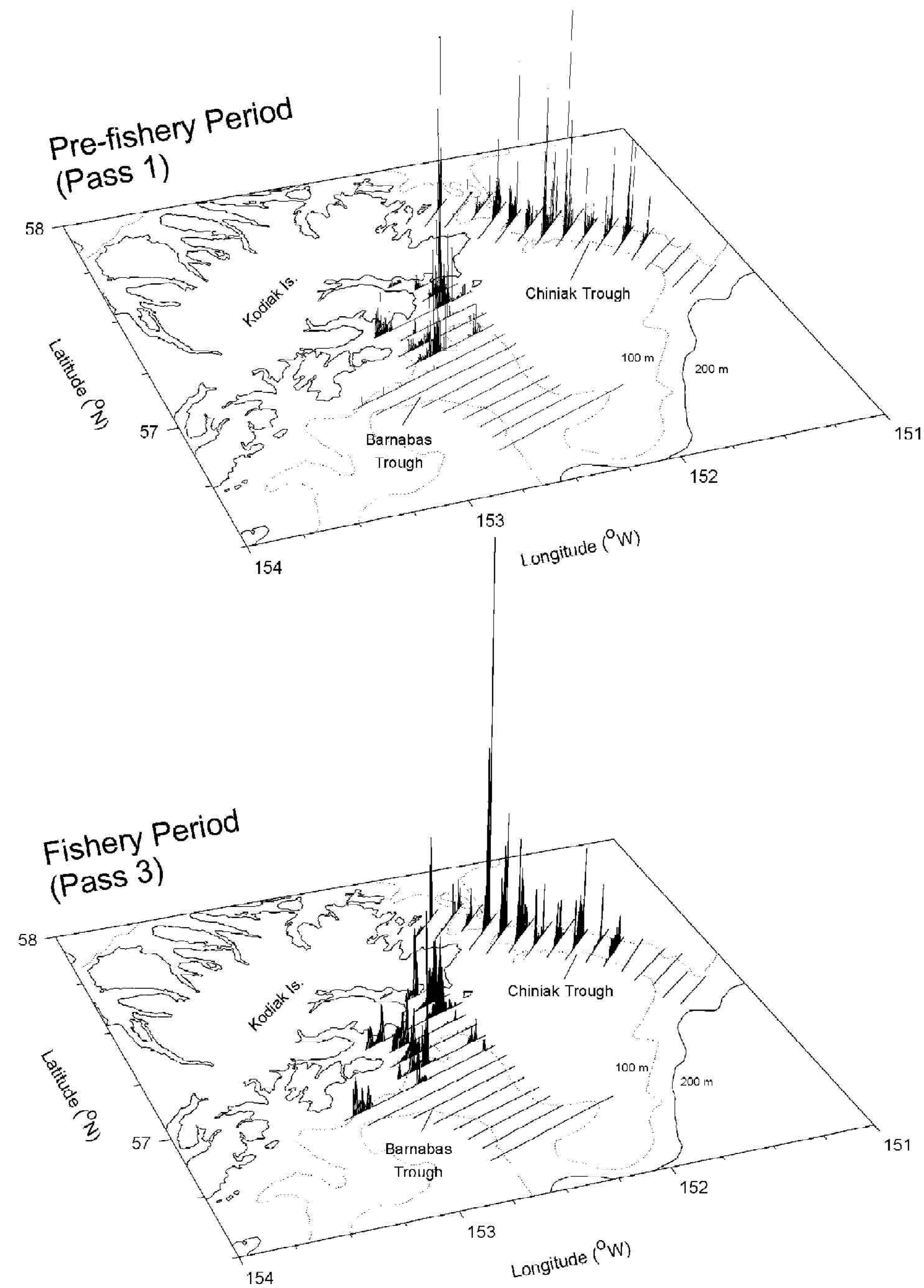

Figure 5. Acoustic backscatter mainly attributed to juvenile walleye pollock along transects during a representative pass from the pre-fishery and fishery periods in August 2001. See text for explanation. Vertical (z-axis) scale is 0 to 35,000 m^2 nmi^{-2}.

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.

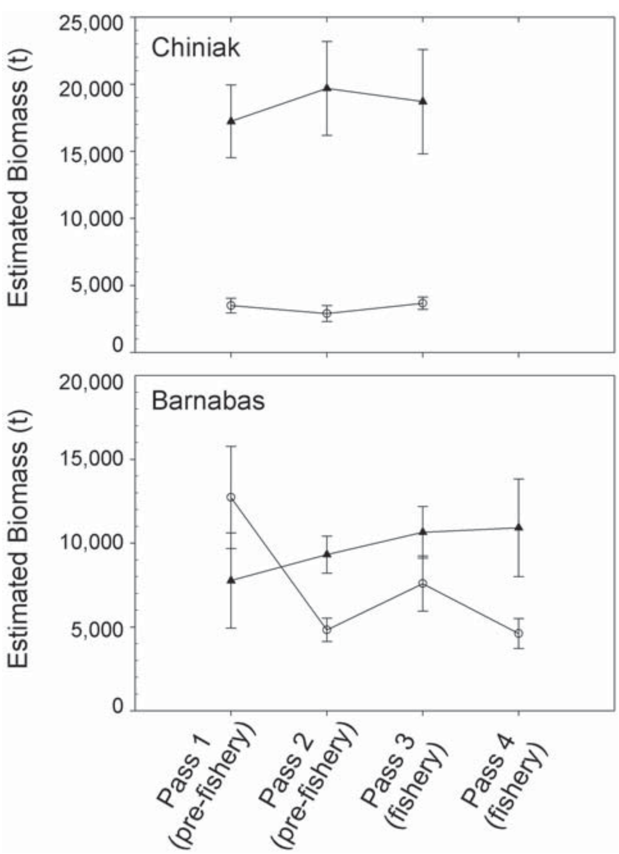

Figure 6. Biomass estimates and 95% confidence intervals for juvenile (triangles) and adult (circles) walleye pollock in Barnabas and Chiniak Troughs during August 2001.

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 ($P > 0.05$).

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.

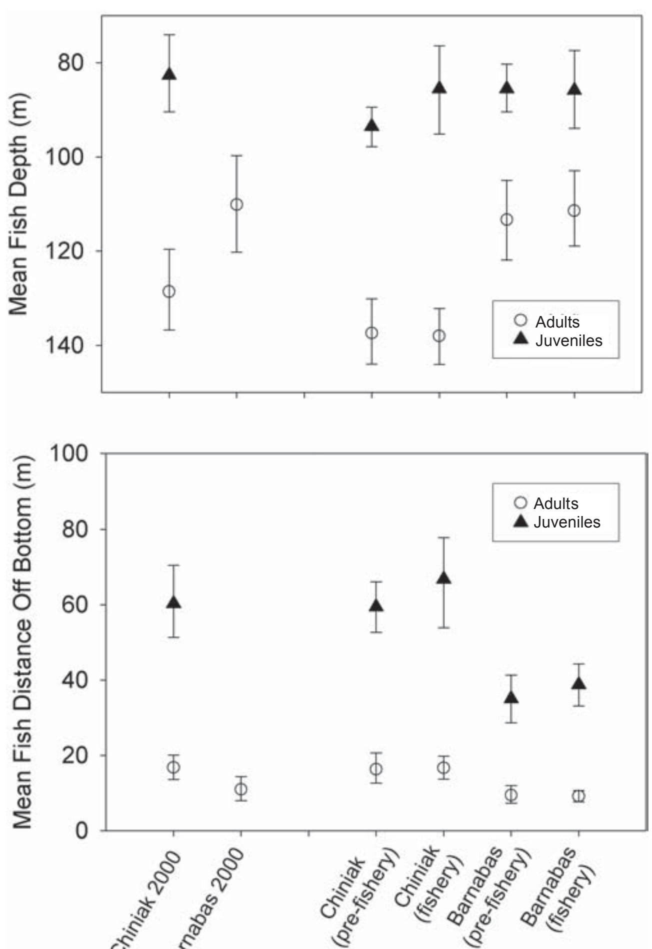

Figure 7. Weighted mean fish depth (upper) and mean distance off bottom (lower) estimates for walleye pollock in Barnabas and Chiniak Troughs during August 2000 and for passes combined into pre-fishery and fishery periods during August 2001. Ninety-five percent confidence intervals are shown.

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

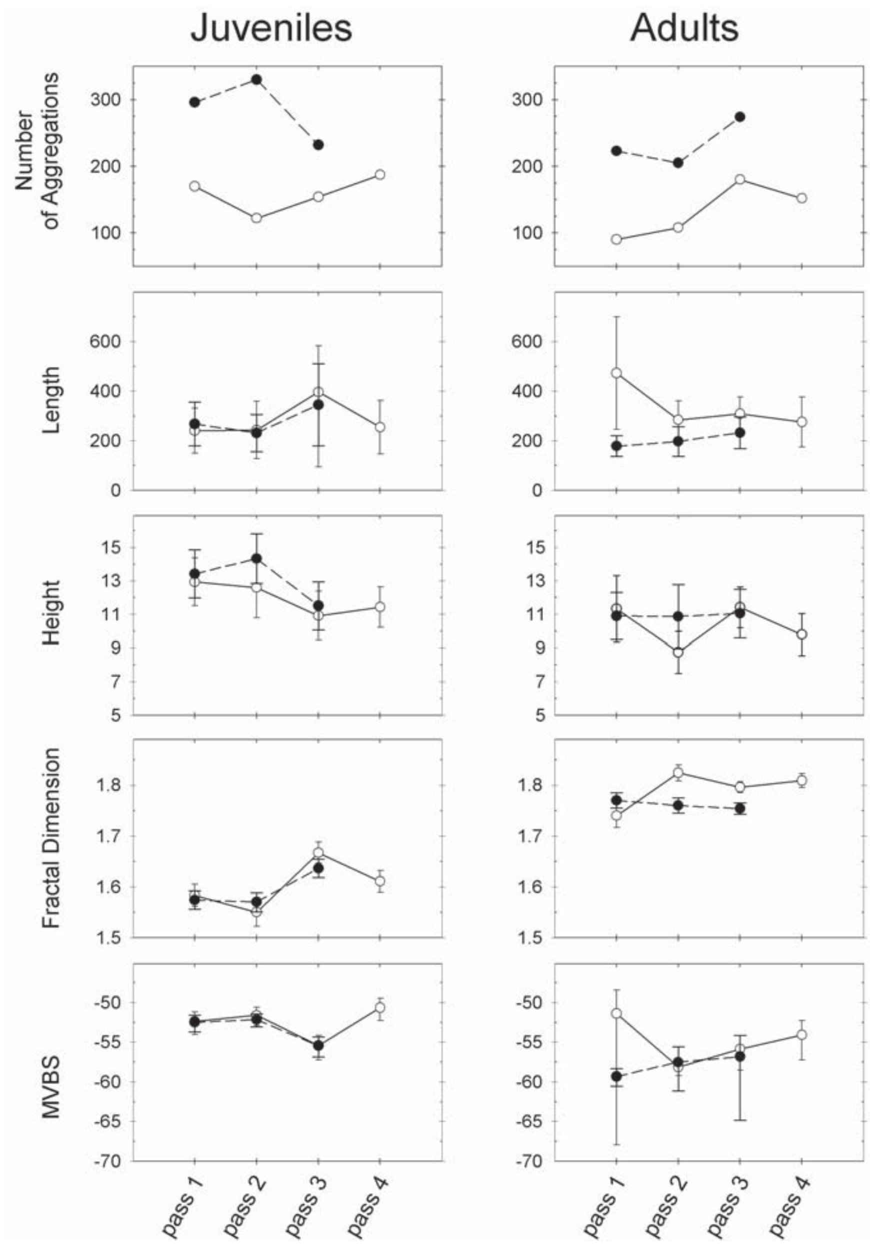

Figure 8. Mean estimates of walleye pollock aggregation descriptors, and 95% confidence intervals, for adult and juvenile walleye pollock in Chiniak (filled circles) and Barnabas (open circles) Troughs during August 2001. MVBS is mean volume backscattering (dB); other descriptor units are in meters.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

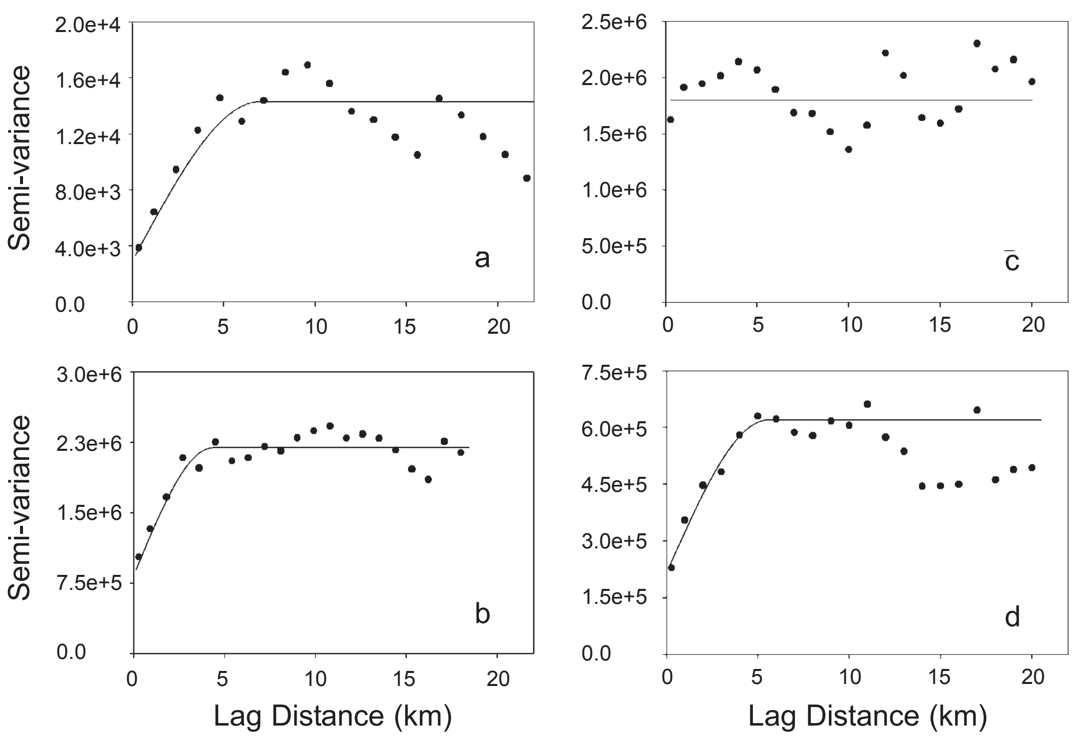

Figure 9. Variograms from pass 1 for adult walleye pollock in Chiniak (a) and Barnabas (b) Troughs and juvenile walleye pollock in Chiniak (c) and Barnabas (d) Troughs. Lag intervals were about 1 km (see Table 2). All variograms were computed for 20 lags, resulting in a maximum lag distance of about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

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