

# Pribilof Island Working Group: Final Report

<a href="#">Pribilof Island Working Group: Final Report</a> .....	1
<a href="#">Overview of the Pribilof Island Ecosystem</a> .....	2
<a href="#">Workshop and Working Group Participants</a> .....	3
<a href="#">Working Group Products:</a> .....	3
<a href="#">1. How large an area is the Pribilof region?</a> .....	3
<a href="#">2. How does the abundance of juvenile pollock near the Pribilof Islands compare with abundance along the Bering Sea shelf, how accessible is this area from major pollock spawning regions and what percentage of juvenile pollock is represented by the Pribilof Island population?</a> .....	5
<a href="#">    A. Comparison of Pribilof Island Pollock abundance to that in other areas of the Bering Sea Shelf.</a> .....	5
<a href="#">        a. Net samples from Oshoro Maru</a> .....	5
<a href="#">        b. Net trawl data from the NMFS MACE survey group</a> .....	7
<a href="#">        c. Acoustic Survey Comparisons between Pribilof and Inner Front Surveys</a> ..	11
<a href="#">    B. Evidence concerning access of the Pribilof area to larvae from different spawning regions</a> .....	13
<a href="#">    C. What percentage of juvenile pollock is represented by the Pribilof Island population?</a> .....	14
<a href="#">3. How does the abundance of pollock near the Pribilof Islands relate to diet, survival and energetics of higher predators?</a> .....	15
<a href="#">    Bird Survival and energetics</a> .....	15
<a href="#">    Studies of pollock otoliths in fur seal scat collected on the Pribilof Islands 1994-1999 (Rolf Ream)</a> .....	17
<a href="#">4. How important is predation to pollock abundance near the Pribilof Islands?</a> .....	19
<a href="#">    ii. Predation by fish on age-0 pollock near the Pribilof Islands compared with other areas in the Eastern Bering Sea (Troy Buckley)</a> .....	20
<a href="#">    iv. Results of ECOPATH analysis for 1996-1997 by Lorenzo Ciannelli</a> .....	21
<a href="#">5. Pribilof age-0 pollock as an index of pollock year-class-strength. – Jim Ianelli</a> .....	22
<a href="#">References</a> .....	25
<a href="#">APPENDICES</a> .....	27
<a href="#">    Appendix I. Comparison of abundance of juvenile pollock and zooplankton between the Pribilof Islands and other shelf areas in the Eastern Bering Sea based on acoustic surveys in 1997, 1998 and 1999 by Andreas Winter and Kenneth Coyle</a> .....	27
<a href="#">    Methods</a> .....	28
<a href="#">    Results</a> .....	31
<a href="#">    Discussion</a> .....	32

## Overview of the Pribilof Island ecosystem

The Pribilof Island ecosystem has been a major focus area for study as part of the Southeast Bering Sea Carrying Capacity Program (SEBSCC) and the Bering Sea Fisheries-Oceanography Coordinated Investigations (FOCI) projects sponsored by NOAA Coastal Ocean Program. The region was chosen in part because it is thought to be a major nursery area for age-0 walleye pollock (*Theragra chalcogramma*), the target species for these projects. Early hydroacoustic studies suggested higher than background abundance of juvenile pollock (Traynor and Smith 1996). Satellite tracked drifters released in a pollock spawning area (Unimak Island) slowly drifted northwest toward the Pribilof Islands, arriving in late summer and fall (Stabeno et al., 1999).

The Pribilof area has had extensive survey activity during late summer from 1994-1999. Acoustic surveys, with concomitant physical and biological sampling, occurred along four transects (Figure 1). These transects were chosen to be representative of different habitats around the Pribilof Islands.

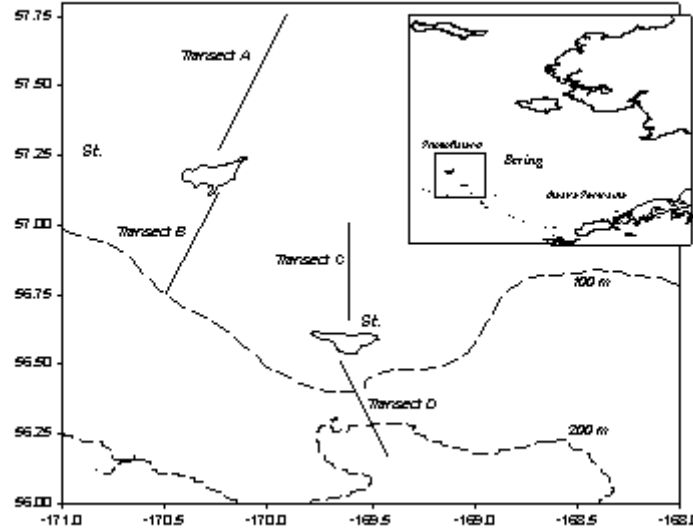


Figure 1. Pribilof Island study region showing transects A-D repeatedly sampled both day and night during September 1994-1999.

This report is an overview of our best understanding at present of ecosystem dynamics in the neighborhood of the Pribilof Islands. It also explores the possibility of gleaned information from past and present studies to create an index of pollock year-class-strength. Such an index will prove valuable in helping to forecast future year classes in the important pollock fishery. Work leading to this report was discussed at a series of three workshops. The first was held at the Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington, September 20-21, 2001, the second in Victoria, BC, Canada, on October 12, 2001 and the third at PMEL on April 22-23, 2002.

## **Workshop and Working Group Participants**

Gordie Swartzman - University of Washington (facilitator)  
Rick Brodeur – Northwest Fisheries Science Center  
Troy Buckley - Alaska Fisheries Science Center  
Lorenzo Ciannelli - University of Washington  
Ken Coyle – University of Alaska Fairbanks  
George Hunt – University of California Irvine  
Jim Ianelli - Alaska Fisheries Science Center  
Allen Macklin - Pacific Marine Environmental Laboratory  
Jeff Napp – Alaska Fisheries Science Center  
Rolf Ream – National Marine Mammal Laboratory  
Bruce Robson – National Marine Mammal Laboratory  
Beth Sinclair – National Marine Mammal Laboratory  
Phyllis Stabeno – Pacific Marine Environmental Laboratory  
Lucy Vlietstra – University of California Irvine  
Andreas Winter - University of Washington

## **Working Group Purview:**

The working group focussed on a synthesis of available information concerning the Pribilof Island ecosystem. To this end we developed a web site containing a table of links to available data sets and to relevant supporting and summarizing literature. The web site link is [http://www.pmel.noaa.gov/sebscc/PWG\\_data\\_matrix.html](http://www.pmel.noaa.gov/sebscc/PWG_data_matrix.html)

Cognitive issues addressed by the working group and used to structure this report are:

1. How large an area is the Pribilof region? How far does the influence of the islands extend?
2. How does the abundance of juvenile pollock near the Pribilof Islands compare with abundance along the Bering Sea shelf, how much transport is there to this area from major pollock spawning regions and what percentage of juvenile pollock is represented by the Pribilof Island population?
3. Is there a relationship between the abundance of age-0 pollock near the Pribilof Islands and the diet breadth, feeding energetics, survival or recruitment of apex predators (seabirds, fish and mammals)?
4. How important is predation to pollock abundance near the Pribilof Islands?
5. Can information about the distribution, condition or abundance of juvenile pollock near the Pribilof Islands be used to develop an index of pollock year-class-strength?

### **1. How large an area is the Pribilof region?**

The Pribilof Island region is an oceanographically complex region with several habitats in a small area. Large numbers of species inhabit the area, at least for part of the year. To

define a region of influence of the Pribilof Islands we suggest a biological assessment of combining the species composition at different distances from the island with the energetic balance of this biota in the defined area. The working region is then the one with the greatest self-containment; i.e. having the largest percentage of the energetics demand satisfied within the region of interest. An energy balance model, ECOPATH (Polovina et al., 1984, Ciannelli, 2002), was used to compute the percentage of annual energetic demand for each species or functional group in the model satisfied by feeding within the region around the Pribilofs. ECOPATH is a linear, non-dynamic compartment model framework in which flow rates between the compartments as parameter values by searching the literature and available data for diet compositions for the groups in each compartment. Biomass estimates for each compartment are made by multiplying population estimates by average weight. There are 41 compartments in the Pribilof Island region model including phytoplankton, small and large jellyfish, fur seals, crabs, small and large flatfish, common and thick-billed murre, juvenile gadids (over 95% of which are age-0 pollock) and macrozooplankton. The model produces a steady-state computation of how much of each prey item is eaten by each predator. The ratio of output (amount removed by predation or fishing) to input (amount eaten or synthesized) or ecological efficiency is computed for each compartment. An ecological efficiency greater than 1 suggests that, since outputs are greater than inputs some source of input, outside the study ecosystem, must be available to maintain energetic balance.

The model was run for circular regions around the Pribilof Islands with radii of 50, 100 and 150 nautical miles. The resulting computations suggested that at a radius of 100 n.m. the ecological efficiency is closest to 1.0 for the most groups, implying that this region is the most energetically self contained. While we recognize that there is significant migration into and out of the Pribilof Region, we have decided to define the region as the area within 100 nautical miles of the midpoint between the Pribilof Islands. We use the 100 nautical mile boundary loosely, since a radius of this size around the Pribilof Islands (Figure 1) encloses both basin and shelf habitat and the basin habitat is quite different from the shelf and front habitats. Thus the Pribilof habitat should not extend as far into the basin region. Having a 100-n.m. radius region is consonant with oceanographic and phytoplankton production considerations (Flint et al., 2002), which suggests that the outer front regions around the Pribilofs are at about this distance from the area. Also, this is close to the dimensions of the slow gyre, which frequently appears around the Pribilof Islands during the summer (Stabeno et al., 1999). As such, we will use this region in considerations concerning biomass, production and distribution of biota and in comparing these quantities to other areas (i.e., how relatively productive is the Pribilof Island region compared to other areas of the eastern Bering Sea, and how similar is the standing stock of dominant species).

**2. How does the abundance of juvenile pollock near the Pribilof Islands compare with abundance along the Bering Sea shelf, how much transport is there to this area from major pollock spawning regions and what percentage of juvenile pollock is represented by the Pribilof Island population?**

**A. A comparison of Pribilof Island pollock abundance to other areas of the Bering Sea shelf**

This question relates to the importance and of the Pribilof Island stock to the total pollock abundance and to how typical year-to-year changes in age-0 pollock abundance in the Pribilof region is to changes in other areas along the Bering Sea shelf. To establish a baseline for comparison with the abundance of pollock in the Pribilof Island region we found data sets that either spanned the Pribilof Islands and neighboring areas or used similar sampling methods to assess pollock abundance in other shelf areas of the Bering Sea. The relative abundance of age-0 pollock in the Pribilof Island area to other shelf and front areas throughout the eastern Bering Sea was considered using:

- a. Net samples for age-0 pollock taken at selected stations both near the Pribilof Islands and beyond in July aboard the Japanese T/S *Oshoro Maru* (Jeff Napp);
- b. Net trawls for age-0 pollock taken aboard the *R/V Miller Freeman* during MACE acoustic surveys (Jim Ianelli and Neil Williamson)
- c. Comparison of acoustic abundance near the Pribilof Islands with abundance on transects in the Inner Front, the Bering Sea shelf and shelf-break region running along the Alaska continental shelf (Andreas Winter and Ken Coyle).

*i. Net samples from Oshoro Maru*

Surveys of the southeastern Bering Sea shelf for juvenile (age -0) walleye pollock have been conducted in collaboration with scientists from the Faculty of Fisheries, Hokkaido University, Japan every summer since 1995 (1995-2001). The survey grid is fixed (approximately 30-n.m. between stations), although not all stations are sampled every year. The time of the cruise has not varied from late July. Double oblique tows of a rectangular midwater framed trawl (5-m<sup>2</sup> mount opening) with 3 x 2-mm mesh in the body of the net and 1 mm mesh in the cod end was used each year. A flow meter mounted in the mouth of the net records distance traveled. A "rough count" of age-0 pollock was taken immediately after the tow using either a sub-sample or the entire catch. The catch was then preserved and sent to Poland for processing at the Polish Plankton Sorting and Identification Center. Rough counts were standardized to 100-m<sup>2</sup> area surveyed.

To test the hypothesis that catches of juvenile pollock were higher around the Pribilof Islands than other parts of the shelf, the survey area was divided into two strata (Fig. 2). The size of the Pribilof stratum took into account recent research (Ciannelli, 2002) that concluded that the influence of the Pribilof Islands extended 100 n.m. around the islands (excluding the basin region south of the Pribilof Islands). A fourth root transformation was applied to the age-0 pollock rough count data to eliminate heteroscedasticity. We then used an ANOVA to test for differences among years, between the two strata, and interactions between strata and years. There were no significant interactions between year and stratum (P=0.101), but there were significant differences among years (P =

0.011) and between the two strata ( $P \ll 0.001$ ) with the mean value for abundance around the Pribilof Islands significantly higher than abundance in the other stratum. The ratio of abundance within the Pribilof region to that outside it, which can be used as a rough index of the relative abundance, by year for juvenile pollock in the Pribilof region to that in the surrounding eastern Bering Sea shelf region is given in Table 1.

Table 1. Ratio of abundance per 10 m<sup>2</sup> for the Pribilof Region to that in the surrounding area based on Oshoro Maru surveys from 1995-2002

Year	1995	1996	1997	1998	1999	2000	2001	2002
Abundance ratio	0.808	5.168	1.035	7.975	3.782	1.487	1.281	2.035

. On average about the ratio of per-area abundance in the Pribilof vs. surrounding area is 2.95.

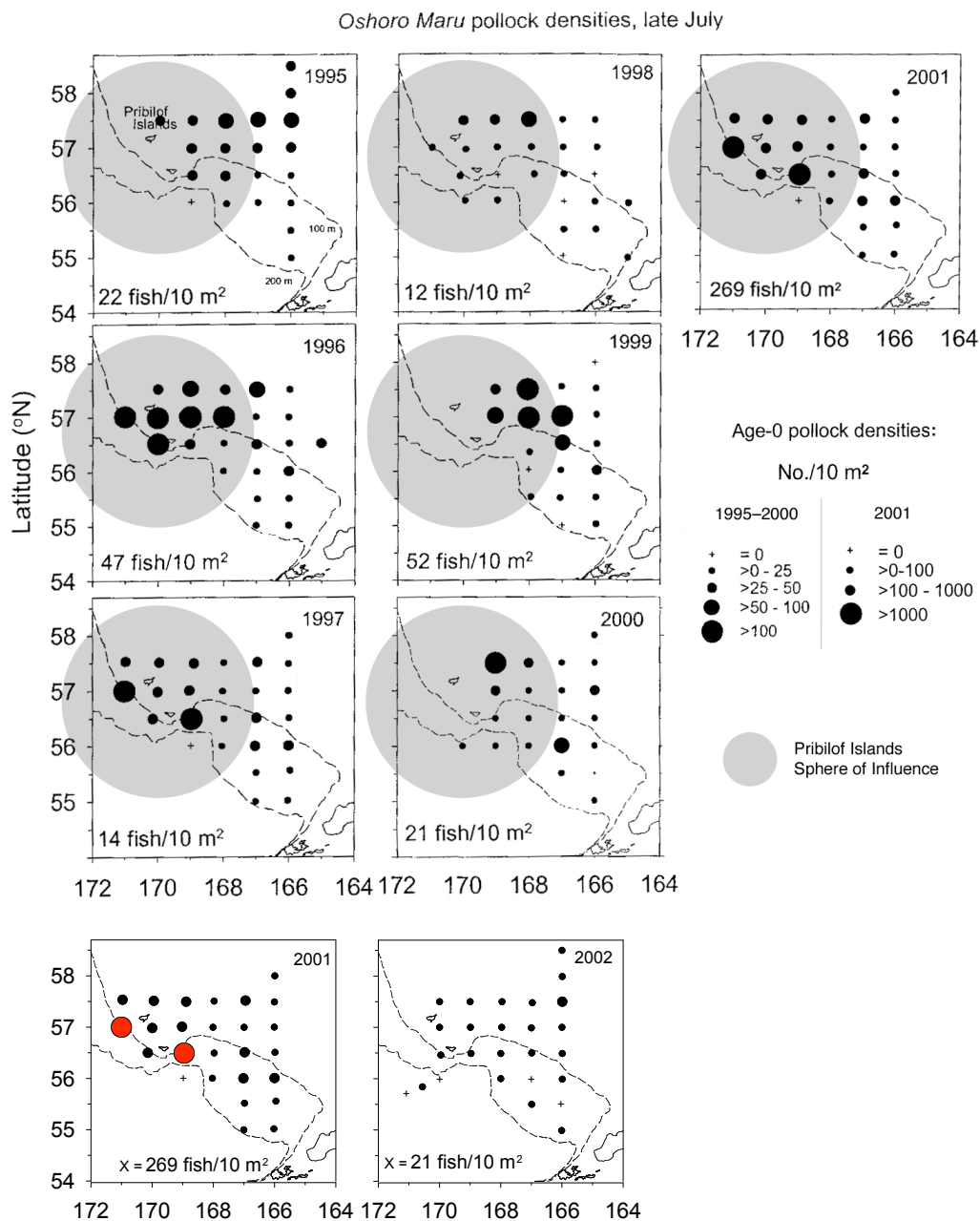


Figure 2. Distribution of age-0 pollock from net hauls taken in July 1995-2001 from the T/S *Oshoro Maru*.

*ii. Net trawl data from the NMFS MACE survey group.*

Initial analysis of oblique tow Methot data collected during MACE surveys in 1982, 1984 and 1985 (Traynor and Smith, 1996) provided estimates of age-0 pollock abundance in the Eastern Bering Sea. Additional Methot samples taken during summer 1999 were summarized by Honkalehto et al., (2002). All these results show the Pribilof region to be highly variable in age-0 pollock in July or late June, with abundance of age-0 pollock in 1984 and 1985 being higher than other regions, while in 1999 they were lower. Additional data, not yet analyzed, are available from surveys in 1996, 1997 and 2000 using Methot trawls and in earlier years (e.g. 1991, 1994 and others) using Marinovich and/or Methot trawls.

Traynor and Smith, (1996) wrote that the center of abundance (based on surveys in 1982, 1984 and 1985) was in the vicinity of the Pribilof Islands but that there were also other areas of high abundance (Figure 3). However, these distributions may not be consistent from one year to the next. For example, Honkalehto et al. (2002) showed that from limited 1999 sampling the abundance of age-0 gadids (presumably primarily pollock) were distributed in areas generally outside of the Pribilof Islands (Figure 4). Note that this appears somewhat inconsistent with the 1999 age-0 abundance presented here for the Pribilof Islands. However, the two samples are taken at different times of the year, and, considering the likely transport of age-0 pollock from spawning areas near Bogoslov Island and Unimak Pass, high densities along the shelf may end up by September near the Pribilof Islands. Continued sampling of age-0 pollock in the greater shelf region over the July-September period would help provide a better indication of inter-annual spatial variability as well as within-season temporal variability – apparently essential for constructing an accurate picture of the factors that contribute to pollock year-class success in their first year of life. The timing of the samples is important since there now appears to be some evidence of different spatial distributions of adult pollock in years leading to strong year-classes (Buckley et al., 2001, Figure 5), which may influence the dominance of different spawning habitats, which in turn would affect the timing of arrival of different cohorts of age-0 pollock to the Pribilof region. That there is significant change in the spatial distribution of age-0 pollock over the summer is supported by a comparison of the distribution of age-0 pollock in early July 1999 from the MACE survey (Figure 4) with the same distribution from the *Oshoro Maru* in late July 1999 (Figure 2). Clearly more pollock were close to the Pribilof Islands later in the summer. The pattern may have been different, however, in 1984 and 1985, when age-0 pollock

abundance was highest near the Pribilof Islands in early July (Figure 3a) and in 1987, when abundance was high near the Pribilof Islands, but higher still near Unimak Pass (Figure 3b). Changes in spatial patterns of age-0 pollock in early summer could result from changes in the spawning distribution of different cohorts (Figure 5).

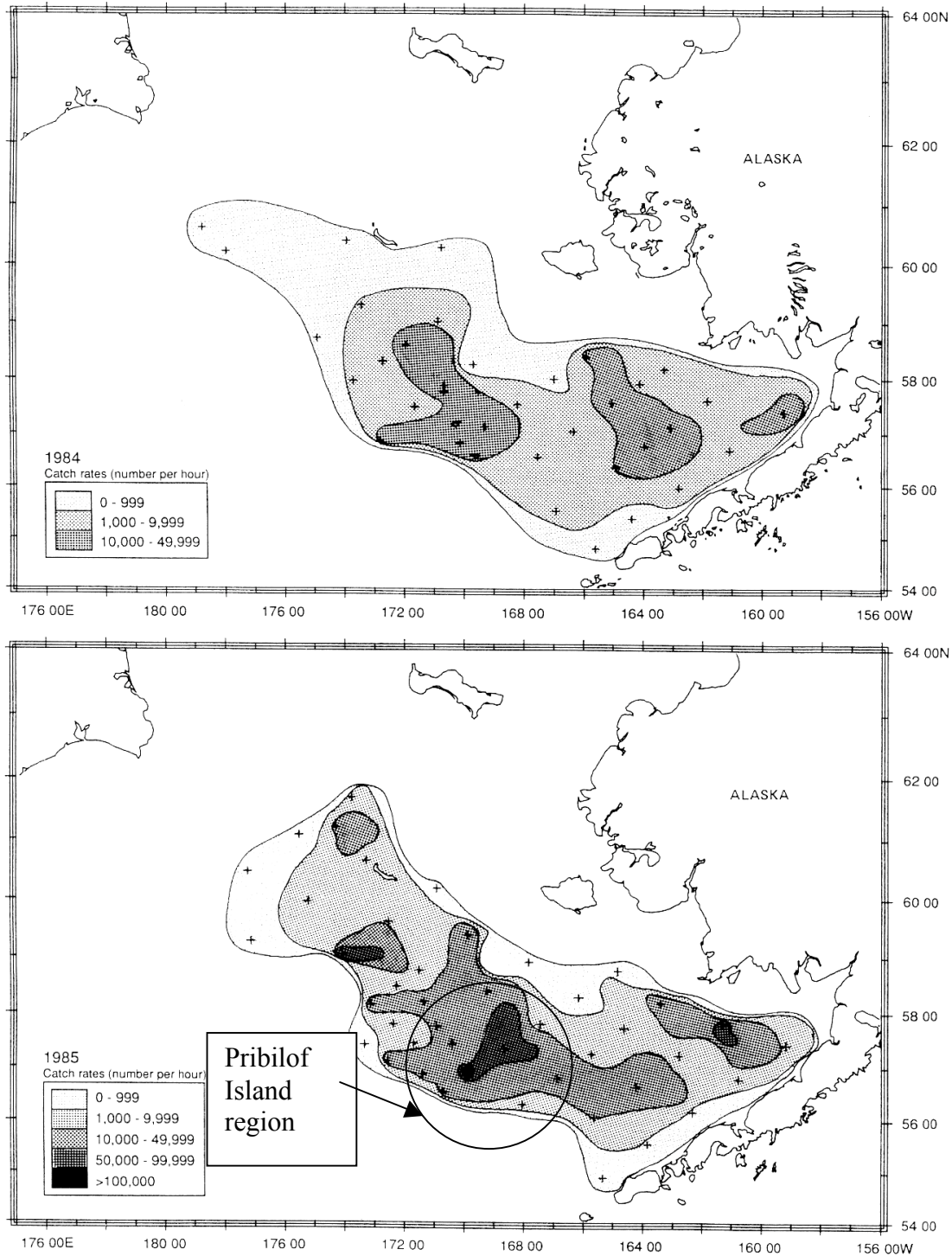




Figure 3a. Catch-rate distributions for age-0 walleye pollock in the EBS during 1984 (upper panel) and 1985 (lower panel). Reproduced from Traynor and Smith, (1996). A 100-n.m. radius region is shown around the Pribilof Islands.

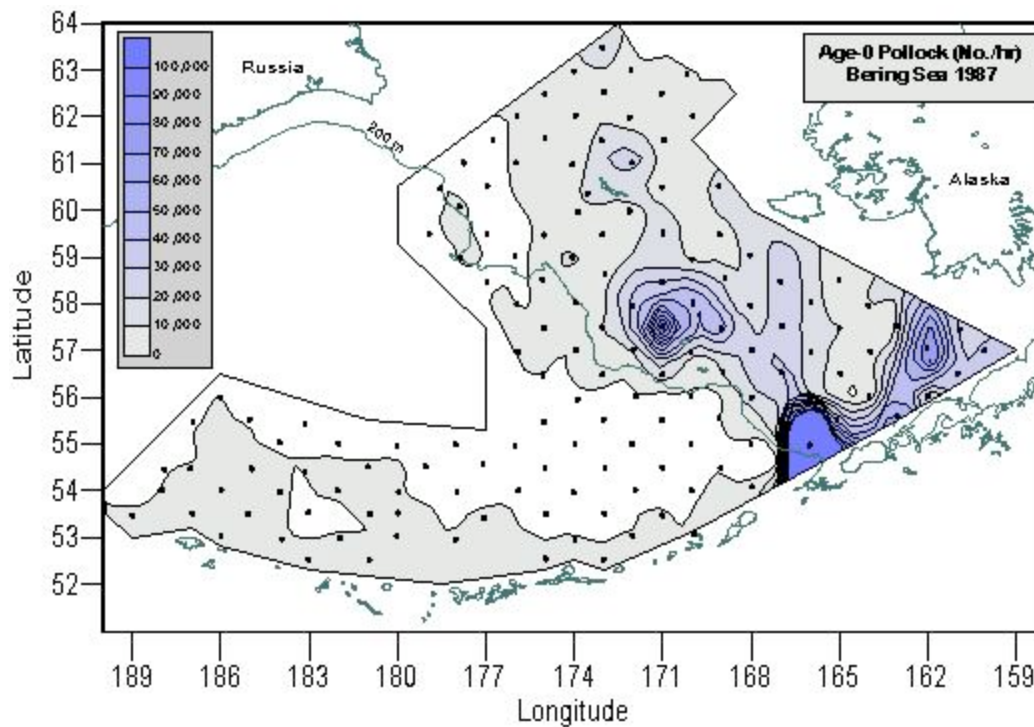


Figure 3b. Distribution for age-0 walleye pollock in the EBS during summer 1987 taken from the Russian survey aboard the *MV Darwin*.

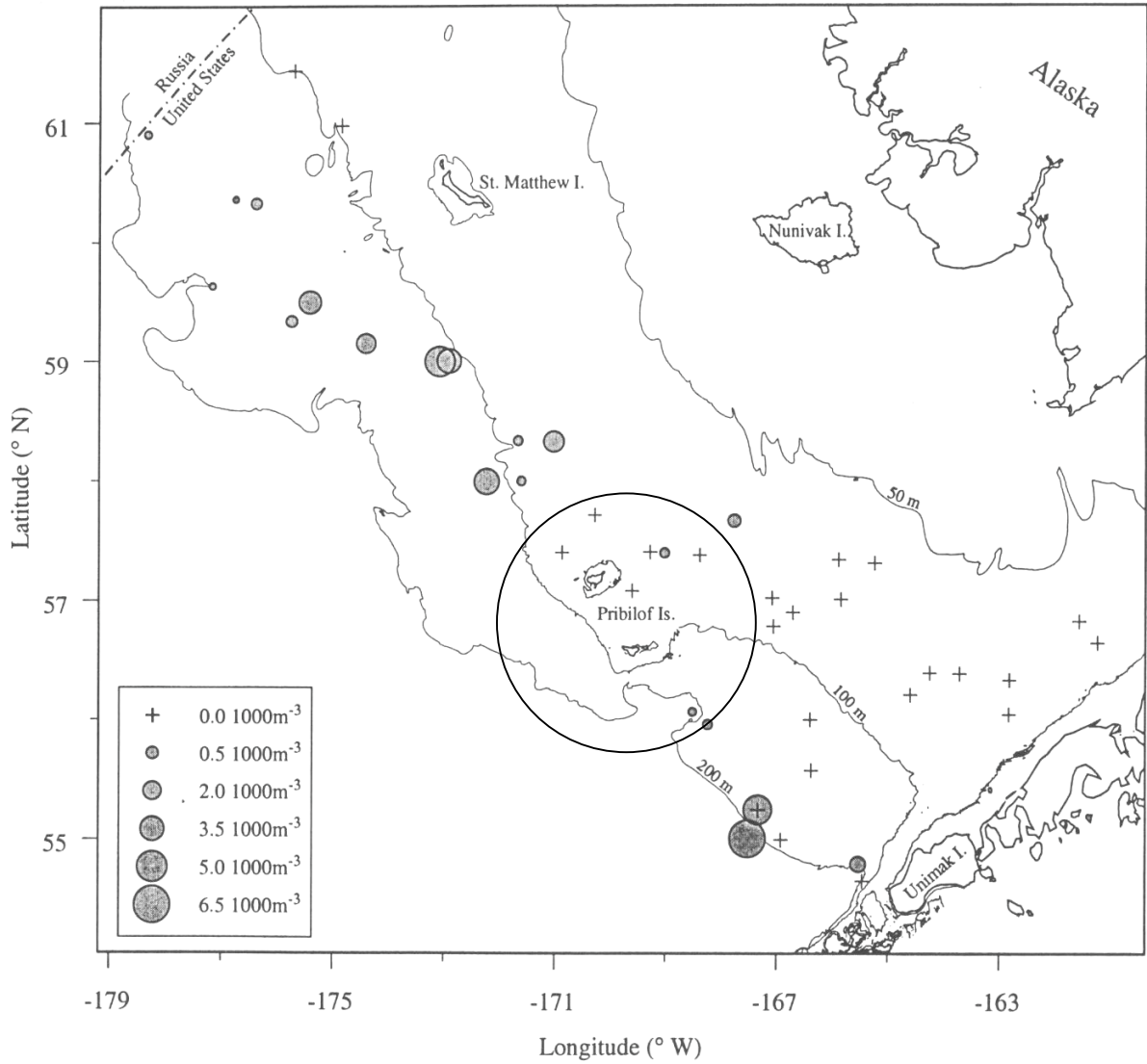


Figure 4. Distribution of age-0 gadids observed from the 1999 summer (June-July) EIT survey (from Honkalehto et al., 2002).

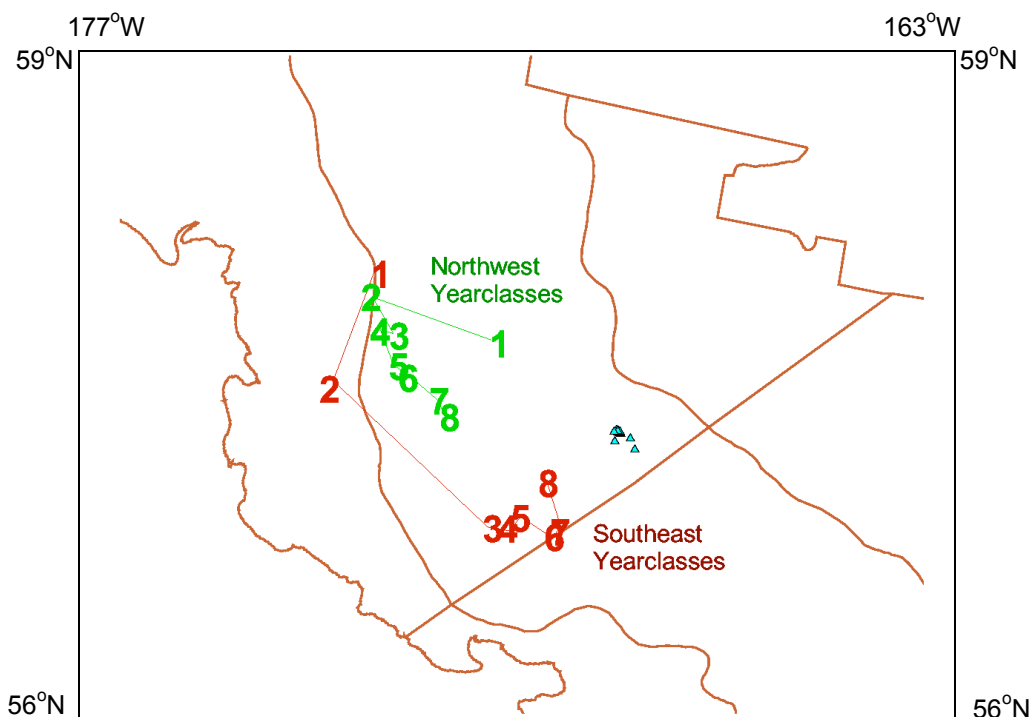


Figure 5. The average locations (centroids), ages 1-8 for pollock year-classes that remain concentrated in the NW area of the EBS shelf and those that shift southeastward as they age. Triangles represent the centers of survey operations in each year. The average is computed from the period 1975-2001 with 1975-1978, 1989, and 1990 representing the “southeast” year-classes and all other (since 1975) representing “northwest” year-classes.

*iii. Acoustic survey comparisons between Pribilof and Inner Front surveys.*

A comparison of acoustic data between the Pribilof region and several acoustic transects in the Inner Front region of the eastern Bering Sea was conducted by Andreas Winter and Ken Coyle. Initial work was needed to standardize the data between the two surveys, because different acoustic systems were used for the different surveys. The main difference between the acoustics was the horizontal resolution of the data. Direct comparisons of pollock and zooplankton abundance were made for 1997, 1998 and 1999 survey years, when data were available in both areas. Acoustic data were collected across the Inner Front at four locations; at Slime Bank near Unimak Pass and Port Moller along the Aleutian inner front and Nunivak and Newenham transect off the Yukon-Kuskokwin river delta (Figure 6). Net sample data collected by Coyle and Pinchuk, (2002) suggested that the abundance of both age-0 pollock and zooplankton be about the same order of magnitude as the Pribilof. This was corroborated by the current acoustic data comparison. In each region data were subdivided into nearshore, offshore stratified and transition regions. A comparison was made with data collected along transect A near the Pribilof Islands (Figure 1). Winter and Coyle found that the nearshore domains in all transects and years generally had the lowest abundance of both fish and zooplankton, while the stratified region generally had the highest abundance for both groups (Figure 7; details in Appendix I). Also, there was general agreement in year-to-year changes in age-0 pollock

abundance between all Inner Front and Pribilof transects, with 1997 having the lowest and 1999 generally having the highest abundance. A comparison of the depth distribution of young-of-the-year pollock and zooplankton showed no apparent differences between regions and no consistent patterns (Appendix I). It is likely that the daytime depth distribution of fish and zooplankton depends on the size and abundance of the fish as well as the depth and strength of the thermocline (Swartzman et al., 2002).

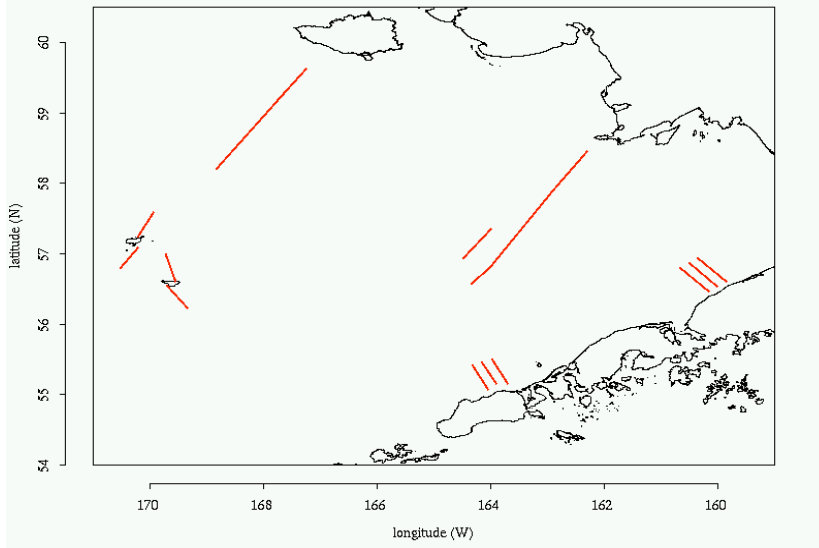


Figure 6. Acoustic survey areas used in comparing the Pribilof Island with other shelf areas in the Bering Sea.

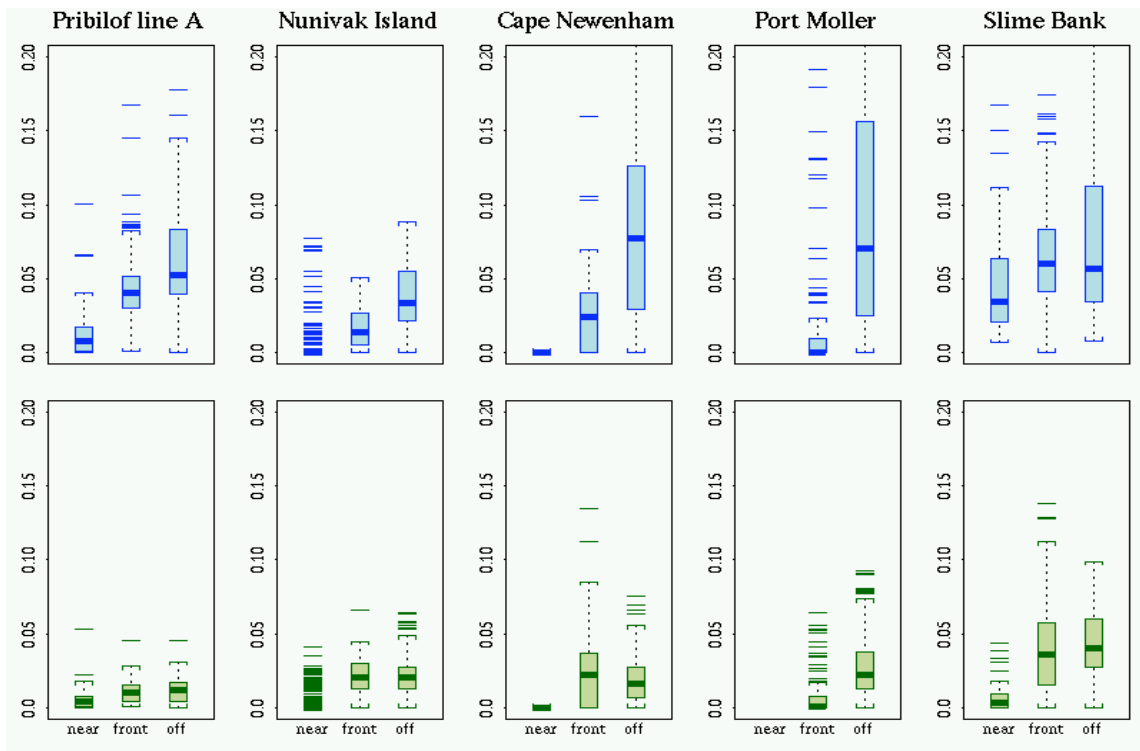


Figure 7. Comparison of age-0 pollock (upper panels) and zooplankton (lower panels) abundance per 250-m horizontal bin in the nearshore tidally mixed, transition front, and offshore stratified zones in four surveyed areas along the Bering Sea shelf in 1999.

## B. Evidence concerning access to the Pribilof area by larvae from different spawning regions

An indication of how many larvae ended up near the Pribilof Islands is available for most years from 1994-2000 based on drifters released near the two major known pollock spawning areas in the eastern Bering Sea – Bogoslov Island and the Unimak Pass area (Napp et al., 2000). Plots of the paths of these drifters are available online at <http://www.pmel.noaa.gov/foci/visualizations/drifter>. There is also a third large spawning area near the mouth of the Pribilof Canyon, smaller than the other two (Napp et al., 2000). Most drifters were drogued at 45-m depth during April or early May. This depth appears to be somewhat deeper than the average depth of pollock larvae (Napp et al., 2000 report an April 1992 study showing highest aggregations of pollock larvae at a depth of 30 m with few larvae below 50-m). A significant fraction of these eventually drifted near the Pribilofs and some were entrained in the slow current around the islands. Stabeno (PMEL, Seattle WA, personal communication) estimated, for the years 1994-2000, of the relative fraction of drifters that passed the Pribilof Islands. The classes were low (less than 20%), medium (20-40%) and high (> 40%) of the drifters passing the Pribilofs. All the years were classed as medium, except 1995 and 2000 (high) and 1998 (no data). In all cases drifters released in April or May did not arrive near the Pribilofs until late August or September, at the earliest. Since the Unimak Pass spawning generally occurs in April (Napp et al, 2000) it is unlikely that the age-0 pollock observed in the Pribilof region in June and July (see above) came from Unimak Pass. Bogoslov Island

spawning is generally earlier (March) and thus, it is feasible, if drifter data are representative of larval drift, that larvae could be advected toward the Pribilofs and arrive there in June or July. However, this, and other evidence on the distribution of adult pollock (Figure 5 and Buckley section below), suggest that the primary source for pollock observed in June and July may be the Pribilof Canyon and other smaller spawning areas closer to the Pribilof Islands. There may also be some genetic differences between pollock found northwest and southeast of the Pribilof Islands (Kevin Bailey, Alaska Fisheries Science Center, personal communication), which may make possible identification of the age-0 pollock spawning location.

### **C. What percentage of juvenile pollock is represented by the Pribilof Island population?**

The region around the Pribilof Islands has been suggested as a region of unusually high production in the eastern Bering Sea, and it has been termed a green belt (Springer et al., 1996). This hypothesis is supported by evidence from Sambroto et al., (1986) and Flint et al., (2002). These studies showed higher primary and secondary production in the Pribilof Island frontal regions. Flint et al., (2002) argue that current and mixing processes around fronts bring higher nutrient concentrations to the euphotic zone, enhancing production.

Comparison of the abundance of zooplankton and fish around the Pribilof Islands with other front areas (work by Winter and Coyle reported here) suggest that abundance in the Pribilof region is no higher than in other eastern Bering Sea frontal regions. While standing stocks are higher in the front region than nearshore, they appear to be generally higher in stratified waters offshore of the coastal front (Figure 7). However, T/S *Oshoro Maru* data (Figure 2) suggest that abundance of age-0 pollock around the Pribilof Islands is consistently higher than in adjacent shelf and offshore stations.

Thus, we hypothesize that abundance of age-0 pollock and macro-zooplankton around the Pribilof Islands and in other frontal regions in the eastern Bering Sea is generally elevated compared with shelf and basin abundance, but not with abundance in other frontal areas of the eastern Bering Sea. That the Pribilof area supports elevated densities of seabirds and marine mammals compared with other Bering Sea frontal areas without increased age-0 pollock abundance may be due to its isolation and the closeness of the front regions to land more than its elevated production. We hypothesize that, although front regions may have elevated primary production relative to adjacent stratified areas, the abundance of macro-zooplankton and juvenile fish may be consistently higher in the stratified than in front areas. The greater depths of the stratified regions may provide some protection from predation for zooplankton and age-0 pollock through diel migration (Swartzman et al., 2002). The greater distance from shore in stratified regions may result in some reduction for age-0 pollock in marine mammal and bird predation, through providing a wider area to disperse. Finally, stratified areas adjacent to frontal regions may have enhanced production due to transport from the front regions. The stratified regions at the extremities of transect A (away from the islands) did not show any reduction in age-0 pollock abundance (Swartzman et al., 2002), while the *Oshoro Maru* data did show reduced age-0 pollock abundance in shelf regions more remote from the Pribilof Islands.

This suggests that a longer transect than transect A might have been necessary to detect a lessening in pollock abundance away from the Pribilof Islands.

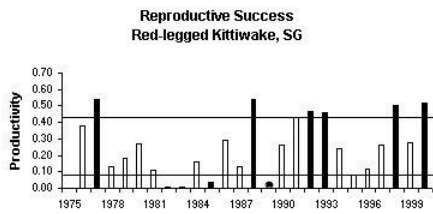
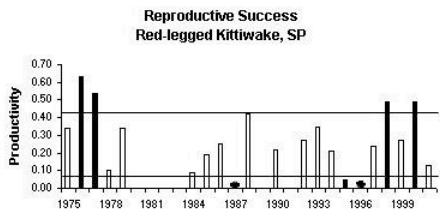
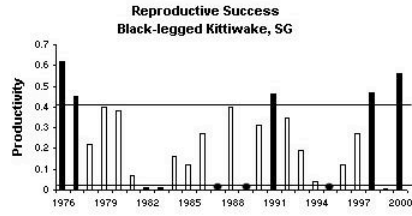
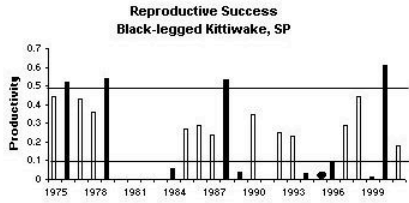
Given data, as discussed above, on age-0 pollock abundance near the Pribilof Islands, near other Inner Front regions, along the MACE survey route and in shelf areas farther from the Pribilof Islands (*Oshoro Maru* data), it is possible to compute the fraction of the entire eastern Bering Sea age-0 pollock abundance near the Pribilof region by computing the total area in five habitats: nearshore, front and shelf adjacent to fronts, other shelf and basin and then multiplying these areas by the density of pollock per unit area. However this was not done because it was difficult to relate the abundance from data taken at different times of the summer (late June, late July and early September), because 1) these distributions appear to change over time and 2) substantial mortality accrues between the early and later periods. Thus we provide only the rough abundance ratios in Table 1.

The dominance of particular year classes and differences in their spatial distribution may explain why in some years early July surveys showed high abundance of age-0 pollock around the Pribilofs (e.g., 1984 and 1985), while in others (e.g., 1999) their abundance was lower than in other survey areas. From 1994-2000 the abundance of age-0 pollock, sampled in late July by the T/S *Oshoro Maru*, was consistently higher near the Pribilof Islands than in surrounding areas. Perhaps as the age-0 pollock become larger and more able to maintain position, they tend to congregate near the Pribilof Islands, whereas earlier in the year happenstance of birth location determines how abundant they are near the Pribilof Islands.

### **3. How does the abundance of age-0 pollock near the Pribilof Islands relate to diet, survival and energetics of higher predators?**

#### **Bird survival and energetics (George Hunt and Lucy Vlietstra)**

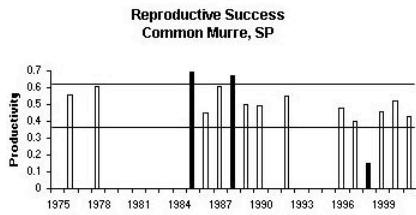
It has been difficult to establish a relationship between pollock abundance near the Pribilof Islands bird population or energetics parameters. Fledging success on St. George and St. Paul islands were highly correlated for black and red-legged kittiwakes and common murre, but not for thick-billed murre (Figure 8). This would suggest that some environmental conditions around the islands are affecting all the breeding colonies on the islands in the same way, except not thick-billed murre. However, no relationship to age-0 pollock abundance and fledging success of any of these species was found. The only significant relationship was with black-legged kittiwake fledging success and age 3+ pollock abundance, and it was a negative relationship (Figure 9). This may possibly indicate competition for age-0 pollock (or maybe zooplankton?) food resources. Current efforts on diets of these bird species may shed some light on the importance of age-0 pollock to these birds. Hunt and Vlietstra did find that diets of black-legged kittiwakes in the 1970s changed through the summer, from primarily age-1 pollock in July-August to primarily age-0 pollock in September. Since these birds are near-surface feeders, this suggests that the age-1 pollock became deeper and unavailable sometime in later summer, while age-0 pollock became large enough to provide some energetic resources for the kittiwakes (Figure 10).



Black-legged Kittiwake  
 Reproduction between islands:  
 $r = 0.87, P < 0.0001$

Red-legged Kittiwake  
 Reproduction between islands:  
 $r = 0.84, P < 0.0001$

Vlietstra and Hunt



Common Murre  
 Reproduction between islands:  
 $r = 0.84, P = 0.0006$

Thick-billed Murre  
 Reproduction between islands:  
 $r = 0.06, P = 0.827$

Vlietstra and Hunt



Figure 8. Reproductive success in murres and kittiwakes on the Pribilof Islands, AK. Horizontal bars show range of mean ( $\pm$ SD). Solid bars indicate years in which reproductive success exceeds or falls below this range.

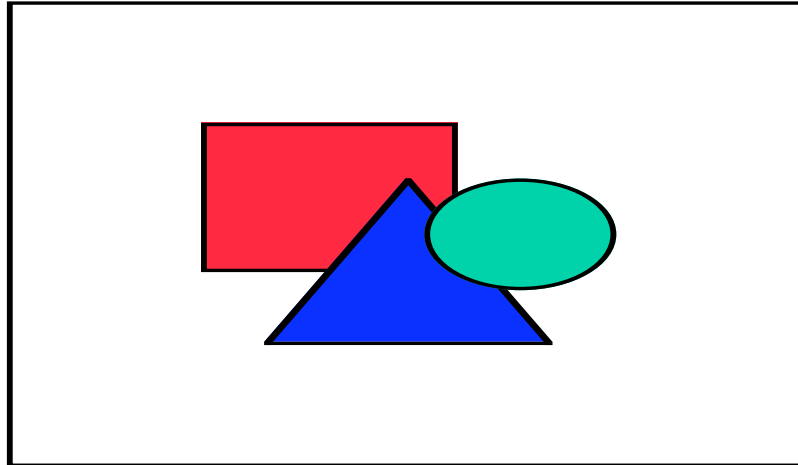


Figure 9. Relationship between black-legged kittiwake on the Pribilof Islands, AK and shelf-wide, age-3 pollock abundance

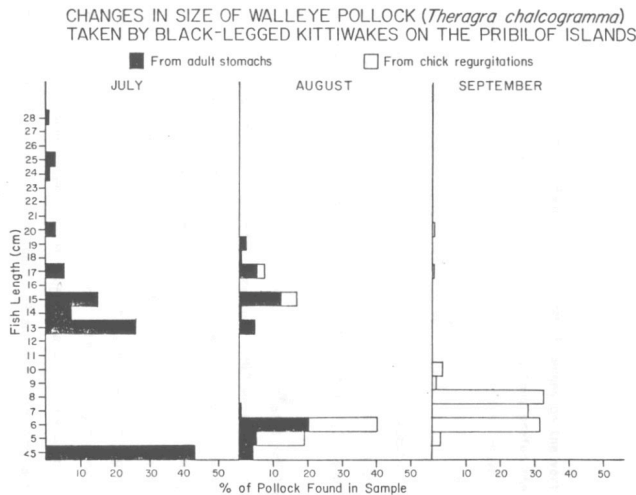


Figure 10. Seasonal length distribution of walleye pollock taken by black-legged kittiwakes on the Pribilof Islands, AK.

**Relationship between age-0 pollock and fur sea diets - Studies of pollock otoliths in fur seal scat collected on the Pribilof Islands 1994-1999 (Rolf Ream)**

Scat samples from female foraging fur seals have been collected for many years on the Pribilof Islands. We investigated the possibility that the abundance of age-0 pollock otoliths in the scat can be used as a surrogate for pollock abundance to extend the data base to previous years and perhaps use scat for prediction of age-0 pollock abundance. Although they feed over a wide area, it has been suggested that female fur seals resident for the summer on the Pribilof Islands may top up their stomachs with age-0 pollock just

before returning to land. This is supported by scat data, which show a consistently high presence (and percentage) of age-0 pollock in the scats (Figure 11) and diving behavior from tagged seals (data from Mike Goebel, University of California, Santa Cruz). As such, it was felt that age-0 pollock otoliths in fur seal scat might be indicative of their near-Pribilof abundance.

Trajectories of tagged, feeding fur seals (Robson, 2001, Jeremy Sterling, National Marine Mammal Laboratory, personal communication) suggest that the feeding areas of fur seals depend on the location of their rookery. We examined the percent occurrence of age-0 pollock otoliths in fur seal scat collected on rookeries adjacent to the four Pribilof Island acoustic transects (Figure 1) for 1994-1999 with an eye to the relationship of this percentage to the acoustic abundance of age-0 pollock on each of these transects and years.

Scats were collected from rookeries at the end of August. Adult, post-parturient females are the main group of feeding northern fur seals present and the rookery and thus the scat data primarily represent their diet. Based on preliminary telemetry data (Jeremy Sterling, National Marine Mammal Laboratory, personal communication), females forage closer to the island than juvenile males, so their scats may better represent the food base, and availability of pollock, closer to the Pribilofs. The data may be biased towards the last meal on the return leg of the foraging trip, which is desirable for this study because this percentage is more indicative of pollock abundance on the study transects rather than farther afield where fur seals usually feed before returning to the Islands.

Otoliths were used to identify and age pollock. Percent occurrence (PO or FO) was calculated as the number of samples with a given age class of pollock, divided by the number of samples with pollock otoliths that could be aged.

Data were examined first for all rookeries combined on St. Paul in 1994-1999 (1994, 1996 highest for age 0 pollock, 1998 lowest). 1997 had the lowest age-0 pollock abundance. There appears to be an increased percent occurrence in scat of older rather than age-0 pollock in 1997.

Data from individual rookeries on St. Paul were then assigned to acoustic transects A, B, and C (Swartzman, personal communication) based on the overlap of the female foraging locations and the location of the transects. Note that some rookeries were assigned to two transects. For transect A (NE St. Paul) the percent occurrence of age-0 pollock was highest in 1994 and lowest in 1998 and 1995). Transect B (SW St. Paul) had a similar percent occurrence of age-0 pollock for most years, with the exception of 1998 when it was much lower. On transect C (SE St. Paul) the percent occurrence of age-0 pollock was highest in 1994 and 1996, lowest in 1998 (Figure 11). Data from 1999 is included only for completeness because the sample size is too small.

Finally, data for all rookeries on St. George were combined to correspond to transect D. The percent occurrence of age-0 pollock was highest in 1995 and 1996, lowest in 1998

and 1997. In general it appears that the percent occurrence of older pollock is greater on St. George (Rolf Ream, unpublished data), though 1996 had very few older pollock.

These results (Figure 11) suggest that percentage of age-0 pollock in fur seal scat cannot be used to distinguish large year classes because the percentages of age-0 pollock in the scats are so high in most cases. It would be preferable to explore the relationship between age-0 pollock otoliths in scat and pollock abundance using the percentage of otoliths in the scat rather than percent occurrence (percent of the samples that have any age-0 pollock otoliths). Nonetheless, the data suggest that low abundance year classes may be distinguishable using percent occurrence of age-0 pollock otoliths in fur sea scat.

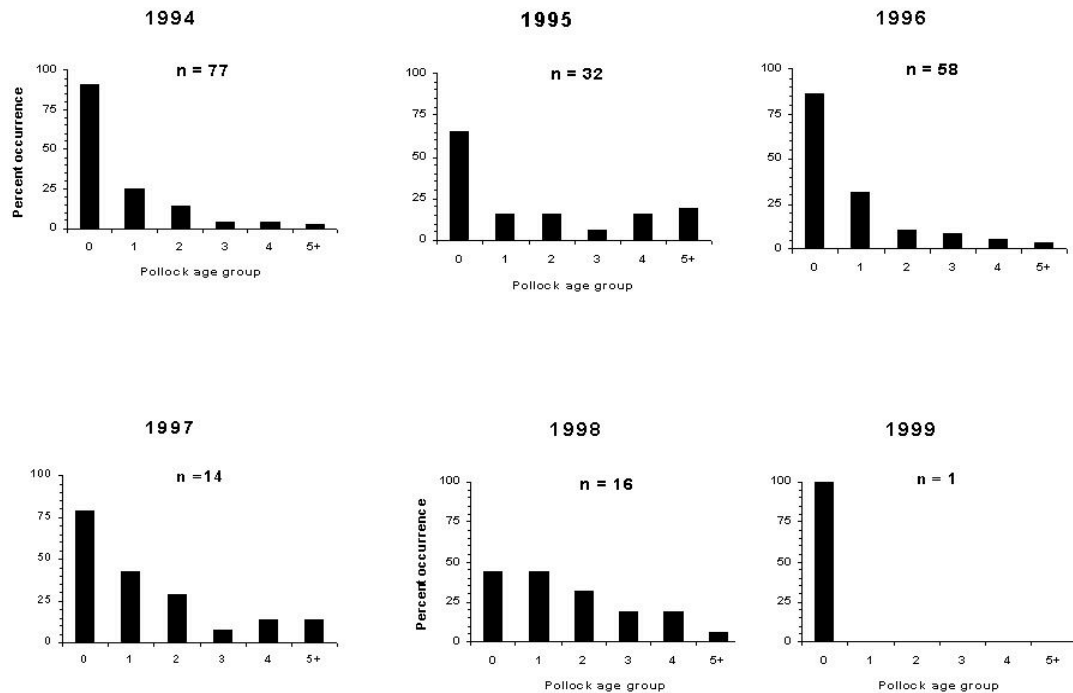


Figure 11. Percent occurrence of different age classes of pollock in fur seal scat collected on St. Paul Island rookeries adjacent to transect A.

#### 4. How important is predation to pollock abundance near the Pribilof Islands?

Several approaches were adopted to look at the importance of predation to the abundance and distribution of age-0 pollock near the Pribilof Islands:

- A. Comparison of pollock abundance and distribution along transect A (Figure 1) to the abundance of groundfish predators (see Lang et al., 2000).
- B. Comparison of the relative abundance of age 1+ pollock and other age-0 pollock fish predators by year in the Pribilof Island region to their abundance in other shelf regions including the Inner Front region and to the abundance of age-0 pollock (from acoustic surveys) in the Pribilof Island region. This comparison will be based on data collected in the annual groundfish survey in July-August (1978-2001).

- C. Review of the Pribilof Island acoustic surveys and the Inner Front surveys (by Andreas Winter) to assess where fish schools having large target strength (for individual targets) were encountered along the transects and to relate this to the distribution of age-0 pollock (i.e., are they proximate or divergent from the predator locations?).
- D. Use of the ECOPATH model (Ciannelli) for the Pribilof Island region to estimate the amount of consumption during September of each study year (1994-1999) of age-0 pollock by fur seals, fish predators, jellyfish and birds and compare this to standing stock and production. Diet information will be updated with input from Troy Buckley (groundfish), Rolf Ream and Beth Sinclair (fur seals) and George Hunt and Lucy Vlietstra (birds).

Of these approaches, work on A is already published and work on C. has not yet been attempted.

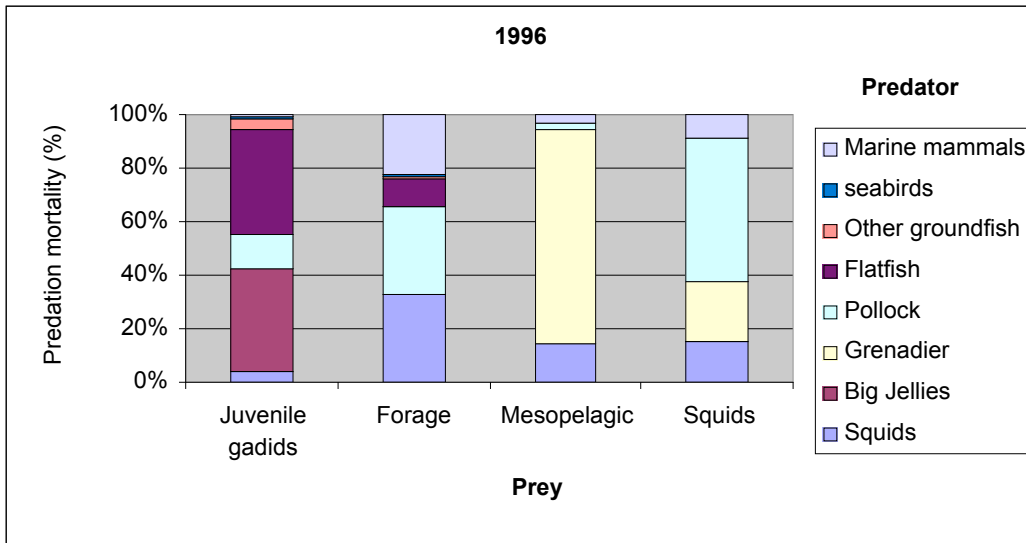
### **B. Predation by fish on age-0 pollock near the Pribilof Islands compared with other areas in the Eastern Bering Sea (Troy Buckley)**

Predation by fishes on age-0 walleye pollock has been described as part of a larger, ongoing study examining the trophic relationships in the eastern Bering Sea (Livingston 1991, Livingston et al., 1993, Livingston and deReynier, 1996, Lang et al., in prep.). In these documents the length composition, the relationship to predator size, and the geographic distribution of predation of walleye pollock are described. From these documents it appears that signals from strong year classes can be seen in the prey-length composition of various fish predators. Currently these data are being compiled and analyzed with regard to the spatial distribution of the prey including age-0 walleye pollock. The diet of predatory fish in the Pribilof region will be examined to see whether these diets include more age-0 walleye pollock than the diet in other areas and whether this changes from year to year. If the diets of Pribilof Island region groundfish are higher in age-0 pollock, this could suggest higher densities of age-0 pollock and/or that there is higher vulnerability to predation in that area. A majority of these data are collected during the spring and summer when piscivory tends to be lower because of the abundance of zooplankton. Lang et al. (2000) conducted a study directed toward examining predation on age-0 walleye pollock in the vicinity of the Pribilof Islands in late summer and found very high rates of predation. Ciannelli (2002) reviewed data from Lang et al., (2000) and suggested that predation pressure may vary considerably from year to year.

Information on the distribution of walleye pollock year classes ages 1 through 8 suggested that some year classes predominated in the northwestern part of the eastern Bering Sea, while others appeared to predominate in the southeastern part of the EBS (Figure 6; Buckley et al.; <http://www.afsc.noaa.gov/refm/reem/Default.htm>). Northwest year classes, which appear to remain from year to year in the northwestern region during the summer, may not be contributing to the Bogoslov and Unimak spawning stocks. Spawning has been observed northwest of the Pribilof Islands from June through August (Hinckley, 1987).

**D. Results of ECOPATH analysis for 1996-1997 by Lorenzo Ciannelli**

The ECOPATH model (Polovina et al, 1984), which was discussed earlier on the basis of an average year, was run for the Pribilof Island region for 1996 and 1997 separately. These years were chosen because the age-0 pollock abundance was extreme for the study period, being highest in 1996 and lowest in 1997. Figure 12 compares the percentage of total consumption of several groups, including juvenile gadids (over 90% age-0 pollock) for 1996 with that in 1997. While the model runs in Figure 12 include differences in age-0 pollock abundance for the two years, they assume the same diet selectivity for all their



predators does not account for possible differences in abundance between these predators.

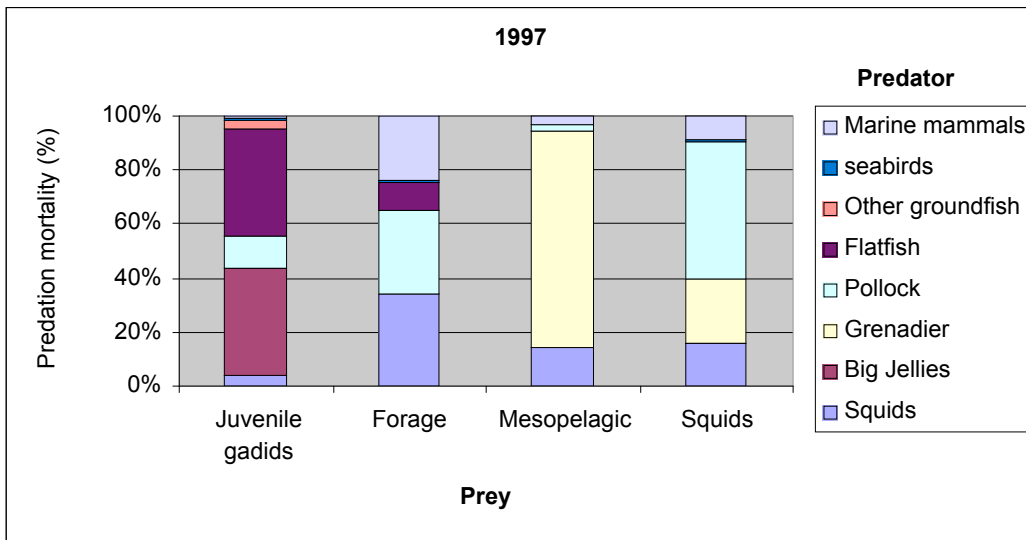


Figure 12. Partition of predation mortality of key forage species, 1996 & 1997

As can be seen (Figure 12), there is little to choose from between the two years. In both years flatfish and large jellyfish dominate predation on juvenile gadids, with adult pollock also contributing a significant amount of mortality through cannibalism. The results are almost identical despite the large difference in abundance. These results, which are admittedly speculative, reflect the linear nature of the model as well as the model parameters chosen. There was not enough time to analyze the groundfish stomach contents in those two years to distinguish any major change in diet composition. As such, only the biomass estimate of age-0 pollock changed, which apparently did not affect mortality sources as much as the diet compositions did. Future work, with diet information, as outlined the previous section of this report may remedy this situation. The extremely high predation by jellyfish on juvenile gadids is surprising. Although large jellyfish and age-0 pollock are seen in close association, the two being forced together in the cod end of nets may bias the consumption of pollock by jellyfish. On the other hand jellyfish showed extremely large increases in abundance near the Pribilof Islands during the 1990s and in theory could have eaten a lot of age-0 pollock in 1996 and 1997.

Although we have not attempted the calculation, because of our concerns about model parameter estimates, it is possible to compute, for each year, the total consumption of age-0 pollock by various predators and its percentage of the standing stock. To do so, however, considerable effort will be needed to improve our estimates of year-to-year changes in predator abundance as well as diets in the neighborhood of the Pribilof Islands – work that is proceeding apace, but not yet finished. Given the predicted large impact of jellyfish predation on age-0 pollock, further effort is needed on substantiating the consumption rates, abundance and diet composition of jellyfish – a project not yet attempted.

## **5. Pribilof age-0 pollock as an index of pollock year-class-strength – Jim Ianelli**

Each year the EBS pollock stock is analyzed for fishery management purposes. This analysis consists of an integrated statistical assessment based on several different types of observations. The primary data analyzed include annual bottom-trawl surveys of the entire shelf area (within the US EEZ), bi-annual echo-integration trawl (EIT) surveys of this region, annual fishery catch data from scientific observers aboard fishing vessels, and estimates of biological characteristics (e.g., age composition, growth, and maturation). These assessment analyses lead to recommendations on risk-averse harvest levels for the coming year.

The risk-averse aspects of harvest recommendations include levels of uncertainty in both the observations and the physical processes affecting the population. For example, pollock in this region are well known to have highly variable year classes (coefficients of variation on the order of 60%). As this variability propagates through the population, a key variable quota determination is affected: estimated pollock biomass. It is therefore useful to be able to reliably estimate the abundance of incoming (pre-recruit) pollock.

One suggestion is that for a relatively small sampling effort, abundance of age-0 pollock around the Pribilof Islands can provide a useful index of year-class strength. Preliminary comparisons (Swartzman et al., 2002) with results from assessment analysis (Ianelli et al., 2001) suggest that an index of this type might prove useful (Figure 13). This is particularly appealing when one examines similarly constructed indices with other pollock surveys since both the bottom trawl and EIT surveys provide some indication of pre-recruit abundance at later stages (Figures 14 & 15). The root mean squared errors for these three indices (relative to the assessment model prediction in log-space) are:

Pribilof Age 0	Age 1 Bottom trawl survey	Age 3 EIT survey
0.725	0.532	0.713

Note that in the assessment analyses, the overall abundance estimates (e.g., the area-swept estimate of total population numbers) are treated independently from estimates of the age composition. This appeals to the way the population is sampled and sub-sampled for age compositions and avoids independence problems of statistically fitting several separate sets of indices-at-age. Furthermore, the indices as presented above are only for representation and do not reflect the fact that assessment model allows for changes in age-specific availability over time (Ianelli et al., 2001).

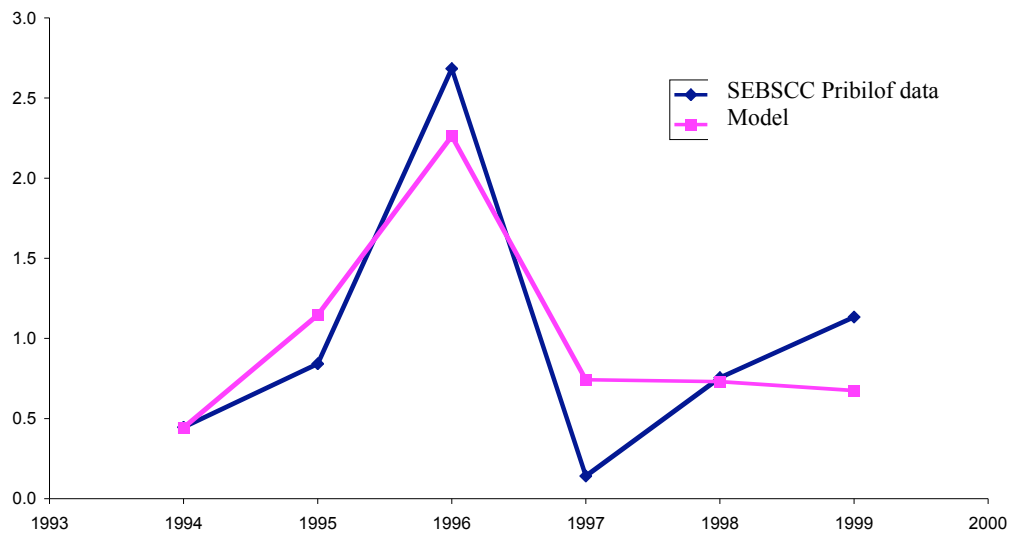


Figure 13. Pribilof young-of-the-year index relative to assessment results from Ianelli et al., (2001). Units are arbitrary.

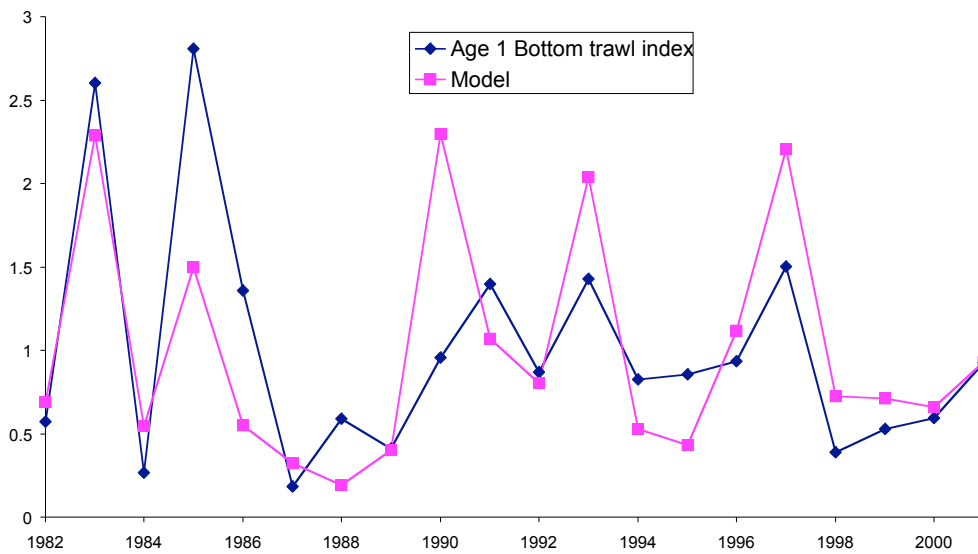


Figure 14. NMFS bottom trawl survey age-1 index relative to assessment results from Ianelli et al., (2001). Units in numbers rescaled to have a mean value of 1.

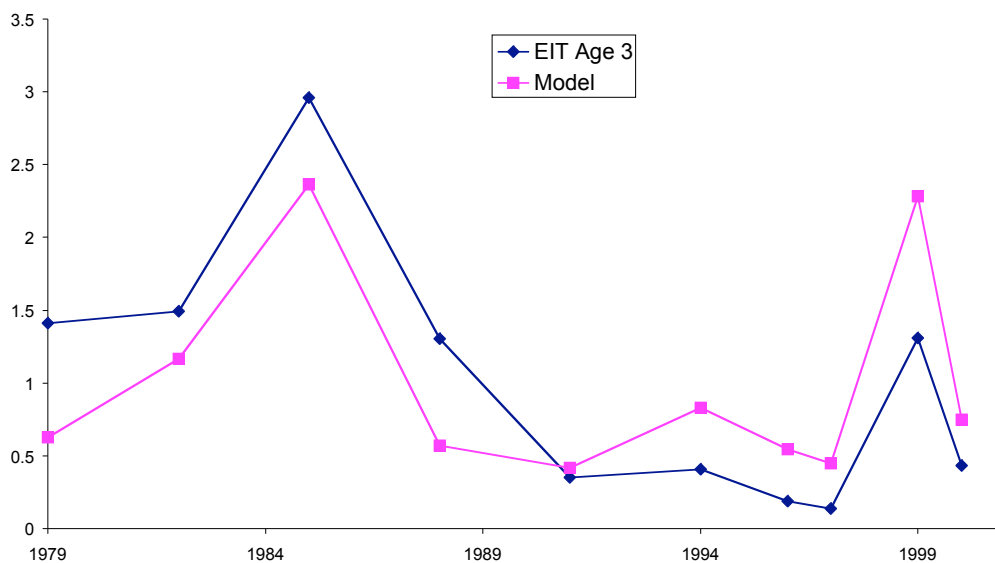


Figure 15. NMFS EIT survey age-3 index relative to assessment results from Ianelli et al., (2001). Units in numbers re-scaled to have a mean value of 1. Note that the observations do not occur in every year.

## Summary and Conclusions

In this report we addressed the importance of age-0 pollock in the Pribilof Island region as a possible indicator of Eastern Bering Sea pollock recruitment and the relationship of age-0 pollock to their predators. To this end we also considered how large an area to include as the Pribilof Region and how age-0 pollock abundance in the Pribilof Island region relates to their abundance in other parts of the Eastern Bering Sea.



- We defined the Pribilof Island region as an area extending along the shelf and shelf-break 100 nautical miles from the center of the Islands, based on runs of the energetic-trophic web- based ECOPATH model that suggested that this region had the highest ecological efficiency – that is the largest percentage of the energetic demand of region biota was met by food sources within the region.
- We examined the abundance density (abundance per unit area) of age-0 pollock near the Pribilof Islands relative to abundance in surrounding shelf areas and areas along the Inner Front, and found that, while pollock abundance was generally higher than in the surrounding area it was about the same as abundance in the Inner Front region.
- Based on drogued buoys released during the spawning season near the Unimak pass pollock spawning area, a significant percentage of the buoys ended up near the Pribilof Islands, suggesting that the pollock during summer are likely coming from these spawning areas. There were year-to-year changes in the percentage of released buoys reaching the Pribilof Islands. Based on the timing of these results pollock found near the Pribilof Islands during June and July, on which some of our comparisons are based, could not have come from the Bogoslov and Unimak spawning areas and were spawned closer to the islands.
- There may be an interaction between the spatial distribution of adults, that appears to have two modes over the years – a northwest and southeast mode – the relative importance of different pollock spawning areas and the summer wind patterns which can influence changes in the distribution of age-0 pollock over the summer. To wit, the abundance of age-0 pollock near the Pribilof Islands may change drastically throughout the summer.
- It is difficult to establish a relationship between bird and mammal diets and abundance of age-0 pollock near the Pribilof Islands. No such relationships were found for murrelets or kittiwakes. Percent occurrence of age-0 pollock in fur seal otoliths was high throughout most summers, which suggests that large year classes cannot be distinguished from moderate sized year class from scat samples. However, small pollock year classes may be distinguishable using scat data.
- When autumn age-0 pollock abundance near the Pribilof Islands, assessed using a acoustic survey from 1994-1999, was compared to pollock recruitment from the AFSC pollock model, the root mean square error was about the same as similar comparisons of the pollock model to age-1 estimates from the annual bottom trawl survey and age-3 estimates from the EIS survey. This suggests that age-0 pollock may provide an acceptable early predictor for pollock year-class-strength.

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## **APPENDICES**

### **Appendix I. Comparison of abundance of juvenile pollock and zooplankton between the Pribilof Islands and other shelf areas in the Eastern Bering Sea based on acoustic surveys in 1997, 1998 and 1999 by Andreas Winter and Kenneth Coyle**

The waters around the Pribilof Islands, AK have been identified as an important nursery area for juvenile walleye pollock (Swartzman *et al.* 2002). Hydrographic fronts surrounding these islands (Stabeno *et al.* 1999) are believed to play an important role in

structuring the habitat and concentrating food resources for the juvenile fish (Ciannelli *et al.* 2002), as likewise fronts occurring in other regions of the eastern Bering Sea (Coyle and Pinchuk 2002).

It has been suggested that conditions for juvenile pollock in the Pribilof Islands area may be representative of rearing conditions throughout the Bering Sea (Brodeur and Wilson 1999, Swartzman *et al.* 2002) and serve as an indicator for Bering Sea pollock production. Thus, a question of current interest is how the Pribilof Islands area compares to other frontal regions with respect to the population of juvenile pollock it supports from year to year. In this paper, we address the question by examining echo-integration data from three recent years (1997, 1998, 1999) in which acoustic fishery surveys were conducted, at approximately the same times, around the Pribilof Islands and four other locations of the eastern Bering Sea.

## Methods

The Pribilof surveys were carried out in September of each year under the Bering Sea FOCI (Macklin 1999a) and SEBSCC programs (Macklin 1999b), and occupied four transects radiating north and south from St. Paul and St. George Islands (Figure 1). Acoustic data on these surveys were collected using a hull-mounted SIMRAD EK-500 split-beam echo-sounder system operating at 38 and 120 kHz, and integrated to horizontal x vertical resolutions of ~9 m x 0.5 m in 1997 and 1999, and ~9 m x 1 m in 1998.

Nunivak Island, Cape Newenham, Port Moller and Slime Bank were surveyed between late July and early September as part of the Inner Fronts project (Coyle and Pinchuk 2002). Each sampling location comprised up to three parallel transect lines running orthogonal to the bathymetry (Figure 1). Acoustic data were collected with an HTI model split-beam system operating at 43 and 120 kHz. Sampling was conducted during the day only. The transducers were towed beside the vessel about 4 m from the hull and 2 m below the surface. Echo data were integrated to (horizontal x vertical) ~180 m x 2 m in 1997, and ~45 m x 1 m in 1998 and 1999.

The acoustic data were processed to delineate shoals of fish and patches of zooplankton. In order to derive comparable biomass indices, a common algorithm was applied to the data of both sets of surveys. This algorithm is described in Swartzman *et al.* 1999 and 2002. Briefly, the spatial echo-integration units (i.e., pixels) are thresholded to the ranges of backscatter expected for fish or zooplankton aggregations at the appropriate frequency, and morphologically filtered to retain only contiguous areas (patches) greater than a given minimum size. Fish shoals only are expected to have backscatter within threshold range at the low frequency, and having higher backscatter (above a minimum value) at the high frequency than at the low frequency identifies zooplankton patches.

Since this algorithm was designed for the Pribilof Islands surveys (38 and 120 kHz; ~9 m horizontal resolution), adjustments had to be taken into consideration for using it on the Inner Fronts surveys (43 and 120 kHz; ~45 – 180 m horizontal resolution). The difference between 38 and 43 kHz as the low frequency turned out to be negligible for juvenile pollock, as evidenced by target strength vs. length plots calculated from the

Kirchhoff ray mode model (E. Hazen and J. Horne, University of Washington, pers. comm.).

However, the large discrepancies in echo-integration resolution (9 m vs. 45 – 180 m horizontally) required calibration of the backscatter-difference value used to identify zooplankton patches. Since each pixel averages the echo return over its area, a larger pixel size (lower resolution) requires a lower backscatter-difference value to represent the same level of discrimination between the two frequencies. Through empirical testing we found an appropriate calibration factor to be given by dividing the backscatter-difference value by the square root of the ratio of the spatial resolutions that need to be normalized with each other. For example, 5 dB is used as the standard backscatter-difference value for spatial resolutions averaging 9 m x 0.5 m (Swartzman et al. 1999). A spatial resolution of 45 m x 1 m would thus be set to a backscatter difference of:

After processing of the echo-integration data, acoustic biomass indices for fish and zooplankton were calculated as the sums of backscatter ( $s_A$ ) per pixel x pixel area. Acoustic biomass totals were calculated separately for sampling locations and for habitat regions at each location; i.e., nearshore (mixed), front, and offshore (stratified) habitats. Boundaries between habitat regions follow the definition of Stabeno *et al.* (1999), and are described in Ciannelli *et al.* (2002), Kachel *et al.* (2002), and Swartzman *et al.* (2002).

Acoustic biomass totals of pollock and zooplankton per area and habitat are summarized as box plots in Figures 2 – 4 for each year of the study. Following the convention used by Swartzman *et al.* (1999), the data were binned by 250 m of horizontal distance. The acoustic biomass totals per bin were then modeled as a function of distance using generalized additive models (GAM; Hastie and Tibshirani 1990). In order to standardize transects and highlight the effect of fronts, distances were scaled to an index such that the front region of each transect goes from 0 (nearshore boundary) to 1 (offshore boundary). These GAMs are plotted in Figures 5 – 7. The relative distributions by depth of the acoustic biomass are plotted in Figure 8 for each study area and year.

At this point, only transect lines ‘A’ of the Pribilof Islands surveys have been included in the analysis.

## Results

Three of the five study areas were surveyed in all three years. Pribilof line A had its lowest average pollock biomass density in 1997, and the acoustic pollock sign tended to be clustered near the inner boundary of the front. In 1998 and 1999 the pollock sign was denser, and more evenly distributed among habitats, with maximum concentration near the outer boundary of the front. Both pollock and zooplankton average acoustic biomass were concentrated closest to the bottom in 1997, and highest in the water in 1999. Among individual transects within each year the depth distribution was variable.

In the Nunivak Island area, average pollock biomass was lowest in 1997 over the nearshore and front habitats, and lowest offshore in 1998. One acoustic transect was recorded in 1997, and showed pollock sign to be maximal near the outer boundary of the front, with vertical distribution throughout the water column. Offshore, the heaviest pollock sign occurred high in the water, with a second mode at intermediate depth, and near shore small schools were present mid-water and near bottom. In 1998, density increased from nearshore outwards, leveled through the front and increased again offshore. The nearshore pollock sign occurred on the bottom, and from the front towards offshore formed a narrow mid-water band. In 1999, very little pollock sign was detected nearshore; the acoustic density increased through the front, leveled off around the outer boundary of the front; then increased again offshore.

The Slime Bank area also had its overall lowest pollock densities in 1997 (although the near-shore was not surveyed that year). Pollock density decreased beyond the outer boundary of the front and predominantly moved to deeper water. In 1998, average pollock densities increased from shore to the front leveled off across the front then increased again offshore. In 1999, densities increased through the outer boundary of the front, then decreased. In both 1998 and 1999, acoustic pollock sign occurred mostly near-bottom in the shallows and slope of the transects, and throughout the water column in the deep part. In 1998, the offshore depth distribution spread towards distinct modes in deep- and mid-water. In 1999, a dense, narrow band of pollock sign was also detected just below the surface.

Cape Newenham was surveyed in 1998 and 1999. In 1998, pollock density increased from the outer part of the front towards offshore. Separate aggregations high and low in the water column were evident across the length of the transects. The smaller, upper bands of acoustic sign appeared distinctly restricted by the thermocline below. In 1999, pollock density increased near-monotonically from nearshore to offshore, with a slight plateau at the outer boundary of the front. No pollock sign at all was detected in the nearshore region. Horizontally stratified biomass distributions, similar to 1998, occurred throughout the front and offshore.

Port Moller was surveyed only in 1999, from the front to offshore. Average pollock density increased in the offshore direction until just beyond the outer boundary of the front, then leveled off. The average vertical distributions were the most uniform of any of the surveys, although some evidence of stratification did appear on the transects.

## Discussion

The 2001 eastern Bering Sea pollock stock assessment (Ianelli *et al.* 2001) estimated 1-year old stock sizes of 16482, 16233, and 14994 millions from respectively the 1997, 1998, and 1999 year classes. The relative sizes of those stock assessments are not supported by the acoustic survey data presented here. Rather, 1997 appeared to be substantially the weakest year-class throughout the eastern Bering Sea. The temporal variability of the Inner Fronts surveys prohibits definite conclusions about the absolute quantities of biomass, but the data are sufficiently consistent to indicate larger numbers of age-0 fish in 1998 and 1999 than in 1997. The average offshore densities were highest in 1999 in all areas surveyed (non-significantly different from 1998 in the Pribilof area), and lowest in 1997 in all areas except Nunivak Island. The three easternmost areas (Cape Newenham, Port Moller and Slime Bank) had very consistent average offshore densities in 1999; the year that all three were surveyed. Cape Newenham and Slime Bank were similar also in 1998, suggesting that the juvenile pollock populations in those areas be closely related. Pribilof and Nunivak Islands varied independently of the other three areas, but their acoustic biomass were always within the same order of magnitude.

Average acoustic plankton biomass was lowest in all habitat regions in 1997 for Nunivak Island and Slime Bank areas, and lowest on Pribilof line A everywhere except the front region. All areas except the Nunivak Island front region had higher average plankton biomass in 1998 than in 1999, although the differences were generally not very great. By contrast, Coyle and Pinchuk (2002) found no evidence of significant interannual differences in euphausiid biomass. The relative density distributions of acoustic plankton sign, as a function of distance index, closely matched the distributions of fish sign in most areas and years (Figures 5 – 7). The only two really visible exceptions are Pribilof line A in 1997, where plankton densities remained near maximum in the offshore while fish densities strongly decreased; and Slime Bank in 1997 where fish densities were high throughout the front, while plankton densities increased from the inner to the outer boundary of the front.

Frontal structures had an evident impact on the horizontal distributions of fish biomass. In five of the twelve survey areas, the maximum of the GAM density smooth occurred within 30% of the frontal width from the outer boundary (i.e., distance index 0.97 – 1.30). In three further surveys, either the absolute or a local maximum density occurred inside the front. Overall, maximum fish density, and maximum plankton density, was offshore of the fronts in all surveys except Pribilof line A 1997 and 1998.

The relative depth distributions of pollock and zooplankton substantially correlated over most of the surveys. Exceptions occurred primarily in areas of high pollock density, e.g. Slime Bank and



Port Moller offshore in 1999; and Pribilof line A front and offshore in 1998 (Figure 8). Those observations may indicate consumption or avoidance, but are possibly due to masking of the acoustic zooplankton sign by pollock. As the transects in this study were recorded by day, the patterns cannot be directly interpreted as feeding interactions, which are known to take place primarily at dusk (Schabetsberger *et al.* 2000). A common overall trend among the surveys appears to be that pollock were deepest in the water in 1997, intermediate in 1998, and nearest to the surface in 1999. Further data analyses will be needed to examine possible causes for this outcome, e.g. predation pressure from above or below; or the water temperature gradients.

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### Figure legends

Fig. 1. Locations of late summer/fall acoustic surveys in the eastern Bering Sea, 1997 – 1999.

Fig. 2. Box plots of acoustic biomass per 250 m bin, by habitat region, in each survey area, 1997. Top panels (blue): pollock. Bottom panels (green): zooplankton.

Fig. 3. Box plots of acoustic biomass per 250 m bin, by habitat region, in each survey area, 1998. Top panels (blue): pollock. Bottom panels (green): zooplankton.

Fig. 4. Box plots of acoustic biomass per 250 m bin, by habitat region, in each survey area, 1999. Top panels (blue): pollock. Bottom panels (green): zooplankton.

Fig. 5. GAM smoothed plots of acoustic density as a function of distance index per survey area in 1997. Vertical lines on the plots mark the inner and outer boundaries of the hydrographic fronts.

Fig. 6. GAM smoothed plots of acoustic density as a function of distance index per survey area in 1998. Vertical lines on the plots mark the inner and outer boundaries of the hydrographic fronts.

Fig. 7. GAM smoothed plots of acoustic density as a function of distance index per survey area in 1999. Vertical lines on the plots mark the inner and outer boundaries of the hydrographic fronts.

Fig. 8. Bar plots of the relative depth distributions in 1 m decrements of acoustic pollock (blue) and zooplankton (green) biomass in each survey area by year and habitat region. Each panel represents from left to right the nearshore, front, and offshore regions.

