Abstract—Effects of year and region on young-of-the-year (age-0) walleye pollock abundance and size were examined by using bottom and midwater trawl collections made during 1985–88. Samples were collected from shelf and coastal areas in three adjacent regions of the western Gulf of Alaska. The primary focus was to examine regional differences in recruitment prediction and annual differences in fish distribution. Fish density was used to indicate abundance, and length was included as a relevant factor in fish production. Year and region significantly interacted as effects on age-0 density. Recruitment prediction was best in the Kodiak Island region, upstream of the main spawning area, where fish densities were high during 1985 and 1988 in relation to 1986 and 1987. On a large scale, fish were evenly distributed every year, except during 1987 when their density increased strongly from east to west. Age-0 length also varied with year and region. This was apparent after accounting for daily increases in mean length (0.09 cm/d). Fish were comparatively small during 1986, intermediate during 1985, and large during 1987 and 1988. Regional differences in fish length were due to a relative abundance of large-size fish around Kodiak Island where the average size was about 0.75 cm larger than elsewhere. Thus, a relative abundance of large individuals in this region was associated with good recruitment prediction. These results are discussed in terms of their relevance to spatial variation in the production of recruits.

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Effects of year and region on the abundance and size of age-0 walleye pollock, *Theragra chalcogramma*, in the western Gulf of Alaska, 1985–1988*

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Young-of-the-year (age-0) fish abundance is used in managing temperate marine resources (Goodyear, 1985; Bailey et al., 1986; Johannessen and Tveite, 1989; Sundby et al., 1989; Galaktionov, 1993; Corten[1]). Estimating the abundance of age-0 fish, however, is complicated by their broad and sometimes variable spatial distributions. This variability, which can obscure shifts in distribution from changes in abundance (Olsen and Soldal, 1989; de LaFontaine et al., 1992; Polacheck et al., 1992; Anderson et al., 1995), may affect survival.

Walleye pollock, *Theragra chalcogramma*, are semidemersal gadids that reside in the North Pacific Ocean (Lynde, 1984; Springer, 1992; Wolotira et al., 1993). The National Oceanic and Atmospheric Administration (NOAA) has sought to understand and predict pollock recruitment better because of the commercial importance and recruitment variability of the species (Kendall and Duker, 1998; Hollowed et al.[2]; Wespestad et al.[3]). Much of the research on pollock recruitment has been done in the western Gulf of Alaska (GOA) as part of NOAA's Fisheries Oceanography Coordinated Investigations (FOCI) program (Schumacher and Kendall, 1991; Kendall et al., 1996).

In the GOA, many pollock spawn during early April in southwestern Shelikof Strait (Picquelle and Megrey, 1993) (Fig. 1). This spawning is believed to be primarily responsible for replenishing the GOA pollock stock (Kendall and Picquelle, 1990; Hollowed et al.[2]). FOCI researchers have devised a transport paradigm for young pollock of Shelikof Strait, in which they move with the prevailing currents from the main spawning area in the Strait to shelf and coastal nurseries farther southwest (Schumacher and Kendall, 1995; Kendall et al., 1996). Although some individuals may be carried beyond the shelf, the oceanic North Pacific is not considered an important pollock nursery area (Smith et al., 1984). This pattern of dispersal, hereafter referred to as the FOCI recruit-pathway paradigm, was demonstrated in 1987 (Hinckley et al., 1991), and it has been simulated by a model of larval transport that incorporates detailed physical and biological information (Hermann et al., 1996a,

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[1] Corten, A. 1986. Application of the results from international young fish surveys in fisheries management in recent years. ICES, Doc. C.M. 1986/G:54, 26 p.

[2] Hollowed, A. B., E. Brown, J. Ianelli, P. Livingston, B. Megrey, and C. Wilson. 1997. Walleye pollock. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 31–119. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

[3] Wespestad, V. G., J. N. Ianelli, L. Fritz, T. Honkalehto, N. Williamson, and G. Walters. 1997. Bering Sea-Aleutian Islands walleye pollock assessment for 1998. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 35–102. Prepared by the Bering Sea/ Aleutian Islands Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

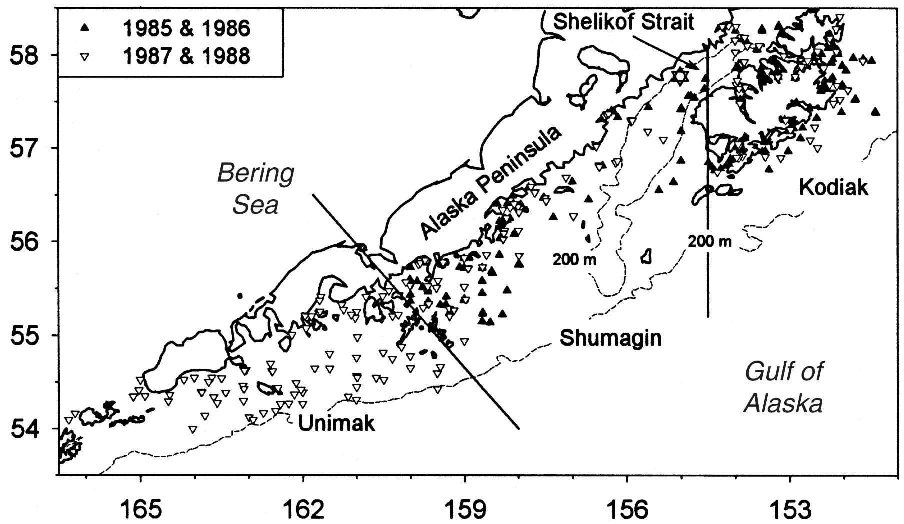

Figure 1

Map of the NMFS exploratory sampling locations for age-0 pollock in the western Gulf of Alaska, August–October, 1985–88. The straight lines delineate the three regions used to group the data geographically. The star (☆), near the head of the arrow pointing to Shelikof Strait, marks the major pollock spawning area.

1996b). Consequently, the shelf area west of Shelikof Strait has received the most attention recently regarding pollock nurseries in the western GOA (Brodeur et al., 1995; Wilson et al., 1996).

Not all observed distributions of age-0 pollock, however, are consistent with the FOCI recruit-pathway paradigm. In 1980–82, some incidental collections of age-0 pollock were made during bottom trawls for shrimp in bays throughout the western GOA. High age-0 densities were found northeast of the main spawning area and led Smith et al. (1984) to conclude that important spawning areas probably exist farther upstream. Small concentrations of pollock eggs, larvae (Kendall and Picquelle, 1990; Dunn et al.[4]), and spawning adults have been found throughout the western GOA (Hirschberger and Smith, 1983; Hollowed et al.[2]; Williamson[5]; Karp[6]; Wilson et al.[7]). This does not, however, preclude the possibility that dispersal of young from Shelikof Strait is more variable than previously thought.

In response to conclusions drawn by Smith et al. (1984), the National Marine Fisheries Service (NMFS) conducted more spatially extensive surveys designed to map age-0 abundance and size (Spring and Bailey[8]). These surveys occurred during 1985–88. The data were included in a compilation of information by Bailey and Spring (1992) primarily to show that year-class strength was set by the age-0 stage. Like Smith et al. (1984), however, Bailey and Spring also found that many juveniles were present in the Kodiak region during some years.

This study presents a re-examination of the 1985–88 survey data. In this study, however, the effects of year and region were evaluated statistically and length was included due to its relevance to recruitment. Among juvenile fish, size often has a positive effect on survival (Sogard, 1997; Hurst and Conover, 1998; Schultz et al., 1998). Emphasis was placed on annual variability within each of three regions owing to interest in developing a recruitment predictor. Emphasis was also placed on within-year regional variability because of the possibility

[4] Dunn, J. R., A. W. Kendall Jr., R. J. Wolotira Jr., J. H. Bowerman Jr., D. B. Dey, A. C. Materese, and J. E. Munk. 1980. Seasonal composition and food web relationships of marine organisms in the nearshore zone—including components of the ichthyoplankton, meroplankton, and holoplankton. Final Report OCSEAP RU551. Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112, 393 p.

[5] Williamson, N. J. 1989. Acoustic-midwater trawl surveys for walleye pollock in the Gulf of Alaska in 1989. *In* Condition of groundfish resources of the Gulf of Alaska in 1989 (T. K. Wilderbuer, ed.), p. 281–311. U.S. Dep. Commer., Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115.

[6] Karp, W. A. 1990. Results of echo integration midwater-trawl surveys for walleye pollock in the Gulf of Alaska in 1990. *In* Stock assessment and fishery evaluation report for the 1991 Gulf of Alaska groundfish fishery, Appendix 3, 42 p. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

[7] Wilson C., M. Guttormsen, and S. K. de Blois. 1996. Echo integration-trawl survey results for pollock in the Gulf of Alaska during 1996. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, p. 417–443. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

[8] Spring, S., and K. Bailey. 1991. Distribution and abundance of juvenile pollock from historical shrimp trawl surveys in the western Gulf of Alaska. U.S. Dep. Commer., NOAA Proc. Rep. AFSC 91-18, 66 p.

that the Kodiak region is sometimes a relatively important nursery area despite its position upstream of the main spawning area.

Materials and methods

The data selected for this study comprise the longest time series available from the GOA where the collection method was consistent (Bailey and Spring, 1992; Spring and Bailey[8]). They were collected in late summer (August–October) 1985–88 by the NMFS (Fig. 1, Table 1). The purpose of these surveys was to obtain a coarse picture of the distribution and size of age-0 pollock in the western GOA; These surveys were the first to target age-0 pollock in this area and, as such, were exploratory.

The area surveyed was the continental shelf and bays around Kodiak Island and as far southwest as time allowed (Fig. 1). The Alaska Coastal Current (ACC) flows southwestward through the area but circulation is complicated by sea valleys, islands, and other topographic complexity (Lagerloef, 1983; Reed and Schumacher, 1986; Stabeno et al., 1995). The largest sea valley forms Shelikof Strait and it forms a natural division within the western GOA between eastern and western regions. The Kodiak Island Archipelago is a prominent feature of the eastern region. Smaller islands characterize the western region, which has a relatively broad shelf.

Sampling was accomplished by trawling on echo layers. Echo sign was monitored along predetermined transects. No effort was made to include acoustic data because a preliminary study found no relation between echo sign and age-0 catches (Bailey and Spring, 1992). Samples were collected only during the day, so that the problem of diel vertical fish migration was avoided.

Echo sign believed to be age-0 pollock was sampled by using an 18.6-m high, opening shrimp trawl with steel V-doors (1.5 m × 2.1 m, 568 kg) attached by 18-m bridles. The trawl was made of 3.2-cm stretched-mesh, nylon netting, and a 3-mm mesh liner was inserted into the codend. For bottom samples, a 16.8-m tickler chain was used and the footrope of the net was held above a bottom contact chain by 30-cm chain lengths. For midwater tows, a 363-kg weight was attached to each lower wing to help hold the trawl mouth open, and the chain on the footrope was removed. A netsonde system (BEN-MAR or Furuno) was used to position the trawl vertically at the desired depth. It was not possible to open and close the net at depth. Towing speed and duration averaged about 4.5 km per h and 10–15 min, respectively. At each sampling location, sea surface temperature was measured with a bucket thermometer.

All taxa caught were identified, enumerated, and weighed. At this time of year, age-0 pollock are readily distinguished from older individuals by a clear separation in size (Bailey et al., 1996b; Brodeur and Wilson, 1996a; author's unpubl. data). Fork length was measured to the nearest centimeter. All age-0 pollock were measured except those in large catches, when about 100 randomly selected fish were measured. Length data were missing for five samples, each of which comprised only a few fish.

Table 1

Dates and number of tows made during the 1985–88 NMFS surveys of age-0 pollock in the western Gulf of Alaska. The estimated Gulf-wide abundance for each year class at age-2 from Bailey et al. (1996a) is included as an index of recruitment.

Year	Dates sampled	Number of tows	Recruitment ($\times 10^9$)
1985	21 Aug–10 Sep	113	1.43
1986	3 Sep–9 Oct	95	0.22
1987	12 Aug–20 Sep	118	0.30
1988	18 Aug–10 Sep	80	2.16

The effect of year and region was examined first on age-0 abundance, and then on age-0 length. Finally, year- and region-specific abundance and size estimates were compared with recruitment.

Examination of effects of year and region on age-0 abundance was accomplished in five steps. The first step was to standardize the catch to account for differences in the volume filtered between tows. Volume filtered for each tow was calculated as the trawl mouth area times distance fished. The mouth area was assumed to be 37 m^2 for hauls on the bottom (Wathne, 1977) or 28 m^2 for hauls in midwater (Wilson et al., 1996). No adjustment was made for differences in the depth sampled because most (92%) samples were collected at depths where net dimensions are relatively stable (Wilson et al., 1996). Distance fished was the straight-line distance between two geographic points along which the net was fished at depth. Dividing each age-0 catch by the volume filtered produced fish density (fish per m^3), which was used to indicate abundance. Volume was not converted to sea surface area because of uncertainty about the depth and area represented by each sample. By using density, the assumption of a constant depth and area is explicit, and different values can easily be applied *post-hoc* if an estimate of absolute abundance is desired.

The second step was to adjust for mortality during the 3–5 week survey period. An instantaneous daily mortality rate of 0.014 (Hollowed et al., 1996) was used to adjust each density to the overall median survey date (3 September).

The third step was to account for 22 tows throughout the survey area that were apparently replicates of other tows. Samples were judged to be pseudoreplicates if they were consecutive, were the same type (bottom or midwater), and were within one nautical mile and 50 m depth of each other. The pseudoreplicates were averaged together to give 384 samples from the original 406 trawl hauls.

The fourth step was to group fish densities by geographic area by using the three regions defined by Bailey and Spring (1992). A minor adjustment to this stratification scheme involved moving the delineation between the Unimak and Shumagin regions farther west to better reflect annual differences in sampling effort (Fig. 1). The Unimak Island region was surveyed only during 1987–88. Thus, samples from the area upstream of the main spawning site were separated from samples collected farther downstream, and the difference in large-scale coverage was accommodated.

Finally, statistical tests were conducted to examine effects of year and region on age-0 density, which was not straightforward owing to the occurrence of many zeros and a few very large values in the catch data. Four different procedures were employed and the results were compared. All statistical tests were accomplished with SYSTAT for Windows (Wilkinson, 1996).

The first procedure was a two-way analysis of variance (ANOVA) of two different transformations of all four years of data. One ANOVA was based on a log-transformation (Sparholt et al., 1991) ($\log_{10}$(density)+0.00001, nonzero catches ranged from 0.00001–0.6 fish per m^3) and the other was based on rank-transformed data (Conover, 1980). Neither transformation, however, removed the spike of zeros in the frequency histogram of densities and thus made the requisite assumption of normality tenuous. To avoid empty cells data from the Unimak region were omitted; they were collected only during 1987–88.

The second procedure was a distribution-free, nonparametric test to again look for effects of year and region (Methven and Bajdik, 1994). Unlike Methven and Bajdik (1994), however, the age-0 data were not paired; therefore the signed rank test was replaced by the Kruskal-Wallis test. Because this is a one-way test, subsets of the data were selected so that the effect of the first factor was examined within a level of the second factor (e.g. year within a region) and *vice-versa* (e.g. region within a year) (Valle et al., 1999). In all, seven tests were run. Significance of the outcome for each test was based on the Bonferroni-corrected alpha level of 0.05.

The third and fourth procedures were conducted primarily as a means to circumvent the zero-catch problem but also because of differences in the information conveyed by zero and nonzero catches (Pennington, 1983; Randa, 1984). Zero catches indicate absence, and nonzero catches indicate presence as well as some measure of abundance.

The third procedure involved chi-square tests to test whether the presence or absence of age-0 pollock was associated with year or region. Annual or regional differences in age-0 frequency of occurrence indicate a change in fish patchiness, or a change in the ability to target them; both may be associated with a change in abundance. It was necessary to conduct one chi-square test for each region to examine annual differences and then for each year to examine regional differences. Thus, Bonferroni corrections were again necessary.

The fourth procedure was a two-way ANOVA test of effects of region and year on nonzero densities. The nonzero densities appeared normally distributed after being $\log_{10}$-transformed. Again, the Unimak data were omitted.

A year-region interaction term was included in the ANOVA tests of the first and fourth procedures. Significance of the interaction term indicates that annual differences vary by region, or that regional differences vary by year. The former identifies regions with high annual variability; whereas the latter implies annual variation in fish distribution. Significance of the interaction term determined which multiple comparison test was used *post hoc*. If it was not significant, a Bonferroni multiple comparison test was used for comparing levels of significant main effects. If it was significant, Fisher's least significant difference (LSD) test was preferred. In SYSTAT, the LSD test does not automatically correct for the number of comparisons being made (Wilkinson, 1996). This correction was desirable because only a subset of all possible pair-wise comparisons was of interest. Only comparisons among regions within year and among years within region were of interest, those involving different years and regions (i.e. 1985 Kodiak versus 1986 Shumagin) were excluded. A Bonferroni correction was then applied to the remaining comparisons to maintain an overall 0.05 alpha level.

Examination of effects of year and region on age-0 length was accomplished by using a two-way analysis of covariance (ANCOVA). An ANCOVA was necessary to account for variation in length due to differences in the collection day-of-year (expressed as the number of days since 1 January). The first ANCOVA was used to examine data collected from the Kodiak and Shumagin regions during all four years. The second ANCOVA was conducted with just the 1987 and 1988 data to compare lengths among all three regions. The covariate was not allowed to interact with the main effects (ie. slope homogeneity was assumed rather than tested) owing to the short duration of collecting in some regions and years in relation to the variation in mean length per haul. As in Anderson et al. (1995), the dependant variable was mean length per haul rather than individual length measurements; this variable simplified the model but allowed no within-haul variability. Mean size was weighted by mortality-adjusted fish density.

The relationship between annual estimates of age-0 density or size and recruitment was examined graphically because there were insufficient degrees of freedom for a global significance test of correlation. Pollock recruitment was indicated by the Gulf-wide abundance of age-2 individuals (Bailey et al., 1996a). No attempt was made to account for autocorrelation in this time series because pollock exhibit low autocorrelation in recruitment (Hollowed et al., 1998).

Results

Overall, 406 trawl samples were collected yielding 384 density estimates (zero and nonzero catches) and 335 estimates of mean length (Table 2). Stations were occupied from west to east, except in 1985 when sampling progressed from east to west and then doubled back to end near northeast Kodiak Island. Sampling around Kodiak Island was mostly over the inner shelf and in bays (Fig. 1). Coverage of the outer shelf was best farther west, between 158° and 164°W longitude. Sample depth varied considerably, and it appears that the daytime vertical position of age-0 pollock was also quite variable (Fig. 2).

Abundance

Results from each of the four statistical procedures consistently indicated that year and region interact in their

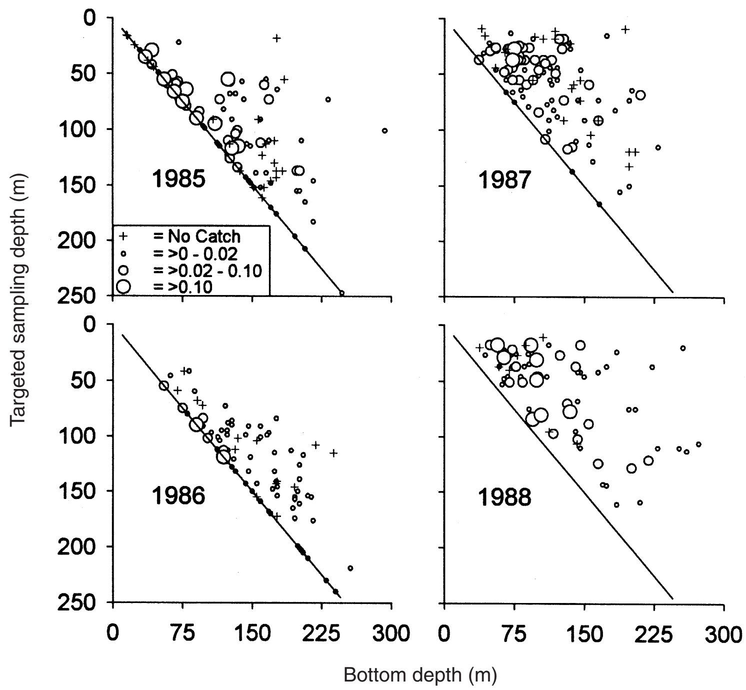

Figure 2

The vertical distribution of age-0 pollock density in the western Gulf of Alaska, August–October, 1985–88. Symbol size indicates the mortality-adjusted number of fish/m^3. The diagonal line indicates bottom depth.

effect on age-0 density. Annual differences were always limited to the Kodiak region where fish densities were high during 1985 and 1988 in relation to 1986 and 1987 (Table 2). Within other regions, annual differences were not significant. As to within-year patterns, regional differences were mostly limited to 1987 when fish density increased strongly from east to west (Fig. 3, Table 2). The distribution in each other year was more even. For brevity, only results from the first statistical procedure are tabulated.

In the first procedure, significant year-region interaction was indicated by each two-way ANOVA of transformed fish densities (Table 3). Fisher's LSD test indicated annual differences only in the Kodiak region (Table 4), where age-0 density was relatively high during 1985 and 1988 (Table 2). The LSD test also indicated regional differences, but only during 1987 or 1988, depending upon transformation (Table 4). When log-transformed, the regional effect was associated with low age-0 densities in the Kodiak region during 1987. When rank-transformed, it was associated with high densities in the same region but during 1988. The Unimak region was excluded from these tests.

In the second procedure, only two of the seven Kruskal-Wallis tests rejected the null hypothesis of equal fish densities. The first indicated an annual effect within the Kodiak region (Kruskal-Wallis test statistic=25.31, P<<0.0001). The second indicated a regional effect within 1987, which included the Unimak region (Kruskal-Wallis test statistic=32.24, P<<0.0001).

In the third procedure, only one chi-square test outcome was significant (chi-square=15.19, P=0.0005). During 1987, the frequency of occurrence around Kodiak Island was low (65%) in relation to occurrences in the Unimak region (98%) (Table 2).

In the fourth procedure, the two-way ANOVA of nonzero densities revealed a significant year-region interaction (df=3,241, F=4.462, P=0.005). Fisher's LSD test indicated that all differences occurred within the Kodiak region where nonzero density was relatively high during 1985 and 1988 (Table 2).

Length

Overall, 35,530 age-0 pollock were measured. They were collected from 335 trawl hauls and ranged from 3 to 13 cm FL. Significant effects of year and region were detected after accounting for a day-of-year effect (Table 5).

Daily increases in mean length per haul averaged 0.090 cm (Fig. 4), which is within the range of published growth rates for these fish (0.6–1.2 mm/d) (Bailey et al., 1996b). Two samples had unusually low mean length per haul (in 1986 and 1987) and were from bays; these represented few fish and so had little effect on the fitted lines.

Annual differences in length were due to a comparatively small mean size during 1986, a medium size during 1985, and large sizes during 1987 and 1988 (Fig. 4, Table 2). A Bonferroni multiple comparison test indicated that 1985 and

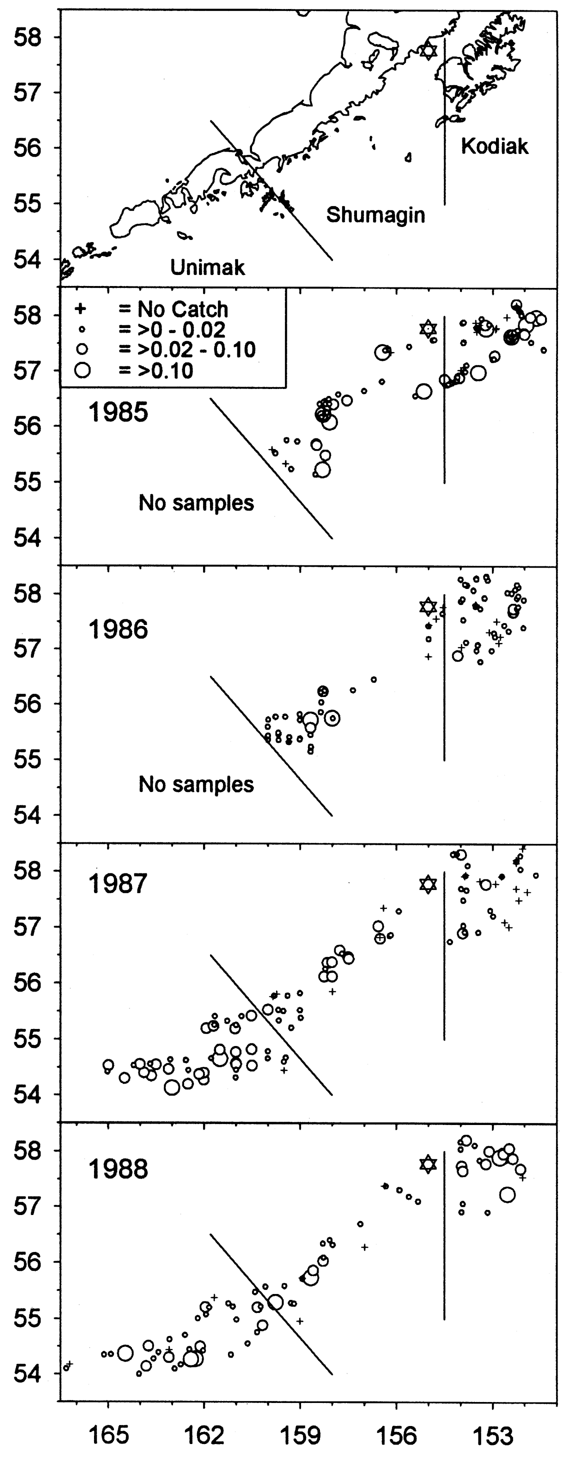

Figure 3

The geographic distribution of age-0 pollock density in the western Gulf of Alaska, August–October, 1985–88. Symbol size indicates the mortality-adjusted number of fish/m³. The star (☆) marks the major pollock spawning area in Shelikof Strait.

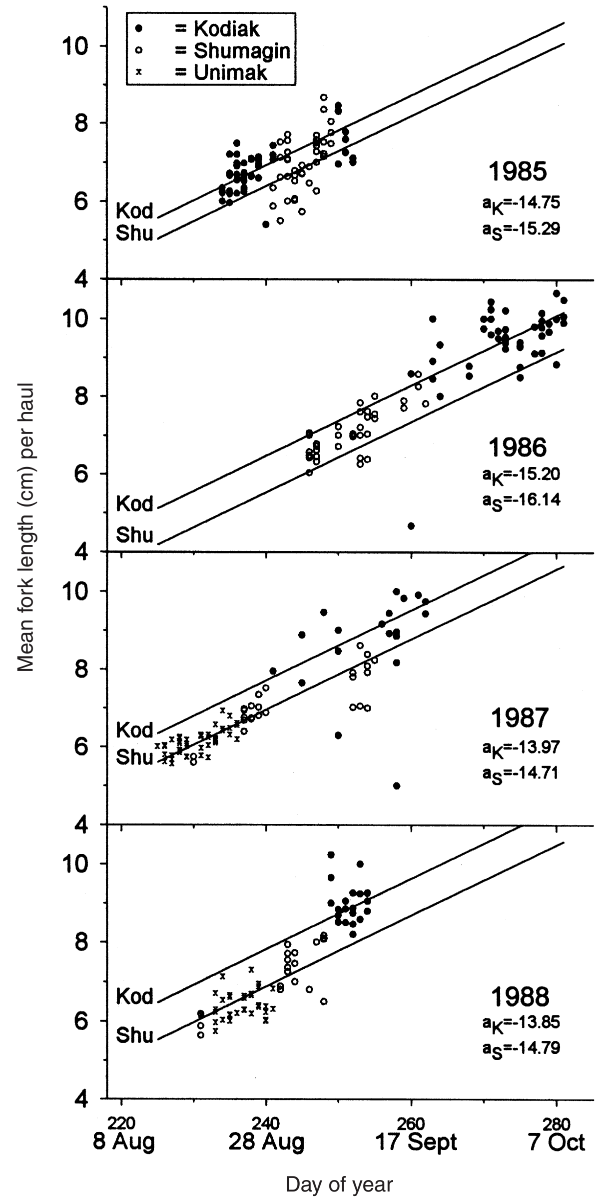

Figure 4

Age-0 pollock mean fork length per haul versus collection date for each year sampled August–October, 1985–88. Symbol type indicates region (see Fig. 1). Lines represent the least-squares linear fit from the ANCOVA of Kodiak and Shumagin data (slope=0.090; intercepts, a_K and a_S, respectively, are given)

1986 were each significantly (P<0.05) different from all other years. The year-region interaction term was marginally not significant (Table 5). A noteworthy correspondence between mean size and water temperature is apparent in Table 2.

Regional differences were due to a relative abundance of large-size fish in the Kodiak region. These fish were on average about 0.5–1.0 cm larger than the fish from elsewhere

Table 2

Catch and sample statistics, by region and year, for age-0 pollock collected in the western Gulf of Alaska during 1985–88. Mean $\log_{10}$, mean fork length (FL), mean sample depth, and mean sea-surface temperature were based on samples where age-0 pollock were caught. As stated in the text, fish density and length were adjusted to the median survey date (3 Sept) to account for differences in collection date. (Freq. occur.=frequency of occurrence).

Year class	Region	Total sample number	Freq. occur. (%)	Mean $\log_{10}$ (fish/m^3)	Mean (fish/m^3)	Median (fish/m^3)	Mean FL (cm)	Mean depth (m)	Mean temp. (°C)
1985	Kodiak	62	77	–2.19	0.0303	0.0038	7.5	101	10.5
	Shumagin	41	90	–2.19	0.0496	0.0073	6.9	88	10.9
1986	Kodiak	52	83	–2.84	0.0060	0.0008	7.0	136	9.3
	Shumagin	40	88	–2.74	0.0147	0.0015	6.1	116	10.8
1987	Kodiak	37	65	–3.06	0.0046	0.0001	8.2	75	11.2
	Shumagin	29	83	–2.32	0.0180	0.0053	7.5	70	11.6
	Unimak	44	98	–1.86	0.0302	0.0264	7.6	40	11.2
1988	Kodiak	20	95	–1.76	0.0544	0.0225	8.4	95	10.8
	Shumagin	23	83	–2.59	0.0242	0.0024	7.4	64	11.7
	Unimak	36	92	–2.12	0.0263	0.0063	7.7	35	11.0

(Table 2). The data from 1985 clearly show how the Kodiak and Shumagin regions contrast in terms of fish size (Fig. 4). Note that the difference in mean size coincides roughly with regional delineation. On closer inspection, it was apparent that large fish tended to concentrate near the northeast- and east-side of Kodiak Island in 1985 and 1988. Thus, size variability appears to also exist on a finer geographic scale. In Figure 4, most mean lengths from the Shumagin region in 1986 are above their respective line because one sample of relatively small fish accounted for almost 30% of the total density. During 1987 and 1988, means from the Unimak region were not different from those in the Shumagin region (Bonferroni, P=0.054) but they were different from the Kodiak group (Bonferroni, P=0.003). This difference was indicated by a second ANCOVA, and a second *post-hoc* multiple comparison test, wherein day (df=1 and 156, F=196, P<0.001) and region (df=2 and 157, F=22, P<0.001) were the only significant effects.

To address a possible association between regional mean size and mean sample depth (Table 2), the ANCOVA of 1985–88 data was rerun with sample depth as a third effect. Sample depth was included as a categorical effect with two levels: 50–100 and 100–150 m. Only 174 mean length estimates were used because the number of estimates at other depths was low or zero in some regions and years. Results were similar to the first run and there was no significant depth effect. Depth was neither significant by itself (df=1 and 157, F=0.118, P=0.731) nor did it interact with other effects (P>0.05). The difference in fish size between the Kodiak and Shumagin regions was therefore not likely due to differences in sampling depths.

Table 3

Results from two ANOVA tests used to examine year (1985–88) and region (Kodiak versus Shumagin) effects on age-0 pollock density in the western Gulf of Alaska. The first ANOVA was on log-transformed densities and the second was on rank-transformed densities.

Source	df	MS	F	P
ANOVA, log-transformed fish densities				
year	3	9.072	5.3893	0.0013
region	1	0.805	0.4782	0.4898
year × region	3	9.204	5.4679	0.0011
error	296	1.683		
ANOVA, rank-transformed fish densities				
year	3	70809	6.3609	0.0003
region	1	1374	0.1234	0.7256
year × region	3	66291	5.9550	0.0006
error	296	11132		

Recruitment

Future development of a direct relationship between age-0 abundance and recruitment seems most likely for the Kodiak region (Fig. 5). In this region, linear relationships were evident for the average, log-transformed, nonzero density and for the overall mean density. There was no convincing evidence of a direct linear relationship between mean length and recruitment.

Discussion

The geographic distribution of age-0 fish integrates the effects of dispersal of young from spawning areas and of spatial differences in mortality; therefore, it helps reveal

Table 4

Probabilities from Fisher's LSD tests, which followed the ANOVA tests summarized in Table 3. The hypothesis that means of transformed age-0 densities are equal was rejected if $P<0.00313$. This reflects a Bonferroni correction of the 0.05 overall alpha level (e.g. 0.05/16). Significantly different pairs of means are indicated by probabilities in bold.

	Comparison by year						Comparison by region
	Kodiak region			Shumagin region			Kodiak vs. Shumagin
	1985	1986	1987	1985	1986	1987	
P-values, log-transformed fish densities							
1985							0.16537
1986	0.11119			0.05592			0.46505
1987	**0.00079**	0.06104		0.31479	0.45564		**0.00307**
1988	0.00716	**0.00018**	**0.00000**	0.10872	0.97748	0.53177	0.00665
P-values, rank-transformed fish densities							
1985							0.21982
1986	0.03708			0.02599			0.49393
1987	**0.00159**	0.21323		0.41495	0.22086		0.00441
1988	**0.00294**	**0.00001**	**0.00000**	0.11894	0.73141	0.45407	**0.00253**

Table 5

ANCOVA results of region, year and day effects on the mean length per haul of age-0 pollock collected from two regions, Kodiak and Shumagin, in the western Gulf of Alaska during August–October, 1985–88. Length was weighted by fish density.

Source	df	MS	*F*	*P*
Year	3	35036	73.907	0.0000
Region	1	37407	78.907	0.0000
Year × Region	3	1211	2.555	0.0560
Day	1	144833	305.518	0.0000
Error	247	474		

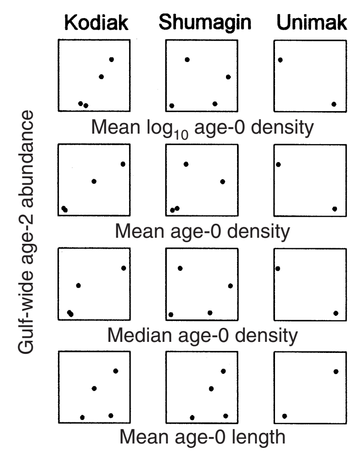

Figure 5

Gulf-wide age-2 pollock abundance (from Table 1) plotted against the regional indices of age-0 abundance and size (from Table 2) for the 1985–88 year classes of pollock in the Gulf of Alaska.

major recruit pathways. In the GOA, the largest aggregation of spawning pollock occurs in Shelikof Strait; and the FOCI recruit-pathway paradigm shows that larvae are carried southwestward from this area (Hinckley et al., 1991; Hermann et al., 1996a, 1996b; Kendall et al., 1996). However, the widespread occurrence of age-0 pollock throughout the areas surveyed, and probably beyond, indicates that the FOCI recruit-pathway paradigm needs to account for more complex dispersal, multiple spawning areas, and possible geographic differences in mortality.

The FOCI recruit-pathway paradigm was expanded to the early juvenile stage by Hinckley et al. (1991) with the inclusion of age-0 distribution data. Their study, however, included only data from 1987. It is now apparent that the age-0 distribution during 1987 was more geographically skewed than in other years during 1985–88. Perhaps this skewed distribution relates to sea surface drift in the greater GOA, which may have been rapid during 1987 (Ingraham et al., 1998), although larval distributions in the Shelikof Strait vicinity seemed normal (Kendall and Picquelle, 1990; Hinckley et al., 1991; Bailey et al., 1996c). Regardless, the 1985 and 1988 age-0 distribution data suggest that the FOCI recruit-pathway paradigm should include the Kodiak Island vicinity as part of the principal nursery for young pollock in the GOA.

Deep countercurrent flows (Reed et al., 1987; Stabeno et al., 1995), eddies (Schumacher and Kendall, 1995), retention near shore, and possible directed movements by juveniles all complicate "typical" southwestward dispersal of pollock eggs and larvae from Shelikof Strait. For example, the high age-0 densities around Kodiak Island during 1985 may be explained by high larval abundances upstream of the main spawning area (Kendall and Picquelle, 1990), which in turn may reflect northeastward transport of eggs at depth in the countercurrent. On the other hand, the high age-0 densities around Kodiak during 1988 are more difficult to explain. Countercurrent flows have been detected off the Gulf-side of Kodiak Island (Musgrave et al., 1992) but historically this is not an area of high egg or larval abundance. Furthermore, widespread occurrences of high age-0 density suggest that dispersal was both downstream and upstream, or that some fish originated from elsewhere.

The existence of multiple spawning areas further complicates our understanding of pollock recruitment pathways. Sporadic survey effort by the NMFS indicates that spawning occurs at a number of different locations throughout the western GOA between Prince William Sound and Unimak Pass. The percentage of pollock biomass in non-Shelikof spawning areas was 10, 21, 19, 29, and 14% of the total in all areas surveyed in 1989, 1990, 1994–96, respectively (Williamson[5]; Karp[6]; Wilson et al.[7], and references therein). These estimates are conservative because not all known spawning areas were surveyed each year and survey timing may not have coincided with peak spawning. In addition, other surveys of pollock, summarized by Bechtol,[9] indicate that the biomass of prespawning aggregations in Prince William Sound ranged from 28,855 to 114,344 metric tons during 1995, 1997, and 1998. Although these surveys occurred after 1988 and conditions may have changed during the intervening period, it seems likely that at least some age-0 pollock were spawned in areas outside of Shelikof Strait. Estimating relative production, however, is difficult because it is impossible to identify where individual recruits were spawned and because of spatial variations in the processes that remove prerecruits from the GOA. As indicated by studies of other species (Pulliam and Danielson, 1991; Frank, 1992), the relationships among these different spawning groups could be very complex.

The use of age-0 densities in the Kodiak region in forecasting recruitment suggests that "atypical" dispersal of young from Shelikof Strait and production of fish from other spawning areas may be relevant factors in understanding GOA pollock recruitment. Admittedly, this use is based on only a few years of data. However, Smith et al. (1984) reported age-0 densities for the 1980–82 year classes in some bays within the Kodiak region that corresponded with year-class strength estimates. Furthermore, if sampling method is ignored, a time series of mean age-0 density near northeast Kodiak Island is available for the 1980–88 year classes, except 1983, and it corresponds reasonably well with recruitment (Pearson, r=0.74, P=0.04, n=8) (author's unpubl. data). The Shumagin and Unimak regions were comparatively less promising for predicting recruitment, although the relative strength of the 1985 and 1988 year classes was indeed evident among the Shumagin densities. Age-0 fish from both the Kodiak and Shumagin regions may move into Shelikof Strait during winter as indicated by large aggregations of age-1 fish observed there during early spring (McKelvey, 1996). This movement probably involves a relatively constant proportion of the Kodiak and Shumagin age-0 populations because their abundance as age-1 fish in Shelikof Strait continues to be indicative of recruitment (McKelvey, 1996; Guttormsen and Wilson[10]). Farther southwest, in the Unimak region, juveniles may leave the GOA sometime after their first summer. This movement may explain why age-0 densities in the Unimak region during 1987 and 1988 had no relation to recruitment despite a 7-fold variation in subsequent year-class strength.

Given their relevance to recruitment, age-0 pollock around Kodiak Island warrant closer consideration. As previously discussed, some may come from Shelikof Strait. Others may move downstream from spawning areas such as those in or near Prince William Sound and Resurrection Bay (Nelson and Nunnallee, 1985; Muter and Norcross, 1994; Norcross and Frandsen, 1996; Karp[6]). Downstream drift is probable given the distance, currents (Schumacher and Reed, 1980; Stabeno et al., 1995), spawning time (Muter and Norcross, 1994), and estimated age-0 ages.[11] Drift from eastern areas may be relatively important to establishing age-0 populations along the upstream- and Gulf-side of Kodiak Island when the influx of Shelikof fish is low. Retention of young along this part of Kodiak Island may be facilitated by shoreward flows and vortices created by topographical influences on the prevailing current (Lagerlof, 1983; Dunn et al.[4]). Local spawning is another possible source of age-1 pollock as evidenced by adults in prespawning condition in Marmot Bay, which is on northeast Kodiak Island (Karp[6]; Williamson[12]).

The relatively large size of many age-0 fish may reflect favorable conditions in the Kodiak Island vicinity, and size is generally regarded as having a positive effect on survival. Walters et al. (1985) first reported a southwest-to-northeast increase in age-0 size; however, a more rigorous

[9] Bechtol, W. R. 1998. Prince William Sound walleye pollock: current assessment and 1999 management recommendations. Regional Information Report No. 2A98-41, 25 p. Alaska Department of Fish and Game, Division of Commercial Fisheries Management and Development, 333 Raspberry Rd., Anchorage, AK 99518.

[10] Guttormsen, M., and C. Wilson. 1998. Echo integration-trawl survey results for walleye pollock in the Gulf of Alaska during 1998. *In* Stock assessment and fishery evaluation report, p. 509–530. Prepared by the Gulf of Alaska Groundfish Plan Team, North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK 99510.

[11] Mean age of age-0 pollock in the Kodiak region during 1985–88 ranged from 127 to 143 d. These estimates are based on age-0 length and length-age relationships for the same age-0 populations (Bailey et al., 1996b), to which mortality-adjusted density weights were applied.

[12] Williamson, N. 1999. Personal commun. National Marine Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98115.

comparison with their study is complicated by differences in gear and survey strategy. One possible explanation for the effect of region on fish size is growth rate variability. Growth rates, estimated from larval and juvenile length-at-age data, were found to increase from southwest to northeast, at least during 1987 (Yoklavich and Bailey, 1990; Brown and Bailey, 1992). Prey quality (Merati and Brodeur, 1996), and physical conditions (Strickland and Sibley, 1989) have also been observed to vary, the supposition being that the Kodiak Island area is a richer nursery habitat than are more southwestern areas. Variation in time of spawning is another possibility; particularly in 1986 and 1988, when regional differences in growth were not evident (Bailey et al., 1996b). It appears, however, that time of spawning throughout the western GOA is fairly synchronous (Picquelle and Megrey, 1993; Muter and Norcross, 1994), except near the Shumagin Islands were it happens about one month earlier (Wilson et al.[7]). Size-related migration and mortality are other possible effects on fish size but evidence is lacking.

Spatial differences in size may translate into spatial differences in mortality. In a review of size-selective mortality among juvenile fishes, Sogard (1997) identified over-winter mortality and predation as major size-selective processes. These mortality vectors may be particularly strong because the first-winter growth of juvenile pollock in the GOA is negligible (Brodeur and Wilson, 1996a), and predation is prevalent (Brodeur and Bailey, 1996). Thus, geographic differences in age-0 size may contribute a spatial component to year-class strength determination. The poor relationship between age-0 size and year-class strength, however, suggests that age-0 size is a minor factor, at least in terms of determining relative recruitment among year classes.

The practice of targeting echo layers was a drawback of these data. This practice has been shown to bias estimates of fish density (Wilson et al., 1996), but its effect on distribution patterns is uncertain. It is possible that the area represented by mean fish density varied with year and region, thereby causing density to be a poor indicator of abundance. Estimates of year- and region-specific density were, however, closely related to the absolute abundance estimates of Bailey and Spring (1992) (Pearson, r=0.78, P=0.008, n=10). On the positive side, the practice of targeting echo sign does reduce the effort needed to collect biological samples (Brodeur and Wilson, 1996b), but this must be carefully weighed against possible adverse effects.

In summary, age-0 pollock appear to have been evenly distributed throughout much of the western GOA during 1985–88, except during 1987 when a strong, east-to-west increase in fish density was observed. The Kodiak region was an important pollock nursery despite its position upstream from what is presumed to be the most important spawning area in the GOA. The Kodiak region was particularly well suited as a recruitment predictor owing, perhaps, to a relative abundance of large-size individuals. Questions emerged about annual variability in the origin and dispersal of young pollock, and regarding the possibility that geographic effects on survival or retention could affect the relative production of GOA recruits among different spawning areas.

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