Summer distribution of early life stages of walleye pollock, *Theragra chalcogramma,* and associated species in the western Gulf of Alaska*

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Abstract.—A midwater trawl survey was conducted during July 1991, to examine the large-scale distribution patterns of late larval and early juvenile walleye pollock, *Theragra chalcogramma,* and associated fish taxa in the western Gulf of Alaska. Gear comparisons between the anchovy and Methot trawls were conducted to evaluate which was the more efficient sampler for the size range of *T. chalcogramma* present during this time of the year. Both gears showed similar densities through the dominant size class of fish caught, but the Methot trawl caught significantly more *T. chalcogramma* in the smallest (mostly larval) size ranges available. Accordingly, a grid of stations was occupied in which only the Methot trawl was used.

Although 53 fish taxa were collected overall in the 61 Methot trawls, the majority (84%) of the larval catch consisted of only five taxa: flathead sole, *Hippoglossoides elassodon*; walleye pollock, *T. chalcogramma;* arrowtooth flounder, *Atheresthes stomias;* Pacific cod, *Gadus macrocephalus;* and unidentified sculpins, *Icelinus* spp. *Theragra chalcogramma* and *G. macrocephalus* were the dominant (>99%) juveniles collected in the survey. The highest catches of larval (13–25 mm SL) and juvenile (26–52 mm SL) *T. chalcogramma* were found inshore along the Alaska Peninsula and near offshore island groups. Recurrent Group Analysis and Two-way Indicator Species Analysis both showed that *T. chalcogramma* tended to be frequently associated with a large heterogeneous grouping of taxa, including *G. macrocephalus*, several pleuronectids, and other winter-spring spawning species. The rankings of the dominant taxa in the Methot trawl survey exhibited a greater coherence to the rankings of adult fishes from bottom trawl surveys in the previous year than did those of an ichthyoplankton survey that used bongo nets a few months earlier than the Methot trawl survey.

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The spatiotemporal distribution of the pelagic early life stages of marine fishes is influenced by a number of biotic and oceanographic processes. Thus, with sufficient elapsed time since spawning, the distribution of late larvae and early juveniles of many species shows only a limited relationship to the distribution of spawning adults. The taxa that make up an assemblage of larval fishes show a high diversity of sizes, stage durations, morphologies, and behaviors (Moser, 1981; Matarese et al., 1989; Moser and Smith, 1993) that can affect their distribution patterns in a dynamic and fluid environment, as is the situation in most coastal areas. The early larval stages have received the most attention from fisheries oceanographers because of their presumed importance in regulating recruitment variability but also because of the ease of sampling such weakly swimming organisms (Heath, 1992). Recent observations, however, have given rise to the suggestion that later larval and early juvenile stages may be as important as early larval stages in regulating year-class strength (Peterman et al., 1988; Campana et al., 1989; Bailey and Spring, 1992), which has stimulated development of new sampling gear to quantitatively assess the abundance of larger ichthyoplankton and micronekton (Methot, 1986; Munk, 1988; Potter et al., 1990; Dunn et al., 1993).

The Fisheries Oceanography Coordinated Investigations (FOCI) program is a joint effort by scientists at the Alaska Fisheries Science Center (AFSC) and the Pacific Marine Environmental Laboratory (PMEL) to understand the biological and physical processes which cause variability of recruitment in commercially valuable fish and shellfish stocks in Alaskan waters. The primary goal of the FOCI program is to understand the effects of the biotic and abiotic environment on the early life stages of walleye pollock, *Theragra chalcogramma,* in the western Gulf of Alaska (Schumacher and Kendall, 1991). A secondary objective is to provide quantitative estimates of population size to predict recruitment strength for fisheries management (Schumacher and Kendall, 1991; Bailey and Spring, 1992). Other than the study of Hinckley et al. (1991) in late

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June, no data are available on the distribution and abundance patterns of late larval or early juvenile *T. chalcogramma* during mid-summer, when they are at a size that makes them vulnerable to plankton gear. Moreover, little is known about the relationship of *T. chalcogramma* distribution to that of the other common ichthyoplankton taxa that are caught with the same type of gear. Our aim in this study was to examine the large-scale distribution patterns of age-0 *T. chalcogramma* and their associations with other larval and juvenile fishes. We also estimate for the first time the relative abundance of age-0 *T. chalcogramma* compared with other co-occurring early life history stages of marine fish taxa present during mid-summer on the continental shelf in the western Gulf of Alaska.

Methods

A FOCI survey of late larval and early juvenile *T. chalcogramma* was conducted aboard the NOAA ship *Miller Freeman* from 23 to 31 July 1991 (Dewitt and Clark[1]). The Methot trawl was selected as the most appropriate sampling gear for this stage of *T. chalcogramma* life history on the basis of previous gear comparisons (Shima and Bailey, 1994). The 5-m^2 rigid frame trawl (2 × 3 mm oval mesh) is designed to sample micronekton that evade smaller plankton nets and that pass through the mesh of larger trawls (Methot, 1986). A grid of stations perpendicular to the coast along the Alaska Peninsula was occupied (Fig. 1) and 61 successful Methot trawls were completed (39 day and 22 night), with repeat tows at several stations. All tows were made at an average ship speed of 6 km·h^{-1} and in a double oblique pattern to within 10–20 m of the bottom. Temperature profiles were taken at each station by using expendable bathythermographs.

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[1] Dewitt, C., and J. Clark. 1993. Fisheries Oceanography Coordinated Investigations: 1991 field operations report. NOAA Data Rep. ERL PMEL-41, 112 p.

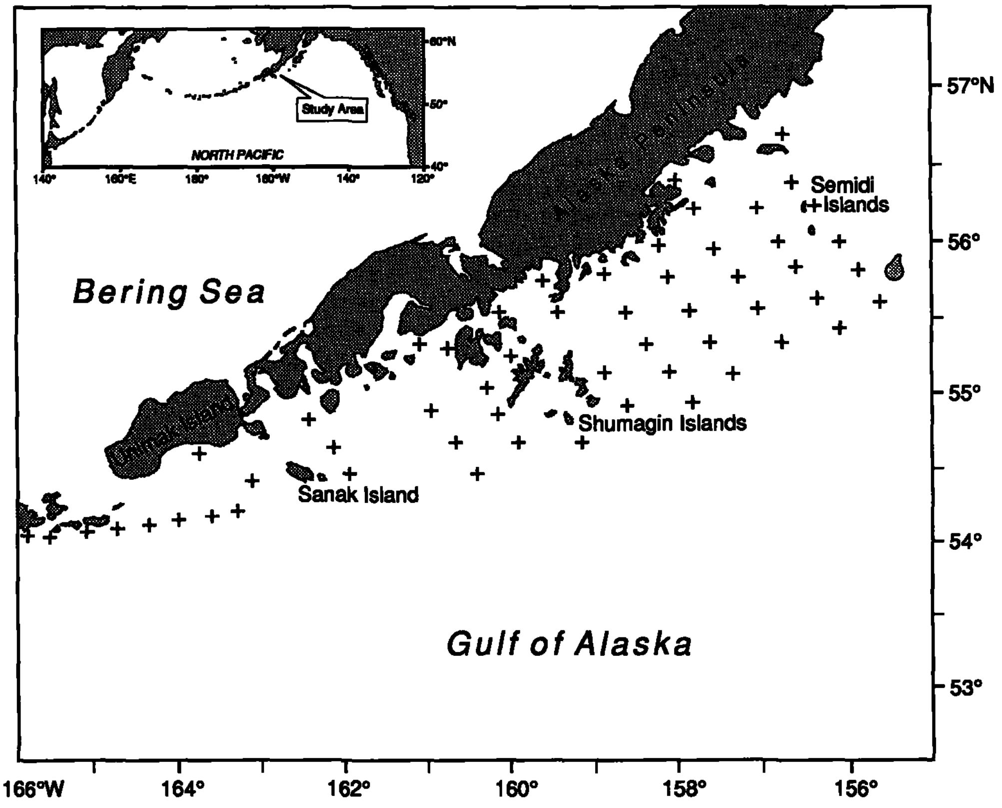

Figure 1

Grid stations sampled during July 1991 with the Methot trawl and location of study area within the North Pacific Ocean (inset).

Because we were uncertain whether any larger *T. chalcogramma* were present at the time of sampling, we conducted a set of gear comparisons at four different stations to examine whether the Methot trawl was adequately sampling the largest age-0 individuals available. Paired tows (2 pairs during the day and 2 at night) were made with the Methot trawl and an anchovy trawl. The anchovy trawl has a variable mouth opening depending on depth and was estimated to range from 110 to 135 m^2 for the four tows on the basis of the relationships given by Wilson et al. (in press). The trawl body contained variable-size mesh grading from 15.2 cm (stretched) in the forward section to 3.8 cm in the codend, which contained a 3-mm liner. At each gear comparison station, oblique tows with each gear type were done in random order down to the same depth. Standardized catches of *T. chalcogramma* in each gear were compared by length categories by using a nested ANOVA, with haul as the nesting factor.

The trawl samples were preserved in 5% formalin buffered with marble chips. The samples were later sorted in the laboratory and all the fish were removed. Fish were identified by using Hart (1973), Eschmeyer et al. (1983), and Matarese et al. (1989). Standard length (SL) of all fish was measured to the nearest millimeter with a stage micrometer or measuring board. Larval and juvenile stages were separated by using a combination of information on length of transformation and osteology provided by Matarese et al. (1989) and Busby (unpubl. data). Larval and juvenile *T. chalcogramma* and Pacific cod, *Gadus macrocephalus,* were separated at 25.0 mm SL by using the criteria of Dunn and Matarese (1987).

Raw numbers of larvae and juveniles from each taxon collected were converted to number per unit area or density per volume filtered. Consistent with the results of previous studies on larval and juvenile *T. chalcogramma* (Hinckley et al., 1991; Shima and Bailey, 1994), we did not find significant density differences overall between day and night sampling (Mann-Whitney Test, P=0.09); thus, we did not make corrections in our abundance estimates for time of day of sampling. Total abundance of each taxon in the study area was calculated by multiplying the weighted mean catch per 10 m^2 for each station by the polygonal area represented by that station (see Richardson [1981] and Kendall and Picquelle [1990] for details). Abundances were calculated separately for both larval and juvenile *G. macrocephalus* and *T. chalcogramma* and then summed for the total abundance for each taxon.

Classification of the catches was done with analyses by using both occurrence and abundance data. Species associations were identified on the basis of co-occurrence of taxa in catches by using Recurrent Group Analysis (Fager, 1957). This analysis places taxa that co-occur into groups based on an affinity level set at 0.4, as previously used for other assemblage analyses in this region (Kendall and Dunn, 1985; Doyle et al., 1995). Only taxa that occurred in more than 15% of the collections were included in this analysis. A second type of hierarchical classification was performed on the abundance data to see whether a different technique produced different results in identifying assemblages. Two-way Indicator Species Analysis, a polythetic, divisive technique (Gauch, 1982), was used in conjunction with the program TWINSPAN (Hill, 1979). This analysis starts with all the entities (taxa or stations) belonging to one group and then ordinates them by reciprocal averaging. Each group is progressively divided until it contains no more than the predetermined minimum number of members, as opposed to an agglomerative technique, such as cluster analysis, which starts with individual entities and progressively combines them. Station groupings were also formed by using TWINSPAN, and these were described in relation to the species matrix on the basis of whether a particular taxon had a high or low affinity with that station grouping.

To interpret the ecological significance of these station groupings, we examined environmental and station variables such as water depth and temperatures from different depth intervals available from expendable bathythermograph data taken at each station. We also calculated station position variables, such as distance from nearest land (including islands) and alongshore distance from a line perpendicular to the coast just northeast of our first transect of stations (Fig. 1). Differences among the median values for all variables by the different TWINSPAN groupings were tested by using a Kruskal-Wallis test.

We compared the abundance estimates from the 1990 AFSC Gulf of Alaska groundfish trawl survey with those determined from the Methot trawl survey and another ichthyoplankton survey conducted a few months earlier than our study. The trawl survey took place from 1 June to 9 September 1990, covered a broader area of the Gulf of Alaska (132–170°W), and sampled depths ranging from 20 to 530 m (see Stark and Clausen [1995] for additional sampling details). For the purposes of this analysis, only abundances from the western Gulf of Alaska strata (506 stations) were summarized. Abundances for each stratum were estimated by dividing the biomass of each species caught by its mean weight (given in Stark and Clausen [1995]), and then these were summed across all depths and strata.

Ichthyoplankton collections were made at 92 stations off Kodiak Island and the Alaska Peninsula (151–159°W) from 17 to 25 May 1991 by using a 60-cm bongo with either 333- or 505-µm mesh. Processing of these samples and abundance estimates were done as described for the Methot trawl collections. More complete sampling details are provided by Dewitt and Clark.[1]

Results

Gear comparisons

The two gear types did not show significant differences in overall mean standardized catches of age-0 *T. chalcogramma* for the four paired gear-comparison hauls, but when the densities were partitioned by size of fish, the Methot trawl caught significantly more fish in the smallest size groups, although there were no density differences between the two gears for the size groups >35 mm (Fig. 2). Although it was not possible to examine diel differences in overall age-0 densities for both gear types from only four stations taken in different locations, it appears that the catchability of small *T. chalcogramma* by the anchovy trawl is relatively poor during the daytime. In all four comparisons, the Methot trawl caught smaller individuals and a broader overall range of age-0 sizes than did the anchovy trawl, but the distributions of lengths were significantly different in only two of the four tows (Fig. 3). The overall average (±SD) length of individuals caught by the Methot net was 34.5 (±7.0) mm, whereas the average length of fish caught by the anchovy trawl was 36.3 (±4.5) mm.

Taxonomic composition and abundance

Altogether, 53 larval and 4 juvenile taxa were identified in the Methot trawl survey (Tables 1 and 2). Several taxa, notably *Sebastes* spp. and Cyclopteridae, were probably represented by several as yet unidentifiable species; therefore, the overall taxonomic diversity was probably underestimated. The family Cottidae exhibited the greatest diversity, with at least 15 taxa represented (Table 1).

Hippoglossoides elassodon, *T. chalcogramma*, and, to a lesser extent, *Atheresthes stomias*, *G. macrocephalus*, and *Icelinus* spp., were the dominant taxa collected on the basis of mean density (Table 1). *Hippoglossoides elassodon* larvae were the most abundant overall and occurred at all but one station. Most of the fish caught were late-stage larvae, but *T. chalcogramma* and *G. macrocephalus* were also represented by a large number of juveniles (Table 2). On the basis of total abundance in the study area, *H. elassodon*, *T. chalcogramma*, and *A. stomias* are clearly the most abundant taxa; there is less distinction among the rest of the dominant taxa (Fig. 4). The abundance of *H. elassodon* (3.24×10^{10} fish) was almost three times that of the next most abundant species *T. chalcogramma* (larvae and juveniles combined: 1.12×10^{10} fish) and represented 53.6% of the estimated total abundance of ichthyoplankton in the survey area (6.04×10^{10} fish).

Spatial and length-distribution patterns

The geographic and length distributions of the six most abundant larvae and *T. chalcogramma* and *G. macrocephalus* juveniles are shown in Figures 5–8. The distribution of *T. chalcogramma* larvae and that of juveniles were very similar, with centers of abundance near the Semidi and Shumagin Islands (Fig. 5). *Gadus macrocephalus* juveniles tended to be distributed slightly more offshore and farther west (downcurrent) than were larvae (Fig. 6). *Hippoglossoides elassodon* larvae were found in greatest numbers near the Alaska Peninsula and Shumagin Islands, whereas *A. stomias* larvae were collected over a broad size range and displayed no distinct patterns of distribution (Fig. 7). In contrast, *Icelinus* spp. larvae showed a narrow size distribution and were found in high concentrations northeast of Sanak Island

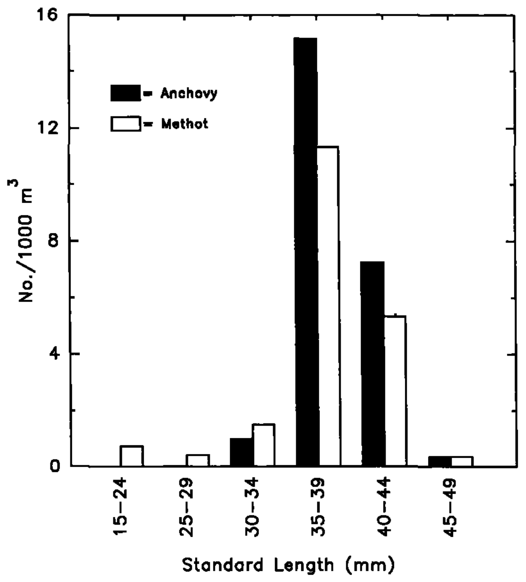

Figure 2

Comparison of the standardized catches for the Methot and anchovy trawl by length category in the gear comparison tows.

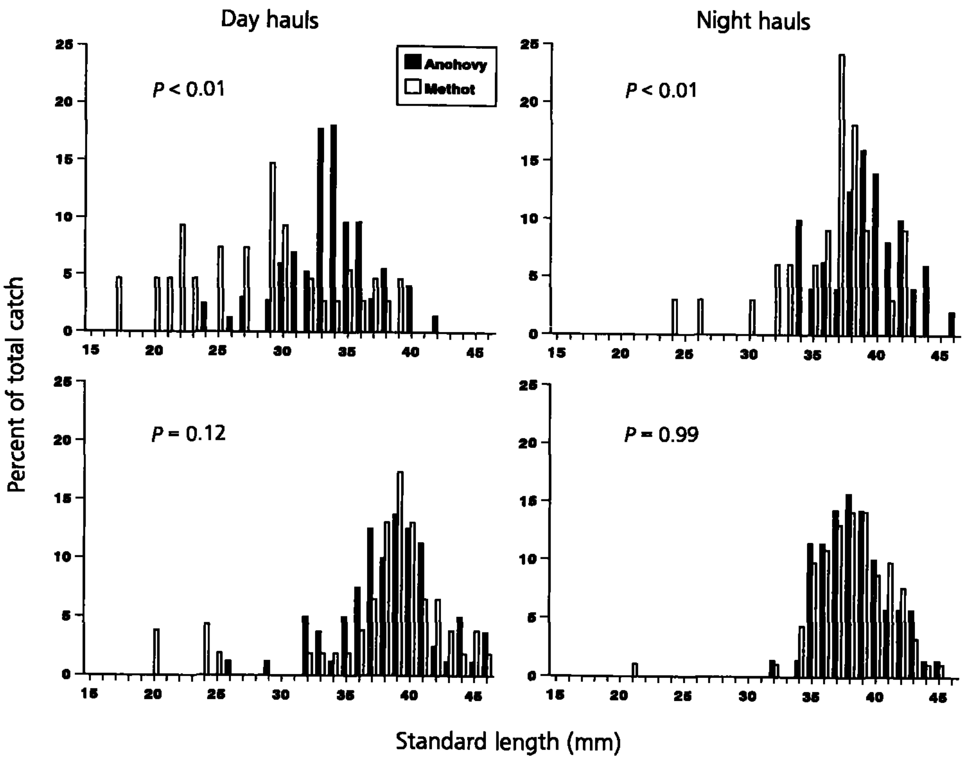

Figure 3

Comparison of the length distributions by haul for the Methot and anchovy trawls for the four paired comparisons done at different stations. Also shown are the results of a Kolmogorov-Smirnov test in which the distributions of each gear type were compared.

(Fig. 8). *Sebastes* spp. catches also comprised relatively small larvae and were found almost exclusively at offshore stations but were evenly distributed among these stations (Fig. 8).

Species associations

The Recurrent Group Analysis identified one main grouping of taxa that showed a common affinity level of at least 0.40 (Fig. 9). Curiously, the nine taxa with the highest densities were members of this grouping, even though the groupings are formed on the basis of common occurrences. *Zaprora silenus* larvae were associated with eight of the nine taxa but showed a low association with *Sebastes* spp. larvae. The larval and juvenile stages of *T. chalcogramma* and *G. macrocephalus* occurred within the same species grouping and thus were not differentiated in this analysis.

The TWINSPAN results were similar to the Recurrent Group Analysis in that a large grouping was formed. However, in this instance, *Sebastes* spp. larvae were not closely related to this grouping, but *Ammodytes hexapterus* larvae were related (Fig. 10).

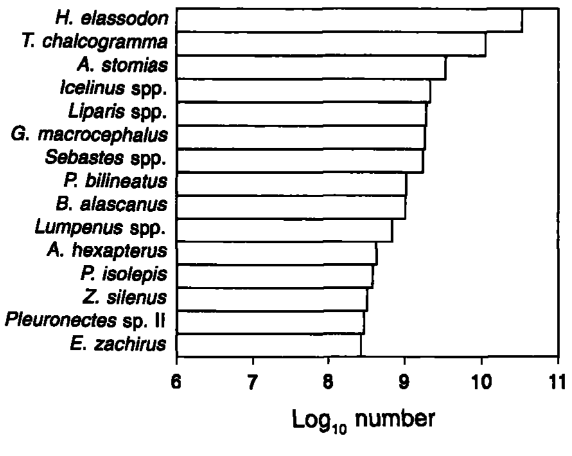

Figure 4

The estimated total abundance in the survey area for the 15 most abundant taxa collected in the Methot trawl survey. Abundances for *Theragra chalcogramma*, *Gadus macrocephalus*, and *Zaprora silenus* include combined totals for larval and juvenile stages.

Table 1

Summary of fish larvae collected in Methot trawls during 1991. Scientific names follow Robins et al. (1991) with the exception of the family Agonidae which follows Kanayama (1991).

Scientific name	Common name	Percent occurrence	Mean abundance (no./1000m^3)	Length range SL (mm)
Clupea pallasi	Pacific herring	1.64	<0.01	21.8
Mallotus villosus	capelin	3.28	0.01	52.0–60.0
Thaleichthys pacificus	eulachon	3.28	<0.01	63.0–75.0
Bathylagus pacificus	Pacific blacksmelt	1.64	<0.01	19.0
Leuroglossus schmidti	northern smoothtongue	8.19	0.01	22.0–34.0
Stenobrachius leucopsarus	northern lampfish	1.64	<0.01	10.8
Gadus macrocephalus	Pacific cod	34.43	0.15	15.1–22.0
Microgadus proximus	Pacific tomcod	1.64	<0.01	17.5–18.5
Theragra chalcogramma	walleye pollock	78.69	1.03	13.0–25.0
Gadidae	unidentified gadids	18.03	0.04	15.1–22.0
Macrouridae	unidentified grenadiers	1.64	<0.01	28.0
Sebastes spp.	unidentified rockfishes	49.18	0.30	6.0–18.0
Artedius fenestralis	padded sculpin	1.64	<0.01	12.0
Artedius harringtoni	scalyhead sculpin	3.28	<0.01	11.1–11.7
Artedius lateralis	smoothhead sculpin	1.64	<0.01	10.9
Ruscarius meanyi	Puget Sound sculpin	3.28	0.01	12.0–15.1
Clinocottus acuticeps	sharpnose sculpin	3.28	0.01	13.0–15.0
Clinocottus embryum	calico sculpin	1.64	<0.01	13.0
Dasycottus setiger	spinyhead sculpin	6.56	0.01	15.0–21.8
Icelinus borealis	northern sculpin	1.64	<0.01	13.5
Icelinus spp.	unidentified sculpins	72.13	0.57	10.0–18.0
Malacocottus zonurus	darkfin sculpin	1.64	<0.01	10.0
Nautichthys oculofasciatus	sailfin sculpin	1.64	<0.01	23.2
Psychrolutes paradoxus	tadpole sculpin	3.28	<0.01	15.9–16.3
Psychrolutes sigalutes	soft sculpin	4.92	0.01	12.0–17.0
Radulinus asprellus	slim sculpin	6.56	0.01	13.0–16.0
Rhamphocottus richardsoni	grunt sculpin	6.56	0.02	11.7–14.4
Cottidae	unidentified sculpins	3.28	0.01	15.0–18.0
Anoplagonus inermis	smooth alligatorfish	1.64	<0.01	19.0
Bathyagonus alascanus	gray starsnout	68.85	0.21	10.5–19.0
Bathyagonus infraspinatus	spinycheek starsnout	27.87	0.04	12.0–18.0
Bathyagonus spp.	unidentified poachers	1.64	<0.01	12.0
Leptagonus frenatus	sawback poacher	1.64	<0.01	26.2
Aptocyclus ventricosus	smooth lumpsucker	13.11	0.02	8.5–14.0
Liparis spp.	unidentified snailfishes	63.93	0.29	9.5–27.0
Careproctus spp.	unidentified snailfishes	1.64	0.01	10.7–17.8
Cyclopteridae	unidentified snailfishes	1.64	0.01	15.0
Ronquilus jordani	northern ronquil	1.64	<0.01	12.5
Lumpenus maculatus	daubed shanny	4.92	0.01	44.0–53.0
Lumpenus spp.	unidentified pricklebacks	16.39	0.14	37.0–59.0
Cryptocanthodes aleutensis	dwarf wrymouth	6.56	0.01	26.2–32.2
Ptilichthys goodei	quillfish	4.92	<0.01	91.0–105.0
Zaprora silenus	prowfish	26.23	0.05	9.6–30.0
Ammodytes hexapterus	Pacific sand lance	22.95	0.10	38.5–57.0
Atheresthes stomias	arrowtooth flounder	72.13	0.60	15.0–40.0
Embassichthys bathybius	deepsea sole	4.92	0.01	10.2–15.3
Errex zachirus	rex sole	26.23	0.06	19.0–39.5
Hippoglossoides elassodon	flathead sole	98.36	7.52	12.0–36.0
Hippoglossus stenolepis	Pacific halibut	6.56	0.01	20.4–24.0
Platichthys stellatus	starry flounder	6.56	0.01	8.1–9.5
Pleuronectes bilineatus	rock sole	65.58	0.26	10.0–27.0
Pleuronectes sp. II[1]	unidentified sole	19.67	0.05	7.0–18.0
Pleuronectes isolepis	butter sole	13.11	0.06	13.5–19.5

[1] See Matarese et al. (1989).

Table 2

Summary of juvenile fish collected in Methot trawls during 1991.

Scientific name	Common name	Percent occurence	Mean abundance (no./1000m^3)	Length range SL (mm)
Gadus macrocephalus	Pacific cod	65.57	0.44	26.0–43.5
Theragra chalcogramma	walleye pollock	88.52	1.42	26.0–52.0
Leptagonus frenatus	sawback poacher	3.28	<0.01	30.0–31.0
Zaprora silenus	prowfish	11.48	0.02	31.0–71.0

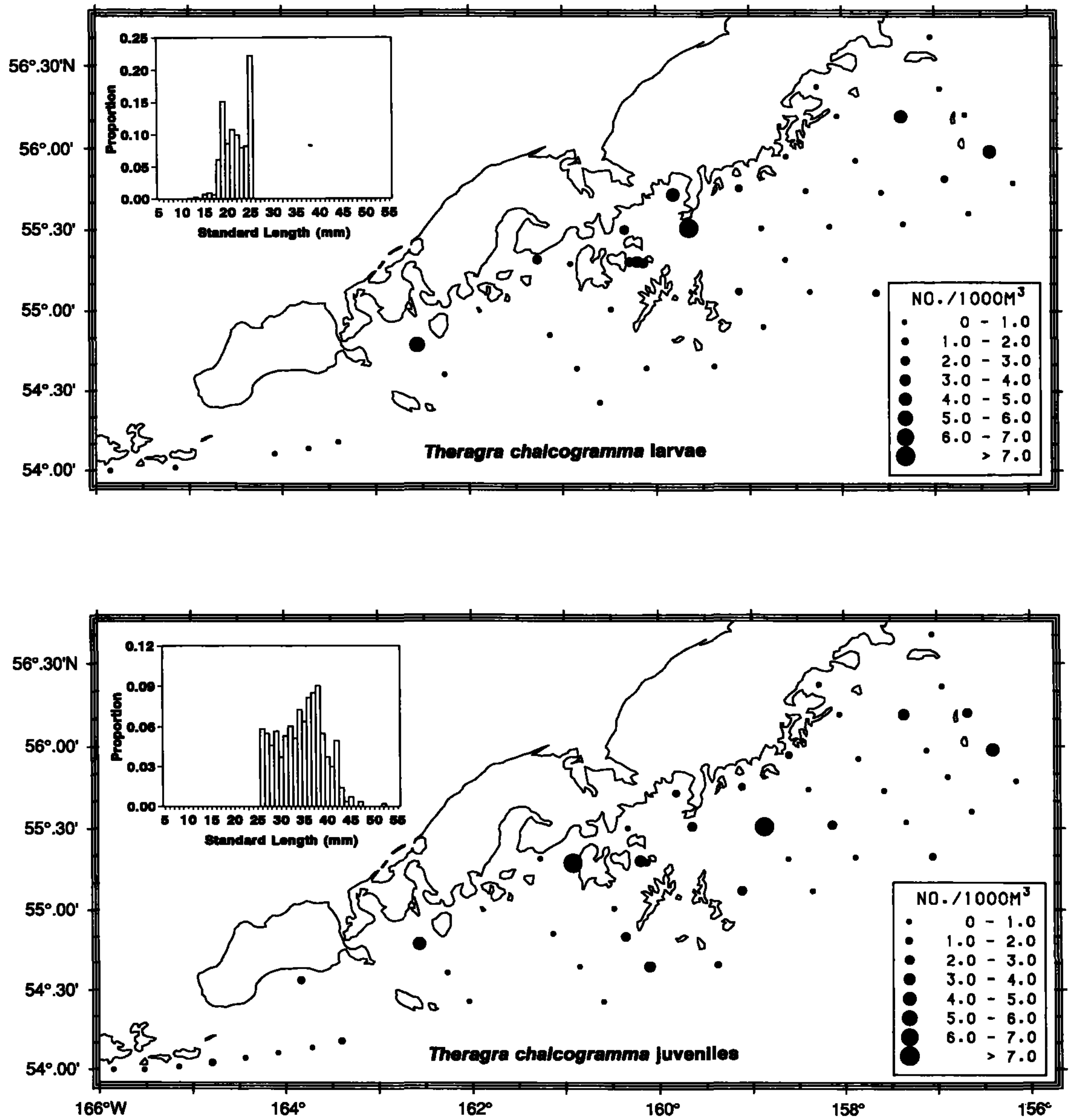

Figure 5

Distribution of larval and juvenile stages of *Theragra chalcogramma* in the study area. Also shown are the standardized length distributions for each life stage (inset).

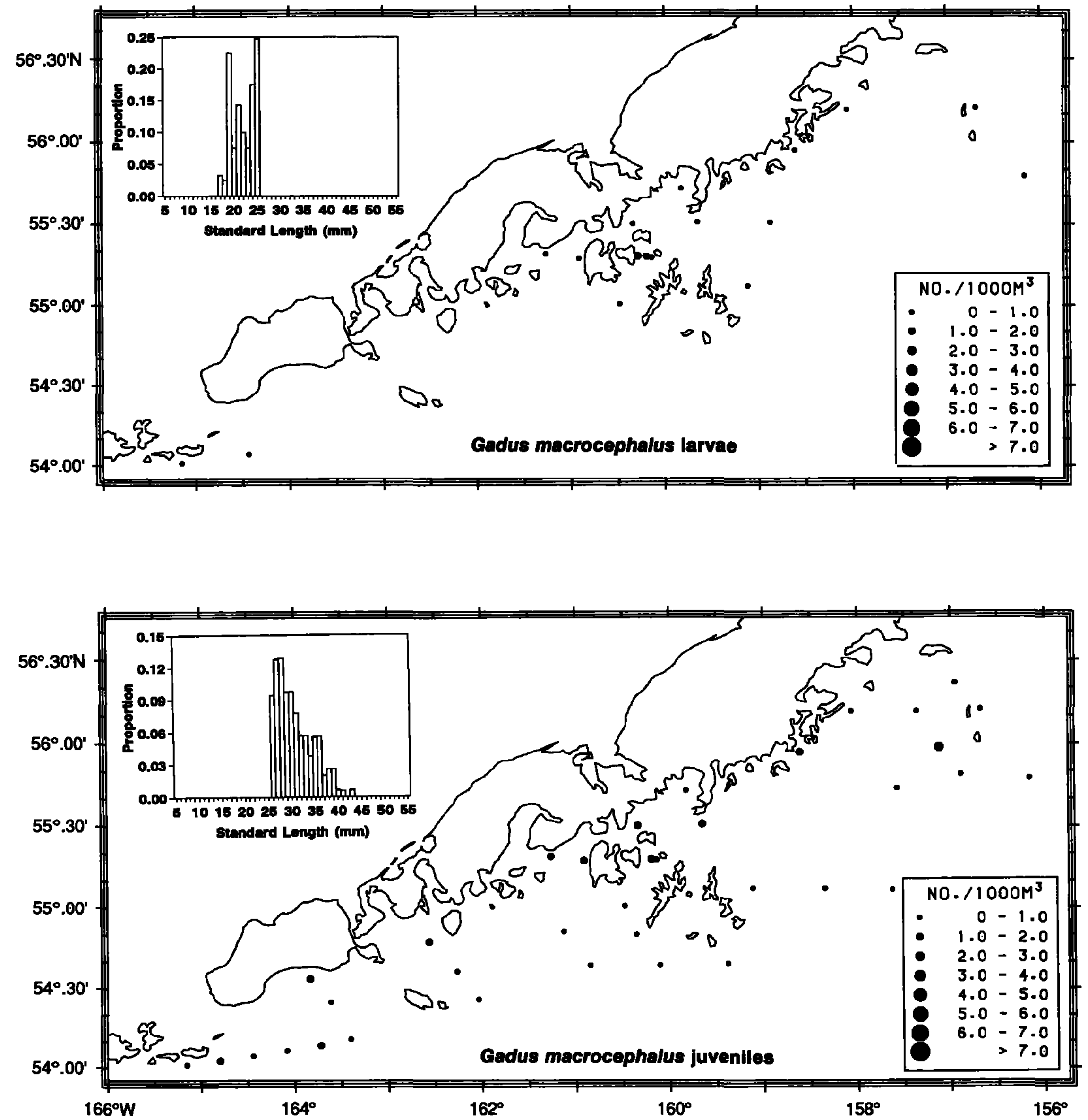

Figure 6

Distribution of larval and juvenile stages of *Gadus macrocephalus* in the study area. Also shown are the standardized length distributions for each life stage (inset).

Gadus macrocephalus larvae were differentiated from juveniles on the basis of this analysis.

Four station groupings were recognized by TWINSPAN (Fig. 11). An inshore group (group 4) showed a high positive association for *G. macrocephalus*, *T. chalcogramma*, and *H. elassodon* larvae and a negative association for *Sebastes* spp. larvae (Table 3). An offshore group (group 3) showed a high affinity for *Sebastes* spp. and *Bathyagonus alascanus* larvae and a low affinity for *A. hexapterus*, *H. elassodon*, and *Icelinus* spp. larvae. Many taxa, including larval and juvenile *T. chalcogramma*, *H. elassodon*, *A. hexapterus*, *Lumpenus* spp., and *A. stomias* showed high affinities, whereas *Bathyagonus infraspinatus* and *Sebastes* spp. larvae showed low affinities with a widely scattered midshelf grouping (group 2). Finally, a poorly defined grouping (group 1) was positively associated with *Sebastes* spp. larvae and negatively with *G. macrocephalus* and *Z. silenus* larvae. Ichthyoplankton densities were rela-

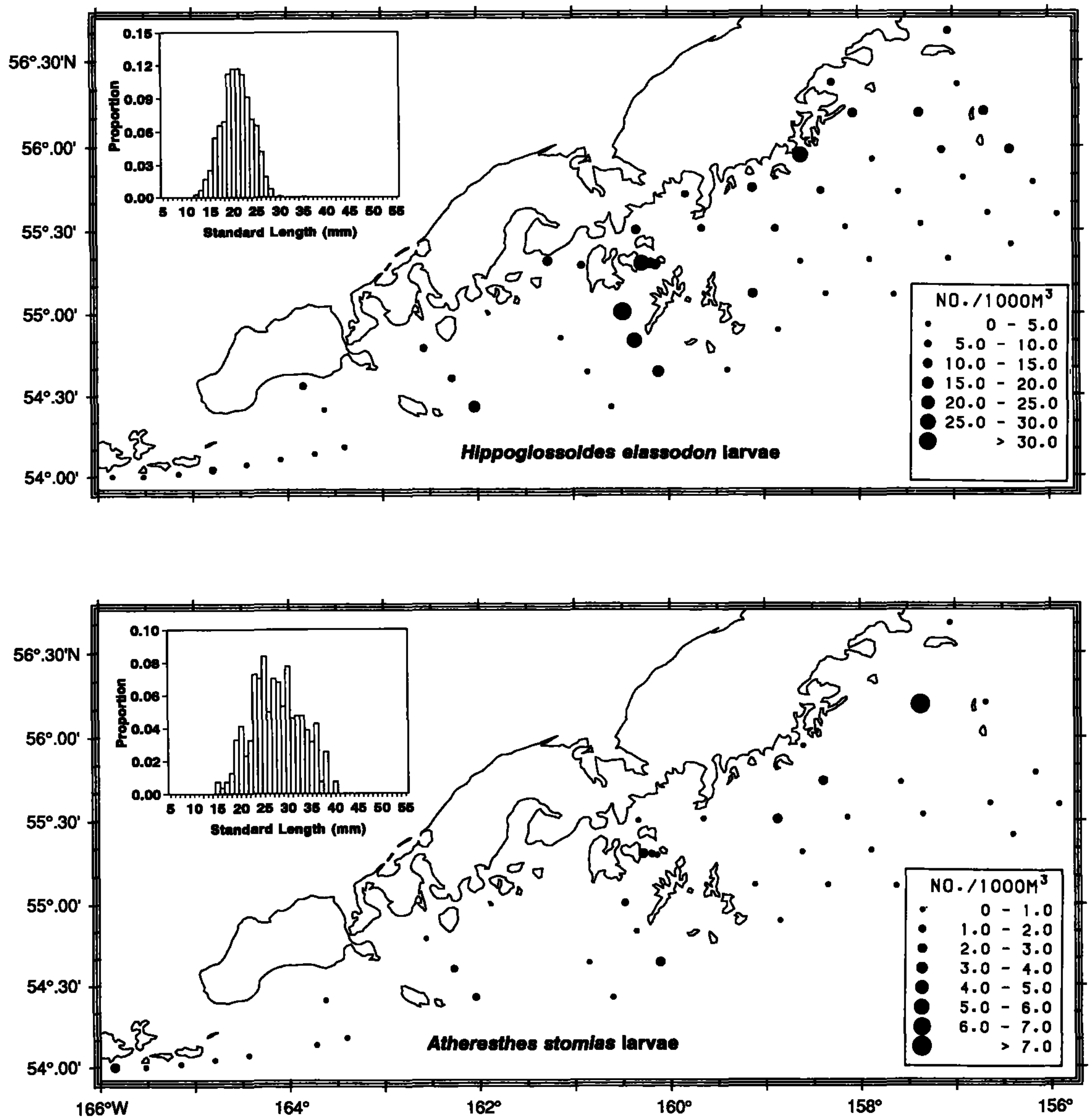

Figure 7

Distribution of larvae of *Hippoglossoides elassodon* and *Atheresthes stomias* in the study area. Also shown are the standardized length distributions for each species (inset).

tively high in group-2 and group-4 stations and low in group-1 and group-3 stations (Table 3).

Station groups showed little correspondence with the environmental variables examined. Distance from shore was the only variable that showed a clear relationship to the station groups (Table 4). Group 3 (offshore) and group 4 (inshore) were clearly differentiated from the remaining two midshelf groups. Although group 4 was the closest to shore, it also showed the greatest average bottom depth. Group 2 exhibited the shallowest mean depth and warmest mean surface temperature of the four station groupings (Table 4). Among the six variables examined, only distance from shore ($P<0.001$) and water temperature at 50 m depth ($P=0.048$) showed significant differences among the four groupings. In addition. the group closest to shore (group 4) had the warmest temperatures at 50 m ($\bar{x}$=7.1°C) and the one farthest from shore (Group 3) was colder ($\bar{x}$=6.4°C) at 50 m than the intermediate groupings (Fig. 11).

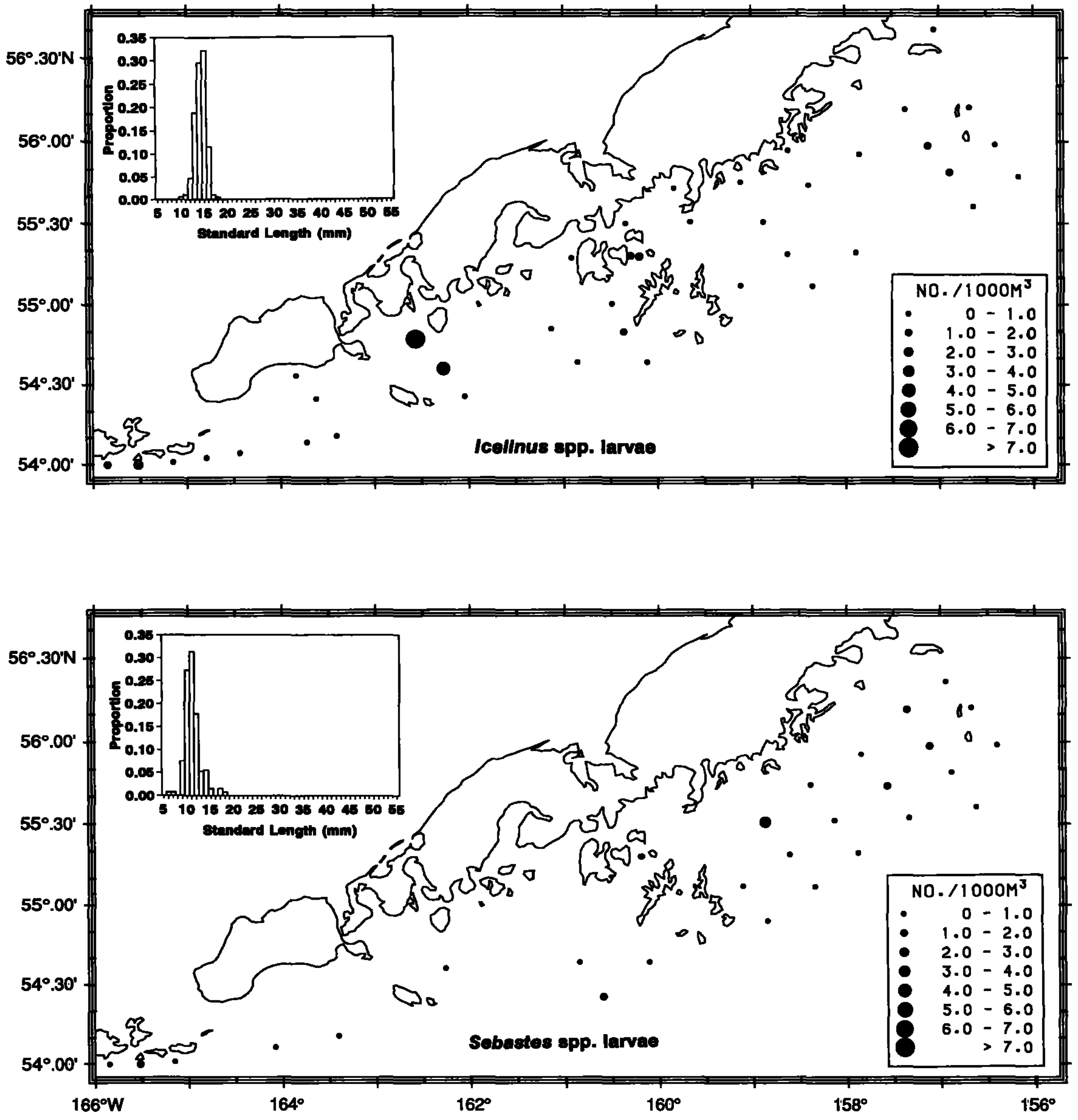

Figure 8

Distribution of larvae of *Icelinus* spp. and *Sebastes* spp. in the study area. Also shown are the standardized length distributions for each species (inset).

Comparison of abundance rankings with other surveys

The abundance rankings of the dominant taxa estimated showed some similarities among the three surveys (Table 5). The six most abundant taxa in the bottom trawl surveys were represented in the 10 most abundant taxa in both ichthyoplankton surveys, but the coherence was stronger (top three species the same) for the July Methot trawl survey than for the May bongo-net survey. The seventh most abundant species in the trawl survey, *Errex zachirus*, was ranked 14th in the Methot trawl collections but did not appear in the bongo-net sampling. A comparison of the ranks of only the taxa that were mutually present in samples from each gear type showed that the trawl survey was more similar in ranking to the Methot trawl survey data (Spearman Rank Correlation, $r_s = 0.50$) than to the bongo-net survey data ($r_s = 0.23$).

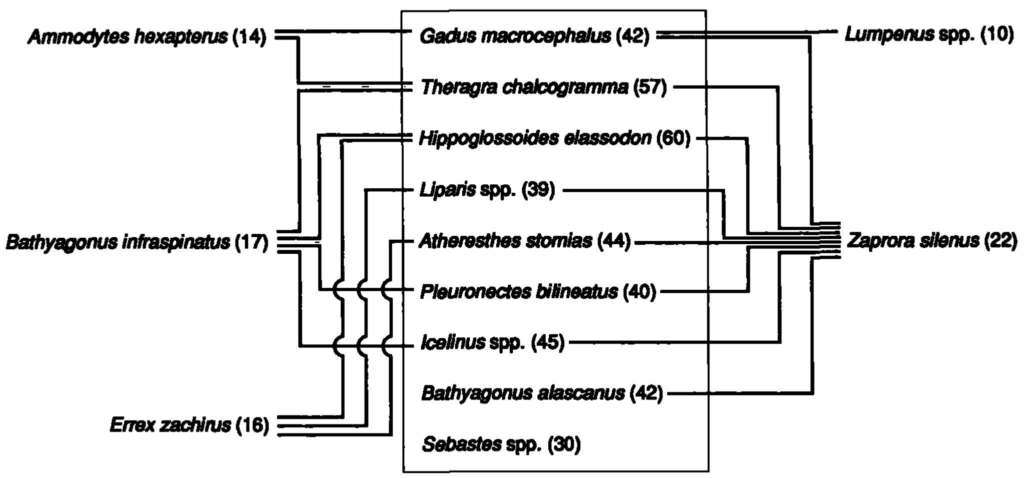

Figure 9

Results of the Recurrent Group Analysis showing the main grouping (within box) and associated taxa (outside box) at an affinity level of 0.40. The numbers in parentheses are the occurrences of each taxon.

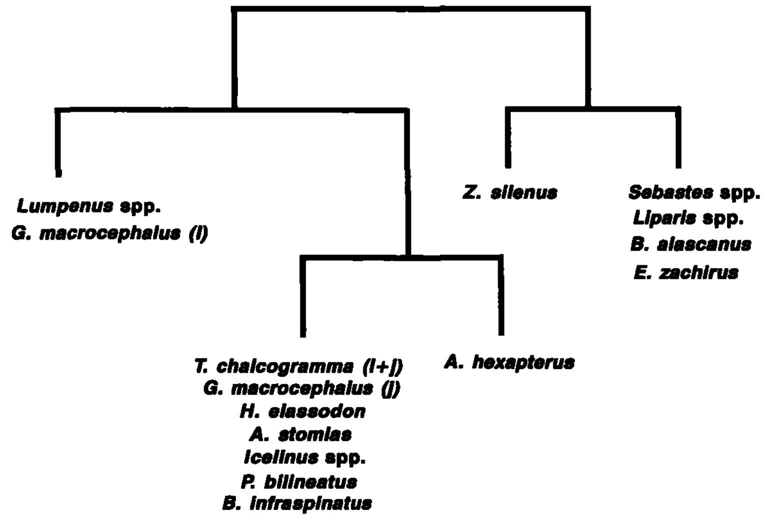

Figure 10

Taxa groupings resulting from the Two-way Indicator Species Analysis. The larval (*l*) and juvenile (*j*) stages of *Theragra chalcogramma* and *Gadus macrocephalus* are indicated separately.

Discussion

Despite the relatively large biomass of adult fishes that inhabit this region, the mid-summer abundance and distribution patterns of ichthyoplankton have received little attention. The one previous study (Hinckley et al., 1991), which used a Methot trawl to sample the western Gulf of Alaska in June and July 1987, examined only the distribution of late larval and early juvenile *T. chalcogramma*. The highest densities of this species were found east of the Shumagin Islands, a finding that was similar to what we found. The only other surveys conducted during the summer employed net gear with small mouth openings (see Kendall and Dunn [1985] and references therein) and caught mainly eggs and early larvae. Some of the differences in species composition between the most commonly used ichthyoplankton gear (e.g. bongo nets) and that used in this study are likely due to extrusion of smaller larvae through the meshes of the Methot net. For example, one of the numerically dominant taxa collected during June and July in small-mesh bongo-net gear is *Bathymaster* spp. (Kendall and Dunn, 1985; Rugen[2]) which did not, however, occur in our Methot trawl collections. Since *Bathymaster* spp. larvae average only around 10 mm in length in early June (Rugen[2]), they are probably too small to be caught by the Methot trawl in July. Conversely, some taxa (e.g. *T. chalcogramma*) that

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[2] Rugen, W. C. 1990. Spatial and temporal distribution of larval fish in the Western Gulf of Alaska, with emphasis on the period of peak abundance of walleye pollock (*Theragra chalcogramma*) larvae. NWAFC Proc. Rep. 90-01, 162 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-0070.

Table 3

Two-way table of dominant taxa showing the station and species groups as determined by TWINSPAN. Numbers in parentheses represent the number of stations in each station group. The numbers within the matrix correspond to the mean density (no./1000 m^3) of that taxon for each station grouping (— = taxon not present). Life stages of *T. chalcogramma* and *G. macrocephalus* are designated after species name (l=larvae, j=juvenile). The total ichthyoplankton for each station group represents all species including the rare taxa not included in the TWINSPAN analysis.

	Station group			
Taxon	1 (13)	2 (6)	3 (22)	4 (19)
Lumpenus spp.	0.02	1.05	—	0.09
G. macrocephalus (l)	—	0.02	0.02	0.38
A. hexapterus	0.08	0.66	—	0.05
H. elassodon	5.02	13.10	2.11	14.15
T. chalcogramma (l)	0.36	1.96	0.28	2.53
G. macrocephalus (j)	0.44	0.53	0.36	0.71
Icelinus spp.	0.70	1.88	0.28	0.44
P. bilineatus	0.34	0.24	0.10	0.40
A. stomias	0.44	2.18	0.44	0.45
T. chalcogramma (j)	0.63	6.33	0.70	1.35
B. infraspinatus	0.06	—	0.03	0.05
Z. silenus	—	0.10	0.30	0.08
B. alascanus	0.19	0.15	0.31	0.15
Liparis spp.	0.30	0.42	0.36	0.16
E. zachirus	0.10	0.12	0.02	0.04
Sebastes spp.	0.47	0.21	1.04	0.08
Total ichthyoplankton				
Mean	9.16	29.74	5.52	21.11
Standard deviation	3.63	5.19	2.84	8.12

spawn during spring are poorly sampled as late larvae and early juveniles by bongo-net gear in summer (Shima and Bailey, 1994).

Another study that examined the distribution of late larvae and early juveniles in our study area used neuston sampling gear, which tends to capture significantly larger specimens than do bongo nets (Doyle et al., 1995). These collections, however, were made mostly before June, and the taxonomic composition of the catch was markedly different from that of the present study in that only 3 of the 15 most abundant larvae (*A. hexapterus, T. chalcogramma*, and *Mallotus villosus*) caught in the neuston nets occurred in our samples.

One motivation for conducting ichthyoplankton surveys is to provide an alternative estimate to trawl surveys for the abundance of commercially exploitable fishes (Heath, 1992). Although there are biases involved with both ichthyoplankton and trawl surveys that may result in an incomplete picture of true fish population sizes, it is of interest to compare the results of these two assessment methodologies for the stocks in the western Gulf of Alaska (Kendall and Dunn, 1985). Trawl surveys tend to exclude small and cryptic taxa, particularly those that inhabit untrawlable bottom types. Diel differences in vertical distribution and aggregation patterns may also influence trawl survey abundance estimates. Ichthyoplankton surveys are restricted to sampling only the life stages that are pelagic at the time of the survey, therefore they are strongly dependent on the timing of spawning and the mode of development. Moreover, extrapolation of catches to population abundance requires additional information on basic life history strategies (e.g. hatch size, pelagic/demersal eggs, number of spawning events, oviparity/viviparity), spawning locations, population egg production, and mortality rates.

Differences in life history patterns may explain some of the disparities observed between the trawl and ichthyoplankton rankings. Two abundant trawl species, *Pleuronectes asper* and *Microstomous pacificus*, spawn in late spring and early summer off Alaska (Hirschberger and Smith, 1983; Matarese et

Table 4

Mean values of station and environmental variables for the four TWINSPAN station groups. Numbers in parentheses below each station group represent the number of stations in each group. Standard deviations are given in parentheses below each mean.

	Station group			
Mean variables	1 (13)	2 (6)	3 (22)	4 (19)
Surface temperature (°C)	12.80 (0.68)	13.06 (1.10)	12.83 (1.41)	12.73 (0.83)
50-m temperature (°C)	6.89 (1.01)	6.99 (0.95)	6.44 (1.19)	7.06 (0.54)
100-m or bottom temperature (°C)	6.22 (0.83)	6.42 (0.75)	6.05 (1.07)	6.38 (0.55)
Bottom depth (m)	103.5 (24.8)	87.0 (39.9)	116.4 (54.9)	137.9 (48.3)
Distance from shore (km)	28.8 (17.8)	25.9 (19.7)	54.4 (33.6)	13.9 (9.7)
Distance alongshore (km)	233.4 (205.2)	263.6 (127.2)	282.8 (223.4)	224.3 (103.1)

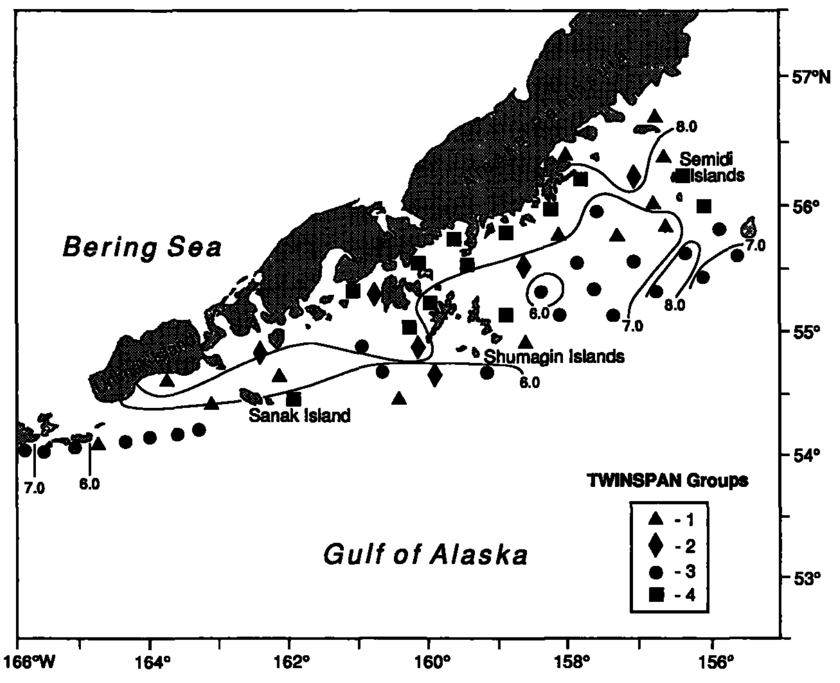

Figure 11

Station groupings from Two-way Indicator Species Analysis displayed on a map of the study area. See Table 3 for the dominant species comprising each station grouping. Also shown are the isotherms at 50 m measured at the time of sampling.

al., 1989) and are not usually represented as larvae in Gulf of Alaska ichthyoplankton sampling (Kendall and Dunn, 1985; Rugen[2]). Rex sole, *Errex zachirus*, spawn in the southern part of their range and are also rarely found in ichthyoplankton collections in the area. The other dominant trawl species, *Clupea pallasi*, spawns demersally in shallow water, and the early life stages are generally restricted to nearshore environments. Conversely, several taxa that are abundant in the ichthyoplankton samples are not well represented in the trawl sampling. These include fish of small maximum size (e.g. *A. hexapterus, Icelinus* spp., *Liparis* spp.), nearshore distribution (e.g. *B. alascanus, Z. silenus, Lumpenus* spp.) (Hart, 1973), or mesopelagic species that are found primarily offshore, but whose larvae are advected onshore (e.g. *Stenobrachius leucopsarus*).

Table 5

The top 10 most abundant taxa in the western Gulf of Alaska based on research trawl surveys during the summer of 1990 and on ichthyoplankton surveys during May and July of 1991.

Rank	Trawl survey	Bongo-net survey	Methot survey
1	*A. stomias*	*T. chalcogramma*	*H. elassodon*
2	*T. chalcogramma*	*A. hexapterus*	*T. chalcogramma*
3	*H. elassodon*	*Bathymaster* spp.	*A. stomias*
4	*Sebastes* spp.[1]	*A. stomias*	*G. macrocephalus*
5	*P. bilineatus*	*H. elassodon*	*Icelinus* spp.
6	*G. macrocephalus*	*Sebastes* spp.	*Sebastes* spp.
7	*E. zachirus*	*S. leucopsarus*	*P. bilineatus*[2]
8	*P. asper*	*G. macrocephalus*	*Liparis* spp.
9	*C. pallasi*	*P. bilineatus*[2]	*B. alascanus*
10	*M. pacificus*	*Icelinus* spp.	*Lumpenus* spp.

[1] Because larvae of *Sebastes* are presently not identifiable to species, all adult rockfishes from the trawl survey were combined into this category.

[2] Includes larvae of *Pleuronectes* sp. II which are morphologically similar to *P. bilineatus*. Adults were not distinguished in the trawl survey.

Despite the limitations involved with conducting ichthyoplankton abundance surveys with only one gear type (Suthers and Frank, 1989), our sampling with a relatively small number of Methot trawls during mid-summer of 1991 provided abundance rankings that were quite similar to the groundfish abundance rankings estimated during 1990 and were much more similar than those estimated from larval collections only two months earlier in 1991. Additional collections taken earlier in 1991 (late April and early May) showed even less coherence with the adult groundfish community (Brodeur, unpubl. data). Apparently, many of the smaller species not vulnerable to the survey trawls leave the plankton and settle to rocky habitats or in nearshore areas during the summer, leaving many of the numerically dominant gadids and pleuronectids to be sampled. We chose to correlate the rankings rather than the actual abundance of species among the surveys because small differences in timing of spawning relative to the timing of the survey can have drastic effects on abundance owing to mortality and changes in catchability. For example, on the basis of the Methot trawl catches, *H. elassodon* appear to be much more abundant than *T. chalcogramma* in our survey area. This may be due to the fact that they hatch out about one month later than pollock (Rugen[2]) and thus have undergone substantially less larval mortality. Subsequent studies have also indicated that the 1991 year class of *T. chalcogramma* had very high larval mortality owing to either poor feeding conditions or to advection off the shelf (Bailey et al., 1995), resulting in very low recruitment that year (Bailey et al.[3]).

The similarity in the species groupings found with the two methods (Recurrent Group Analysis and TWINSPAN), each of which uses different resolutions of the same data (presence/absence vs. abundance), substantiates the conclusion that certain taxa tend to be associated in our study area. Whether these groupings result from behavioral aggregation by certain species that have been adapted to a particular habitat (Frank and Leggett, 1983) or whether hydrographic conditions passively transport larvae spawned in the same area to the same nursery area (Richardson et al., 1980; Olivar, 1987; Sabatés and Masó, 1990), or some combination of both (Cowen et al., 1993), cannot be determined from our data. However, many of the specimens collected in the Methot net may no longer be considered passive organisms because they can actively swim against currents while seeking out or remaining within favorable habitats. Because juvenile fishes respond not only to environmental conditions but also readily respond to the presence of conspecifics and potential predators (Olla et al., in press), several factors can influence their distribution patterns in natural conditions.

The lack of clearly defined boundaries between the station groups that we observed may be characteristic of this dynamic environment. In our study area, vigorous mixing and strong currents (Reed and Schumacher, 1986) do not allow formation of well-defined mesoscale physical boundaries (see also Doyle et al., 1995). However, the mid-summer ichthyoplankton community appears to reflect a large-scale onshore to offshore gradient of environmental characteristics that include midwater temperatures.

The ultimate usefulness of age-0 surveys for predicting year-class strength depends upon the relative mortality pressure occurring after the survey period. Although managers seek information on the relative strength of a year class as early as possible, the accuracy and precision of the index may be low for this life history stage for species that suffer variable late juvenile predation losses. For *T. chalcogramma*, substantial predation upon juveniles may occur in late summer (Livingston[4]), which may affect the magnitude of subsequent recruitment during some, if not all, years. A distinct advantage for early or mid-summer surveys of juveniles is that fish at this stage have not developed complicated diel vertical and inshore migrations or complex aggregation and schooling patterns that generally make later stage assessment so difficult (Koeller et al., 1986; Godø et al., 1991; Lough and Potter, 1993; Wilson et al., in press). Determining whether year-class strength for this population is set by mid-summer will require more years of abundance estimates, as well as sampling for several other life history stages in months both before and after the period surveyed in this study (Bailey and Spring, 1992; Bailey et al.[3]).

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