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Distribution of Juvenile Pacific Ocean Perch *Sebastes alutus* in the Aleutian Islands in Relation to Benthic Habitat

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Abstract: The habitat of juvenile Pacific ocean perch (POP) *Sebastes alutus* was identified using data from trawl surveys conducted by the National Marine Fisheries Service and linear modeling techniques. Analyses were carried out to evaluate the POP catch per unit effort (CPUE) data in relationship to depth, temperature, and sponge and coral CPUE. Sponge and coral CPUE were positively correlated, while depth and temperature were negatively correlated. Over 96% of the juvenile POP catch was from depths of 76 to 225 m and their CPUE increased with depth, and decreased with increasing temperature. The most important finding of this analysis was that juvenile POP CPUE increased significantly with increasing sponge and coral CPUE. Multiple regression analysis predicting juvenile POP CPUE explained 16%–17% of the CPUE variability using sponge and coral CPUE and either bottom temperature or depth. Juvenile POP were most abundant at sites in the western Aleutian Islands (beyond 170º W longitude), on large underwater banks (Stalemate and Petrel banks), and in passes between islands where currents are strong and prey availability may be higher than surrounding areas. These results suggest sponge and coral have an important role in the early life history of juvenile POP.

INTRODUCTION

Pacific ocean perch *Sebastes alutus* is an important component of Alaska groundfish fisheries, with landings of 20,500 t (exvessel value of $4.5 million) in commercial trawl fisheries in Alaska in 2002 (NMFS 2004). The catch of Pacific ocean perch (POP) in commercial fisheries occurs primarily in the northern Gulf of Alaska (GOA) and Aleutian Islands region, with minor, but regionally important catches along the Bering Sea shelf break. Landings of POP in Alaska declined substantially in the early 1980s, increased slightly in the last half of that decade, and have stabilized since 1992 (NPFMC 2003). Because POP are long-lived (up to 90 years), and slow growing, they may be susceptible to overfishing (Chilton and Beamish 1982), yet there is a critical lack of knowledge about their life history and habitat use.

Pacific ocean perch age of maturity is approximately 5–7 years, and they reach a total length of about 200–250 mm (Paraketsov 1963; Chikuni 1975). Larval distributions suggest adults spawn near the shelf break at depths of 200–250 m in the spring (Lisovenko 1964). Pacific ocean perch are ovoviviparous, releasing pelagic larvae that settle after approximately one year (Carlson and Haight 1976). Early stage juveniles feed primarily on copepods, graduating to a diet of euphausids as they grow and mature (Paraketsov 1963; Carlson and Haight 1976). Adult POP are generally found in high concentrations near the shelf break and in gullies, predominantly in the northern GOA (Major and Shippen 1970; Lunsford et al. 2001). Adult POP make extensive diel migrations to feed (Skalkin 1964; Lyubimova 1965; Major and Shippen 1970) and have been found in high densities near the bottom in sea whip beds (Brodeur 2001). The habitat used by juvenile stage POP has not previously been quantified. Submarine observations in southeast Alaska indicate the early juveniles school near rock outcroppings with epibenthic invertebrates (Carlson and Straty 1981). These observations, along with information about the distribution of other rockfish juveniles (Love et al. 1991), indicate a probable preference for physically complex habitat by juvenile POP.

One of the major features adding complexity to rocky habitat in the GOA and Aleutian Islands region is epibenthic invertebrates such as deepwater sponges and corals. These invertebrates are susceptible to damage by mobile fishing gear (Freese 2001; Krieger 2002) and are long lived and slow growing (Leys and Lauzon 1998; Stone and Wing 2001; Andrews et al. 2002; Risk et al. 2002), suggesting recovery times that may

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be on the order of decades or centuries. For example, Freese et al. (2001) found that 47% of the sponges in the path of a trawl were damaged during one pass of fishing gear, and no sign of recovery could be seen after one year. Although the effects of commercial trawling on sponge and coral are becoming clearer, less clear is how the disturbance of this habitat affects commercial fish species. Pacific ocean perch population dynamics suggests that juvenile habitat may be a factor limiting adult recruitment in this species (Iles and Beverton 2000). If true, the destruction of critical juvenile habitat may reduce the recruitment potential for the species.

In general, little is known of the functional relationships between juvenile POP and their habitat or the scale at which these relationships occur (Carlson and Haight 1976; Carlson and Straty 1981). Data to help us determine the functional relationships is lacking, or is too small scale to apply across broad areas. This study utilized bottom trawl survey data from the Aleutian Islands to evaluate the distribution of POP across a large region encompassing a variety of different habitat types defined by catch rates of sponge and coral.

MATERIALS AND METHODS

Study area

The Aleutian Islands are a chain of volcanic islands stretching from southwest Alaska across the North Pacific, dividing the western GOA from the Bering Sea (Figure 1). The Alaska Coastal Stream and Alaska Coastal Current flow westward on the GOA side of the Aleutian Islands, while on the Bering Sea side the current flows eastward, with extensive transport through passes in the chain from the GOA

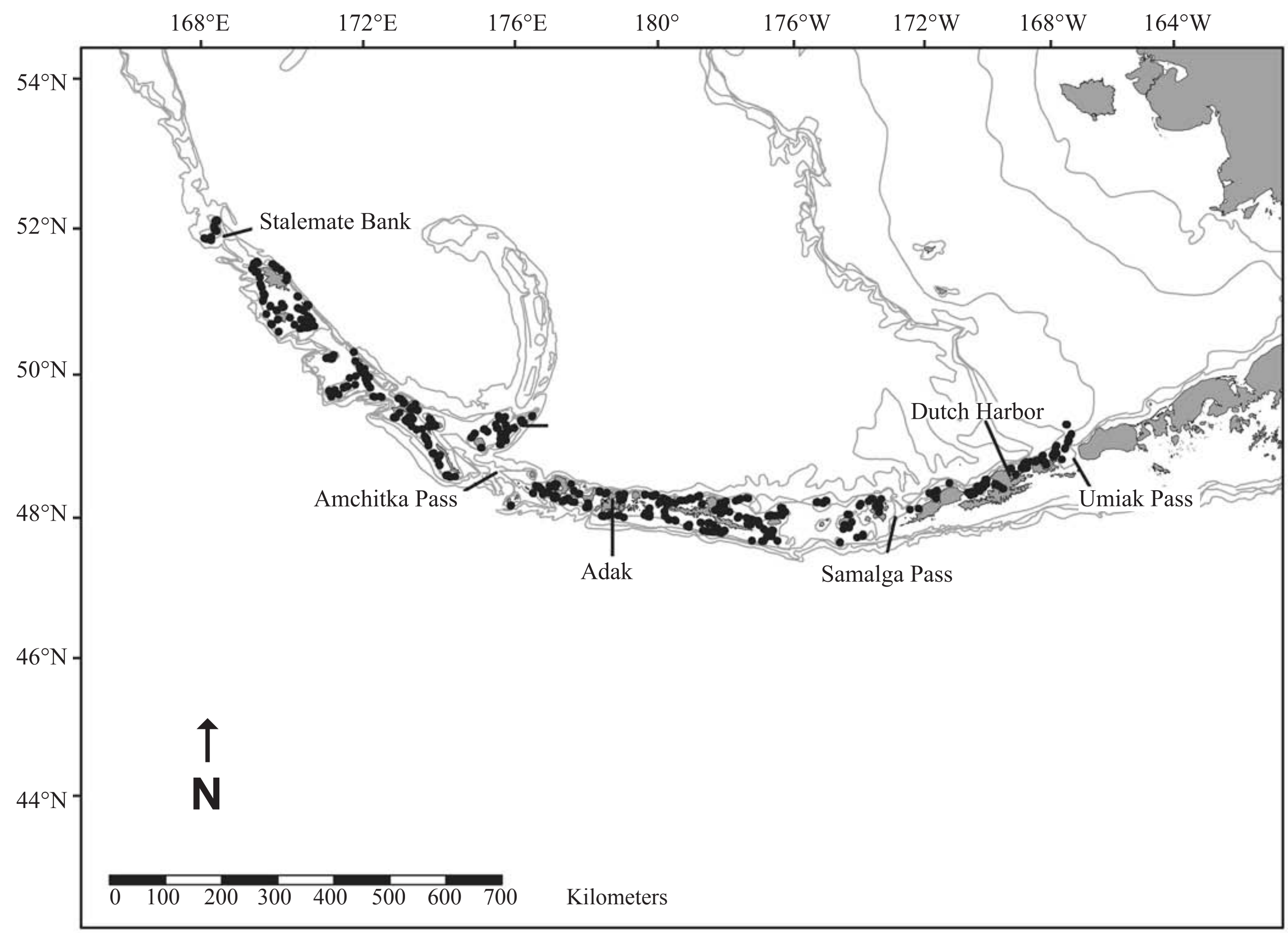


Figure 1. Map of the Aleutian Islands, showing important features, depth contours, and trawl survey stations in the 1994, 1997 and 2000 trawl surveys.

to the Bering Sea (Stabeno et al. 1999; Stabeno et al. 2002). The Aleutian Islands bottom trawl survey is conducted along the island chain from longitude 165°W to 170.5°E on the Bering Sea side and from longitude 170°W to 170.5°E on the GOA side. The continental shelf is narrow along the Aleutian Islands chain, and depths sampled by the bottom trawl survey range from 10 to 550 m.

Trawl survey data

The Alaska Fisheries Science Center has conducted bottom trawl surveys in the Aleutian Islands region since 1980. Surveys were conducted triennially between 1991 and 2000. For this analysis we used only Alaska Fisheries Science Center data from the 1994 (n=384), 1997 (n=439), and 2000 (n=415) Aleutian Islands trawl surveys, because data collection and species identification methods were consistent. A general description of trawl survey methodology can be found in Harrison (1993). Records were only used where trawl performance was satisfactory and where the distance fished and net width were recorded. Additionally, trawl survey sites without bottom depth or temperature data were eliminated. Bottom depth and temperature were measured using a temperature-depth recorder attached to the trawl net and averaged over the length of the tow.

All fish captured during the survey trawls were sorted by species, counted, measured for total length, and the total weight and number of each species in the catch was determined. In the case of some large catches, the total catch was weighed and subsampled. When more than 200 individual POP were captured in a tow, POP lengths were subsampled. The POP catch was divided into juvenile (<250 mm) and adult stages (>250 mm) based on published literature on POP size at maturity (Paraketsov 1963; Chikuni 1975). Catch per unit of effort (CPUE, no. $\times$ ha^{-1}) of juvenile POP was calculated using the area swept computed from the average measured net width for each tow multiplied by the distance towed recorded with geographical positioning systems. The juvenile POP catch data were transformed for analyses using LN(CPUE+1) to meet normality assumptions, hereafter shortened to juvenile POP CPUE.

Although some invertebrates are identified to species during the survey, for this analysis sponges were defined as species from the phylum Porifera, while black corals, gorgonian corals, hydrocorals, cup corals, soft corals were all grouped as corals. The CPUE of sponge (kg $\times$ ha^{-1}) and coral (kg $\times$ ha^{-1}) in each tow was calculated and LN(CPUE+1) transformed to meet normality assumptions for analysis, and are hereafter defined as sponge and coral CPUE.

Data analysis

Raw juvenile POP catch data and the habitat variables were mapped over the Aleutian Islands region using a geographic information system (GIS). The combined coral and sponge catch was interpolated to a layer in the GIS using inverse distance weighting (power=2, maximum search distance=20,000 m) with an output cell size of 1 ha. The catch of juvenile POP was overlaid onto maps of sponge and coral distribution showing the bathymetry of the Aleutian Islands trawl survey area.

Data analyses were carried out in a 2-stage process. Two dependent variables were examined: 1) the presence or absence of juvenile POP, and 2) juvenile POP CPUE. The presence–absence data as a function of trawl depth were used to determine the depth distribution of juvenile POP. Data were then used only from tows made in the depth range where over 96% of the trawls catching juvenile POP occurred. This eliminated portions of the survey area in which juvenile POP were rarely observed simply because the data were collected outside the normal depth range for POP, and allowed us to analyze habitat variables over an appropriate depth range for POP.

Correlations among the 4 habitat variables (depth, temperature, sponge CPUE and coral CPUE) were computed to determine significant relationships that existed. Based on this analysis, the CPUE of sponge and coral were added for each trawl survey haul to facilitate further analysis of juvenile POP CPUE. Juvenile POP CPUE was compared to the 3 habitat variables (depth, temperature, sponge and coral CPUE) using multiple linear regression (Zar 1974).

RESULTS

Sponge and coral CPUE was typically high in areas of intermediate depth along the Aleutian chain west of 170°W. The highest CPUE of coral and sponge was found at Petrel Bank (Figure 2). This coincided with some of the highest juvenile POP CPUE values (Figure 2). Juvenile POP was highest in areas of elevated coral and sponge CPUE (Figure 2). The distribution of juvenile POP was strongly influenced by depth (Figure 3). Over 96% of the total juvenile POP catch was between 76 and 225 m. Juvenile POP were caught at only 23% of the survey sites in this depth range. So even at trawl sites located in a suitable depth range for juvenile POP, they were not caught in over 75% of the tows.

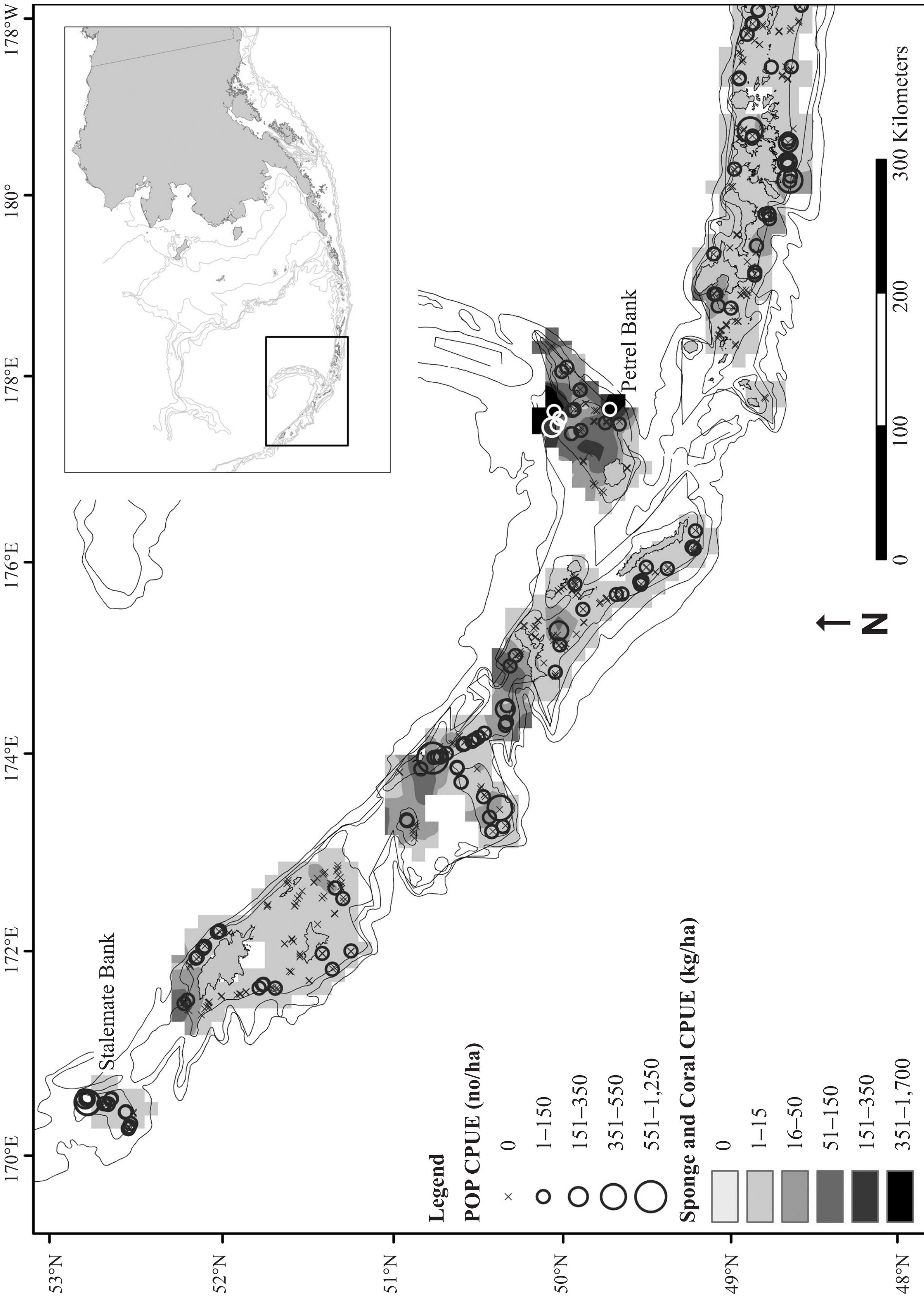
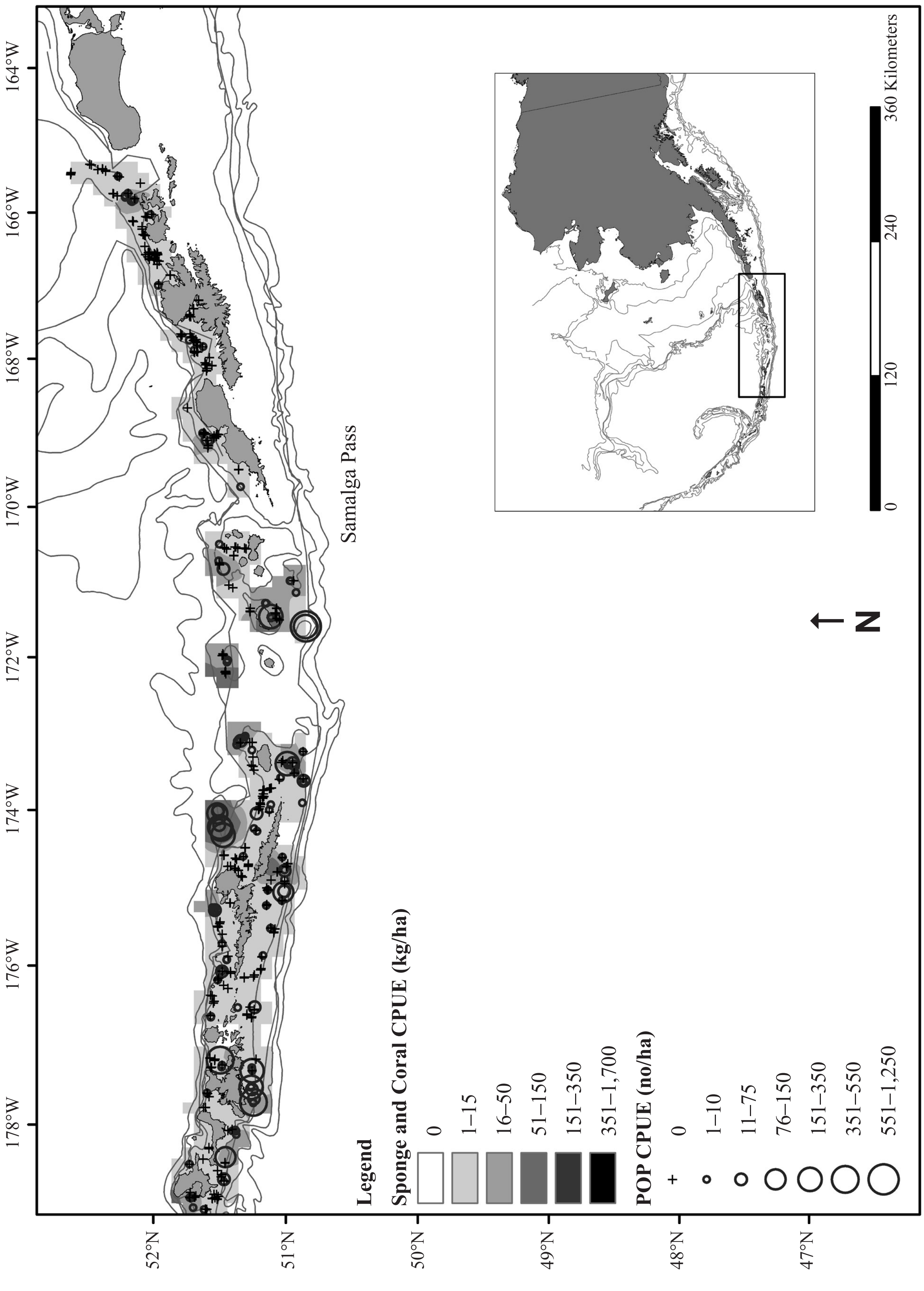


Figure 2. Map of raw juvenile POP catch data in the Aleutian Islands including raw sponge and coral catch data and depth contours. Sponge and coral catches are interpolated using inverse distance weighting (grid size=1 ha).



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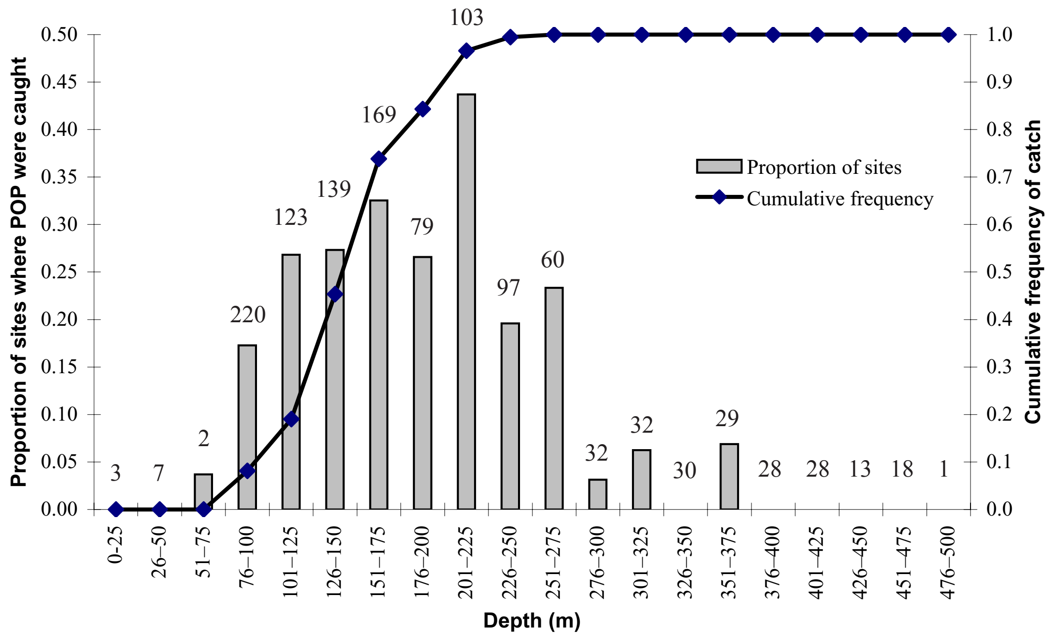

Figure 3. Cumulative frequency distribution of juvenile POP CPUE and proportion of trawl survey sites with one or more juvenile POP present. Data are presented in 25-m depth bins, and the number of tows completed in each depth bin are given.

Only data from trawl sites in the suitable depth range (76–225 m) were used in further analyses ($n=833$).

Most of the habitat variables used in the analyses, depth, temperature, sponge CPUE, and coral CPUE, exhibited significant cross-correlations (Figure 4). Sponge and coral were weakly correlated, although the relationship was statistically significant ($P<0.05$). Neither sponge nor coral were correlated with temperature ($P=0.45$ and $P=0.43$). Temperature, sponge CPUE, and coral CPUE were all significantly correlated with depth. Temperature and coral CPUE decreased with increasing depth, while sponge CPUE increased at deeper depths. There was substantial unexplained variability associated with the depth-invertebrate relationships, although depth and temperature were tightly linked.

The strong correlation between depth and temperature precluded their simultaneous use in a single multiple regression, leading to 2 analyses with either temperature or depth combined with sponge and coral CPUE (Tables 1 and 2). When depth was used in the multiple regression analysis, it was significantly positively related to juvenile POP CPUE (Figure 5). The resulting model equation was:

$$\text{Juvenile POP CPUE} = -0.363 + 0.295 \times S + 0.004 \times D + \varepsilon,$$

where S is sponge and coral CPUE, D is depth and ε is error. When temperature was included in the place of depth, it was significantly negatively correlated to juvenile POP CPUE (Figure 6). The resulting model equation was:

$$\text{Juvenile POP CPUE} = 0.990 + 0.305 \times S + -0.189 \times T + \varepsilon,$$

where T is temperature. The percentage of variability explained in the depth model (17.3%) was only slightly larger than the percentage explained in the model including temperature (16.3%). In both these analyses juvenile POP CPUE was positively correlated with sponge and coral CPUE (Figure 7).

DISCUSSION

The separation of adults and juveniles by depth is a common feature among rockfishes (Love et al. 1992; Murie et al. 1993), as well as other fishes, including flatfishes that utilize nursery areas physically distinct from the adult population during juvenile stages (Krygier and Pearcy 1986; Gunderson et al. 1990). Juvenile POP were only captured in a limited depth range during the 1994–2000 triennial trawl surveys. Juvenile POP were distributed shallower than adult POP, which exhibited highest densities in depths from 190 to 260 m. Juvenile POP catch was unpredictable even at sites in the preferred depth range, as seen by the high proportion of zero catches at depths from 76 to 225 m (> 0.75). Temperature and depth at each survey site covaried and neither variable could be estimated independently.

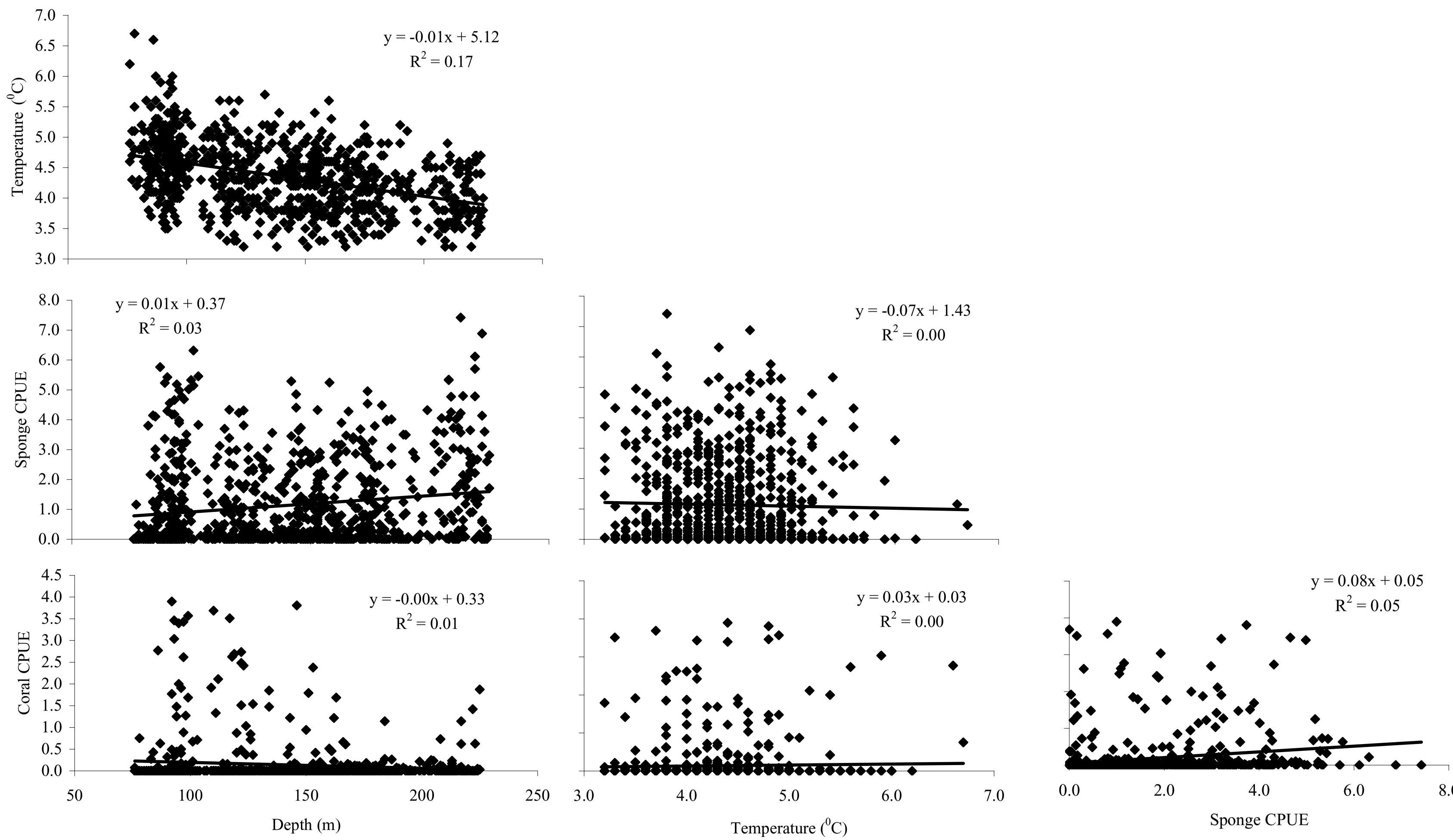

Figure 4. Scatterplot matrix of habitat data collected during the 1994, 1997, and 2000 Aleutian Island trawl surveys. The equations and line represent the best fitting relationships for a linear correlation of the plotted variables.

Table 1. Results of multiple regression analysis of juvenile POP CPUE in the Aleutian Islands bottom trawl survey database ($R^2 = 0.174$). Degrees of freedom (DF), P values, and F ratios for each factor are shown. The mean squared error (MSE) and DF for the error term are shown in the bottom row. Factors were judged to be significant with $P < 0.05$. Sponge and coral CPUE and juvenile POP CPUE were all LN+1 transformed prior to analysis.

Source	DF	F/MSE	P
Depth (m)	1	16.72	<0.0001
Sponge + coral CPUE	1	156.58	<0.0001
Error	830	1.29	

Table 2. Results of multiple regression analysis of juvenile POP CPUE in the Aleutian Islands bottom trawl survey database ($R^2 = 0.163$). Degrees of freedom (DF), P values, and F ratios for each factor are shown. The mean squared error (MSE) and DF for the error term are shown in the bottom row. Factors were judged to be significant with $P < 0.05$. Sponge and coral CPUE and juvenile POP CPUE were all LN+1 transformed prior to analysis.

Source	DF	F/MSE	P
Temperature (°C)	1	6.81	0.0092
Sponge + coral CPUE	1	154.75	<0.0001
Error	830	1.30	

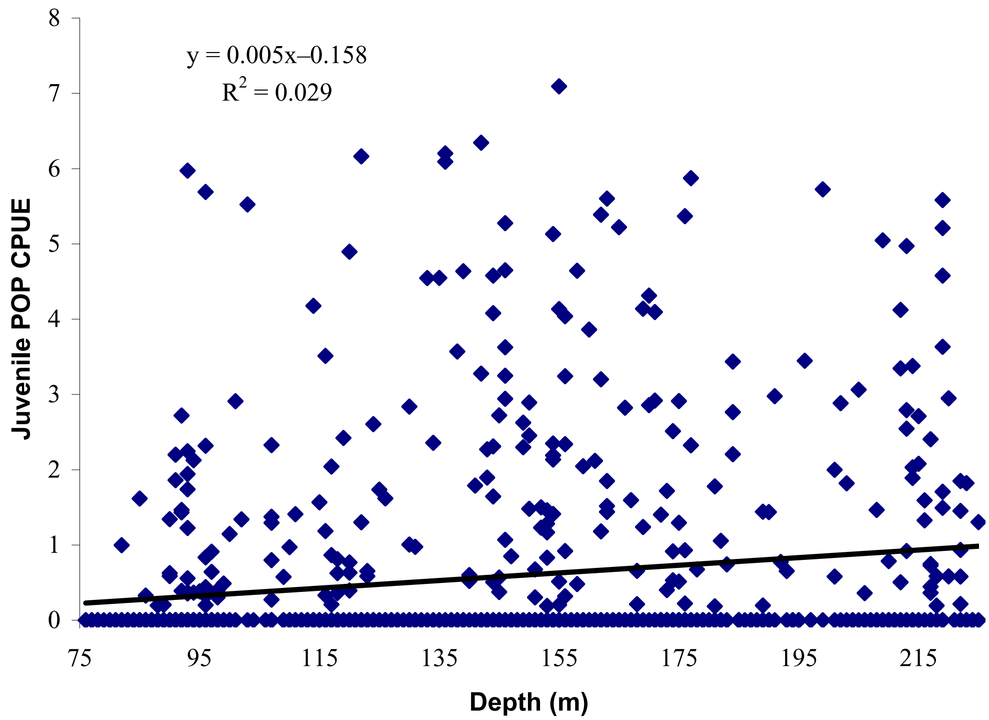

Figure 5. Relationship between depth and juvenile POP CPUE during 1994, 1997 and 2000 Aleutian Islands trawl surveys. Data include only depths from 76 to 225 m and juvenile POP CPUE are LN+1 transformed.

The data suggest a significant association of juvenile POP with sponge and coral. This is similar to results reported for juvenile fishes in other areas of Alaska, as well as in temperate ecosystems on the west coast of North America (Carlson and Straty 1981; Matthews 1989; Pearcy 1989; Love et al. 1991; Stein et al. 1992). Most previous studies have been qualitative, typically relying on observations from submarine dives and remote operated vehicles, and have had difficulty testing the strength of habitat associations. In submersible studies, Carlson and Straty (1981) found that juvenile rockfish (presumed by the authors to be POP) were found in association with epibenthic invertebrates, primarily *Metridium* sp. in Southeast Alaska fjords and inlets. Likewise Pearcy et al. (1989) observed schools of small rockfish in rocky, high relief areas where the fish swam for cover in anemones and rock crevices when startled. Small, mostly juvenile, rockfishes were found to school at ridge tops in high relief areas over Heceta Bank, Oregon (Stein et al. 1992). Young-of-the-year shallow-water rockfishes in Puget Sound, Washington have also been found to exhibit a preference for high relief, hard-bottom areas (Matthews 1989). In a review of multiple studies, Love et al. (1991) found that shallow-water rockfishes generally recruit to hard bottom areas with emergent

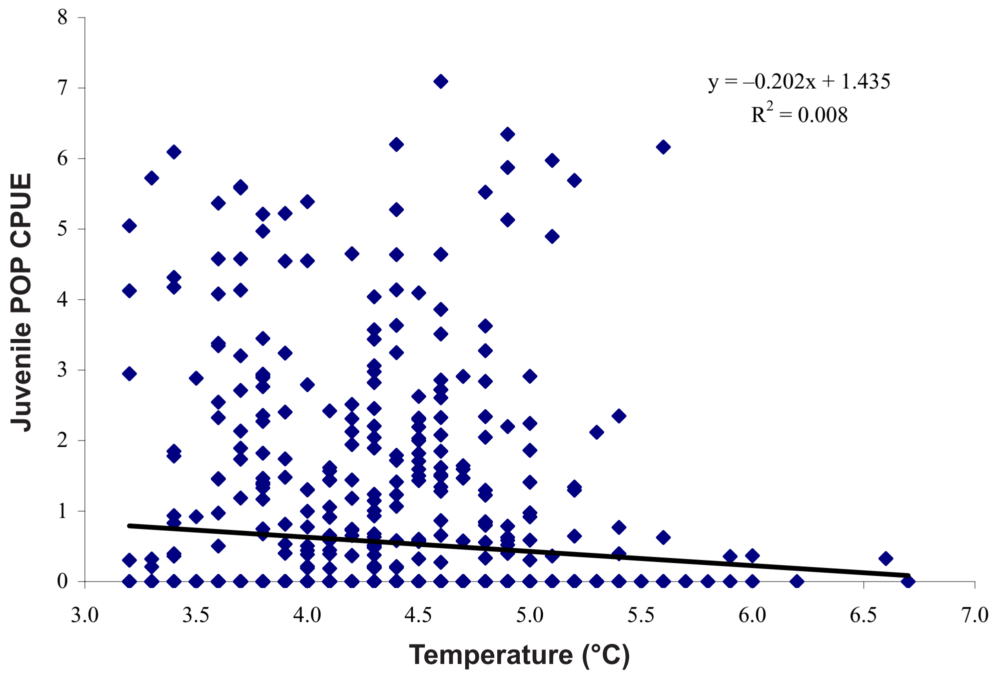

Figure 6. Relationship between temperature and juvenile POP CPUE during 1994, 1997 and 2000 Aleutian Islands trawl surveys. Data include only depths from 76 to 225 m and juvenile POP CPUE are LN+1 transformed.

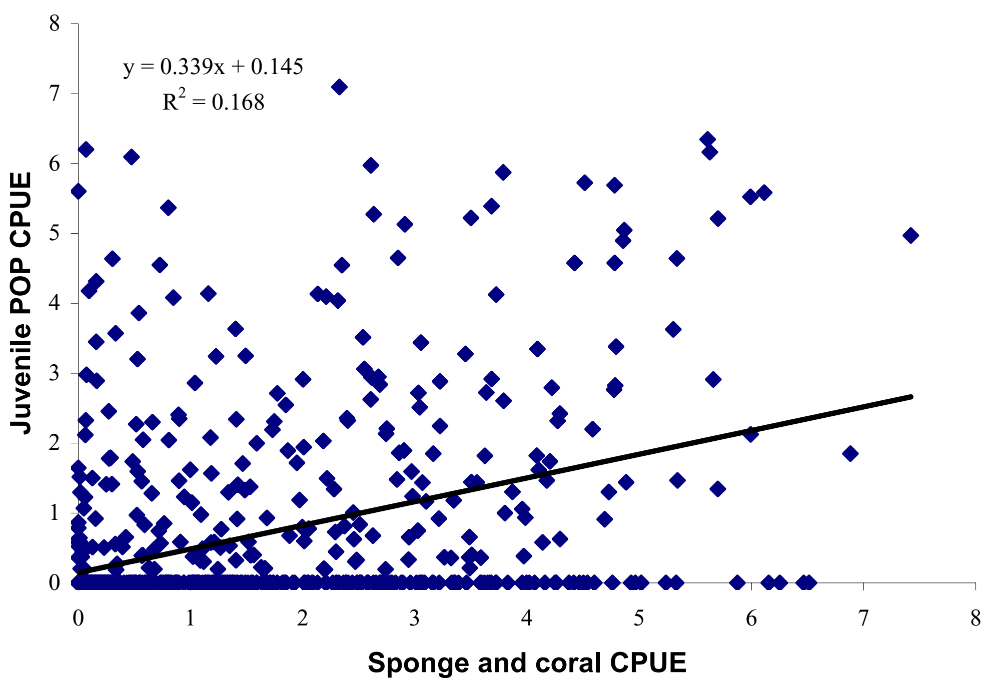

Figure 7. Relationship between sponge and coral CPUE and juvenile POP CPUE during 1994, 1997 and 2000 Aleutian Islands trawl surveys. Data include only depths from 76 to 225 m, and the sponge, coral, and juvenile POP CPUE are all LN+1 transformed.

macrophytes available for shelter. This evidence suggests high relief habitat covered with epibenthic invertebrates or vegetation appears to be vital habitat for small juvenile rockfishes.

Considerable variability in the juvenile POP CPUE was unexplained by the analyses presented here. Some of this variability may be due to sampling biases associated with the sampling gear and survey design. The particular bottom trawl used for the Aleutian Islands survey is equipped with 36-cm bobbins on the footrope separated with 10-cm rubber disks which keep the net elevated off the seafloor. This reduces the catchability of sponges and corals that are small enough to slip under the footrope. Thus, the sponge and coral catch data presented here is probably only an index of the epibenthic invertebrate shelter available to the juvenile POP. Additionally, some hard bottom areas are not fishable due to obstructions (pinnacles, snags, etc.), therefore the survey does not cover the entire range of sponge, coral, or juvenile POP distribution. The survey data, however, do cover an extensive region populated by juvenile POP, sponge, and coral, and although uncertainties associated with sampling bias undoubtedly exist, the data set is large and the patterns observed appear to be robust over the Aleutian Islands.

Additional unexplained variability in juvenile POP CPUE may be due to habitat characteristics that were not measured during the trawl surveys. Only 4 variables were available for this analysis of juvenile POP distribution, and additional information on predation rates, prey availability, current patterns, or other features would have improved the analysis. Previous work in Alaska has suggested that juvenile rockfish are found in areas of high currents, where little sediment is deposited (Carlson and Haight 1976). In the trawl surveys analyzed for this study, high juvenile POP CPUE commonly occurred over banks such as Stalemate Bank and Petrel Bank, as well as the larger deepwater passes common on the central and eastern Aleutian shelf west of 170° (Figure 1). West of Samalga Pass, a different oceanic regime exists, with more marine conditions than those east of the pass (Ladd et al. 2005). All Aleutian passes have been found to exhibit high currents, with net flow flowing northward from the GOA to the Bering Sea (Stabeno et al. 2002). Surface drifter studies have indicated that cyclonic circulation patterns around some of the banks and islands west of Samalga Pass can occur (Ladd et al. 2005). These circulation features may provide a retention or concentration mechanism for pelagic POP larvae spawned in the central and western Aleutian Islands, which in turn could provide a reasonable explanation for the occurrence of relatively large abundances of juveniles nearby. Additionally, zooplankton abundance is especially high at the northern end of passes (Coyle 2005). These patterns in the oceanography and biological characteristics may help explain the prevalence of juvenile POP populations around passes and banks in the Aleutian Islands.

The importance of sponge and coral habitat to juvenile POP is apparent when considering the species recruitment dynamics. Their stock-recruit relationship suggests that POP recruitment variability is dampened by the concentration of juvenile fish in nursery habitats (Iles and Beverton 2000). The strong association between juvenile POP and the complex structure of sponge and coral indicates this may be an important nursery habitat for the species. Anthropogenic disturbances to sponges and corals can be significant (Freese 2001) and persistent due to slow growth rates, raising concerns about long-term damage to juvenile POP nursery habitat. There have been few studies that document the importance of coral and sponge to commercially important fish species. This study links areas where the abundance of sponges and corals to the catch of juvenile POP, a feature that has long been suspected and documented qualitatively (Carlson and Straty 1981; Heifetz 2002; Malecha et al. 2005).

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