

Abstract—The relative value of pelagic habitat for three size classes of juvenile Pacific ocean perch (*Sebastes alutus*) was investigated by comparing their abundance and condition in two areas of the Aleutian Islands. Diet, zooplankton biomass, and water column temperatures were examined as potential factors affecting observed differences. Juvenile Pacific ocean perch abundance and condition, and zooplankton biomass varied significantly between areas, whereas juvenile Pacific ocean perch diet varied only by size class. Observed differences in fish condition may have been due to the quantity or quality of pelagic prey items consumed. For the delineation of essential demersal fish habitat, important ecological features of the pelagic habitat must therefore be considered.

Abundance, condition, and diet of juvenile Pacific ocean perch (*Sebastes alutus*) in the Aleutian Islands

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Studies defining essential fish habitat often focus on associations of marine fishes with seafloor characteristics (Neuman and Able, 1998; La Mesa et al., 2002). Although identifying these associations is necessary to define habitats used by fishes, it is also important to explore other factors that may affect fish survival. Pelagic production of food resources, such as zooplankton, may be a factor that affects the survival of demersal fish. Bottom-up control through variation in pelagic production, may in part explain the observations of large climate-change effects on demersal fishes, including rockfishes (Hollowed and Wooster, 1992; Hollowed et al., 2001).

Pacific ocean perch (*Sebastes alutus*; POP) are an important rockfish species that migrate vertically off the seafloor and consume pelagic prey (Brodeur, 2001), thus providing a direct linkage between pelagic zooplankton and demersal fish production. In general, juvenile POP (defined as individuals <250 mm fork length [FL] based on their size at first maturity) are associated with high-relief structured habitats, such as rocky outcrops, boulder fields, deep-water sponges, and corals (Rooper and Boldt 2005; Rooper et al., 2007). Little is known of the costs and benefits to

juvenile POP of residing in different habitat types or the potential linkage between pelagic prey and demersal habitats.

One measure of the relative value of different habitat types to juvenile POP may be fish condition. Fish diet, habitat, and water temperature are integrated into overall fish condition, which may affect fish growth and subsequent survival (Paul, 1997; Boldt and Haldorson, 2004). The goal of this study was to examine the relative abundance and condition of three size classes of juvenile POP in two different areas of the Aleutian Islands. Fish occupying suboptimal habitats were expected to be in poor condition compared to those living in optimal habitats. Additionally, we explored potential causes for observed differences in fish condition by examining POP diet, prey availability, and water temperature observed in the different habitats.

Methods and materials

Study site

Fieldwork for this study was conducted from 28 May to 9 June 2004, and from 11 August to 23 August 2004, at two

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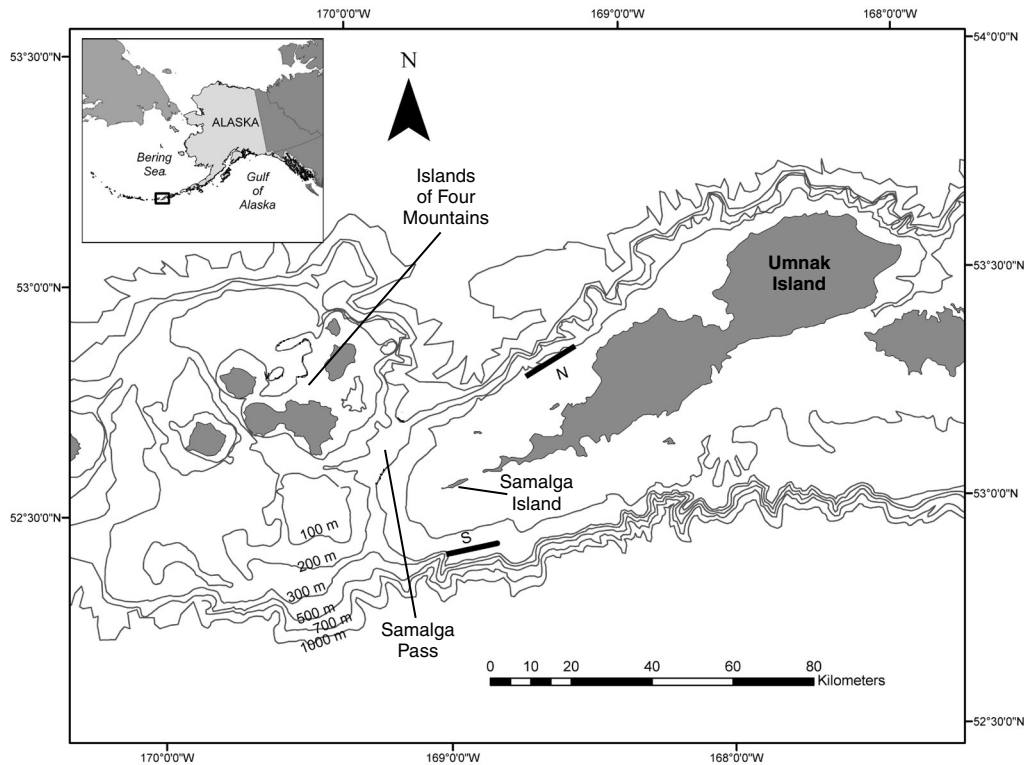


Figure 1

Map of the study area in the Aleutian Islands, Alaska. Study sites were located near the Islands of Four Mountains, north of Samalga Island (N), and south of Samalga Island (S). At both sites, juvenile Pacific ocean perch (*Sebastes alutus*) were collected with a bottom trawl, zooplankton were collected with a ring net, and water column temperature profiles were recorded with a conductivity, temperature, depth recorder.

sites near Samalga Pass in the Aleutian Islands (Fig. 1). One site was located on the south (S) side and one on the north (N) side of Samalga Island (Fig. 1). Two stations were sampled at each of the two sites in August and two stations were sampled at the N site in June. All the stations were located at depths from 117 to 146 m in high relief habitat (boulder fields) inhabited by juvenile POP.

Juvenile POP abundance and size classes

Juvenile POP (<250 mm FL) were collected during daylight hours with a standard NMFS poly Nor'eastern bottom trawl. A net (with average net width of 16.5 m) was towed at a target speed of 3 knots over distances of 0.4–1.0 km. The catch per unit of effort (CPUE in number of juvenile POP per hectare) at each site was calculated by using the area swept. Juvenile POP were measured for fork length and frozen for laboratory analyses. Temperature was measured twice daily at each site with a SeaBird CTD (conductivity, temperature, depth recorder, Sea-Bird Electronics, Inc., Bellevue, WA) to obtain temperature-depth profiles.

In the laboratory, juvenile POP were thawed, measured, weighed, and dissected. Fish stomachs were

weighed full and empty, and stomach contents were preserved in 10% buffered formalin for later diet analyses. Length frequencies of juvenile POP were plotted and natural breakpoints were used to divide the fish into three size categories (<160 mm FL, 160–210 mm FL, and >210 mm FL). Diet and fish condition were analyzed by these size categories and by site.

Juvenile POP condition

Fish condition was assessed by using log-transformed length–wet-weight regression residuals (indicator of somatic growth and hereafter referred to as wet-weight residuals; $n=226$) and log-transformed length–dry-weight regression residuals (indicator of energy storage and hereafter referred to as dry-weight residuals; $n=226$). Also, the energy content of dried fish ($n=226$) was determined with a Parr 1425 Semimicro bomb calorimeter (Parr Instrument Company, Moline, IL). If available, at least 10 fish of each size category per site were dried in a 60°F drying oven or in a freeze dryer until a stable weight was reached. To test for differences in dry weights between the drying methods, thirty randomly chosen fish were individually ground and divided in half; one half of each fish was dried in the drying oven

and the other half in the freeze dryer. Also, twenty two randomly selected fish were homogenized and divided in half; one half was freeze-dried, the other half was oven-dried, and the energy content of both halves was determined with the calorimeter to determine if there were differences in energetic content attributable to the two drying methods.

Juvenile POP diet

Whole blotted wet weights of stomach contents were recorded. Prey items were identified to a general taxonomic level (large (≥ 2.5 mm) copepods, small (< 2.5 mm) copepods, euphausiids, larvaceans, *Limacina* spp., chaetognaths, hyperiid amphipods, other), which were counted and weighed. Numerical and weight proportions of each prey group in an individual stomach were calculated and then averaged over all fish within each size category sampled at a site. The number of empty stomachs was recorded; however, empty stomachs were not included in average diet composition calculations. When the average percent number of a prey item was less than 5%, it was grouped in the "other" category. A stomach content index (SCI) was estimated as the stomach content weight as a proportion of the fish weight and averaged over all fish in each size category at each site.

Zooplankton

In August, two zooplankton samples were collected at each of the north and south sites with a 1-m ring net (505- μ mesh) hauled vertically from depths of 40–105 m. The volume filtered (m^3) was estimated as the product of the area of the ring net opening and the maximum depth from which it was hauled (recorded by a temperature-depth recorder attached to the net bridle). The relative biomass of zooplankton in each study area was estimated as the settled volume of zooplankton per volume of water filtered. Zooplankton samples were preserved in 5% buffered formalin for laboratory analysis. Taxonomic components of the zooplankton samples were examined in the same manner that prey were enumerated from juvenile POP stomach contents.

Statistical analyses

An analysis of variance (ANOVA) was used to test for differences in log-transformed juvenile POP CPUE in August between sites, with site, size class, and the interaction term as factors. An ANOVA was used to test for differences in the juvenile POP response variables: wet-weight residuals, dry-weight residuals, energy content, and percent number and weight of main prey items. Site was the factor tested for all size classes of fish sampled in August. In June, only the north site was sampled for juvenile POP; therefore comparisons with the south site were not possible for the month

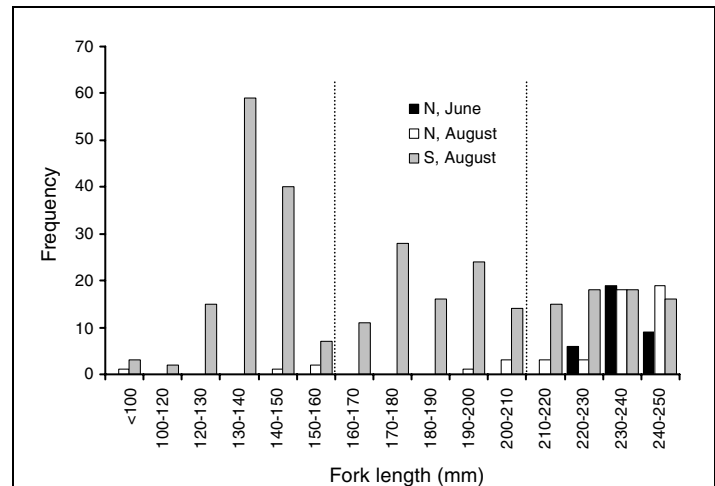


Figure 2

Length frequency of juvenile Pacific ocean perch (POP, *Sebastes alutus*) collected with a bottom trawl at sites north (N) and south (S) of Samalga Island in August and at the N site in June. Juvenile POP were divided into three size classes based on this length frequency (< 160 mm, < 210 mm, and > 210 mm fork length), which correspond to ages 1–2, 3, and 4–5 years, respectively.

of June. For large fish at the north site the factors tested were month, site, and a month–site interaction term. The nonparametric Wilcoxon rank-sum test was used to determine if the SCI was significantly different between sites for each size class of juvenile POP. ANOVAs were used to test for significant differences in the numerical proportions of major taxa found in the zooplankton samples between sites in August.

Results

Juvenile POP abundance and size classes

Juvenile POP were caught in the two trawl hauls conducted at each of the two sites in August and the two trawl hauls conducted at the north site in June. Overall catch per unit of effort ($\log [CPUE+1]$) estimates indicated that the abundance of juvenile POP was significantly higher ($P=0.027$) at the south site (mean=4.22, SE=0.53) than at the north site in August (mean=1.82, SE=0.63). There were no significant differences in CPUE among size classes, and the interaction between size class and site was also insignificant. The average CPUE at the north site in June (mean=2.22, SE=1.71) was slightly higher than that measured in August at the same site.

Juvenile POP fork lengths ranged from 83 to 249 mm. Three size classes of juvenile POP were apparent in a length-frequency plot (Fig. 2): small (< 160 mm FL), medium (160–210 mm FL), and large (> 210 mm FL). These size categories roughly correspond to five age classes of

fish: age 1 and 2 (small), 3 (medium), and 4 and 5 years (large; D. H. Hanselman, Alaska Fisheries Science Center, personal communication). August sample sizes of small, medium, and large fish were 4, 4, and 43, respectively, at the north site, and 126, 93, and 67, respectively, at the south site. Only the large size class of juvenile POP was found in June at the north site ($n=34$).

Juvenile POP condition

Generally, juvenile POP were in better condition at the north site than at the south site in August (Fig. 3). The linear regression of log wet weight as a function of log length was significant, as was the linear regression of log dry weight as a function of log length ($P<0.001$). There was no difference in the dry weight expressed as a function of wet weight between the drying methods; therefore, no correction factor was needed for drying technique. Both wet- and dry-weight residuals were higher at the north site for most size classes. Wet-weight residuals were significantly higher for both small and medium fish at the north site ($P<0.05$; Fig. 3). Dry-weight residuals were significantly higher for medium fish ($P<0.001$) and insignificantly higher for large fish ($P=0.686$) at the north site (Fig. 3). Dry-weight residuals for small fish appeared to be lower for fish at the north site; however, the difference was not significant ($P=0.156$; Fig. 3). Because of small sample sizes of small and medium fish at the north site, variability in estimates were high and contributed to the opposing patterns of dry- and wet-weight residuals for small fish in the north. Large fish had similar wet- and dry-weight residuals at the two locations. Large fish sampled in June had significantly lower dry-weight residuals ($P=0.001$) but similar wet-weight residuals ($P=0.605$) as those for large fish sampled in August at either site (Fig. 3).

Energy content as estimated with a calorimeter provided more precise estimates of fish condition (with lower variability) than length-weight residuals. Oven-drying resulted in a slightly lower energetic content than freeze drying (2% difference in the means between the two methods, $SE=0.002$). A linear relationship (slope=1.31, intercept=-1363.86, $r^2=0.964$) predicting the freeze-dried energetic content from the oven-dried energetic content was applied as a correction factor to the energetic value of the remaining oven-dried fish. Energy content varied significantly between the sites for all size classes ($P<0.006$), but not between sampling times (June and August; $P=0.178$) at the north site. Energy content of all size classes of fish was significantly higher at the north site than at the south site in August (Fig. 3). Energy content of individual juvenile POP ranged from 3,463 to 5,569 cal/g dry weight. Small fish at the south

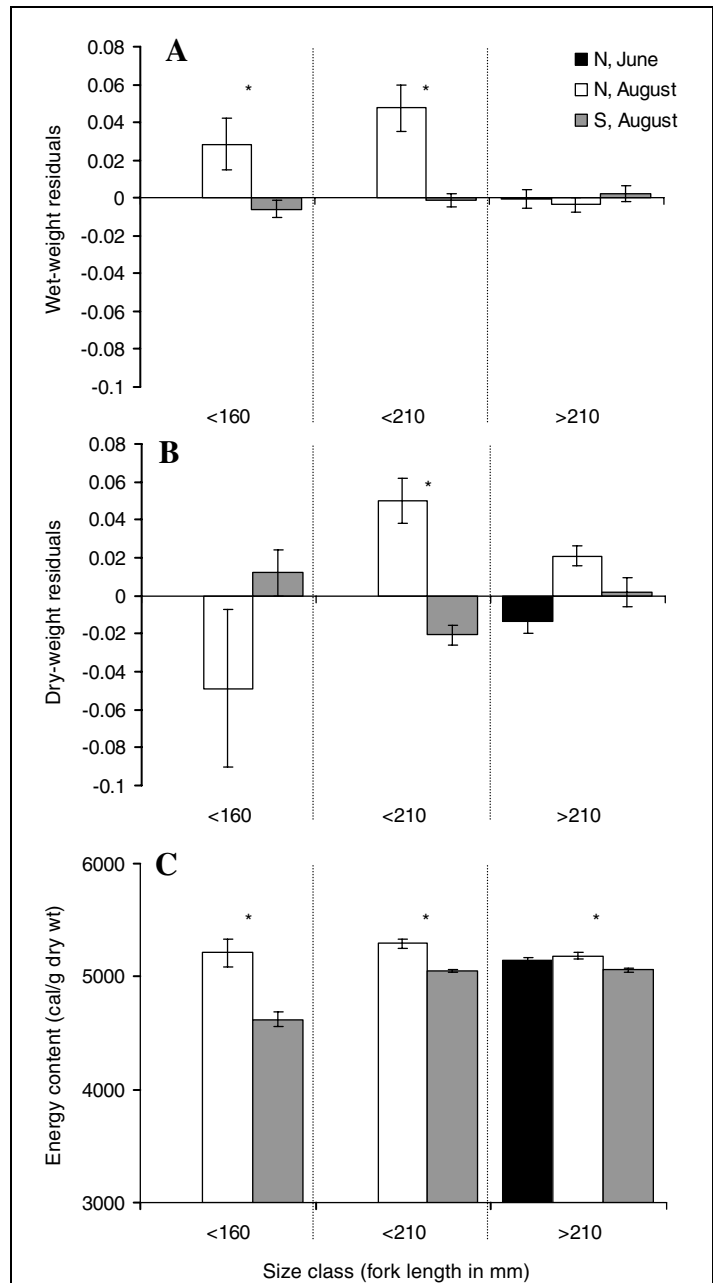


Figure 3
The average condition of three size classes (<160 mm, <210 mm, and >210 mm fork length) of juvenile Pacific ocean perch (*Sebastes alutus*) collected with a bottom trawl at the north (N) and south (S) Samalga Island sites in August and at the N site in June. Condition is shown three ways: (A) log-transformed length-wet-weight residuals; (B) log-transformed length-dry-weight residuals; and (C) whole body energy content (calories per gram dry weight). Standard error bars are shown and asterisks indicate significant differences.

site had the lowest average energy content (4,618 cal/g dry weight), whereas, the small and medium fish at the north site had the highest average energy content (5,295 and 5,213 cal/g dry weight, respectively).

Juvenile POP diet

Generally, the SCI was highest for small fish and lowest for large fish; large fish sampled in June at the north site had significantly fuller stomachs than large fish sampled in August at the north site ($P < 0.001$; Fig. 4). The SCI was similar between sites for both small and medium fish ($P = 0.954$ and 0.229 , respectively). In August, large fish had significantly fuller stomachs at the south site than those at the north site ($P = 0.024$; Fig. 4).

The proportion of POP with empty stomachs varied among sites and months (Fig. 4). In August, the proportion of empty stomachs was higher at the north site for both medium and large POP (0.33 and 0.32, respectively). Empty stomachs were not found in small

POP at the north site in August or in large POP at the north site in June (Fig. 4).

Large copepods (≥ 2.5 mm) comprised the majority of juvenile POP diets for all size classes; however, larger prey items such as euphausiids were consumed by medium and large juveniles (Fig. 5). Small juvenile POP (sampled in August) consumed almost exclusively large copepods, as did the large POP sampled in June. Of the small and medium POP sampled at the north and south sites in August, there were no significant differences by numerical or weight proportions in the three main prey items consumed: large copepods, euphausiids, and larvaceans ($P > 0.05$). The proportion (numerical and weight) of euphausiids consumed by large POP juveniles was significantly higher at the south site ($P < 0.01$).

Large POP juveniles at the north site consumed significantly more large copepods in June than in August ($P < 0.01$).

Zooplankton

Zooplankton biomass, but not community composition, was significantly different between the two sites in August ($P = 0.002$). Average zooplankton biomass was three times higher at the north site than at the south site (Fig. 6). Zooplankton samples at both the north and south sites were numerically dominated by large copepods. Small copepods and hyperiid amphipods were also numerically important at both sites. There were no significant differences in the proportions of large copepods, small copepods, or hyperiid amphipods between sites ($P = 0.109$, 0.159 , 0.365 , respectively; Fig. 6). Other zooplankton components included euphausiids, chaetognaths, *Limacina* pteropods, and larvaceans. Euphausiids were more numerous at the north site than at the south site, but this difference was not significant ($P = 0.792$).

Discussion

The comparison of juvenile POP in two areas of the Aleutian Islands revealed spatial differences in the condition of fish of the same size class. Differences in fish condition have been attributed to food availability in past studies; for example, age-0 pollock with a relatively high index of condition and with high growth rates were found in areas of high prey abundance (Wilson et al., 2005). In the present study, the quantity of prey available, as indicated by the settled volume of zooplankton sampled in the water column, was very different between the sites. The ring net used in this study to sample zooplankton, however, did not sufficiently sample all juvenile POP prey; therefore, conclusions that can be based on these data are limited. In August, zooplankton biomass was high and

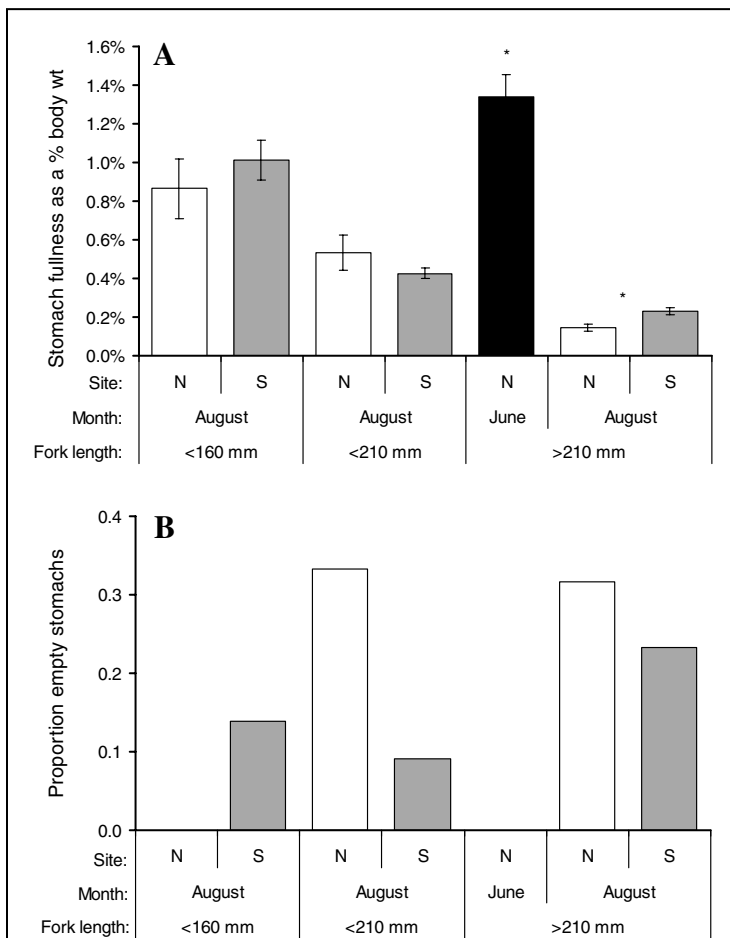
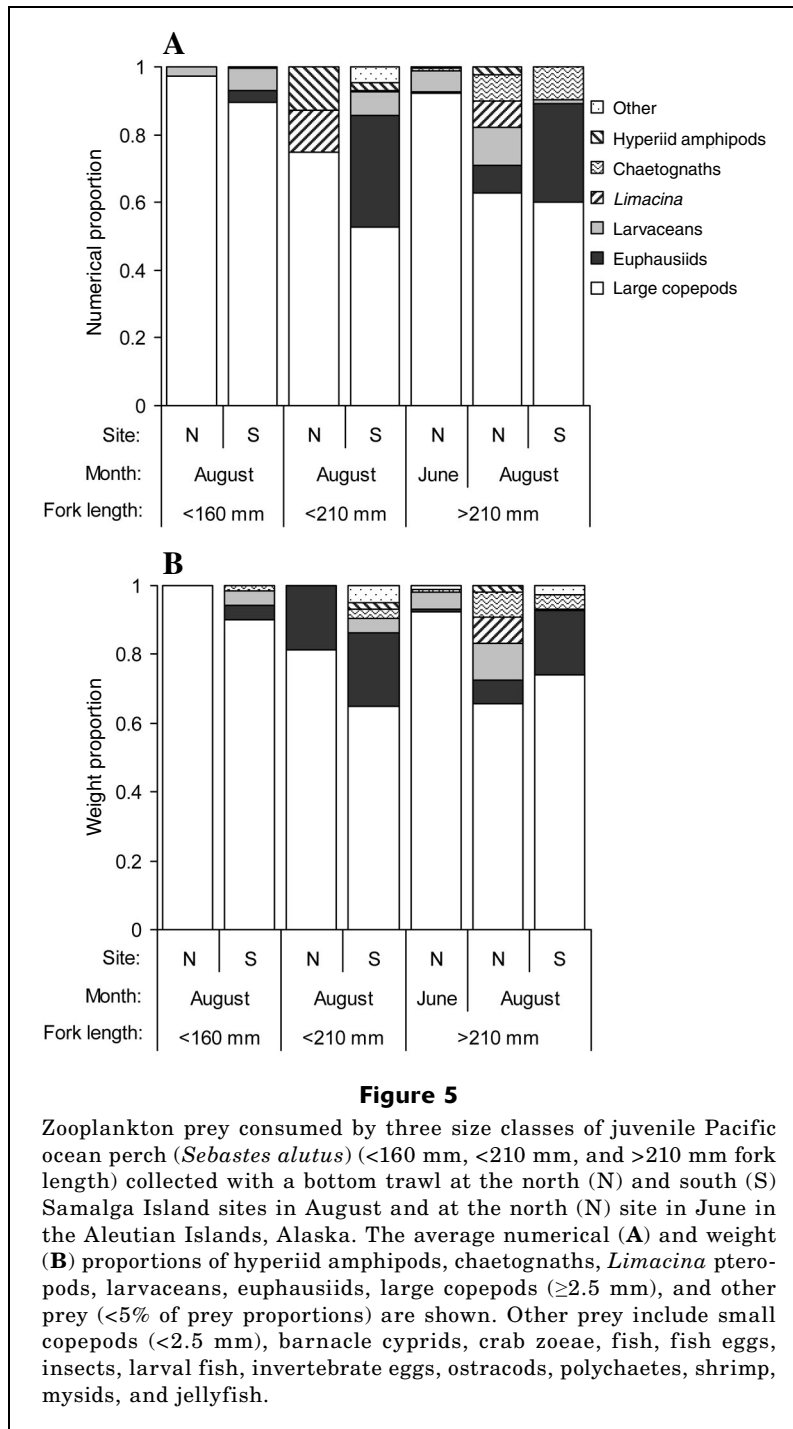


Figure 4

(A) Stomach content weight expressed as a percent of body weight (see SCI under heading "Juvenile POP diet" above), and (B) proportion of empty stomachs for three size classes of juvenile Pacific ocean perch (POP, *Sebastes alutus*) (<160 mm, <210 mm, and >210 mm fork length) at the north (N) and south (S) Samalga Island sites in August and at the N site in June, collected with a bottom trawl in the Aleutian Islands, Alaska. Standard error bars are shown for stomach fullness estimates. An asterisk indicates significant differences for that size class.



juvenile POP abundance was low in the north, where fish condition was highest. If the large zooplankton biomass at the north site indicates enhanced prey availability to juvenile POP, it may help explain the high POP condition observed at that site.

Juvenile POP stomachs sampled in June were more than twice as full as those sampled in August at the north site, indicating that POP are able to consume more than they appeared to consume in August. This

finding, along with differences in juvenile POP abundance and in zooplankton biomass between the two sample sites in August, may indicate that food limitation and competition contributed to the observed geographic differences in fish condition. In August, however, stomach fullness was similar at both sites for all size classes, indicating that fish were consuming similar amounts of food at both sites. Also, the proportion of empty stomachs tended to be higher at

the north site where fish condition was highest. Zooplankton biomass and feeding conditions before our study likely contributed to the observed differences in fish condition.

In this study the types of prey consumed by juvenile POP were very similar between the two areas, and large calanoid copepods comprised the majority of juvenile POP diets of all size classes examined. In fact, the types of prey consumed by juvenile POP varied more by size class of POP than by area. Medium and large juvenile POP consumed more larger prey, such as euphausiids, than the small juvenile POP. These findings are very similar to those found for juvenile POP in southeast Alaska (Carlson and Haight, 1976). We did not quantify juvenile POP prey to the species level; however, the type of large copepods (*Euchaeta*

elongata, *Calanus marshallae*, *Neocalanus cristatus*, and *Metridia* spp.) and euphausiids (*Thysanoessa raschii*) in the zooplankton samples did not appear to differ between sites, indicating that the variety of prey species available to juvenile POP was similar between sites.

Water temperature and water column stratification are other factors that may affect fish condition. Bottom water temperatures were similar at both sites in August (5.4–5.6°C); however, the water column was more mixed at the north site and stratified at the south site. Water column stratification determines, in part, the amount of primary and, hence, secondary productivity by controlling nutrient flow from deeper waters. Previous studies have shown that the area north of Samalga Pass is an area of upwelling and high zooplankton biomass (Swift and Aagaard, 1976; Coyle 2005) and can be characterized as a more productive area than the south site. The higher production at the north site may lead to a higher zooplankton biomass, which we observed in this study, and higher zooplankton lipid stores and energy content, potentially benefitting predators such as juvenile POP.

In summary, we have shown that juvenile POP condition and abundance vary significantly between areas, whereas juvenile POP diet varies by size class of this species. Juvenile POP condition was higher in the area with lower juvenile POP abundance. The differences in fish condition may be due to limitation in the quantity or quality of available prey. In order to delineate essential fish habitat for demersal marine fish species, therefore, one must consider not only the presence or absence of an organism and its benthic habitat, but also the important ecological features of the pelagic habitat.

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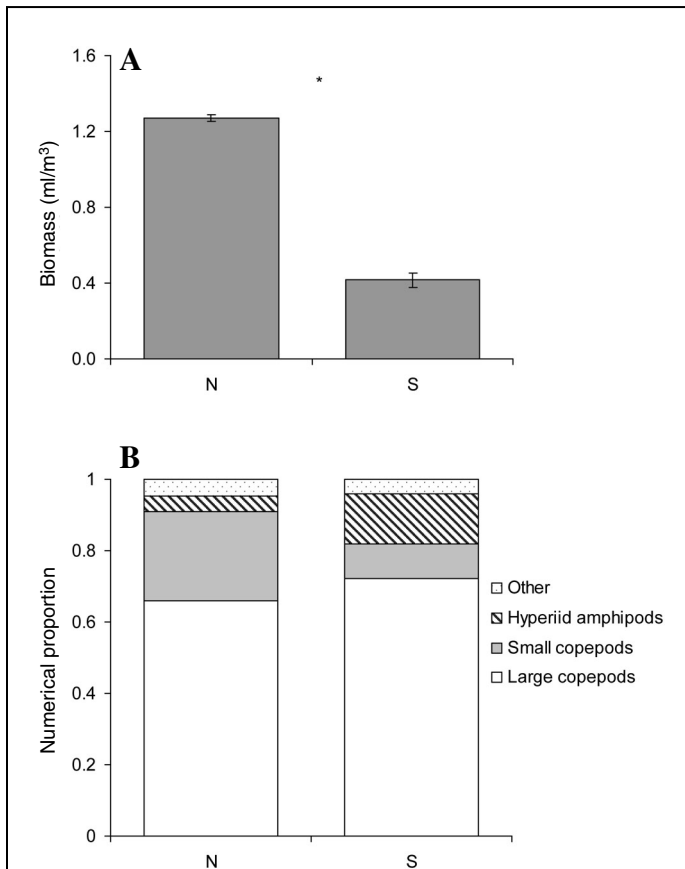


Figure 6

(A) Average zooplankton biomass (mL/m³), and (B) numerical proportion of main zooplankton taxa as sampled with a ring net at the north (N) and south (S) Samalga Island sites in August. Standard error bars are shown for zooplankton biomass and the asterisk indicates a significant difference. Main zooplankton taxa included hyperiid amphipods, small copepods (<2.5 mm) and large copepods (≥2.5 mm). The “other” category comprises zooplankton taxa that individually represented less than 5% of the numerical proportion of the zooplankton samples.

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