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Key Words

Chinook salmon, juvenile salmon, Puget Sound, shallow water habitat, shoreline, fish sampling, enclosure nets, snorkel surveys, fish diet, Seattle

Executive Summary

Shoreline modifications have altered many of the natural habitats in nearshore areas of Puget Sound. Prevalent shoreline modifications include various methods of retaining and armoring (e.g., bulkheads, rip-rap), overwater structures, and filling of intertidal area for industrial, urban and residential development. The effects of retaining structures on ecological processes are poorly known, especially in regards to processes influencing the quality of juvenile salmonid (*Oncorhynchus* spp.) habitats. The main goal of our study was to quantify the abundance and behavior of juvenile salmonids and other fishes along various modified and undeveloped habitat types of Seattle's marine shorelines. We utilized enclosure nets and snorkel surveys to sample fishes during high tides directly along shore at five main habitat types: cobble beach, sand beach, rip-rap that only extends into the upper intertidal, deep rip-rap that extends into the subtidal, and overwater structures.

Minimal differences were found in fish densities between cobble beaches, sand beaches, and rip-rap that only extended into the upper intertidal. Densities were significantly different only for bottom-dwelling fishes, generally higher abundances of juvenile flatfish (Pleuronectidae) at sand beaches, crabs (*Cancer* and *Pugettia* spp.) at cobble beaches, and sculpins (Cottidae) at rip-rap. This suggests that substrate type and slope may be the most important factors influencing fish densities when shoreline modifications only extend to the upper intertidal.

Effects on nearshore fish assemblages were more evident when shoreline modifications extended from the supratidal into shallow subtidal waters. Deep rip-rap and overwater structures truncate the shallow water zone, creating deep water immediately adjacent to the shoreline. We typically found higher densities of total fish and juvenile salmonids along these extensively modified shorelines. This implies that juvenile salmonids occupying deep rip-rap and overwater structure modified habitats are forced to inhabit deeper water and also school more. Our observations showed that juvenile salmonids avoid swimming beneath overwater structures, whereas surfperches (Embiotocidae), crabs, and sculpins were observed beneath or adjacent to pilings. Deep rip-rap sites were characterized by significantly higher densities of surfperches and

gunnels (Pholidae), fishes that are more often found in structurally complex habitats with interstitial spaces.

Behavior data shows that most juvenile salmonids were either schooling or swimming away, and occupying the middle to surface of the water column. Juvenile salmonid categories with Chinook and coho were located more at the surface of the water column at deep rip-rap sites, perhaps due to the underlying rip-rap structure and associated fishes which can hide in the interstitial spaces. At other habitat types they were more distributed between the middle and the surface of the water column. Chum were only observed in the middle of the water column at overwater structures, perhaps due to the greater water depths allowing more elevation to inhabit. At other habitat types, chum were always located at the surface.

Examination of prey consumed by juvenile Chinook in the enclosure nets indicated that input from either marine benthic/epibenthic or terrestrial riparian resources were the two major contributors to their diets. Riparian insects in Chinook guts were lowest at sites with retaining structures at either the intertidal or supratidal zone, suggesting limited availability of terrestrial insect prey resources along such modified shorelines. Terrestrial riparian resources are more important for Chinook as compared to other salmon species, as coho and chum had minimal amounts of insects in their diets, with especially chum feeding more on marine planktonic/neritic prey sources.

Overall, our results indicate that shoreline modifications have the most dramatic effect on nearshore fish densities and behaviors when the alterations extend from the supratidal through the subtidal zone. Densities of juvenile salmonids were most significantly different between shallow gradient shorelines and steep gradient shorelines with extensive modification through or over much of the intertidal zone. While we are confident in our estimates of fish density, interpreting the results in relation to salmon habitat is more ambiguous. Since our surveys were designed to sample directly along the shoreline, it is a question whether our results indicate active selection by fish to various habitat types, or whether the fish are merely responding to indirect effects of shoreline modifications such as changes in water depth and slope. Due to the nature of shoreline modifications that truncate the shallow water zone, fish that may typically be spread-out over a broad intertidal/shallow subtidal area may by compressed against the shoreline.

As it is not feasible to sample along the same depth and distance from shore profiles at all of the various habitat types, it is possible that fish usage patterns would be more similar if all fish could be sampled across a stable array of space (e.g., 5-m water depth and 50-m from shore). We interpret the observed differences in fish responses to more often depend on consequences of shoreline modifications, such as changes in water depth, slope, substrate, and shoreline vegetation. Future research should continue to examine the effects of shoreline modifications on ecological communities in regard to bank type, tidal height, and salinity regimes.

Introduction

Studies of ocean-type juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the Pacific Northwest indicate that they use estuarine and nearshore habitats early in their outmigration and rearing period (Simenstad et al. 1982; Healey 1998). Where relatively undeveloped estuaries yet persist, much of early Chinook rearing takes place in estuarine wetlands and delta ecosystems. Where tidal flood plains and estuaries have been highly modified and made unavailable for estuarine rearing, marine shorelines take on more of a role in providing rearing habitat. This is particularly true of Puget Sound, where most of the deltas and estuaries are highly modified (Blomberg et al. 1988; Emmett et al. 2000). Juvenile Chinook are found along nearshore shorelines in King County from late January through September, with peak outmigration usually occurring in June and July (KCDNR 2001; Toft et al. 2003a). Although previous studies indicate that juvenile salmon are present along City of Seattle marine shorelines, there is little specific information about whether or not juvenile salmon preferentially use or avoid certain types of shorelines, and what functions the different shoreline types may provide them. Research conducted in the Puget Sound region suggests that juveniles of Chinook and chum salmon (*O. keta*) prefer shallow areas along estuarine and marine shorelines, including beaches, mudflats and eelgrass beds (Simenstad et al. 1982; Simenstad and Cordell 2000). However, in urban settings, it is unknown how juvenile salmon behavior is influenced by the diversity of anthropogenic structures and impacts: do salmon select some habitats and avoid others, or are they simply randomly distributed along the shoreline?

The purpose of this study was to determine abundance and behavior of juvenile salmon and other fishes along various habitat types of Seattle's marine shorelines. We focused on five main habitat types: cobble beach, sand beach, rip-rap that only extends into the upper intertidal, deep rip-rap that extends into the subtidal, and overwater structures. Sampling was focused during high tides on habitats directly bordering the shoreline, either in intertidal areas or shallow subtidal areas in cases that modified embankments truncated the shallow water habitat. A secondary goal was to collect prey contents of juvenile salmon for indication of habitat use based on diet composition. This research stems from sampling methods developed during pilot studies in the previous year (Toft et al. 2003a). It is intended that the results, when linked with a habitat classification and delineation of the marine shoreline (Toft et al. 2003b), will be able to test hypotheses such as "there is no significant difference in juvenile salmon abundance among City of Seattle shoreline types." Such statistically rigorous results will be important to resource managers who need to identify potential impacts of nearshore activities on salmon, prioritize recovery actions, and identify approaches that provide maximum protection to those nearshore marine areas that are important to juvenile salmon. This is especially relevant since the listing of Puget Sound Chinook salmon as a threatened species in March 1999 by the National Marine Fisheries Service.

Most prior sampling for shoreline oriented juvenile salmon in the Puget Sound region has been conducted using beach seines, which are only effective for sampling certain habitat types such as shallow beaches at specific tide levels. Density estimates from seining can be severely compromised by varying sampling efficiencies over different substrates and water depths (Rozas and Minello 1997). Seines can also easily get snagged on submerged rocks or other obstacles as they are being hauled. Additionally, either floating or sinking beach seines are used depending on the target fishes to be collected, which can complicate sampling efficiency especially at deep-water sites. Beach seines are also "instantaneous" measures of fish assemblage structure and densities, and as such do not supply information about on-site behavior.

During pilot studies we tested four different sampling techniques in order to determine their effectiveness in sampling juvenile salmonids at various habitat types: (1) enclosure nets, (2) underwater videography, (3) snorkel surveys, and (4) above water observations (Toft et al. 2003a). Based on the results, we determined that enclosure nets and snorkel surveys were the most successful for our purposes. Rozas and Minnelo (1997) recommend using enclosure nets for estimating densities of small nekton in shallow estuarine habitats, as they provide the most reliable quantitative data and provide comparable results between sites and studies (also see Cicchetti and Diaz 2000). Snorkel surveys and other visual census techniques for assessing fish abundance are often conducted with success in freshwater and coral reef environments (Slaney and Martin 1987; Hankin and Reeves 1988; St. John et al. 1990; Graham 1992; Tabor and Piaskowski 2002), but usage in estuarine and shallow water marine settings is limited (Haggarty 2001; Davis et al. 2002). We utilized these two main techniques to assess habitat usage by fishes directly along marine shorelines within the Seattle city limits.

Material and Methods

Study Sites and Experimental Design

Fieldwork was conducted between 5/12/03 and 8/1/03, in order to surround peak outmigration of juvenile Chinook salmon. Sampling locations were all within City of Seattle boundaries (Fig. 1). Main habitat types as illustrated in Figure 1 pertain to those at the high intertidal, as this was the primary focus of the study. Sites were selected based on habitat characteristics included in the Department of Natural Resources Shorezone Inventory, Department of Energy oblique aerial photographs, City of Seattle high-resolution aerial photographs, and field verification. Habitats were only considered for selection if they had a minimum shoreline length of 200-m.

Information on habitat types at different tidal heights are detailed in Table 1, along with an overview of the sampling design. In general, cobble beach, sand beach, and rip-rap sites were sampled on spring tides, along with deep rip-rap and overwater structure sites that were added on neap tides. Deep rip-rap pertains to sites where rip-rap extended from the supratidal to the subtidal, whereas rip-rap sites only extended from the supratidal to the mid-tidal, with exposed beach at low tide. Overwater structures were large apartment or business complexes constructed on a pier, with a range in size (Table

1). Sampling techniques were different on alternate weeks, pertaining to tidal elevations at spring and neap tides, as follows:

- Spring Tides: Enclosure Nets and Snorkel Surveys, two sites per day (2 boats, 8 person crew). As continued for one week, this generated comparative data across eight sites at similar tidal heights for each technique.
- Neap Tides: Snorkel Surveys, three sites per day (1 boat, 4 person crew). As continued for one week, this generated comparative data across fifteen sites at similar tidal heights.

Sampling Techniques

Enclosure Nets

The presence and abundance of fish in shallow-water habitats was tested using enclosure net sampling. This consisted of using a 60-m long, 4-m deep, 0.64-cm mesh net placed around poles to corral a 20-m^2 rectangular section of the shoreline (Fig. 2). The poles were installed at low tide the day before net deployment, so as to minimize disturbance at time of sampling (Fig. 3). The enclosure net was installed at high tide (Fig. 4). Fish were removed with either a small pole seine (1.2-m. x 9.1-m., 0.64-cm mesh) or dip nets as the tide receded, usually starting at mid-tide a few hours after net deployment (Fig. 5). All fish were removed before low tide. Fish and crabs captured in the net were identified and counted, and returned back to their original environment. Hatchery and wild status of salmonids was determined to the extent possible by recording clipped adipose-fins, and testing with coated-wire tag and pit-tag readers. For the purposes of this report, "marked" salmon refer to positive hatchery identification by one of the above methods, while "unmarked" salmon refer to fish with intact adipose fins and no tags. Although unmarked salmon are often assumed to be all wild fish, incomplete marking can complicate this demarcation. Forklengths of salmonids were recorded to at least n = 5 for each: (1) species, (2) marked or unmarked status, and (3) size class (Fig. 6). Standard lengths of all other fish were recorded for at least n = 20. Crabs were measured for carapace width.

The data resulting from the enclosure net sampling produced per unit volume densities of fish and crabs on each unit of shoreline sampled. Volume was estimated by measuring the exact lengths of each side of the net, the water depth at the poles when the net was set, as well as the water depth at shore (if not zero; e.g. due to rip-rap embankment), assuming a steady slope from shore to the poles. Sampling took place during spring tides to take advantage of a large tidal realm, since the goal was to assess fish utilization close to shorelines.

Enclosure net sampling had the additional benefit of allowing diet analysis of fish. This may provide valuable information about habitat use, as foregut contents of fish held for several hours in the enclosure net prior to sampling will most likely reflect food obtained therein. Diets of juvenile salmonids were sampled by gastric lavage to at least n = 5 for each: (1) species, (2) marked or unmarked status, and (3) size class. This method consisted of placing fish in a tray of seawater with a small amount of the anesthetic MS-222 for approximately 30-60 seconds. Each fish was removed from the tray and forklength measured; gut contents were then removed using a modified garden pump sprayer with a custom nozzle and filtered seawater (Fig. 7; Hartleb and Moring 1995). Contents were washed into a 106-micron sieve and fixed in 10% buffered formaldehyde solution. Fish were immediately placed in a bucket of seawater for recovery (approximately 2-3 minutes), and then released. Gut contents were later analyzed in the laboratory, and prey items ranked based on modified Index of Relative Importance values (IRI; Pinkas et al. 1971; Simenstad et al. 1991):

$$\text{IRI} = \begin{matrix}\text{\% frequency}\\ \text{of occurrence}\end{matrix} \text{ X } \left[\begin{matrix}\text{\% numerical}\\ \text{composition}\end{matrix} + \begin{matrix}\text{\% gravimetric}\\ \text{composition}\end{matrix} \right]$$

All sampling techniques were monitored for any potential injury to salmonids and other fish, which could include entanglement in nets or over-anesthetization with MS-222. Based on past research, potential for injury by these methods was expected to be negligible.

Snorkel Surveys

Presence and behavior of fish was examined utilizing snorkel surveys conducted along transects parallel to shore (Fig. 8). Snorkel surveys were centered around high slack tide for proximity to shoreline habitats, with four total transects per site (two transects each by two snorkelers). Successful transects depended on horizontal secchi-disk measurements exceeding 2.5-m for sufficient visibility. All transects attempted with secchi-disk readings below 2.5-m were discarded from the analysis. Transects were 75-m long and typically at 1.5-m water depth, with the distance from shore measured. At modified shorelines with steep banks (e.g. deep rip-rap), transects were 3-m from shore and the water depth measured. Overwater structures were surveyed by snorkeling 2-m away from the edge of the structure (not underneath), and measuring the water depth.

Numbers of fish counts were standardized by length and visibility (number/[transect length x horizontal secchi depth]). Additional data that was collected during snorkeling transects included:

- Transect direction (compass point)
- Direction of observations (away from shore, toward shore)
- Fish identification and number
- Approximate fish length (2.5-cm increments)
- Water column position of fish (surface, mid-water, bottom)
- Distance from diver to fish (m)
- Water depth at fish (m)
- Substrate type (sand, gravel, cobble, boulder, rip-rap, rip-rap/sand interface, kelp)
- Fish behavior (unaffected, swimming away, fleeing, feeding, not moving, schooling, hiding)
- Specific location and movement if next to an overwater structure

Environmental Measurements

Physical measurements of water salinity and temperature were taken with a portable YSI meter at two different depths, surface and bottom. Water visibility was measured by taking horizontal secchi disc depths during snorkel surveys (Fig. 9). Daily weather patterns during sampling were qualitatively observed. High and low tidal heights and times were recorded, as predicted by the computer program Tides and Currents version 2.1.

Statistical Analysis

ANOVA tests ($a = 0.05$) were used to analyze measured variables. When significance was found, the Tukey test for multiple comparisons was used to uncover specific differences between all possible pairs of means (Zar 1996). Regressions were also used to analyze length-time data on fish sizes. Data was entered into Microsoft Excel, and analyzed using S-Plus.

Results

Enclosure Nets

Sampled fish and crabs were placed in functional groups for analysis (Table 2). Densities were analyzed with respect to the main effect of habitat type at high intertidal (cobble beach, sand beach, rip-rap). Enclosure net sampling produced density measurements of fish per water volume, with total average fish densities increasing from cobble beach, to sand beach, to rip-rap (Fig. 10), although total densities were not significantly different. Densities of juvenile salmonid species also generally increased from cobble beach, to sand beach, to rip-rap, but again were not significantly different (Fig. 11). Additionally, no significant differences were found for salmon species both when separated and lumped with regard to marked and unmarked status.

The only functional grouping that was significantly different with regard to habitat type was flatfish densities (Fig. 10; $p < 0.005$). A tukey test of multiple comparisons showed sand beach densities higher than both cobble beach and rip-rap (sand beach ? cobble beach = rip-rap). This difference was driven mostly by juvenile flatfish ($p < 0.05$) as opposed to adults ($p < 0.10$; 100 mm standard length demarcation; Fig. 12). English sole were the major flatfish species, with densities also significantly different with regard to habitat type ($p < 0.05$).

Juvenile salmonid densities varied with timing of outmigration (Fig. 13). Chum were already abundant at the start of sampling, and decreased to low numbers by the end of June. Marked Chinook had a sharp peak the first week of June, and then dropped to medium levels for the remainder of the sampling. Unmarked Chinook had a more constant pulse, with highest numbers in late June and July. Marked and unmarked coho had fairly low numbers, with highest densities in late June.

Forklengths of juvenile salmonids were largest for coho, followed by Chinook, with chum the smallest (Table 3). Unmarked Chinook were significantly larger than marked ($p < 0.05$). There were no significant differences between unmarked and marked coho. Chinook and chum salmon increased in size through time (marked Chinook $R^2 = 0.65$, $p < 0.001$; unmarked Chinook $R^2 = 0.36$, $p < 0.05$; chum $R^2 = 0.85$, $p < 0.0005$) while coho forklengths had no significant trends (Fig. 14). Summary lengths of other fish and crabs are also illustrated in Table 3.

Water volume sampled by the enclosure nets ranged from 157 – 681 m^3. Sample sizes and average net volumes for each main habitat type at the high intertidal are shown in Table 4, with rip-rap having the greatest volume, followed by sand beach, and cobble beach having the lowest volume. The sampled water volumes at the different habitat types were significantly different ($p < 0.00001$), with rip-rap ? cobble beach = sand beach (Tukey test for multiple comparisons).

Snorkel Surveys

Sampled fish and crabs were again placed in functional groups for analysis (Table 2). Densities were analyzed to the effect of main habitat types (cobble beach, sand beach, rip-rap, deep rip-rap, overwater structure). Total average fish densities from snorkel surveys increased from sand beach, rip-rap, cobble beach, overwater structure, to deep rip-rap (Fig. 15). Tukey tests showed deep rip-rap densities significantly higher than sand beach, rip-rap, and cobble beach, and overwater structure higher than sand beach and rip-rap. All functional groupings were significantly different for habitat type at $p < 0.05$, except for forage fish ($p < 0.10$). The more abundant groupings are illustrated in Fig. 15, while the less abundant are shown in Fig. 16. Table 5 shows Tukey test results for specific differences in habitat types.

Identification of salmon species while snorkeling was sometimes difficult, as it was often hard to see distinguishing characteristics due to water turbidity and short time of viewing (Fig. 17). Therefore, identifications were often made in broader categories (Fig. 18). The main salmonid categories were all significantly different for habitat type at p <

0.05 (Chinook, Chinook/coho, Chinook/chum, chum). Tukey test results for multiple comparisons on habitat type are shown in Table 5.

Identification of non-salmonids was not as difficult as salmonids, since characteristics were easier to distinguish. Of the most abundant functional groups (Fig. 15), shiner perch accounted for 83.3% of surfperch records, and Pacific sand lance accounted for 87.5% of forage fish.

Similar to enclosure net data, juvenile salmonid densities varied with timing of outmigration (Fig. 19). Categories with chum were already abundant at the start of sampling, and decreased to low numbers by early June. Categories with Chinook peaked during the second week of June, with mixed Chinook/coho records peaking again in early July. Densities from the eight sites that were sampled on both spring and neap tidal series showed no apparent trends in relation to week of sampling or associated secchi depths (Fig. 20).

Length estimates of juvenile salmonids from snorkel surveys were similar to the enclosure net data, with largest values for coho groupings, followed by Chinook, with chum groupings the smallest (Table 6). Groupings that included chum had the highest school sizes, followed by Chinook, and coho (Table 6). Juvenile salmonid groupings always had larger school sizes at overwater structure, except for coho which had greater school sizes at rip-rap (Table 7). Salmonid groupings were not equally represented at all sites, but when combined overall juvenile salmonid average school sizes were significantly different with regard to habitat type ($p < 5x10^{-11}$), with tukey tests showing overwater structure significantly greater than other habitat types. Summary lengths, counts, and school sizes of other fish and crabs are also illustrated in Table 6.

When juvenile salmon were spotted during a snorkel survey, their main behavior patterns were either schooling or swimming away (Fig. 21). There were some instances of feeding, and few of fleeing and unaffected behavior. Most feeding was observed at the deeper sites, mainly at overwater structures, deep rip-rap and rip-rap. These instances of feeding were typically characterized by salmon darting to the surface to feed off of neuston.

Juvenile salmonid categories with Chinook and coho were located at either the middle or the surface of the water column (Fig. 22). They were found more at the surface at deep rip-rap sites. Chum were always located at the surface, except at overwater structures where they were sometimes in the middle of the water column. Juvenile salmonids were almost never located at the bottom of the water column, with only one occurrence for Chinook/coho at an overwater structure.

Substrate types at juvenile salmonid observations were representative of each main habitat type (Fig. 23). Observations at cobble beaches were mostly over cobble substrate, with some gravel. Sand beaches were a mixture of sand and gravel. Only a small percentage of observations at rip-rap sites were actually over the rip-rap, as the rip-rap was close to shore. Most were over sand, or at the rip-rap/sand interface. Observations at deep rip-rap sites were often over rip-rap, as the rip-rap extended farther from shore. Observations at overwater structures were a mixture of sand, gravel, cobble, or at the rip-rap/sand interface.

Behavior, water column position, and substrate type summarized across all habitat types for functional groupings of fish and crabs is illustrated in Table 8. Juvenile salmonids again were mostly schooling or swimming away, at the surface or middle of the water column, and primarily over sand, gravel, or rip-rap. Forage fish were mostly schooling, in the middle of the water column, and over cobble or gravel substrates. Other nearshore fishes were primarily unaffected or schooling, at the bottom or surface of the water column, and mostly over rip-rap. Surfperches were most often schooling, in the middle or bottom of the water column, and over rip-rap, at the rip-rap/sand interface, or less often over cobble, gravel, and sand. Flatfish were typically unaffected or swimming away, almost always at the bottom of the water column, and mostly over gravel and sand. Other demersal fishes were most often unaffected or swimming away, primarily at the bottom of the water column, and over sand, gravel, or cobble. Gunnels were usually unaffected or hiding, always at the bottom of the water column, and most often at rip-rap or boulders. Crabs were primarily unaffected, always at the bottom of the water column, and most common over cobble substrates, then sand, or rip-rap.

Location of fish observations relative to position of overwater structures was recorded when possible, dependent on visibility and time of viewing. Most juvenile salmonids were observed to be away from the edge of the overwater structure or at the edge, only one school was observed to be underneath (Table 9). Surfperches were also typically away or at the edge of structures, but had the highest percentage of observations underneath (11%). Surfperches were also somewhat associated with Pilings (32%). Of the other species, only Pacific sand lance had one observation underneath overwater structures; most were either away or at the edge (Table 9). Crabs and sculpins were often observed around pilings.

Data on species of fish schooling together was recorded only when visibility and time of viewing was sufficient. Sixteen schools consisting of juvenile Chinook and coho were recorded, with Chinook accounting for 58% of the average numbers in the schools. Twelve schools were observed with chum and either coho or Chinook, with chum 56% of the numbers. Juvenile salmonids were also observed to school at low frequencies with threespine stickleback, Pacific sand lance, Pacific herring, shiner perch, and pile perch. Surfperches were often found schooling together, with twenty observations recorded of pile perch/striped seaperch schools (pile perch accounting for 71% of the numbers). Shiner perch and kelp perch were also observed in mixed perch schools, but at low frequencies. Shiner perch were occasionally observed to be schooling with Pacific herring, Pacific sand lance, and tube-snouts. Smelt and Pacific sand lance were also observed schooling together at low frequencies.

Sample size of snorkel surveys varied with the different habitat types, as deep rip-rap and overwater structures were only sampled on neap tides, cobble beach had less replication on spring tides, and transects were discarded from the analysis if secchi-readings were below 2.5-m (Table 10). Overwater structures and deep rip-rap had significantly deeper water than other habitat types at the shoreline, and therefore transects were also done closer to shore (Table 10). Visibility was also better at deep rip-rap and overwater structures, as measured by horizontal secchi-disk readings. Two of the overwater structure sites were closer to freshwater input than the rest of the sites (Fig. 1; Overwater Shilshole and Overwater Ray's), leading to significantly lower surface salinity readings at overwater structure sites.

Spring tides had an average high of +9.1 and low of -1.1 ft., while neap tides had a high of +9.4 and low of +5.8. Total average secchi readings were almost identical between tidal weeks, 4.90 m for neap tides and 4.92 m for spring tides. Spring tide surveys were always in the morning (average 8:35 A.M.) and neap tide surveys were always in the afternoon (average 3:32 P.M.), centered around high slack tide. Total average salinity readings were 27.7/28.7 ppt (surface and bottom of the water column, respectively) and temperature readings were 13.7/12.8 °C.

Diet Analysis

Prey items of juvenile salmonids consisted of a diverse array of insects, aquatic invertebrates, and fish (Fig. 24). Prey items were grouped by their ecology, in order to determine sources of prey resources. Chinook were the only salmon species that had a high input from terrestrial riparian zones (36% IRI; adult insects, mostly Chironomidae, Psocoptera, and Lepidoptera). Marine benthic/epibenthic prey resources accounted for approximately half of Chinook prey items (primarily the amphipod *Photis* sp., and some Nereidae worms). Marine planktonic/neritic sources were small (15%; mostly cirrepedia exuvia and oikopleura). Coho had similar sources of Marine benthic/epibenthic and planktonic/neritic prey, and a large amount of unknown digested copepods (40%). The majority of chum prey was derived from marine planktonic/neritic sources (79%; primarily the copepod *Corycaeus anglicus*, along with other copepods and invertebrate larvae). Prey items in all juvenile salmonids had minimum input from supralittoral/marsh and plant matter sources.

Diets of Chinook salmon were used to examine prey input across habitat types at the high intertidal (Fig. 25). Chinook from cobble beaches had the highest input from terrestrial riparian zones (69%), although their sample size was fairly small (n=13). Marine benthic/epibenthic contributions were the major source at especially rip-rap habitat types (73%), as well as sand beaches (55%). Sand beaches had the most input from planktonic/neritic sources (22%).

Sites were also separated into categories of shoreline retainment (Table 1), in order to examine possible effects on prey source contributions. Sites with retaining structures at either the intertidal or supratidal were found to have almost identical prey source contributions, mainly from marine benthic/epibenthic sources (Fig. 26). Unretained sites had over twice as much input from terrestrial riparian prey items as retained sites.

Discussion

Shoreline modifications have different effects on fish abundance and behavior patterns dependent on how far they extend into the tidal zone. Minimal differences with cobble and sand beaches were found when rip-rap only extends into the upper intertidal. Mainly, juvenile flatfish (mostly English sole) were more abundant at sand beaches. Higher water volumes were sampled with enclosure nets at rip-rap sites due to steep embankments and greater slopes, which truncate the intertidal zone. So, shallow steady-sloped sand beaches are good nursery habitats for juvenile flatfish, and their preferred habitat can be lost when the intertidal zone is retained with rip-rap. During snorkel surveys cobble beaches had higher numbers of crabs than sand beaches and rip-rap, and rip-rap had more other demersal fishes (sculpins) than sand beaches, perhaps both due to substrate, feeding, or other habitat preferences. All of these results occurred in bottom-dwelling fishes, which suggests that substrate type and slope may be most important when any shoreline modifications occur only in the upper intertidal, as there were no differences in any pelagic fish densities.

More differences are apparent when habitat types are added into the analysis that modify the shoreline farther into the water column, from the supratidal to the subtidal. Deep rip-rap that extends into the subtidal and overwater structures that project over the water column have greater water depths than the other habitat types. Snorkel surveys at these sites were directly along the shoreline, as almost the entire intertidal zone has been modified to a steep-gradient slope (average transect water depths 2.4 – 3.0 m), illustrating that shallow water habitat has been severely truncated. Total fish densities from snorkel surveys again show no difference between sand beaches, cobble beaches, and rip-rap that only extends into the upper intertidal. However, the shoreline modifications that extend into the subtidal do show differences in total fish densities with the other habitat types, but not between each other. Deep rip-rap had higher values than sand beaches, cobble beaches, and rip-rap, while overwater structures had higher values than sand beaches and rip-rap.

Similarly, differences in juvenile salmonid densities were only observed when shoreline modifications extended into the subtidal. Overall juvenile salmonid densities from snorkel surveys were significantly different due to habitat type, with overwater structures higher than the rest. Most salmonid groupings were also higher at overwater structures, with definite Chinook identifications higher at deep rip-rap. Again, these are sites with deeper water at the shoreline due to modified embankments. It remains a question whether these fish are actively selecting these sites, or whether they are steadily migrating along the shoreline and acclimating to specific habitat changes. Since average water depths at fish observations were significantly higher at deep rip-rap (2.4-m) and overwater structures (4.4-m) than the other habitat types, and these observations were directly along the shoreline due to the modified embankments, we were in effect observing every fish from the waters edge to that depth. At other habitat types with more consistent slopes, water depths at fish observations were 1.6 – 1.7 m and distances from shore significantly greater than deep rip-rap and overwater structures (7.7 – 17.2 m), only allowing fish observations within the field of vision (average secchi readings 4.3 – 4.8 m). Counts may be more similar if all fish observations could be standardized within these depth and distance contours at all various habitat types, although this is problematic as a consequence of the shoreline modifications.

Therefore, it seems that when juvenile salmonids are migrating along the shoreline and encounter a modified habitat with the shallow water zone truncated, they may be forced to inhabit deeper water and also school more, as juvenile salmonids had significantly greater school sizes at overwater structures than at the other habitat types. It is also possible that proximity to freshwater sources and thus input of juvenile salmonids could have been higher at overwater structures, as two of the three sites were closer to outflow from the Lake Washington watershed than all other sites (Fig. 1), thus leading to significantly lower salinities at overwater structures.

Most fish, including juvenile salmon, were not observed to be underneath overwater structures, although our snorkel surveys were along the edge of overwater structures so we could typically see about 2-m underneath due to visibility and low light. Juvenile salmon were most often observed away from the edge, towards open water. This supports the premise that juvenile salmon may avoid overwater structures due to barriers to normal movement patterns or low light levels (Simenstad et al. 1999). Surfperches, crabs, and sculpins were the only species that were associated with being underneath and at the pilings of overwater structures.

Differences in other fish densities due to the presence of deep rip-rap that extends into the subtidal can be attributed to the physical structure of the rip-rap embankment. Deep rip-rap had higher densities than all other habitats of surfperches and gunnels, fishes which prefer a complex structural habitat with interstitial spaces. Such fishes occupy the mid to bottom section of the water column, and appear to hide in or around the rocks of the rip-rap embankment. Additionally, other nearshore fishes (threespine stickleback, tube-snout, bay pipefish) were more abundant than at cobble beaches, sand beaches, and rip-rap, again perhaps due to the same reasons as above.

Behavior data shows that most juvenile salmonids were either schooling or swimming away when disturbed, and at the middle to surface of the water column. Juvenile salmonid categories with Chinook and coho were located more at the surface of the water column at deep rip-rap sites, perhaps due to the underlying rip-rap structure and associated fishes which can hide in the interstitial spaces. At other habitat types they were more distributed between the middle and the surface of the water column. Chum were only observed in the middle of the water column at overwater structures, perhaps due to the greater water depths allowing more elevation to inhabit. At other habitat types, chum were always located at the surface.

Juvenile salmonids were often found schooling together, with mixed schools of Chinook, coho, and chum regularly observed. Mixed schools were also found between juvenile salmonids, forage fish, and surfperches. This shows that these fish species can benefit from schooling with each other, and are not always existing in discrete spatial patches. Such data is lost when sampling is solely based on net collections.

Observational patterns for other fish mimicked density patterns, but provide detailed information on the behavior and locations of fish, that again is not learned from net surveys. The information in Table 8 could be used to focus future sampling designs on characteristics of certain fish, or to provide data on how best to restore habitat for specific species based on behavior, location, and substrate preferences.

All fish were held at the various habitat types for an average of 2 hours and 45 minutes by the enclosure nets before sampling. Therefore, gastric lavage samples from juvenile salmonids most likely reflect foregut food items obtained at the specific habitat types, as opposed to instantaneous beach seining where it is unknown where the fish were feeding. On average, digestion rankings for prey items from juvenile Chinook were 75-100% intact, meaning that they were freshly eaten and not heavily digested, lending more credence that they were recently eaten.

Prey input from either marine benthic/epibenthic or terrestrial riparian resources were the two major contributors to juvenile Chinook diets. Based on diet analysis, access to terrestrial riparian insects as prey items were highest at cobble beaches, and sites with no retaining structures along the shoreline in both the intertidal and supratidal. Natural shorelines provide interaction between the terrestrial and aquatic zones, as opposed to shorelines with retaining structures at the intertidal or supratidal, in which case marine benthic/epibenthic prey organisms were most common. This is not to say that fish weren't feeding on the water's surface at modified shorelines, in fact instances of observed feeding in juvenile salmonids during snorkel surveys increased with modifications and water depth (most at overwater structures, followed by deep rip-rap and rip-rap); this could be due to both the greater sample size and the greater elevation of the water column, making feeding more noticeable as the fish were darting to the water surface to feed on neuston. Combined with less input from terrestrial riparian resources in diets of Chinook salmon at retained habitats, this suggests that input from the terrestrial realm is limited. Additionally, shoreline armoring has been shown to generally decrease abundance and taxa richness in certain supratidal benthic infaunal invertebrate and insect assemblages (Sobocinski 2003). Terrestrial riparian resources are more important for Chinook as compared to other salmon species, as coho and chum had minimal amounts of insects in their diets, with especially chum feeding more on marine planktonic/neritic prey sources.

Snorkeling and enclosure nets proved to be a valuable combination of techniques for monitoring fish abundance and behavior patterns at shallow water habitats. It should be stressed that these techniques were utilized directly along the shoreline where habitat effects would be most noticeable, typically in the intertidal zone. Although beach seines can sample a greater area farther from shore, the problems inherent with beach seining at modified shorelines were not encountered, as the entire water column could be sampled and there were minimal issues with snagging nets on underwater obstacles (Rozas and Minello 1997, Cicchetti and Diaz 2000). Additionally, quantitative density measurements can be obtained, all at similar tidal heights. Both enclosure nets and snorkel surveys are useful for obtaining detailed information regarding on-site habitat characteristics, as enclosure nets corral the fish for a few hours allowing feeding therein, and snorkel surveys allow observations on specific behavior and location patterns. Success of the techniques was dependent on development during our pilot studies in the previous year (Toft et al. 2003a), allowing suitable design and implementation for addressing an important gap in our understanding of nearshore processes.

Utilizing two different techniques allows their strengths to be combined and their respective weaknesses to be alleviated. The obvious drawbacks to snorkeling are that fish are not physically captured. This is the best-case scenario for not harming fish, especially in the wake of the endangered species status of Puget Sound Chinook salmon. However, it can cause less precision with species identification and accurate counts. Juvenile salmonid observations from snorkel surveys often had to be lumped into different groupings, due to difficulties in species identification involving visibility and short length of time for viewing. Chinook and coho are especially difficult to tell apart even when they are physically captured, and they also are regularly observed to school together. Therefore, observations were most often combined for Chinook and coho when exact species demarcations could not be made, as well as sometimes with chum. However, the ease of greater replication with snorkel surveys was useful in overcoming water clarity issues, as we accomplished 442 snorkel surveys as opposed to 48 more time and labor-consuming enclosure net samples.

Since water clarity often dictated success during snorkel surveys, it is impossible to know until we are in the water whether or not we will be able to collect meaningful data. Although fish counts are standardized to water visibility, deeper modified sites did have higher secchi readings probably due to waves not stirring-up as much sediment at deeper sites. Snorkel surveys and enclosure nets also had minor biases in target species, although again the two techniques complemented each other. Enclosure nets were not efficient at collecting juvenile forage fish and larval fish that are often small enough to swim through the mesh. Nets also did not catch any lingcod, spotted ratfish, rockfishes, or pricklebacks, species which are rare, large, or often hiding. These taxa were also rare in snorkel surveys, so it may have just been the increased sample size which allowed their detection. Snorkel surveys were not as good at observing bottom-dwelling fishes such as flatfish and other demersal fishes (sculpins), especially juveniles, as these fish are camouflaged against the underlying substrate.

The effects of shoreline modifications on nearshore fish communities and other ecological processes has been a challenging topic to address, both in Puget Sound and elsewhere. This is mainly due to the difficulty involved in sampling at shoreline modifications, especially in a manner that is quantitatively comparable to more natural habitats. With substantial amounts of habitat alteration in urban waterways, such issues have created an important gap in knowledge for both scientists and resource managers. It is apparent from current research that effects can vary in a number of factors, including differences in: (1) freshwater, estuarine, and marine settings, both in resident communities and outmigration patterns of juvenile salmonids, (2) species and lifestages of fish, and (3) scale of analysis (landscape vs. site).

It is important to examine these factors when combining our research with those of others. Tabor and Piaskowski (2002) utilized snorkel surveys and above-water observations and found that juvenile Chinook in Lake Washington avoided armored banks. Friesen et al. (2003) studied fishes in the Lower Willamette River with beach seines and electrofishing, and found that juvenile salmonids expressed preference for alcoves and natural habitat types. One caveat is that Friesen’s methods did not sample the entire water column, so modified banks with deep water at the shoreline are under-represented. However, these projects are both located in freshwater reaches, where juvenile salmonids are smaller and more dependent on shallow water, which may explain their active avoidance of altered shorelines. When juvenile salmonids are in marine environments and are larger as in our study, they are more pelagic and less shoreline dependent. Lifestages in other fish species can also be a factor, as Peterson et al. (2000) used trawl surveys and found that juvenile fishes that typically use the estuarine marsh edge as a nursery habitat are more abundant along natural marshes than at altered marshes.

Some similarities do exist across freshwater to marine zones. Friesen et al. (2003) found that sunfish preferred artificial habitats such as rip-rap and pilings, similar to surfperches in our study. Able and Manderson (1998) used small traps in the Hudson River estuary and found fish abundance and species richness to be low under large commercial piers in Hudson River. Although size of piers can certainly be a factor, there appears to be some consistency in regards to issues of low light levels and barriers to movement patterns caused by overwater structures.

Scales of analysis are always a factor in any research design. Haggarty (2001) used snorkeling, above-water observations, and seines in the Burrard Inlet estuary (Vancouver, BC), and found that juvenile Chinook salmon preferred larger substrates. However, this was dependent on the landscape scale (site vs. basin). Davis et al. (2002) used snorkel surveys in San Diego Bay (CA) and found that the hard-substrates of rip-rap can extend the range of open-coast species into what used to be soft-sediment bays. Such landscape effects are especially important when examining the overall effects of habitat modifications. Jennings et al. (1999) used electrofishing and seining and found that rip-rap in Wisconsin lakes increased species richness at the site level due to complex structural habitat with interstitial spaces. However, when there is too much rip-rap at the expense of other habitats, this causes an overall reduction in species diversity at the landscape scale, leading to detrimental cumulative effects. This is important in regards to our study area, as between 84 – 97% of the shoreline is modified by retaining structures (Parametrix et al. 2000). Jennings et al. (1999) also concluded that fish do not directly respond to shoreline structures; rather, they respond to a suite of habitat characteristics that are the result of the structures. As was the case with much of our results, issues of water depth, substrate, bottom slope, and vegetation are often the main differences.

In conclusion, our results indicate that shoreline modifications have the most dramatic effect on nearshore fish communities when the alterations extend from the supratidal through the subtidal zone. Differences in densities and behavior of fishes are often more dependent on changes in bank-slope, substrate, water depth, and shoreline vegetation, that are caused by the shoreline modification. Utilizing multiple sampling techniques that combine information on fish densities, behavior, and diet analysis is often necessary in order to generate a full spectrum of quantitative habitat measurements, and can overcome biases of specific gear types. Future research should continue to examine the effects of shoreline modifications on ecological communities in regard to bank type, tidal height, and salinity regimes.

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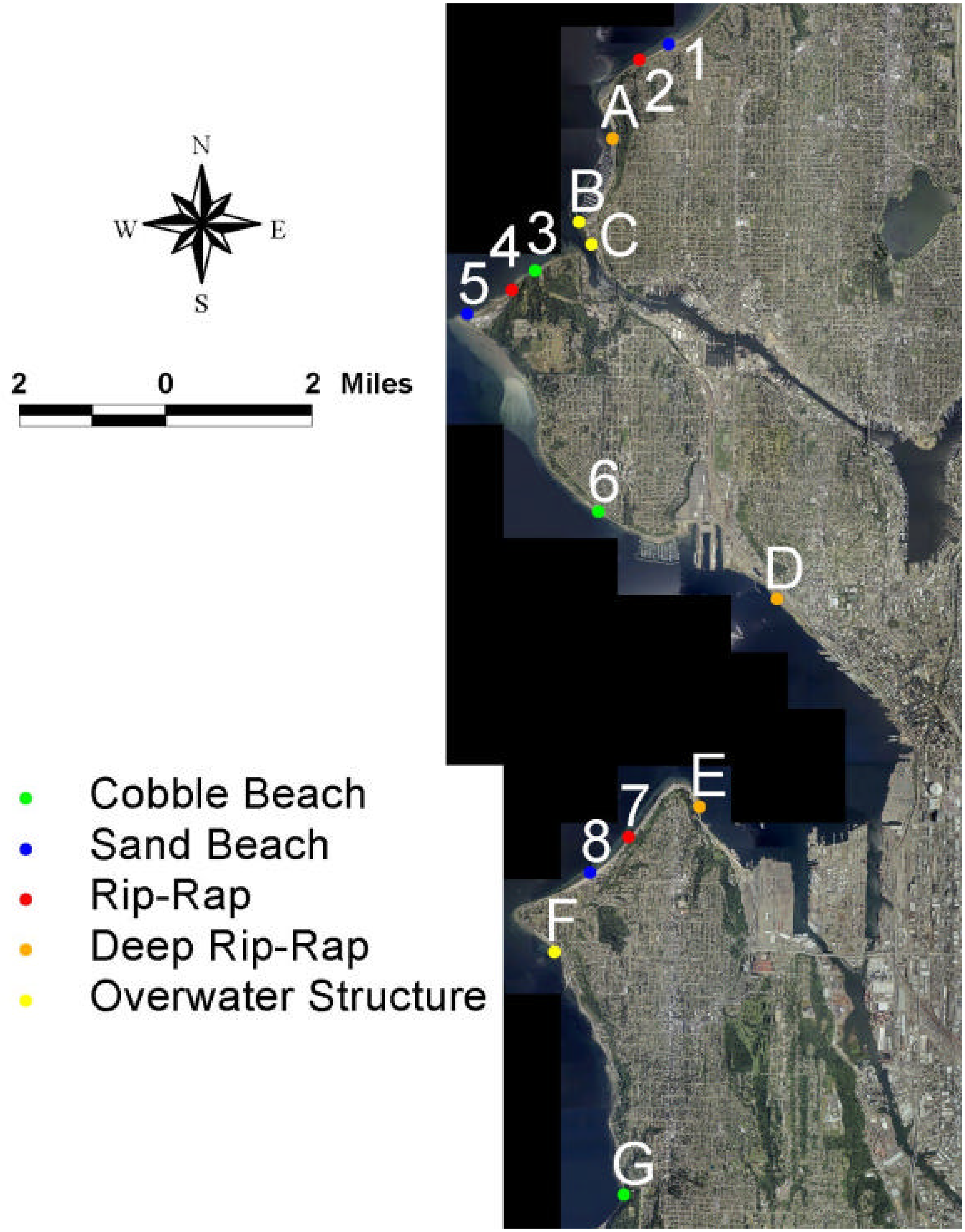

Figure 1. Study sites in the City of Seattle with main habitat types at the high intertidal. Numbers pertain to sites sampled with enclosure nets and snorkel surveys during spring tides, all sites were sampled on neap tides with snorkel surveys. See Table 1 for more detailed information on habitat types.

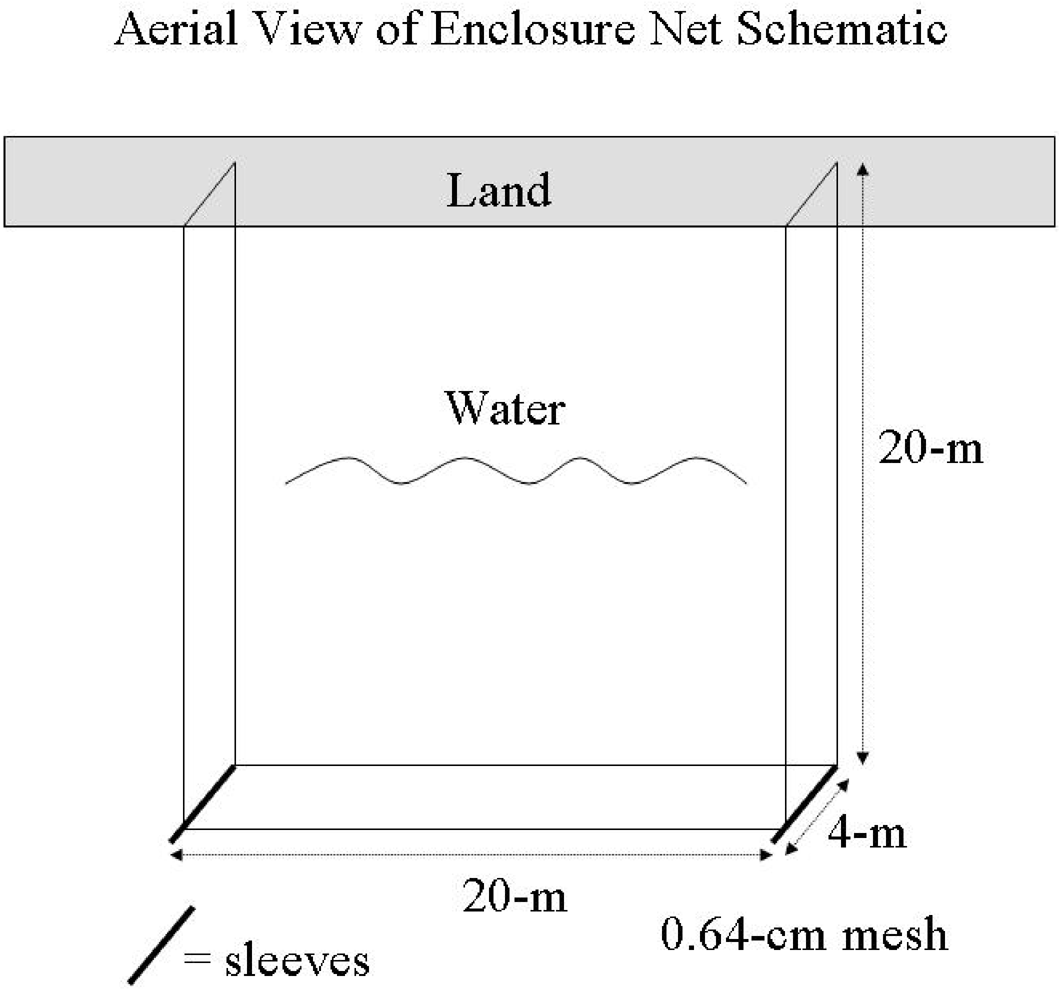

Figure 2. Enclosure net typical deployment: total net is 60-meters long, 4-m high. Sleeves (10.2-cm diameter) are sewn into net 20-m in from each side.

Figure 3. Installation of enclosure net poles at West Point Cobble during low tide the day before sampling.

Figure 4. Enclosure net after deployment at Alki Rip-Rap during high tide.

Figure 5. Pole-seining at West Point Cobble during mid tide.

Figure 6. Measuring the forklength of a juvenile chinook salmon.

Figure 7. Sampling fish gut contents using gastric lavage.

Figure 8. Beginning of a snorkeling transect.

Figure 9. Taking a horizontal secchi disk reading to measure water visibility.

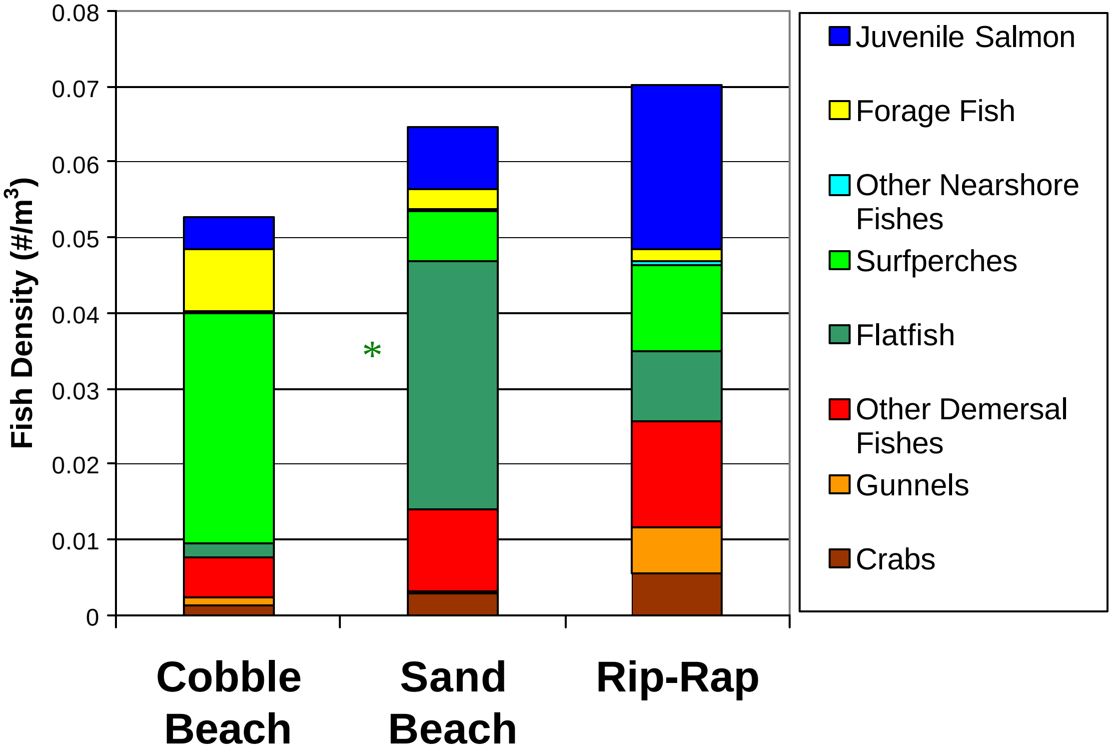

Figure 10. Average enclosure net functional group densities at high intertidal habitat types. Flatfish are the only significant grouping, with asterisk denoting significantly higher densities.

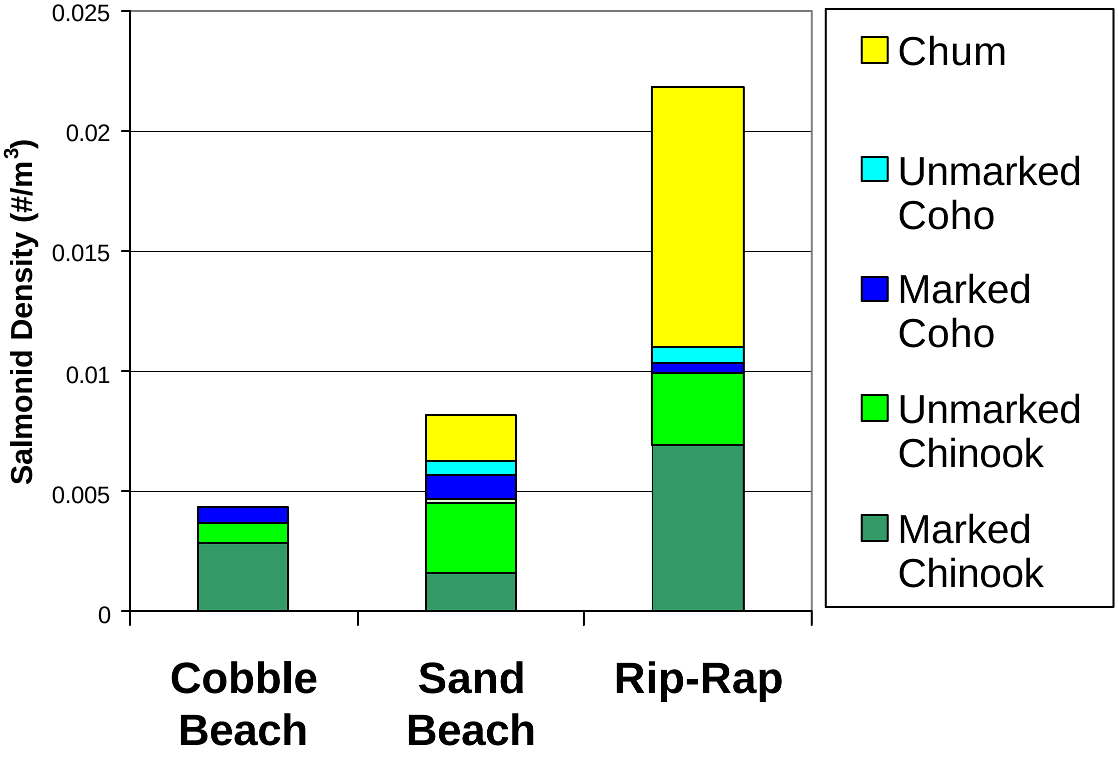

Figure 11. Average enclosure net salmon densities at high intertidal habitat types. No significant differences detected.

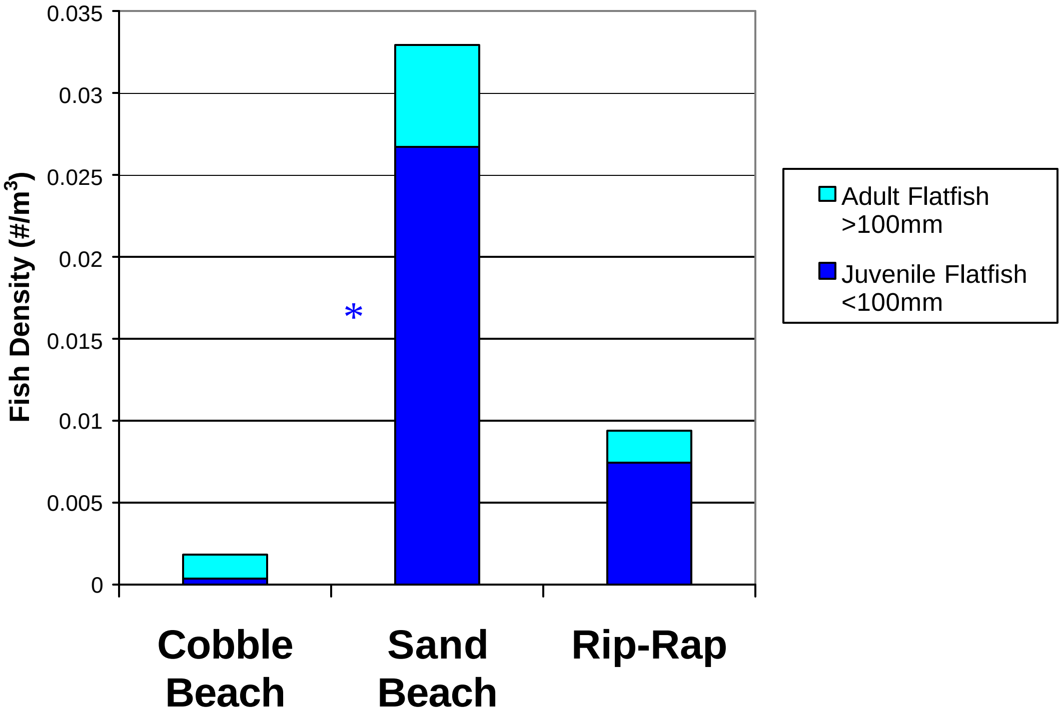

Figure 12. Average enclosure net juvenile and adult flatfish densities at high intertidal habitat types, with asterisk denoting significantly higher densities.

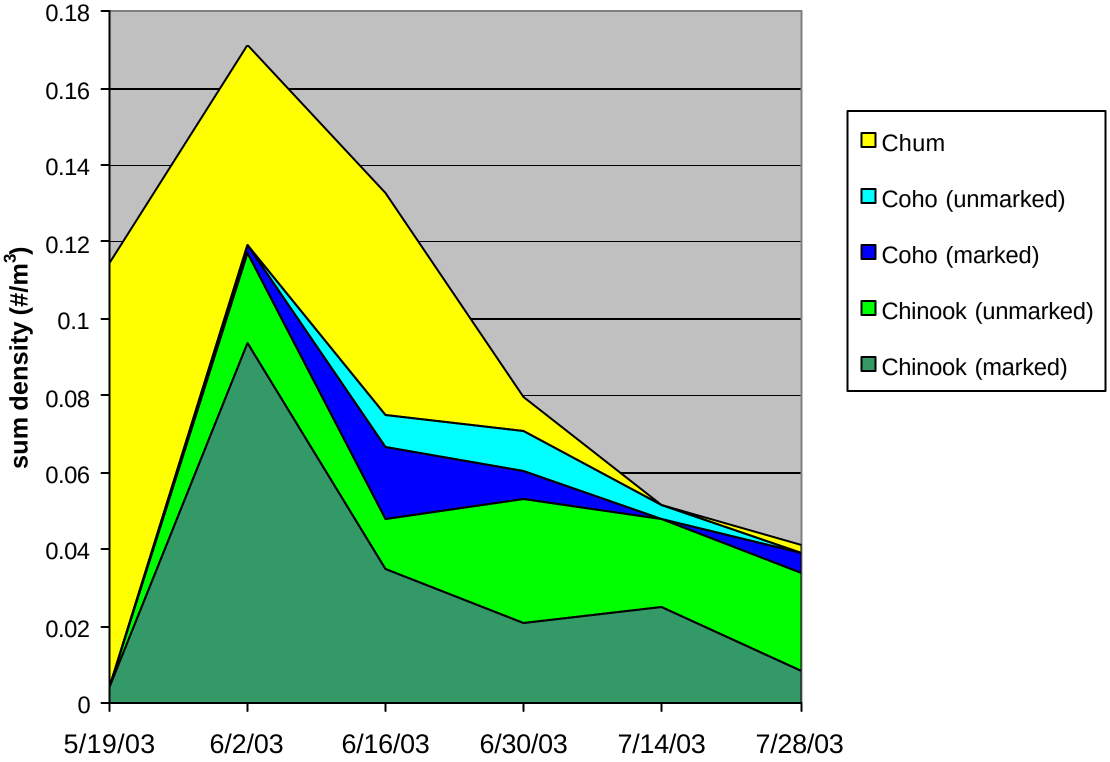

Figure 13. Sum of juvenile salmon densities for each week of enclosure net sampling.

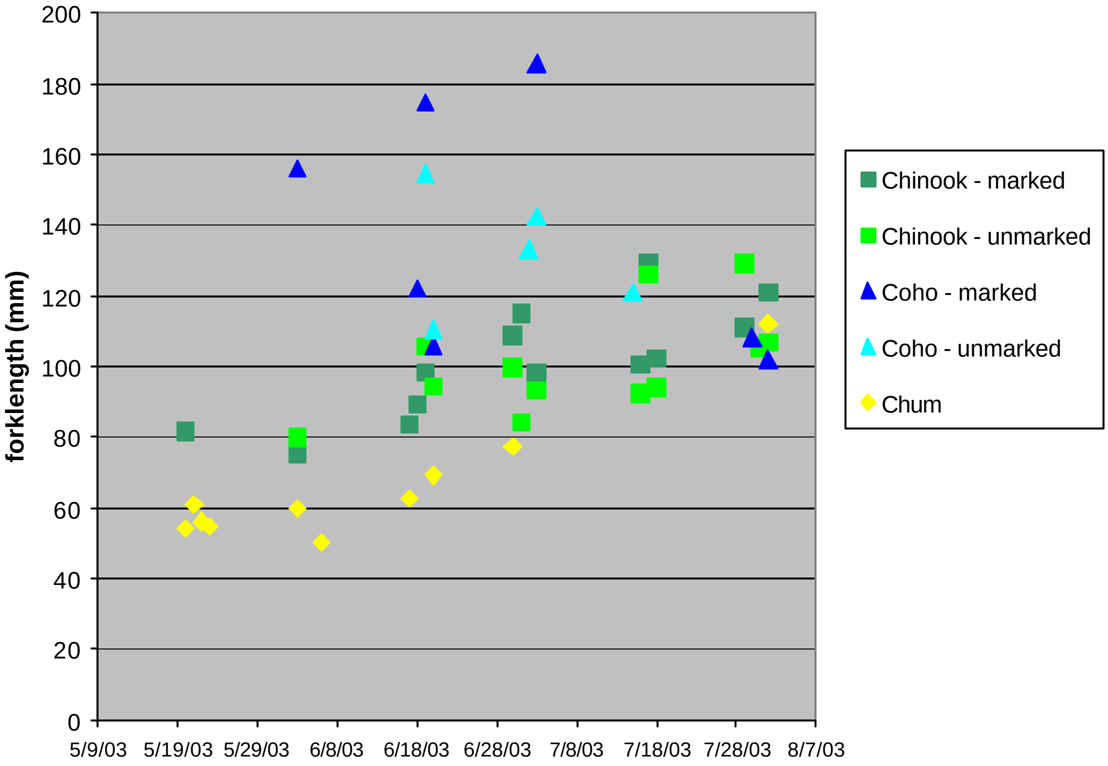

Figure 14. Forklengths (mm) of juvenile salmonids from net sampling through time.

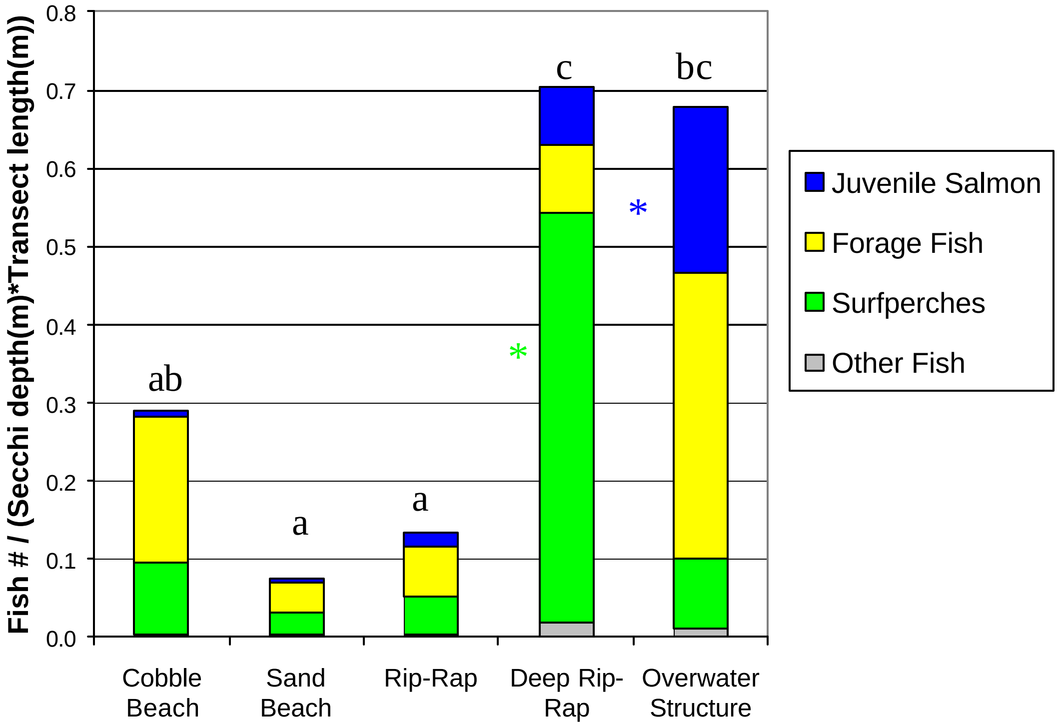

Figure 15. Average snorkel abundant functional group densities at main habitat types. Asterisk denotes significantly higher densities over all other habitat types, succession of letters denotes significantly higher total densities.

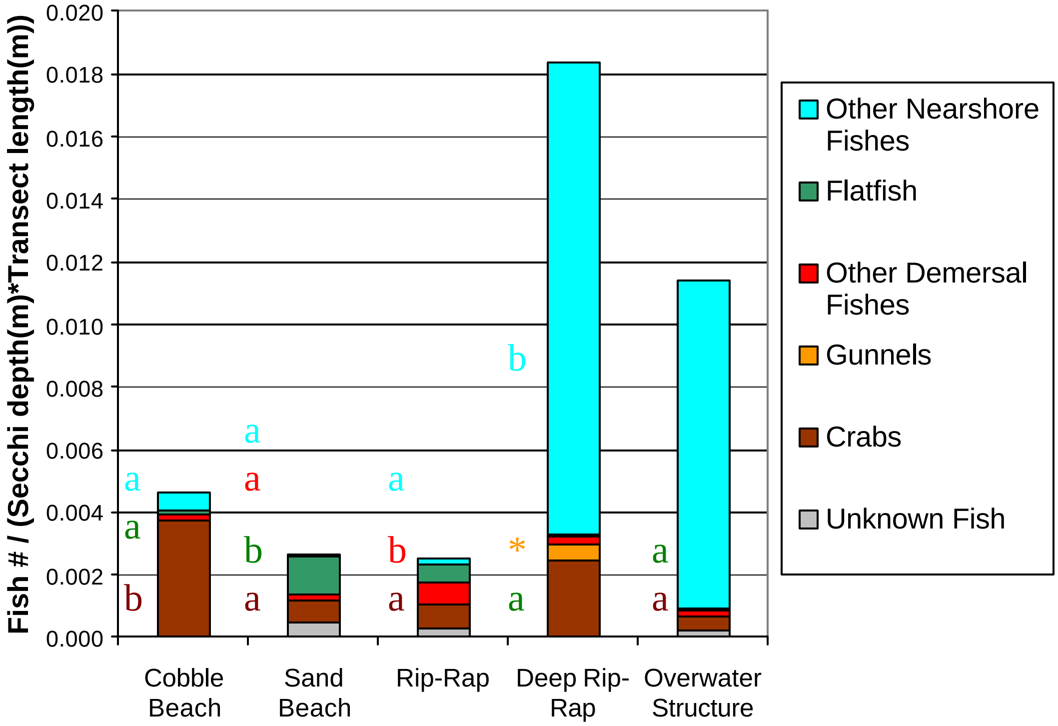

Figure 16. Average snorkel densities of less abundant functional groups at main habitat types. Asterisk denotes significantly higher densities over all other habitat types, succession of letters denotes significantly higher densities.

Figure 17. Example of a salmon school encountered on a snorkel transect.

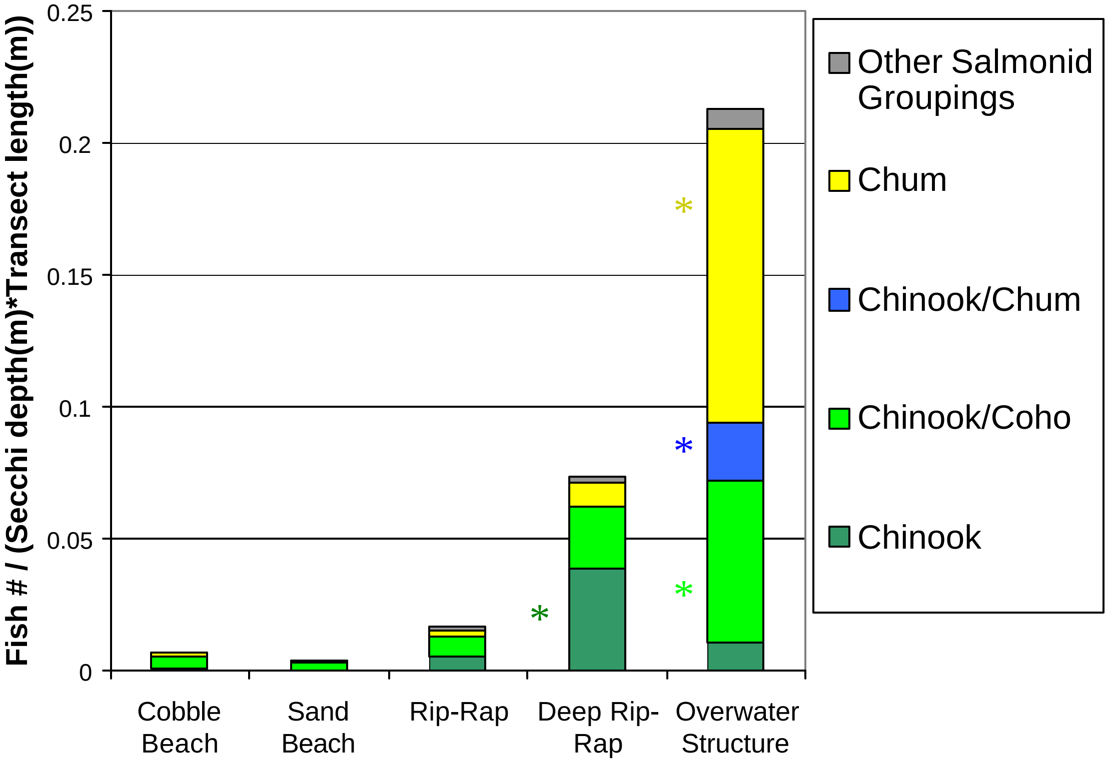

Figure 18. Average snorkel survey juvenile salmon densities at main habitat types, asterisk denotes significantly higher densities over all other habitat types.

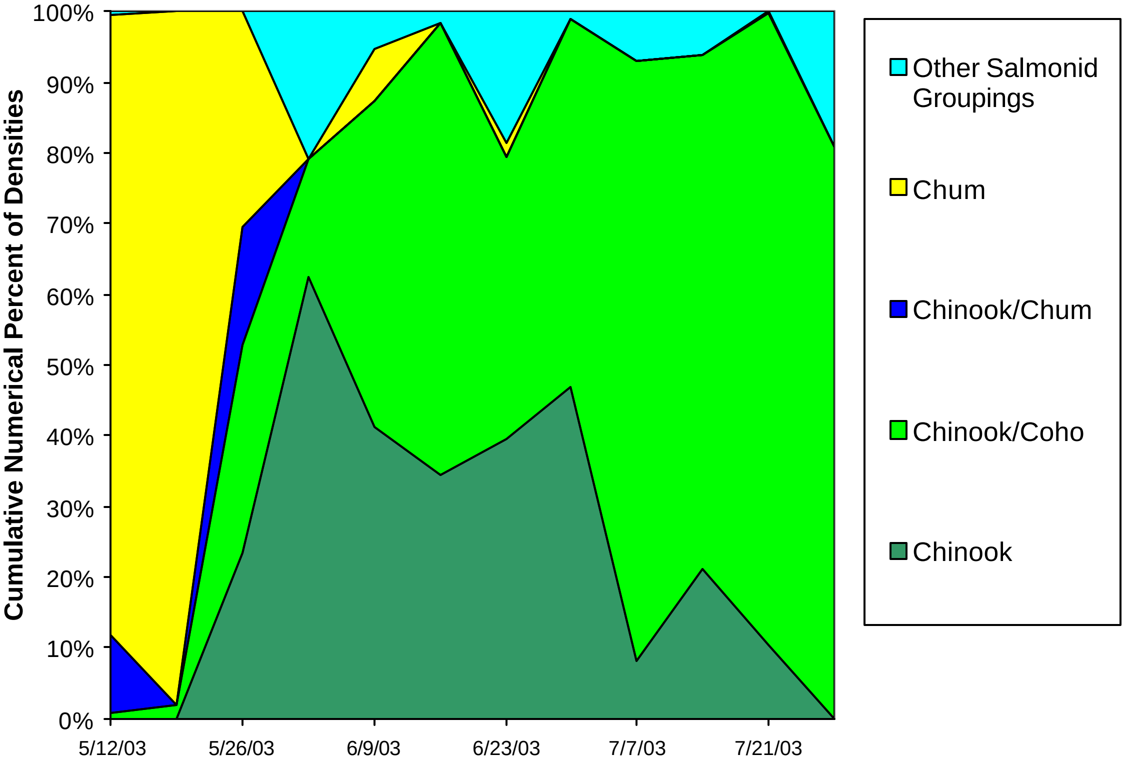

Figure 19. Cumulative numerical percent of average juvenile salmonid densities for each week of snorkel surveys.

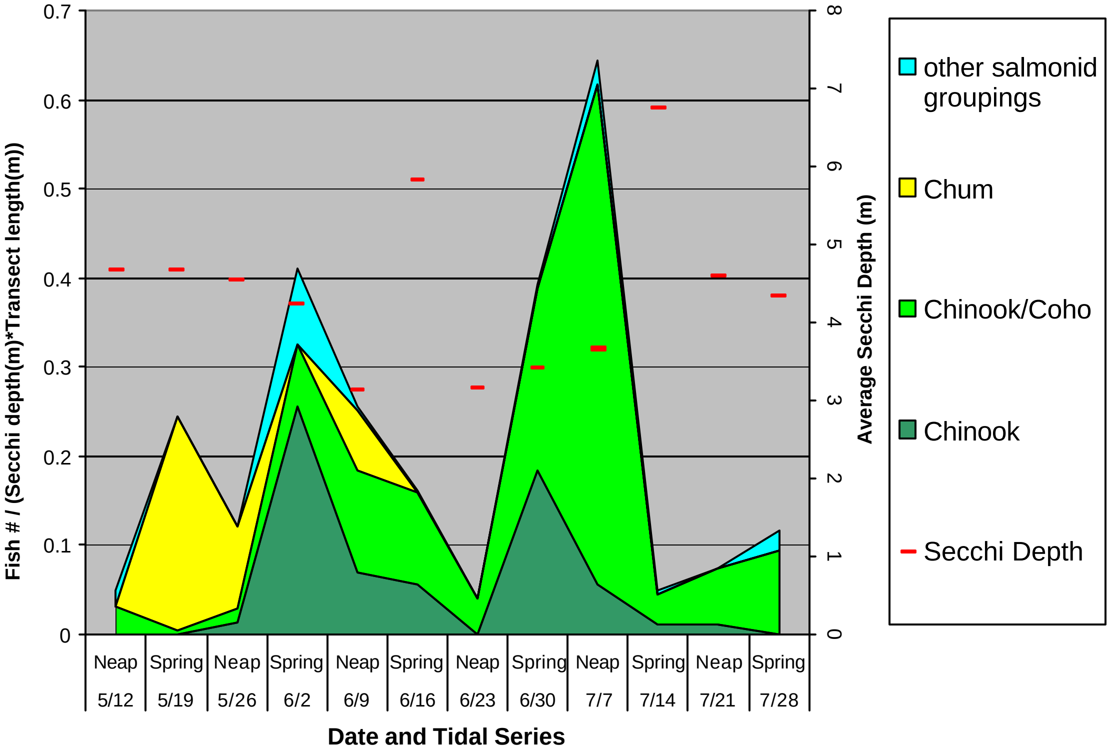

Figure 20. Densities of juvenile salmonids from the eight sites that were snorkel surveyed on both spring and neap tidal series, with associated average horizontal secchi readings.

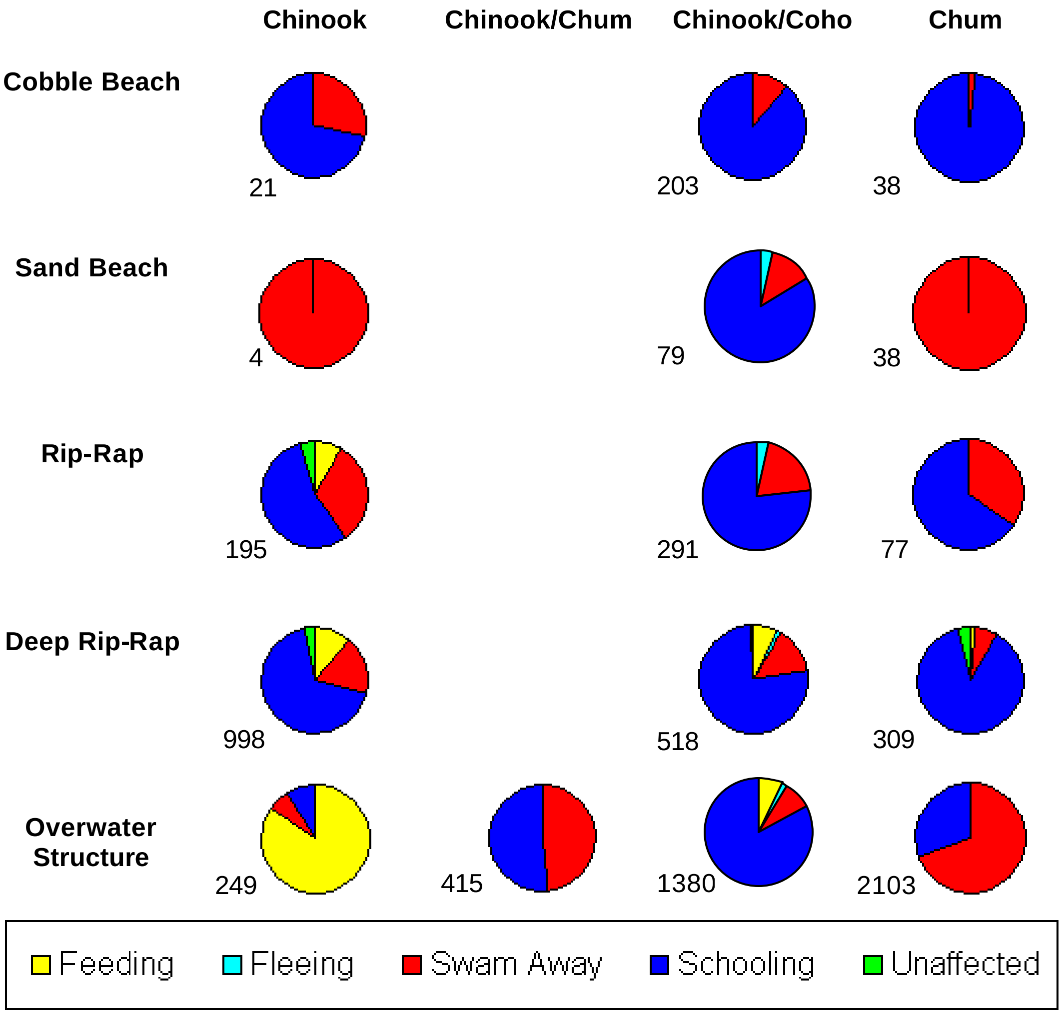

Figure 21. Behavior patterns of juvenile salmonids at main habitat types. Sample size (numbers of fish) are in the lower left corner of each graph.

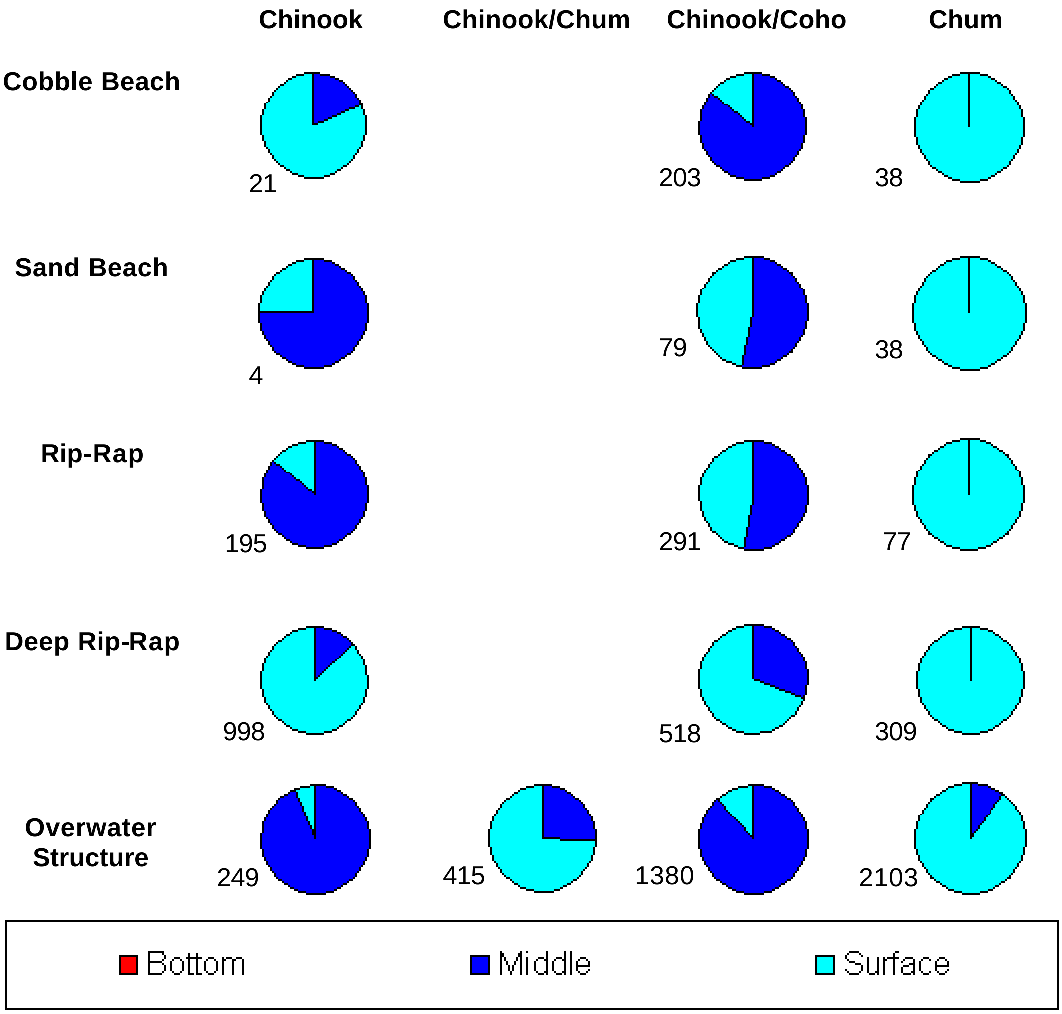

Figure 22. Water column position of juvenile salmonids at main habitat types. Sample size (numbers of fish) are in the lower left corner of each graph.

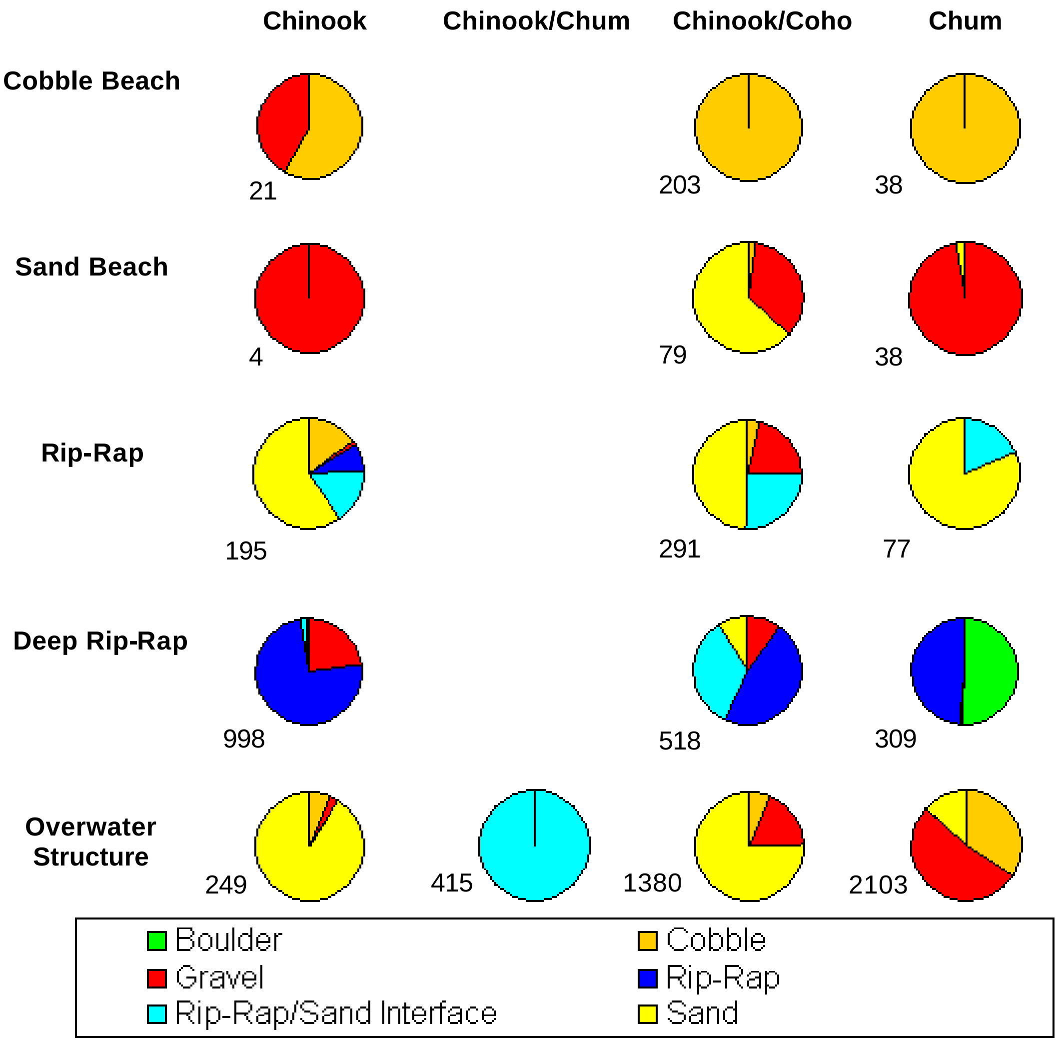

Figure 23. Substrate types of juvenile salmonid observations at main habitat types. Sample size (numbers of fish) are in the lower left corner of each graph.

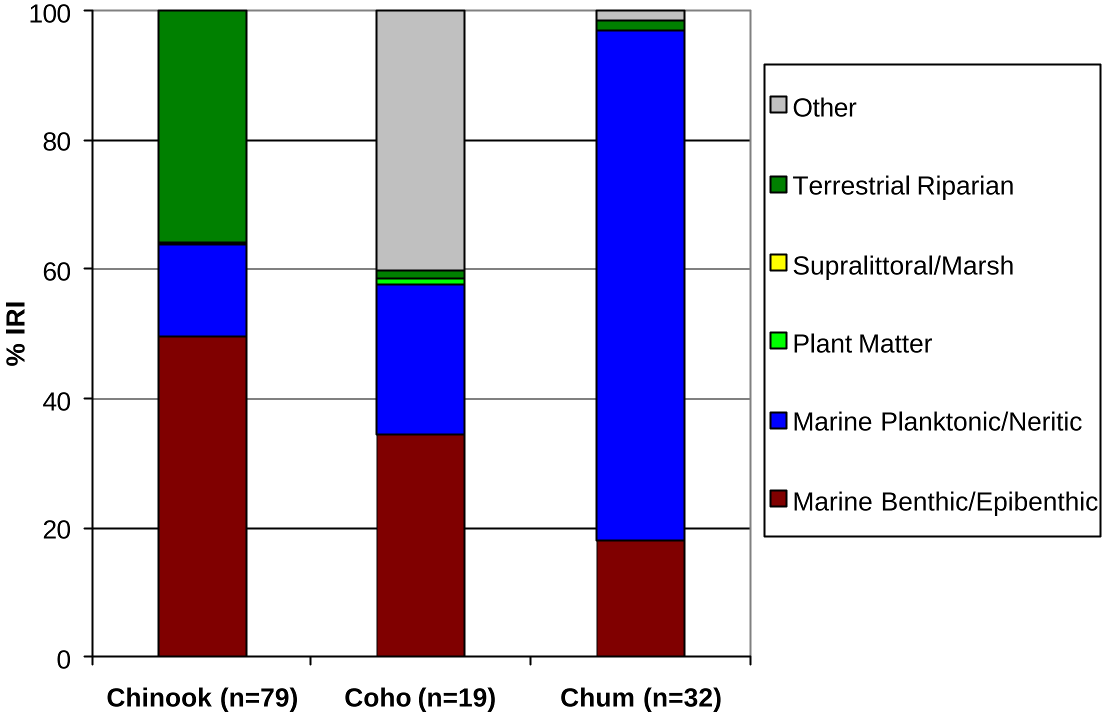

Figure 24. Gut contents of juvenile salmonids sampled with gastric lavage. Prey items are grouped by ecological type. "Other" refers to unknown due to high levels of digestion (all copepods in the case of coho salmon).

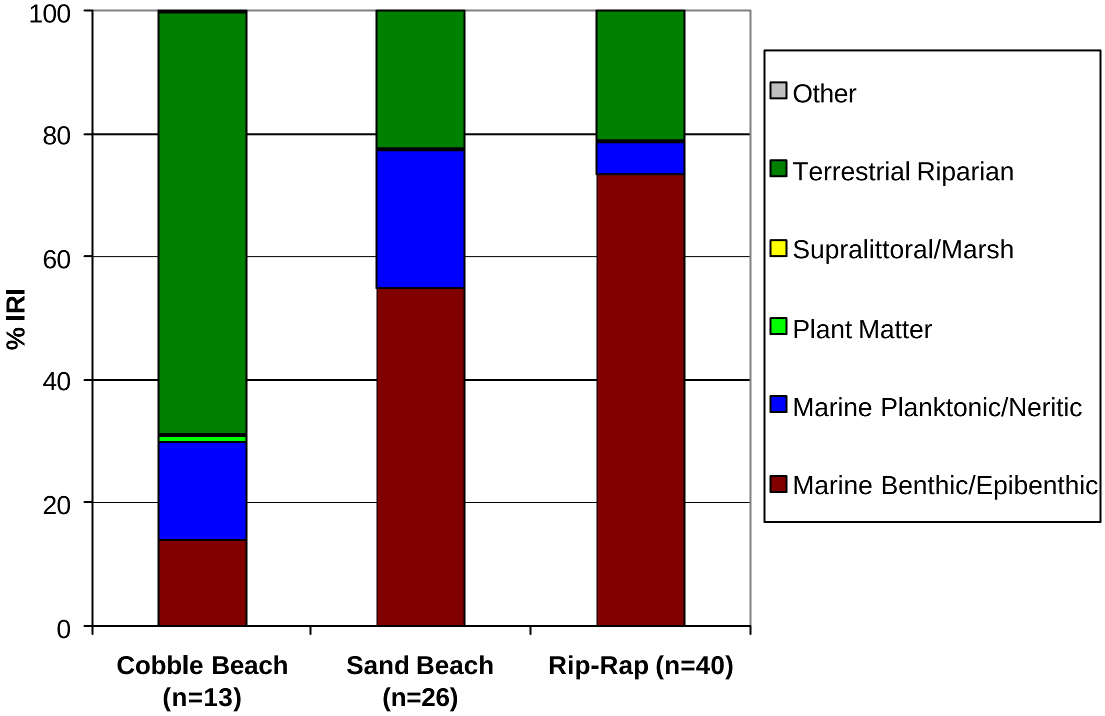

Figure 25. Gut contents of juvenile chinook salmon across main high intertidal habitat types.

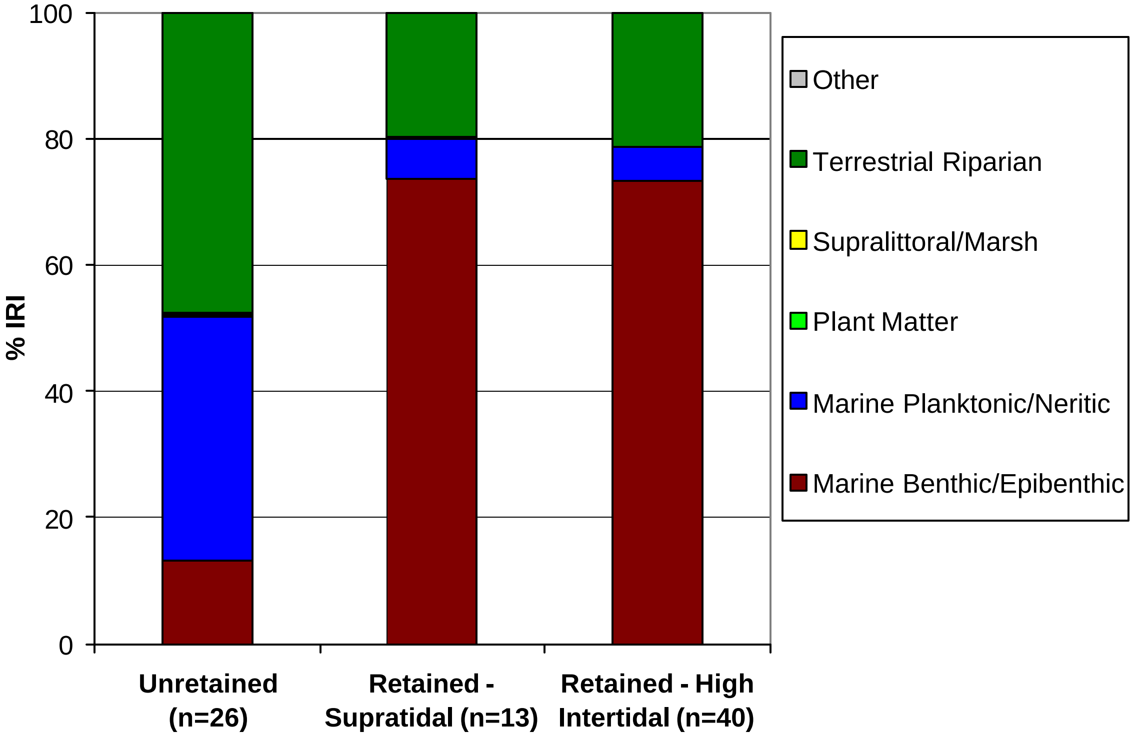

Figure 26. Gut contents of juvenile chinook salmon across levels of shoreline retainment.

Table 1. Overall sampling design, with detailed information on habitat types at different tidal heights for each study site. Surface areas of overwater structures are in parentheses. Shaded column is considered the main habitat type, with deep rip-rap signifying rip-rap across all tidal levels.

Sampling Week: Spring Tides
Study Sites: 8 total
Sampling Methodology: Enclosure Nets and Snorkel Surveys

		Habitat at Tidal Heights		
Study Site	*Code*	*Supratidal*	*High Intertidal*	*Low Intertidal*
Railroad Sand	1	Rip-Rap/Sand Beach	Sand Beach	Sand Beach
Railroad Rip-Rap	2	Rip-Rap	Rip-Rap	Sand Beach
West Point Cobble	3	Steep Cliff/Cobble Beach	Cobble Beach	Cobble Beach
West Point Rip-Rap	4	Rip-Rap	Rip-Rap	Sand Beach
West Point Sand	5	Sand Beach	Sand Beach	Sand Beach
Magnolia Cobble	6	Steep Cliff/Cobble Beach	Cobble Beach	Cobble Beach
Alki Rip-Rap	7	Bulkhead/Rip-Rap	Rip-Rap	Sand Beach
Alki Sand	8	Bulkhead/Sand Beach	Sand Beach	Sand Beach

Sampling Week: Neap Tides
Study Sites: 15 total (the above 8 plus the 7 below)
Sampling Methodology: Snorkel Surveys

		Habitat at Tidal Heights		
Study Site	*Code*	*Supratidal*	*High Intertidal*	*Low Intertidal*
Golden Rip-Rap	A	Rip-Rap	Deep Rip-Rap	Rip-Rap
Overwater Shilshole (582 m^2)	B	Overwater Structure	Overwater Structure	Overwater Structure
Overwater Ray's (4,866 m^2)	C	Overwater Structure	Overwater Structure	Overwater Structure
Myrtle Rip-Rap	D	Rip-Rap	Deep Rip-Rap	Rip-Rap
Armeni Rip-Rap	E	Rip-Rap	Deep Rip-Rap	Rip-Rap
Overwater Alki (2,922 m^2)	F	Overwater Structure	Overwater Structure	Overwater Structure
Lincoln Park Cobble	G	Rip-Rap/Cobble Beach	Cobble Beach	Cobble Beach

Table 2. Functional groupings of fish and crabs for analysis.

	Common Name	Scientific Name
Juvenile Salmon	Chinook salmon	*Oncorhynchus tshawytscha*
	coho salmon	*Oncorhynchus kisutch*
	chum salmon	*Oncorhynchus keta*
	cutthroat trout	*Oncorhynchus clarki*
Forage Fish	surf smelt	*Hypomesus pretiosus pretiosus*
	Pacific sand lance	*Ammodytes hexapterus*
	Pacific herring	*Clupea harengus pallasi*
Other Nearshore Fishes	bay pipefish	*Syngnathus griseolineatus*
	tube-snout	*Aulorhynchus flavidus*
	threespine stickleback	*Gasterosteus aculeatus*
Surfperches	striped seaperch	*Embiotoca lateralis*
	pile perch	*Rhacochilus vacca*
	shiner perch	*Cymatogaster aggregata*
	kelp perch	*Brachyistius frenatus*
Flatfish	English sole	*Pleuronectes (Parophrys) vetulus*
	starry flounder	*Platichthys stellatus*
	rock sole	*Pleuronectes (Lepidopsetta) bilineata*
	sand sole	*Psettichthys melanostictus*
	Pacific sanddab	*Citharichthys sordidus*
Other Demersal Fishes	Pacific staghorn sculpin	*Leptocottus armatus*
	fluffy sculpin	*Oligocottus snyderi*
	padded sculpin	*Artedius fenestralus*
	buffalo sculpin	*Enophrys bison*
	great sculpin	*Myoxocephalus polyacanthocephalus*
	white-spotted greenling	*Hexagrammos stelleri*
	lingcod *	*Ophiodon elongatus*
	rockfishes *	*Sebastes* spp.
	spotted ratfish *	*Hydrolagus colliei*
	pricklebacks *	Stichaeidae spp.
Gunnels	penpoint gunnel	*Apodichthys flavidus*
	saddleback gunnel	*Pholis ornata*
	crescent gunnel	*Pholis laeta*
Crabs	Dungeness crab	*Cancer magister*
	red rock crab	*Cancer productus*
	graceful crab	*Cancer gracilis*
	yellow shore crab	*Hemigrapsis oregonensis*
	northern kelp crab	*Pugettia producta*

* only seen on snorkel surveys, not in enclosure nets

Phylogenetic conventions and common names according to the American Fisheries Society

Table 3. Sum of total catch, average lengths (mm), and standard errors (SE) of lengths for fish and crabs captured in enclosure nets.

Species	Total Catch	Average Length (mm)	SE
Salmonids		**Fork Length**	
Chinook - unmarked	49	97.2	2.37
Chinook - marked	79	89.4	2.11
Chinook - unknown	1	100.0	-
coho - unmarked	11	132.4	6.00
coho - marked	13	151.6	10.15
adult coho - marked	1	600.0	-
chum - unmarked	90	61.0	1.10
cutthroat trout - unmarked	1	172	-
Other Fish		**Standard Length**	
bay pipefish	4	189.5	11.21
buffalo sculpin	3	114.7	9.96
crescent gunnel	6	135.2	12.00
English sole	163	73.1	3.87
fluffy sculpin	46	46.4	2.70
great sculpin	1	113.0	-
kelp perch	2	85.5	26.50
Pacific herring	4	97.3	17.33
Pacific sand lance	9	98.7	16.46
Pacific sanddab	1	203.0	-
Pacific staghorn sculpin	145	86.9	3.60
padded sculpin	11	69.7	11.62
penpoint gunnel	41	130.6	4.84
pile perch	26	166.3	9.82
rock sole	28	130.5	14.16
saddleback gunnel	13	122.0	5.54
sand sole	3	186.1	47.87
shiner perch	219	73.5	1.70
starry flounder	72	74.8	8.76
striped seaperch	65	190.8	7.45
surf smelt	59	76.8	6.42
threespine stickleback	1	35.0	-
tube-snout	3	171.3	21.99
white-spotted greenling	1	91.0	-
unk. Flatfish (juvenile)	15	34.3	1.57
unk. Sole (juvenile)	31	36.9	1.70
unk. Sculpin (juvenile)	9	69.1	8.77
unk. Gunnel	1	225.0	-
Crabs		**Carapace Width**	
Dungeness crab	28	74.3	4.77
red rock crab	16	56.0	10.83
graceful crab	20	50.1	3.43
yellow shore crab	3	16.0	3.51
northern kelp crab	2	40.3	7.31
Cancer sp. (juvenile)	8	37.4	5.17

Table 4. Sample size and average enclosure net volume for main habitat types. Letters denote significant differences in water volumes using the Tukey test for multiple comparisons.

Habitat Type	**Sample Size**	**Average Net Water Volume (m^3)**
Cobble Beach [a]	n=12	337
Sand Beach [a]	n=18	372
Rip-Rap [b]	n=18	519

Table 5. Significant differences in functional group and juvenile salmonid densities from snorkel surveys, using the Tukey test for multiple comparisons on main habitat type. Letters designate significant differences, with succession of letters denoting higher densities.

	Main Habitat Type				
Functional Group	Cobble Beach	Sand Beach	Rip-Rap	Deep Rip-Rap	Overwater Structure
Juvenile Salmon	a	a	a	a	b
Forage Fish	-	-	-	-	-
Other Nearshore Fishes	a	a	a	b	ab
Surfperches	a	a	a	b	a
Flatfish	a	b	ab	a	a
Other Demersal Fishes	ab	a	b	ab	ab
Gunnels	a	a	a	b	a
Crabs	b	a	a	ab	a
sum	ab	a	a	c	bc
Juvenile Salmonids					
Chinook	a	a	a	b	a
Chinook/Coho	a	a	a	a	b
Chinook/Chum	a	a	a	a	b
Chum	a	a	a	a	b

Table 6. Summary table of counts and lengths of fish and crabs encountered during snorkel surveys.

Species	Average School Size	Number of Observed Schools	Sum of Total Counts	Average length (cm)	Average range of length estimates (cm)
Salmonids					
Chinook	13.3	110	1467	10.5	2.81
Chinook/chum	83.0	5	415	9.4	3.80
Chinook/coho	13.8	179	2471	11.3	2.64
chum	50.3	51	2565	6.0	2.97
coho	7.1	17	120	13.5	2.50
trout	1.0	3	3	22.1	2.50
other salmonid groupings	9.0	16	144	11.0	4.01
Other Fish					
bay pipefish	1.0	4	4	16.3	2.50
English sole	1.0	8	8	19.1	2.50
flatfish - other groupings	1.0	29	29	17.2	2.50
gunnels	1.2	12	14	18.2	2.50
kelp perch	1.5	13	20	9.2	2.88
larval fish	52.8	20	1055	4.4	2.50
lingcod	1.0	3	3	101.3	2.50
Pacific herring	1.0	14	14	13.9	2.50
Pacific sand lance	479.5	37	17742	7.7	2.50
perch - other groupings	3.2	58	187	9.4	2.67
pile perch	4.1	600	2489	15.3	4.87
prickleback	1.0	1	1	26.3	2.50
rock sole	1.2	18	22	22.2	3.52
rockfish	1.0	2	2	18.8	2.50
sculpin	1.0	32	32	14.9	2.50
shiner perch	61.6	302	18604	8.3	3.15
smelt	86.8	11	955	7.0	2.50
spotted ratfish	1.0	2	2	53.8	2.50
staghorn sculpin	1.0	14	14	15.7	2.50
starry flounder	1.1	15	16	23.0	3.13
striped seaperch	2.1	483	1034	16.8	3.50
threespine stickleback	8.9	26	231	5.2	2.49
tube-snout	10.9	34	369	11.6	2.50
Crabs					
Dungeness crab	1.2	80	93	10.0	2.50
Red rock crab	1.1	85	97	11.7	2.45
Kelp crab	1.5	11	17	8.6	2.50
Cancer sp.	1.2	19	22	7.8	2.39

Table 7. Average school sizes of juvenile salmonids at main habitat types.

Species	Habitat Type	Average School Size
Chinook	Overwater Structure	41.5
	Deep Rip-Rap	13.5
	Rip-Rap	8.9
	Sand Beach	1.3
	Cobble Beach	4.2
Chinook/chum	Overwater Structure	83.0
Chinook/coho	Overwater Structure	27.6
	Deep Rip-Rap	8.2
	Rip-Rap	7.3
	Sand Beach	8.8
	Cobble Beach	11.9
chum	Overwater Structure	80.9
	Deep Rip-Rap	20.6
	Rip-Rap	15.4
	Sand Beach	19.0
	Cobble Beach	12.7
coho	Overwater Structure	8.8
	Deep Rip-Rap	5.7
	Rip-Rap	11.0
	Cobble Beach	1.0
other salmonid groupings	Overwater Structure	21.2
	Deep Rip-Rap	1.0
	Rip-Rap	2.8
	Sand Beach	1.0
	Cobble Beach	1.0
trout	Deep Rip-Rap	1.0
	Rip-Rap	1.0
	Cobble Beach	1.0
overall	Overwater Structure	44.4
	Deep Rip-Rap	11.5
	Rip-Rap	8.1
	Sand Beach	7.3
	Cobble Beach	9.2

Table 8. Behavior, water column position, and substrate type of functional groupings from snorkel survey observations summarized over all habitat types. For substrate type, NA refers to not available due to deep water and/or low visibility, mostly at overwater structures.

	Functional Groupings of Fish and Crabs							
	Juvenile Salmon	Forage Fish	Other Nearshore Fishes	Surfperches	Flatfish	Other Demersal Fishes	Gunnels	Crabs
Behavior								
Hiding	-	-	-	0.004%	1%	9%	29%	-
Not Moving	-	-	-	0.01%	12%	15%	-	1%
Unaffected	1%	0.1%	63%	17%	40%	31%	57%	95%
Feeding	7%	-	5%	0.2%	-	-	-	3%
Schooling	59%	89%	31%	77%	-	-	-	-
Swam Away	32%	1%	1%	4%	31%	31%	14%	0.5%
Fleeing	0.5%	10%	0.3%	1%	16%	13%	-	-
Water column position								
Surface	60%	32%	34%	1%	-	-	-	-
Middle	40%	52%	9%	61%	1%	7%	-	-
Bottom	0.03%	16%	56%	38%	99%	93%	100%	100%
Substrate type								
Sand	23%	9%	3%	11%	43%	31%	7%	17%
Gravel	17%	19%	2%	11%	44%	30%	-	5%
Cobble	10%	23%	7%	14%	7%	22%	14%	38%
Boulder	2%	13%	14%	2%	-	4%	29%	11%
Kelp	-	-	0.2%	0.004%	-	-	-	2%
Rip-Rap/Sand Interface	7%	1%	1%	15%	7%	2%	7%	7%
Rip-Rap	16%	5%	58%	48%	-	11%	43%	17%
NA	24%	29%	16%	0.4%	-	-	-	4%
Total Counts	7185	19766	604	22334	75	54	14	229

Table 9. Location of fish observations relevant to the parallel edge of overwater structures. Categories are as follows: "Under" is > 1m underneath edge of overwater structure, edge is within 1 m under or away from edge of structure, and away is > 1m away from edge of structure.

	Location to Overwater Structure				
Fish Species	**Under**	**Edge**	**Away**	**Count of Observations**	**Percent Associated with Pilings**
Juvenile Salmonids					
Chinook/Coho	2%	20%	78%	46	
Chinook		17%	83%	6	
Chinook/Chum		80%	20%	5	
Chum		50%	50%	26	
other salmonid groupings		11%	89%	9	
total juvenile salmonids	1%	30%	68%	92	
Surfperches					
shiner perch	8%	35%	58%	52	27%
pile perch	17%	45%	38%	29	38%
striped seaperch	14%	43%	43%	14	36%
other groupings		83%	17%	6	33%
total surfperches	11%	42%	48%	101	32%
Other Fish					
threespine stickleback		7%	93%	15	
Pacific sand lance	14%	29%	57%	7	
larval fish			100%	4	
sculpin		100%		4	75%
smelt		50%	50%	4	
Red rock crab		100%		3	67%
bay pipefish			100%	1	
Dungeness crab		100%		1	100%
gunnels			100%	1	
Kelp crab		100%		1	
Pacific herring		100%		1	
starry flounder			100%	1	

Table 10. Environmental measurements from snorkel surveys at main habitat types. All measured variables are significantly different using ANOVA tests, with succession of letters denoting higher densities. The bottom row equals sum for sample size, and average for the other columns.

Habitat Type	Sample Size	Average Transect Distance from Shore (m)	Average Transect Water Depth (m)	Average Water Depth at Fish (m)	Average Secchi Depth (m)	Surface Salinity (ppt)
Cobble Beach	84	17.2 [a]	1.5 [a]	1.6 [a]	4.3 [a]	28.7 [a]
Sand Beach	110	12.9 [b]	1.5 [a]	1.7 [a]	4.8 [ab]	28.7 [a]
Rip-Rap	124	7.7 [c]	1.6 [a]	1.7 [a]	4.7 [a]	28.8 [a]
Deep Rip-Rap	64	4.8 [d]	2.4 [b]	2.4 [b]	5.9 [c]	27.5 [a]
Overwater Structure	60	3.4 [d]	3.0 [c]	4.4 [c]	5.4 [bc]	23.7 [b]
sum/average	442	9.8	1.9	2.2	4.9	27.7