Biology, Behavior, and Resources of Resident and Anadromous Fish in the Lower Willamette River

Final Report of Research, 2000-2004

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PREFACE

This document is the final report of research for a project funded by the City of Portland (COP) and conducted by the Oregon Department of Fish and Wildlife (ODFW). The general objective was to evaluate aquatic habitat and biotic communities in the lower Willamette River, and provide guidance for protecting species of threatened and endangered salmonids. Our report includes five research papers that describe how we addressed project hypotheses and objectives, how we reached our conclusions, and why we made our recommendations. The papers are listed and numbered in the Table of Contents, and the numbers are used to reference each paper in the Summary. The Summary integrates the results, conclusions, and recommendations, and provides the best overall picture of the status of aquatic resources in the lower Willamette River. The recommendations presented here were developed by the principal investigators, and will not necessarily be adopted as policies or guidelines by the Oregon Department of Fish and Wildlife.

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SUMMARY

Paper 1 - Description and Categorization of Nearshore Habitat in the Lower Willamette River

Our objective in this paper was to define and catalog existing nearshore fish habitat. We also identified habitat categories for subsequent analyses of fish use (Papers 2 and 3). Habitats were initially separated into six categories (beach, alcove, riprap, seawall, rock outcrop, and mixed) and 12 sub-categories based on their appearance and function. The majority (59.2%) of riverbank habitat in the study area (mouth to Willamette Falls) was undeveloped ("natural"), with no obvious modifications such as seawalls, riprap, or piers. Beaches were the most prevalent habitat type in the upper (above Ross Island Bridge; 38.8%) and lower (29.1%) sections of the study area, but the distribution of other types was considerably different. Undeveloped habitats composed 81.1% of the habitat in the upper section, but only 32.8% in the lower section. Nearshore structures (e.g., piers, docks, pilings) were associated with 18.7% of the total shoreline area.

To provide a more quantitative approach to habitat categorization, we intensively surveyed 27 sites during spring, summer, autumn, and winter. We measured 60 physical or chemical parameters at each site, both instream and onshore. We then used cluster analysis and principal components analysis to group habitats and identify the parameters that contributed most to their separation. Sampling sites separated into five or six clusters in each season. Sites initially classified as seawall or rock outcrop always segregated into distinct groups. Sites described as beaches often occurred together in a group; riprap, rock, and mixed habitat types often appeared in multiple groups. These patterns increased our confidence that the initial groupings based on appearance were relatively accurate, and the multivariate analyses were useful in determining categories based on measured parameters.

Bank vegetation, bottom substrate type, hydrology, and bank substrate type explained the majority of the variation in habitat data, and contributed most to the separation of sites into clusters. The percent of the bottom substrate composed of sand and onshore vegetation were important explanatory variables in every season; parameters important in at least two seasons included: river level, water depth, distance to the thalweg, transparency, bank slope, percent beach, percent small riprap, and percent bedrock. River chemistry (temperature, dissolved oxygen, and conductivity) varied little among sites during individual seasons, and did not contribute appreciably to site groupings.

Paper 2 - Migratory Behavior, Timing, Rearing, and Habitat Use of Juvenile Salmonids in the Lower Willamette River

Using electrofishing, beach seines, and radio telemetry, we assessed components of juvenile salmonid biology that would lead to a better understanding of their behavior in the lower Willamette River. We focused largely on nearshore habitat use, but also explored outmigration timing, size structure, growth, migration rate, and residence time.

Most (87%) juvenile salmonids we captured were Chinook salmon. Coho salmon and steelhead composed relatively small proportions of the catch (9% and 3%), and we occasionally observed mountain whitefish, sockeye salmon, and cutthroat trout. Hatchery-produced fish dominated the catch, composing 54% of the Chinook salmon, 66% of the coho salmon, and 91% of the steelhead. The electrofishing catch was dominated by large (>100 mm fork length) hatchery Chinook salmon; beach seines captured mostly small (≤100 mm fork length) Chinook salmon. Based on this gear selectivity and natural breaks in length frequencies, we assumed that Chinook salmon >100 mm fork length were yearlings (age 1) and smaller fish were subyearlings (age 0). Because we observed a large number of subyearling fish, and the abundance of fall Chinook salmon in the Willamette Basin is low, we concluded most small Chinook salmon in the lower Willamette River are spring-run fish that outmigrate as subyearlings.

The outmigration period for Chinook salmon, both hatchery and unmarked, was surprisingly long. The presence of juvenile fish often increased in late autumn and persisted into the next summer, and juvenile salmonids were present in every month we sampled from May 2000 to July 2003. Winter and spring were clearly the periods of greatest abundance, though the presence of different races (spring and fall), size classes, and stocks undoubtedly confounded our ability to completely assess timing. Coho salmon and steelhead were generally present only during winter and spring.

Median fork lengths and weights of hatchery and unmarked Chinook salmon were often significantly greater at downstream sampling sites than at upstream sites during winter and spring, suggesting these fish grow as they migrate through the study area. Observed changes in fork length ranged from 1-14 mm and equated to growth rates that were somewhat higher than described in the literature. Considering the large sample size, consistent pattern, and statistical strength of our analyses, we concluded that Chinook salmon exhibit changes in size during their migration through the lower Willamette River. Because these fish feed extensively (see Paper 4), the size changes we observed are likely a product of growth. Differential mortality among size classes of salmonids is a potential confounding factor that needs to be fully assessed.

We radio-tagged 186 juvenile salmonids from 2001 to 2003, including 95 Chinook salmon, 63 coho salmon, and 28 steelhead. All were >100 mm fork length. These fish moved relatively quickly through the study area, though the median migration rate for coho salmon (4.6 km/d) was significantly slower than for Chinook salmon (11.3 km/d) or steelhead (12.5 km/d). Median residence times in the study area were 8.7 days for coho salmon, 3.4 days for Chinook salmon, and 2.5 days for steelhead. We identified several variables that were related to migration rate. River flow explained much of the variation in migration rate for both Chinook (r^2 = 0.385) and coho (r^2 = 0.476) salmon, and fork length had a strong positive relationship with migration rate for Chinook salmon. Combined in multiple linear regressions, river flow and fork length were positively related to migration rate for Chinook salmon, and explained a considerable amount of the variation (r^2 = 0.445). Release day and river flow explained 67% of the variation in coho salmon migration rates. No significant relationships were observed for steelhead. The implications of migration rate, residence time, and factors affecting them are uncertain. Rapid travel through degraded habitats presumably improves survival, but elements of our study (e.g., feeding, growth, and low predation on salmonids) suggest the lower Willamette River has value as rearing habitat. Exposure to toxins and other poor water conditions (especially in the Portland Harbor area) is a concern, and has not been completely evaluated.

Radio-tagged Chinook salmon were not highly associated with nearshore areas; about 76% of the recoveries occurred offshore (>10% of the channel width). Fish that were recovered near shore were distributed unevenly with respect to the proportional availability of different habitat types; however, they did not show clear selection for (or avoidance of) particular habitats. Coho salmon behaved differently; they were found near shore more often (43%), appeared to prefer beaches, and avoided riprap and artificial fill. Steelhead were rarely (25%) associated with nearshore areas.

To further assess habitat selectivity, we compared electrofishing catch among habitat types. Sampling sites were grouped into generalized habitat categories (e.g., beach, riprap, rock outcrop) and into clustered groups based on similarities in physical and chemical parameters (see Paper 1). Results for these analyses were generally similar, regardless of how habitat groups were defined. Electrofishing catch per unit effort (CPUE) of juvenile salmonids >100 mm fork length varied significantly among habitat types, but differences were almost always associated with low catches of fish at seawall sites. We suspect sampling efficiency was reduced at these sites due to their greater depth relative to other habitats; unlike shallower sites, we did not sample the entire water column. We concluded juvenile salmonids did not use the upper portion of the water column at seawall sites, or tended to avoid them altogether. Other differences in CPUE among habitats were rare; we found no indication that yearling salmonids were associated with specific habitats or groups of habitats, with one exception. Median electrofishing CPUE for coho salmon in spring was significantly higher at rock outcrops than at other habitats, suggesting these areas have a particular value. High catches sometimes occurred more frequently in off-channel areas (alcoves, backwaters, side channels), but were not significantly different from those in the main river channel.

We also analyzed catch rates of juvenile Chinook salmon among individual habitat parameters; we selected those that contributed most to the separation of clustered habitat groups (see Paper 1). With the exception of bank vegetation (catches were lowest at sites with 0-10% vegetative cover), none of the parameters were related to median CPUE during spring. However, higher catches were often associated with sand substrates, shallow water, and moderate amounts of bank vegetation during winter. Some relationships were confused, and we recommended a more rigorous statistical approach for future work.

A final important observation in our study was the large number of subyearling Chinook salmon present in beach seine catches. Nearly all were naturally produced, and therefore protected under the federal Endangered Species Act (ESA). We could not analyze habitat preferences for these fish because seining efforts occurred at a single habitat type, but based on the high numbers of fish and their extended temporal distribution (November to July), we hypothesized that beaches are particularly important habitats for these fish.

Overall, we found little evidence to suggest that nearshore habitat as it currently exists is a critical factor affecting yearling salmonids, and we generally agree with prior studies, which concluded waterway developments in the lower Willamette River present few risks to juvenile salmonids. However, we believe the effects of development are incompletely explored, especially with respect to subyearling fish. Clearly, the lower Willamette River is more than a simple migration corridor. Juvenile Chinook salmon feed (see Paper 4) and apparently grow during their outmigration, and unaltered nearshore habitats appear to be important to smaller fish. Coho salmon also feed extensively on aquatic invertebrates, were associated with nearshore areas, exhibited selection for specific habitat types, and spent relatively long periods in the study area. All off-channel habitats were utilized by juvenile salmonids, and these fish were present for extended periods in all years. While current conditions appear to adequately support fish populations, future development should be planned carefully to avoid detrimental impacts.

Paper 3 - Population Structure, Movement, Habitat Use, and Diet of Resident Piscivorous Fishes in the Lower Willamette River

We investigated several species of piscivorous fish (northern pikeminnow, walleye, smallmouth bass, and largemouth bass) to determine if they pose a risk to threatened and endangered salmonids in the lower Willamette River. We used radio telemetry to examine movement patterns and habitat associations, and electrofishing, gillnetting, and beach seining to evaluate diets and compare catch rates among habitat types.

We radio-tagged and tracked 73 predator-sized fish (those capable of consuming juvenile salmonids) from 2000 to 2003. In general, we found these fish did not travel far from their initial release points, particularly largemouth and smallmouth bass. Walleye traveled a median distance of 9.0 km during the study and appeared to be the most active species. Relocations of radio-tagged fish tended to be close to shore (within 20% of the total river width), and were often associated with pilings and rocky banks. Densities of large predator fishes (from electrofishing catches) were generally low, but consistently higher at sites characterized by riprap, mixed rock, and rock outcrops. We observed very little evidence of predation on juvenile salmonids. By weight, the diets of northern pikeminnow and largemouth bass were dominated by crayfish; the diets of walleye and smallmouth bass consisted primarily of fish. Large predators often had empty stomachs (62%), and identifiable fish in their diets were usually sculpins.

We concluded that walleye are probably too rare in the lower Willamette River to have an effect on salmonid survival, and neither northern pikeminnow nor largemouth bass appeared to prey on salmonids. Considering their relative abundance (all size classes), diet, and ubiquity, smallmouth bass probably pose the most significant potential threat to juvenile salmonids in the lower Willamette River. Currently, densities of all large predator fishes are low, and their effects on juvenile salmonids are likely negligible.

Paper 4 – Diets of Juvenile Salmonids and Introduced Fishes of the Lower Willamette River

In this paper, our primary objectives were to characterize the diets of introduced and anadromous fish, and determine if dietary overlap occurs between naturally propagated (“unmarked”) salmonids and either introduced species or hatchery salmonids. Diet similarities could suggest competition for food resources and have management implications for threatened and endangered species. We used boat electrofishing to collect fish and gastric lavage to obtain diet samples. We collected samples from juvenile salmonids and introduced fish (primarily smallmouth bass and yellow perch) of similar size, and used a variety of indices to characterize and compare diets.

Daphnia were the most important prey item for Chinook and coho salmon, occurring in 65% of the samples and composing >80% of their diets by weight. The amphipod *Corophium* spp. and insects (both aquatic and terrestrial) were also common in salmonid diets. We found no significant diet overlap between juvenile salmonids and introduced species. Daphnia were important prey for smallmouth bass (46% of all prey items), but fish and crayfish composed nearly all (97%) of their diet by weight. Yellow perch, bass, and sunfish generally had more diverse diets than juvenile salmonids, and unlike salmonids, did not specialize on particular taxa. Diets of unmarked and hatchery Chinook salmon did overlap significantly, though unmarked fish exhibited a more selective feeding behavior and consumed larger amounts of prey. Neither Chinook nor coho salmon consumed major food items at the same proportion at which they were present in the environment; both selected daphnia and avoided chironomids, indicating specialized, selective feeding behaviors. Yellow perch and smallmouth bass tended to be generalists, though a few smallmouth bass specialized on daphnia and baetid mayflies.

In terms of food resources, introduced resident fishes do not appear to adversely affect juvenile salmonids in the lower Willamette River. The current high abundance of prey items, especially daphnia, would probably preclude competition even if the diets of the various species did overlap. In a resource-limited environment, smallmouth bass and hatchery salmonids would be most likely to compete with naturally produced salmonids.

Paper 5 – A Brief Survey of Aquatic Invertebrates in the Lower Willamette River

We surveyed macroinvertebrates and zooplankton at 26 sites during spring 2003 using a variety of gears (drift nets, Hester-Dendy multiple-plate samplers, and ponar dredges). Our primary objectives were to inventory the invertebrate biota, provide baseline data on the community structure, and compare assemblages among nearshore habitat types.

We identified approximately 38,000 organisms from 44 taxa. Cladocerans (bosminids and daphnia), copepods, and aquatic insects dominated the drift net samples. Multiple-plate arrays were colonized primarily by daphnia and chironomids (95% of all organisms); oligochaetes and chironomids composed the majority (83%) of the taxa in ponar samples. Density and community metrics varied among gear and habitat types. Beaches tended to have relatively high species diversity, taxa richness, and sensitive taxa richness; seawalls had comparatively low densities and taxa richness. Rock outcrops and floating structures appeared to be preferred habitats for aquatic insects. Riprapped sites had very high densities of invertebrates, and except for multiple-plate samples, relatively high taxa richness.

We noted few differences in the proportional distribution of major taxa groups among habitats, suggesting a generally homogenous community structure. Bosminids and copepods were largely absent in drift samples from rock outcrops and floating structures, but dominated the drift at riprapped sites. Colonization of multiple-plate samplers was similar among habitats, except for riprapped sites, which had much higher densities of daphnia. Densities of *Corophium* spp. in ponar samples also varied somewhat among habitats.

Biotic integrity scores based on the proportion and tolerance of taxa indicated moderate to fairly significant levels of organic pollution, though the taxa we observed were typical of most large rivers. Index scores very consistent among habitats, though the infaunal community (ponar samples) indicated better water quality than the epibenthic community (multiple-plate samplers). The moderate levels of impairment suggest biotic communities in the lower Willamette River may respond well to habitat and water quality improvements.

RECOMMENDATIONS

Recommendations by the principal investigators fall into three categories: (1) primary recommendations, which are recommendations regarding in-water or shoreline activities that are supported directly by study findings, (2) secondary recommendations, which are recommendations regarding in-water or shoreline activities that are supported in part by study findings, but may rely in part on general ecological principles and ecosystem functions, and (3) recommendations for additional studies.

Primary Recommendations

1. **The in-water work period for activities such as dredging, bank stabilization, etc., should be restricted to July 1 – October 31.** Primary considerations for recommending in-water work periods are given to important fish species, including anadromous fish and those receiving protection under federal or state ESAs. The existing work period for the lower Willamette River and Multnomah Channel is July 1 – October 31 and December 1 – January 31 (ODFW 2000). Our findings indicate Chinook salmon, coho salmon, and steelhead (including a large number of unmarked fish) are present during December 1 – January 31, and are often abundant during this period; in-water work should be avoided to prevent harming listed stocks.

   This recommendation does not necessarily reflect policy of ODFW or the COP. ODFW is responsible for providing guidelines for in-water work periods to minimize impacts to fish, wildlife, and habitat. It is likely that ODFW will recommend the winter work period remain open, but that strict criteria be met to ensure impacts to fish, wildlife, and habitat resources are negligible.

2. **Protect existing beach habitat.** Natural beaches appeared to be an important habitat for younger age classes of salmonids (particularly Chinook salmon), were selected by radio-tagged coho salmon, and were not a preferred habitat of large predator fishes; enhancements directed at creating beaches will likely provide a benefit to salmonids. It is unknown to what extent this habitat type can be enhanced by physical restoration efforts (see recommendation

5). Remaining beaches in the lower Willamette River represent relatively undisturbed habitats, and have important recreational and aesthetic value.

3. **Avoid construction of additional seawalls.** Seawalls represent a loss of natural shoreline conditions, provide little habitat for any fish species, and appeared to be under-utilized by juvenile salmonids. Electrofishing catches were low at seawalls; fish either avoid seawalls or change their behavior (move out of the range of electrofishing gear) upon encountering them. Because juvenile salmonids are generally associated with the upper portion of the water column, it is unlikely that low catches were due primarily to fish utilizing deep water along seawalls.

4. **Minimize the use of structures with pilings in the lower Willamette River.** Native and exotic piscivorous fishes were clearly associated with nearshore areas, and all species over-utilized pilings to some degree. We found little evidence of predation by exotic predators on juvenile salmonids; however, effect of exotic fishes extends beyond direct predation on juvenile salmonids. Minimizing the future use of pilings or a net reduction in the overall number of pilings will reduce the amount of habitat favored by exotic species.

Secondary Recommendations

5. **Determine if bio-engineering and other techniques can restore beach habitat functions and processes.** The City of Portland and ODFW should work with engineers and habitat specialists to determine the feasibility of restoring or creating beach habitats while considering other issues, such as commercial shipping, bank stabilization, and flood control. Though yearling Chinook salmon and other species did not exhibit clear preferences for any habitat type, beaches were clearly important to subyearling fish, and catches of larger fish were positively correlated with small substrates (sand), shallow water, and vegetated banks.

6. **Where possible, consider alternatives to riprap.** Densities of large predators were consistently highest at sampling sites dominated by rocky habitats (both natural and riprap), and radio-tagged predators over-utilized riprap in summer and autumn. We found little evidence of predation by exotic predators on juvenile salmonids; however, as noted previously, the effect of exotic fishes extends beyond direct predation on juvenile salmonids. Occurrence frequencies of fish and crayfish in predator diets were highest for samples collected from riprap, suggesting riprap provides good feeding habitat for predators. Radio-tagged coho salmon, and to a lesser extent Chinook salmon, underutilized riprap. Densities of invertebrates (including daphnia) were high at riprapped sites, adding uncertainty to the overall effects of riprap on ecosystem functions.

   The recommendation to consider alternatives to riprap is consistent with recommendations 2 (protect existing beach habitat) and 5 (determine if bio-engineering and other techniques can restore beach habitat functions and processes). Bio-engineered sites are more likely than riprap to facilitate normative ecosystem processes. It is not feasible nor do findings warrant removal of existing riprap; however, the COP and ODFW should work with engineers and habitat specialists to determine the feasibility of using alternatives to riprap in the future while considering other issues such as commercial shipping, bank stabilization, and flood control.

7. **Protect existing off-channel sites.** Many of these areas (alcoves, lagoons, backwaters, secondary channels) have been eliminated from the lower Willamette River; remaining areas are likely important for forage and refuge. All off-channel habitat types were used by migrating yearling salmonids, and at least 12% of our radio-tagged fish migrated through the Multnomah Channel. Habitat alterations should, at worst, not further eliminate habitat important to juvenile salmonids, and at best, provide additional habitat for juvenile salmonids while discouraging predators, potential competitors, and invasive species. The Multnomah Channel should be included in habitat conservation and enhancement activities.

Recommendations for Additional Studies

8. **Focus additional studies on subyearling Chinook and coho salmon.** Very little is known about the origin and race, habitat use, residence time, diet, and survival of age-0 Chinook salmon in the lower Willamette River. Our observations indicated these fish were abundant and used beach sites extensively; however, this study focused largely on yearling salmonids and did not answer critical questions pertaining to smaller age classes (especially habitat use and migration rates). Subyearling fish may be particularly important because nearly all are naturally produced (and therefore federally protected), and unlike older fish, may be associated with specific nearshore habitats (beaches). Investigating subyearling Chinook salmon in the lower Willamette River will greatly improve knowledge of their behavior and habitat requirements, and will enhance the ability of agencies to protect listed races. The habitat requirements of all ages should be considered when implementing fish management strategies.

   Small steelhead were rare in our surveys and probably do not use the lower Willamette River to a great degree; most outmigrate after rearing for two years in their natal streams. However, younger age classes of coho salmon were clearly present. Considering their status as a state-listed endangered species (they are also proposed for federal listing), and apparent behavioral differences compared to other salmonids, we recommend coho salmon be considered in future studies.

9. **Continue monitoring fish diets and macroinvertebrate communities in the lower Willamette River** (see recommendation 11)**.** Daphnia and other invertebrates are clearly important food sources for fish in the lower Willamette River, and are likely a critical component for the survival and success of ESA-listed salmonids. The effects of historic river development on these communities are largely unknown, and the effects of future development may go undetected without some level of monitoring.

10. **Future studies in the lower Willamette River should assess the impacts of other introduced species in relation to resource use, especially Asian shrimp *Exopalaemon modestus* and American shad *Alosa sapidissima*.** Although we found no significant dietary overlap among juvenile salmonids and introduced fishes, we did not evaluate the diets of

some important species. Juvenile American shad, which feed heavily on zooplankton, were the most abundant species observed during the study. Juvenile American shad in the lower Willamette River exhibit overlaps in seasonal abundance and size with juvenile Chinook salmon, and could utilize the same food resources. We did not examine American shad diets because this analysis requires dissection and removal of the digestive tract, which would not have been comparable to our non-lethal sampling of juvenile salmonids.

In addition, we noted freshwater Asian shrimp *Exopalaemon modestus* are abundant at various times of the year in the lower Willamette River. Little information exists about these exotic decapods and potential impacts they pose to native species. Other researchers have raised concerns regarding Asian shrimp predation on *Corophium* spp. in the Columbia River and the potential for dietary overlap with juvenile salmonids.

11. **Continue to monitor invertebrate populations in the lower Willamette River using standardized protocols** (see recommendation 9). Our survey of invertebrates in the lower Willamette River, while similar to previous studies, was largely cursory and emphasizes the need for a coordinated effort. Standardized procedures (sampling gears, locations, timing, level of taxonomic identification, and biotic indices) would be particularly useful for identifying changes in macroinvertebrate communities as anthropogenic development of the lower Willamette River continues. Biomonitoring could also aid in prioritizing habitat restoration projects and documenting the success of these efforts.

12. **Assess factors affecting macroinvertebrate communities in the lower Willamette River.** Water depth, sediment composition, sediment grain size, and percent volatile solids were significantly related to macroinvertebrate density in the lower Columbia River. Identifying similar factors in the Willamette River may help direct habitat restoration efforts and provide benefits for fish populations.

13. **Focus taxa-specific studies on daphnia.** Daphnia were very common in our study, dominating the taxa collected in both multi-plate samplers (which are generally not considered to be effective zooplankton sampling devices) and drift nets. Daphnia are a primary food source for juvenile salmon and other fish in the lower Willamette River, but little is known about their populations and factors affecting them.

Description and Categorization of Nearshore Habitat in the Lower Willamette River

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INTRODUCTION

The loss of natural habitat is one of the most important factors leading to the decline of native fish stocks in rivers and streams (Behnke 1992). Fish depend on natural habitat complexity for feeding, rearing, and spawning. Habitat complexity in lotic systems is a result of a combination of factors, including: 1) riparian vegetation that provides complex root systems and woody vegetation that help stabilize stream banks and provide stream cover, 2) large woody debris that creates important instream habitat for salmonids, 3) undercut banks that provide cover for fish, and 4) off-channel stream habitat that provides rearing areas (Hicken 1984; Meehan 1991). When riparian habitat is removed, many of the factors that contribute to habitat complexity are lost, bank erosion occurs, and sediment loads can increase.

Rock revetment (riprap) is often used to stabilize banks after riparian habitat is removed; however, this solution can result in a reduction of fish habitat and cause channelization (Hjort et al. 1984; Schmetterling et al. 2001). Riprap is often unvegetated, which results in a loss of large woody debris recruitment and stream cover (Dykaar and Wigington 2000). Riprap also prevents any lateral movement or erosion of the stream channel, which causes reductions in secondary channel habitat and undercut bank habitat (Hjort et al. 1984; Schmetterling et al. 2001). Knudsen and Dilley (1987) documented short-term detrimental effects on juvenile salmonids *Oncorhynchus* spp. during construction of bank reinforcements, and Garland et al. (2002) reported Chinook salmon *O. tshawytscha* densities were significantly lower at riprapped sites than at sites consisting of smaller substrates.

The development of the lower Willamette River has transformed much of the natural bank habitat into riprap and seawalls to stabilize banks and control flooding. In addition, commercial shipping has altered the natural landscape and river bottom of the lower reach through construction of docks and channel dredging.

The Willamette River is also used by several evolutionarily significant units (ESUs) of anadromous salmonids listed as threatened under the federal Endangered Species Act (ESA). These include: upper Willamette River spring Chinook salmon (NOAA 1999a) and winter steelhead *O. mykiss* (NOAA 1999b), and lower Columbia River winter steelhead (NOAA 1998) and Chinook salmon (NOAA 1999a). In addition, naturally propagating coho salmon *O. kisutch* in the lower Columbia River ESU are listed as endangered by the State of Oregon (Chilcote 1999). The lower Columbia River ESU includes the Willamette River up to Willamette Falls.

Following a workshop conducted by the City of Portland's ESA Program with regional scientists and fisheries agencies, the decision was made to study habitat use and rearing by these stocks in the lower Willamette River. In May 2000, the Oregon Department of Fish and Wildlife (ODFW), funded by the City of Portland, implemented a four-year study of aquatic habitat and nearshore developments in the lower Willamette River with respect to their use by resident and anadromous fish species. The study was intended to assist the City with permitting, planning, and enforcement, and to maximize the protection of listed species.

The objective of this portion of the study was to describe and categorize nearshore habitats and development types in the lower Willamette River. The identification of habitat categories was intended specifically to help characterize habitat use by resident and anadromous fishes and to develop management recommendations for protecting listed species (see Friesen et al. 2004 and Pribyl et al. 2004). In addition, we identified parameters that contributed most to the separation of habitat groups; these are likely to have the greatest effect on fish use, and may provide managers with specific recommendations pertaining to habitat protection.

A list of abbreviations and acronyms used in this report is provided in Table 1. We refer to habitats and structures constructed by people (e.g. riprap, seawall, pilings) as "artificial"; all others are referred to as "natural."

METHODS

Selection of Sampling Sites

We conducted the study from Willamette Falls at river mile (rm) 26.5, river kilometer (rkm) 42.6, downstream to the confluence with the Columbia River (rm 0.0, rkm 0.0; Figure 1). A list of potential sampling sites was developed based on bank qualification data modified slightly from Greenworks et al. (2000). Each site was identified by a location code consisting of the river mile and bank designation (east or west). For example, 012W denotes a site with a lower bound at rm 1.2 located on the west bank. Alcove sites, which consisted of mixed habitat (no predominant habitat; usually a mixture of beach and riprap) and provided natural or artificial refugia in off-channel areas, were identified by an additional "A" in the location code (e.g. 148WA). Some sites (048E, 051E, 100W) were considered for inclusion because they had been used in a previous study (Ward et al. 1994) or were specifically identified by the City of Portland (006E, 136E). From this list, we randomly selected at least two replicate sites of each habitat type. Several sites were replaced based on reconnaissance surveys during May 2000 or eliminated (031W, 118W, 126E, and 203W) when factors such as distribution within the study area, proximity to nearby sites, consistency of bank habitat, access, and navigational hazards were considered. When differences existed between sites of a general habitat type, they were assigned to subcategories. Selection of subcategory replicates was attempted but was not always possible due to the criteria identified above and a limitation on the overall number of sites that could be sampled. This process resulted in the selection of 19 sites distributed throughout the study area from rm 0.6 to 24.3 (rkm 1.0-39.1). A "bio-engineered" site (133W) and six alcove sites were added in October 2000, resulting in a total of 26 sites (20 "standard" sites and 6 alcove sites; Tables 2 and 3).

We initially segregated sampling sites qualitatively into 12 types based on physical appearance and functionality (Table 4). For most analyses, we combined similar habitat types to increase sample sizes and improve our ability to describe differences among types. These categories included: 1) alcoves, 2) beach, 3) riprap, 4) rock outcrop, 5) seawall, and 6) mixed habitat. The habitat at the bio-engineered site was primarily riprap and was categorized accordingly. We also combined vegetated and non-vegetated riprap sites. "Piling" and "floating" categories were reclassified based on their associated bank type (e.g., a site with a floating dock could also have a riprapped bank).

Table 1. List of abbreviations and acronyms used in this report.

Abbreviation	Description
%10MFORB	Percent ground cover consisting of forbs 10 m above the waterline
%10MGRASS	Percent ground cover consisting of grass 10 m above the waterline
%10MNOVEG	Percent of bank with no vegetative cover 10 m above the waterline
%10MSHRUB	Percent ground cover consisting of shrubs 10 m above the waterline
%10MTREES	Percent ground cover consisting of trees 10 m above the waterline
%20MFORB	Percent ground cover consisting of forbs 20 m above the waterline
%20MGRASS	Percent ground cover consisting of grass 20 m above the waterline
%20MNOVEG	Percent of bank with no vegetative cover 20 m above the waterline
%20MSHRUB	Percent ground cover consisting of shrubs 20 m above the waterline
%20MTREES	Percent ground cover consisting of trees 20 m above the waterline
%ARTFILL	Percent bank substrate consisting of artificial fill
%BEACH	Percent bank substrate consisting of beach
%BEDROCK	Percent bank substrate consisting of bedrock
%CLAY	Percent clay composition (substrate samples)
%LGRIPRAP	Percent bank substrate consisting of large riprap
%ROCK	Percent bank substrate consisting of rock
%SAND	Percent sand composition (substrate samples)
%SEAWALL	Percent bank substrate consisting of seawall
%SILT	Percent silt composition (substrate samples)
%SMRIPRAP	Percent bank substrate consisting of small riprap
BANKSLOPE	Mean bank slope (degrees)
DENSITOM	Densitometer (overhead cover)
DEPTH20M	Depth 20 meters from shore (m)
DISTHAL	Mean distance to thalweg (m)
GIS	Geographic Information System
GPS	Global Positioning System
MRS	Mean river stage (ft)
OUTFALLS	Total number of outfalls
PCA	Principal components analysis
PILINGN	Mean number of nearshore pilings
PORTGAGE	River gauge height at Morrison Bridge (ft)
SCONDN	Mean nearshore surface conductivity (mS/cm)
SLOPEN	Mean nearshore river bottom slope (degrees)
STEMPN	Mean nearshore surface water temperature (^{o}C)
SUBSIZE	Mean substrate size (µm)
SURF0_2N	Mean nearshore surface dissolved oxygen concentration (mg/l)
TRANSPN	Mean nearshore transparency (cm)

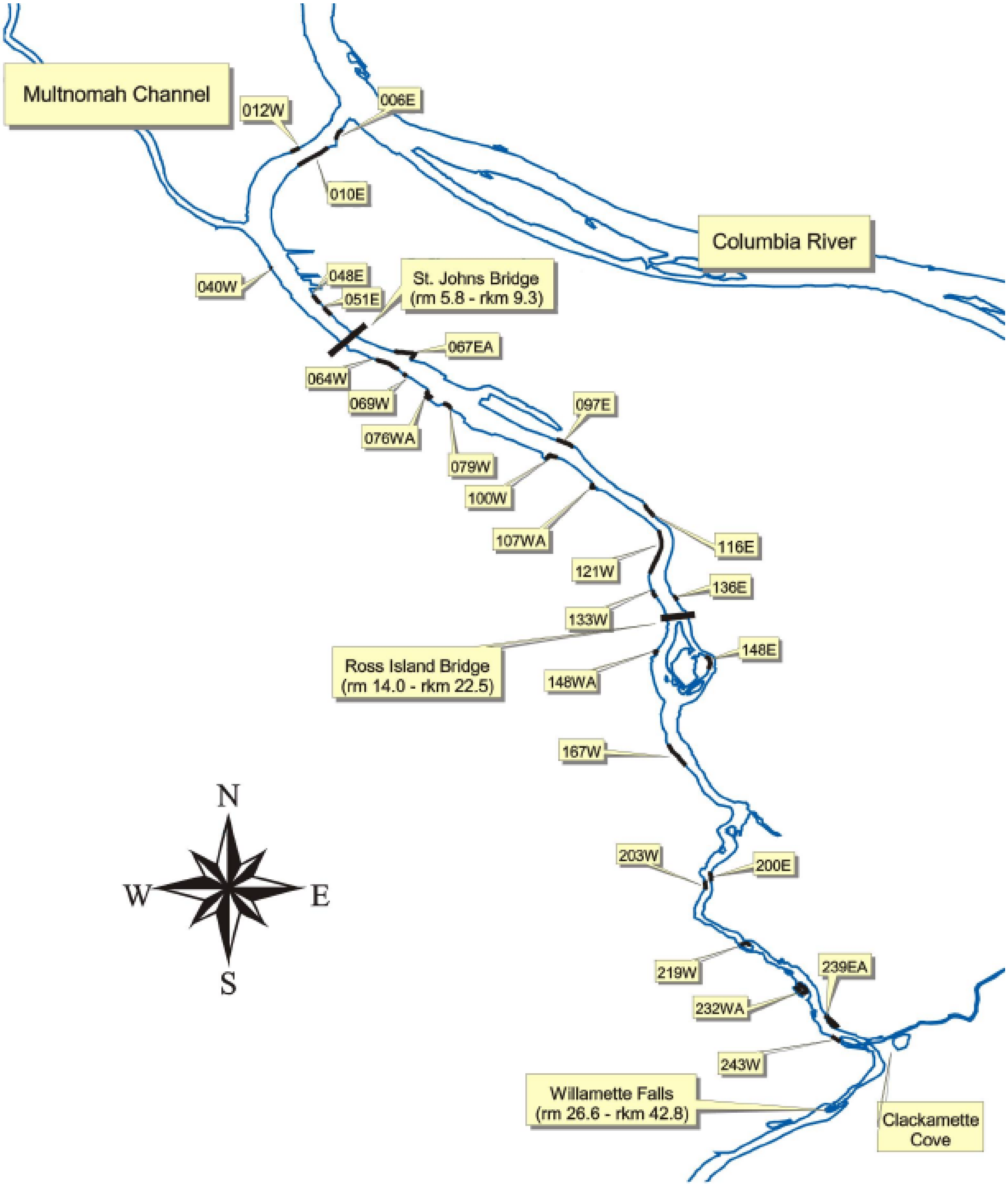

Figure 1. The lower Willamette River and associated features. Sampling site labels denote river mile (rm; xx.x) and east (E) or west (W) shore. A = alcove site; rkm = river kilometer.

Table 2. Description of standard sampling sites in the lower Willamette River, May 2000 - June 2003.

Habitat classification	Site[a]	River kilometer	Length (m)	General bank type[b]	Location / description
Undeveloped					
Beach (7)	006E	1.0-1.3	364	B	Kelley Point
	040W	6.4-6.5	64	B	Across from Terminal 4
	069W	11.1-11.3	--	B	Upstream from Doan Point
	097E	15.6-16.1	456	B	Across from Terminal 2
	148E	23.8-25.0	526	B	Behind Ross Island
	167W	26.9-27.8	804	B	Powers Marine Park
	243W	39.1-39.4	264	B	Downstream of Goat Island
Rock outcrop (2)	200E	32.2-32.6	333	RO	Lake Oswego Railroad Bridge
	219W	35.2-35.6	328	RO	Hog Island
Riprap (5)					
Vegetated (2)	012W	2.0-2.3	240	RR	Between day markers #6 and #10
	136E	21.9-22.0	183	RR	OMSI
Non-vegetated (2)	064W	10.3-11.0	564	Mixed (RR/B)	Doane Point
Bio-engineered (1)	133W	21.4-21.6	186	Mixed (RR/B)	Downstream of Marquam Bridge
Seawall					
Concrete wall (1)	121W	19.5-21.0	1,542	SW	Waterfront Park seawall
Metal sheetpile (1)	048E	7.7-8.0	286	SW	Terminal 4
Pilings					
Allowing light (3)	010E	1.6-2.4	905	Mixed (B/RR)	3 T-docks above Columbia Slough
	079W	12.7-13.0	255	RR	Olympic Tug T-dock
	116E	18.0-18.2	141	Mixed (RR/UNC)	T-dock above Fremont Bridge
Limiting light (1)	100W	16.1-16.2	78	RR	Terminal 2
Floating					
Limiting light (1)	051E	8.2-8.7	310	Mixed (RR/B)	Terminal 4 ship hull

[a] The first two digits represent river mile; the third digit represents river mile tenth. W=West bank, E=East bank

[b] B=beach; RO=rock outcrop; RR=riprap; SW=seawall; UNC=unclassified fill

Table 3. Description of alcove sites in the lower Willamette River, May 2000 - September 2003.

Category	Site[a]	River kilometer	Length (m)	General bank type[b]	Location / description
Natural	067EA	10.8-11.1	577	Mixed (RR/B)	Downstream of Doane Point
	148WA	23.8-24.0	206	Mixed (B/UNC)	Above Spaghetti Factory
	232WA	37.3-37.7	1029	B	Upstream of Cedar Oak boat ramp
	239EA	38.5-38.9	580	B	East side of Meldrum Bar
Artificial	076WA	12.2-12.4	317	Mixed (B/PAL)	Downstream of Chevron piers
	107WA	17.2-17.4	396	Mixed (PAL/UNC)	Below Fremont Bridge

[a] First two digits = river mile, third digit = river mile tenth; W=West bank, E=East bank, A=alcove.

[b] B=Beach; RR=riprap; UNC=Unclassified fill; PAL=Pilings-allowing light. For sites with mixed bank substrates, the predominant type appearing above normal low water is listed first.

Table 4. Definitions of bank nearshore habitat types in the lower Willamette River, May 2000 - March 2003.

Habitat type	Description
Beach	Shallow, shelving shorelines consisting of sand, silt, or gravel up to 64 mm diameter. This may also include native bank materials in their natural position and undisturbed by humans (e.g. clay bank). Vegetation cover varies but may include canopy, understory, and ground cover.
Rock outcrop	Natural bedrock formations consisting of angular ledges, protrusions, and sheer rock faces. May include some associated boulders.
Rock	Natural, round river rock >64 mm that does not fit into the riprap categories.
Seawall	Impervious vertical retaining walls generally composed of concrete, timber, or sheet pile, extending beyond ordinary low water. These habitats are uniformly deep and homogenous (e.g. house foundations in the water, bulkheads).
Vegetated riprap	Continuous stone revetments mechanically placed to curtail erosion and prevent alterations to the main channel. Vegetative cover varies but may include canopy, understory, and groundcover that occupy a minimum of 20% of the active bank below flood state (lower shore zone).
Non-vegetated riprap	Continuous stone revetment devoid (<20%) of vegetation.
Bio-engineered	Engineered banks that incorporate vegetation as a visible component of riprapped banks, but inert and artificial materials provide the physical structure that ensures bank stability. Bio-engineered banks rely on vegetation and natural fabric materials for banks stability (e.g. site 133W).
Unclassified fill	These areas appear to have been filled over time with miscellaneous unconsolidated materials (e.g. cement slabs). The surfaces of banks composed of unclassified fill have not been covered with engineered riprap or structures. Such banks generally contain debris of various types and may have become unstable because of erosion by river forces.
Pilings-allowing light	Stationary support structures consisting of concrete, metal, or timber used to elevate docks, buildings, etc. above the water. Elements of construction allow varying amounts of light to penetrate to the underlying habitat (e.g. T-docks)
Pilings-limiting light	Stationary support structures used to elevate docks, buildings, etc. above water. Construction is such that underlying habitat is not directly exposed to ambient light (e.g. site 100W).

Table 4 (continued)

Habitat type	Description
Floating-allowing light	Structures such as loading docks and piers that maintain buoyancy and move with fluctuating river levels. Design and construction materials allow light to penetrate the habitat below.
Floating-limiting light	Buoyant structures that do not allow light to penetrate the underlying habitat.

Study Area Habitat Evaluation

We conducted an inventory of habitat types and nearshore structures in the study area during January and August 2001 to quantify available habitats. Mean river stage (MRS), defined as the average river elevation for a given sampling period, was based on datum from the U. S. Geological Survey gauge (14211720) at the Morrison Bridge (rm 12.7; rkm 20.4) and ranged from 1.9-4.2 feet. The inventory was conducted by driving a boat as close as possible to the shoreline and recording beginning and ending waypoints (latitude and longitude) of each bank type along all shorelines (approximately 53.0 shoreline miles). The inventory was divided into upper (above Ross Island; rkm 42.8 - 22.6) and lower (below Ross Island; rkm 22.5 - 0.0) sections of the study area. If the shoreline of a continuous habitat unit was sinuous, multiple waypoints were logged to increase accuracy. For any habitat unit <30 m in length, one mid-length waypoint was recorded and length (±1 m) was measured with a laser rangefinder (Bushnell Yardage Pro 1000). We logged waypoints with a handheld Global Positioning System (GPS) receiver (Garmin GPS III) equipped with a differential antenna (±3 m accuracy). Data was layered onto an Oregon Lambert-projected ortho-photo (2' resolution) with ArcView 3.2a software. Waypoints were repositioned onto the shoreline and the length (m) of each bank habitat unit was measured as the distance between waypoints. Lengths of nearshore structures (piers, docks, wharves, and other stationary structures incorporated into, or adjacent to the riverbank) were measured directly from the ortho-photo.

Habitat Transition

Although consistent bank type was an important consideration in the initial selection of sampling sites, low precipitation before and during the study period resulted in abnormally low river levels. As water levels dropped during the study period, it became apparent this anomaly could potentially reduce the homogeneity of bank substrate within several sampling sites as river levels receded to the transition zone between the bank habitat and the riverbed. To evaluate the potential degree of change in bank material within sampling sites, and to determine if bank types should be reclassified seasonally, we evaluated bank substrate from about 5 feet below to 10 feet above ordinary low water (+3 feet; City of Portland datum; Greenworks et al. 2000) during December 2000 and January 2001. Percentages of each bank substrate type were visually estimated throughout each site length in 1-foot elevation increments using criteria in Table 4. Similarly, underwater substrate type was qualified below the waterline by tapping and “feeling” the bottom with a PVC pole throughout the length of the site. By standardizing these classifications to the U. S. Geological Survey river gauge (14211720) at the Morrison Bridge, the waterline bank substrate type at all sites could be estimated at any river stage (Table 5).

To assure subsequent analysis of fish catch rate data (Friesen et al. 2004, Pribyl et al. 2004) were applied to the appropriate habitat type, we assumed the waterline bank substrate should remain predominant (≥80%) to a depth 3 feet below the mean river stage (MRS-3). If a different substrate became predominant from MRS-3 and below, the bank substrate was reclassified accordingly. We adopted these rules to ensure the habitat extended into the water far enough to realistically have an effect on fish use. In January 2003, we surveyed each sample site to ensure seasonal bank substrate classifications were accurate. Six of the 20 standard sampling sites had some bank habitat transition during the year; the most common transition was from riprap to beach during low water conditions.

Habitat Surveys

Field Measurements

Habitat surveys were conducted during various times of the year from 2000 to 2003 to evaluate changes in measurements throughout the year due to fluctuations in river levels and water chemistry; surveys encompassed all seasons, and we performed several seasonal "ground truthing" assessments. The first habitat surveys were conducted in autumn 2000, followed by winter and spring 2001, winter, spring, and autumn 2002, and winter, spring, summer 2003. We collected an array of physical and chemical habitat measurements at each sampling site to group sites and determine similarities and differences among habitat types (Tables 6 and 7). Measurements were divided into two categories: nearshore and onshore. Onshore parameters included: bank slope, shoreline substrate, vegetative cover, number of outfalls, and buffer width. Instream parameters included: depth contour, water temperature, dissolved oxygen, conductivity, transparency, overhead cover, artificial light density, river bottom slope, distance to thalweg, and the number of pilings.

To accurately characterize the physical and chemical components of each sample site, measurements were made along a series of transects perpendicular to the shoreline (Figure 2). Depth contours and onshore parameters were usually measured along five "percentiles", which encompassed the length of the shoreline for each sample site. Instream parameters were usually measured in four "quartiles" (the area between each percentile) at randomly selected nearshore (within 25 m of shore) and offshore (26-50 m from shore) points. At sites with very short shoreline lengths, measurements were made at three percentiles and two quartiles. Water quality measurements were taken at the surface, in the middle of the water column, and at the bottom when depths permitted.

Table 5. Bank substrate percentages by river stage at select sampling sites in the lower Willamette River, May 2000 - June 2001. Ranges of consistent, dominant (≥75%) bank substrates are highlighted. The dashed line indicates normal low water elevation.

	Sampling site and bank substrate type																							
	010E		012W		051E		064W		079W		100W		112E			118W		133W		136E		203W	
Stage[a]	B	RR	B	RR	B	RR	B	RR	B	RR	B	RR	B	RR	UNC	B	RR	B	BE	B	RR	B	RO
13.1-14.0	75	25	0	100	0	100	0	100	0	100	0	100	0	56	44	0	100	0	100	0	100	37	63
12.1-13.0	75	25	0	100	0	100	0	100	0	100	0	100	0	56	44	0	100	0	100	0	100	37	63
11.1-12.0	75	25	0	100	0	100	0	100	0	100	0	100	0	56	44	0	100	0	100	0	100	37	63
10.1-11.0	75	25	0	100	0	100	0	100	0	100	0	100	0	56	44	0	100	0	100	0	100	37	63
9.1-10.0	87	13	0	100	0	100	0	100	0	100	0	100	0	56	44	0	100	0	100	0	100	37	63
8.1-9.0	87	13	0	100	0	100	0	100	0	100	0	100	0	56	44	0	100	0	100	0	100	37	63
7.1-8.0	87	13	0	100	0	100	0	100	0	100	0	100	0	56	44	6	94	0	100	0	100	37	63
*6.1-7.0	87	13	0	100	0	100	19	81	0	100	0	100	0	56	44	0	100	0	100	0	100	37	63
5.1-6.0	87	13	0	100	13	87	19	81	0	100	0	100	0	56	44	0	100	38	62	0	100	37	63
4.1-5.0	87	13	0	100	13	87	19	81	0	100	0	100	0	56	44	0	100	38	62	0	100	37	63
**3.1-4.0	87	13	0	100	13	87	19	81	0	100	0	100	0	56	44	0	100	50	50	0	100	50	50
2.1-3.0	94	6	0	100	19	81	38	62	6	94		[c]	6	50	44	0	100	50	50	0	100	50	50
1.1-2.0	100	0	0	100	28	72	63	37	25	75		[c]	6	50	44	0	100	87	13	0	100	50	50
0.1-1.0	100	0	0	100	81	19	94	6	88	12		[c]	6	50	44	0	100	94	6	19	81	50	50
-1.0- 0.0	100	0	100	0			100	0	88	12		[c]	68	12	19	44	56	94	6	57	43	50	50
-2.0- -1.1	100	0	100	0			100	0	88	12		[c]	81	6	13	68	32	94	6	94	6		

[a] Stage based on U. S. Geological Survey gauge 142411720 at the Morrison Street Bridge (river mile 12.7).

[b] B=beach; RR=riprap; UNC=unclassified fill; BE=bio-engineered; RO=rock outcrop

[c] Either riprap or cement, but likely riprap

* Spring 2000 mean river stage (MRS)=6.2; ** Summer 2000-Spring 2001 MRS=3.1-3.5

Table 6. Description of nearshore habitat parameter measurements at sampling sites in the lower Willamette River, May 2000 - March 2003.

Parameter	Equipment	Measurements	Description of methods
Temperature (^{o}C)	Hydro-lab Quanta multimeter	24	Measured at surface (1 m below), mid-water, and bottom (1 m above substrate) at 1 random site within 0-25 m and 26-50 m from shore by site quartile (0-25, 26-50, 51-75, and 76-100 % of site length).
Conductivity (mS/cm)	Same as above	24	Same as temperature.
Dissolved oxygen (mg/L)	Same as above	24	Same as temperature.
Depth contour (m)	Fathometer (various models)	35	Measured at 5, 10, 15, 20, 30, 40, and 50 m from shore along each percentile. The 0 percentile represented the upstream end of the site and 100 percentile represented the downstream end.
Velocity (cm/s)	General Oceanics mechanical flow meter (model 2030R)	8	Measured at surface (1 m below) and bottom (1 m above substrate) at 1 random site within each site quartile. Measurements conducted 0-25 m from shore in quartiles 2 and 4 and 26-50 m from shore in quartiles 1 and 3. All measurements taken from a stationary boat (anchored or tied to piling).
Water transparency (cm)	Secchi disk (20 cm)	8	Measured at 1 random site within each site quartile at 0-25 m and 26-50 m from shore. The first depth is recorded when the secchi disk is lowered into shaded water and disappears; the second depth is recorded when the disk is lowered deeper and slowly raised until it reappears. The two values are then averaged.
Overhead cover density	Geographic Resource Solutions densitometer/ densiometer	40	Measured percent presence/absence of overhead cover at 0, 5, 10, 15, 20, 30, 40, and 50 m from shore along each percentile of the site.
Pilings	None	1	Count of all pilings at each site.
Outfalls	None	1	Separate counts of active (visible flow) and inactive (no flow) outfalls (sewer or drain pipes) within each site.

Table 7. Description of onshore habitat parameter measurements at sampling sites in the lower Willamette River, May 2000 - March 2003.

Parameter	Equipment	Measurements	Description of methods
Bank slope (degrees)	Suunto Clinometer	5	Measured at five perpendicular axes to the shoreline (0, 25, 50, 75, and 100% of site length).
Vegetative cover (%)	Tape measure	5	Measured within a 2 m wide by 10 m long swath perpendicular to the waterline at each percentile of the site. This measurement is conducted twice, for a total length of 20 m from the waterline. Vegetation percentages are visually estimated; classifications include: no vegetation, grasses, forbs, shrubs, and trees.
Buffer width (m)	Bushnell Yardage Pro 1000 laser rangefinder	5	Measured as the distance (m) from the shoreline to the nearest impervious structure or surface (paved road, building, etc.) at each percentile.
Shoreline substrate type	None	1	Measured as the percentage of each substrate in a 1-m^2 area, 1 m above the waterline, at each percentile. Substrate classifications are: beach (0-64 mm); rock / small riprap (65-256 mm); large riprap (257-512 mm); bedrock; seawall; artificial fill.

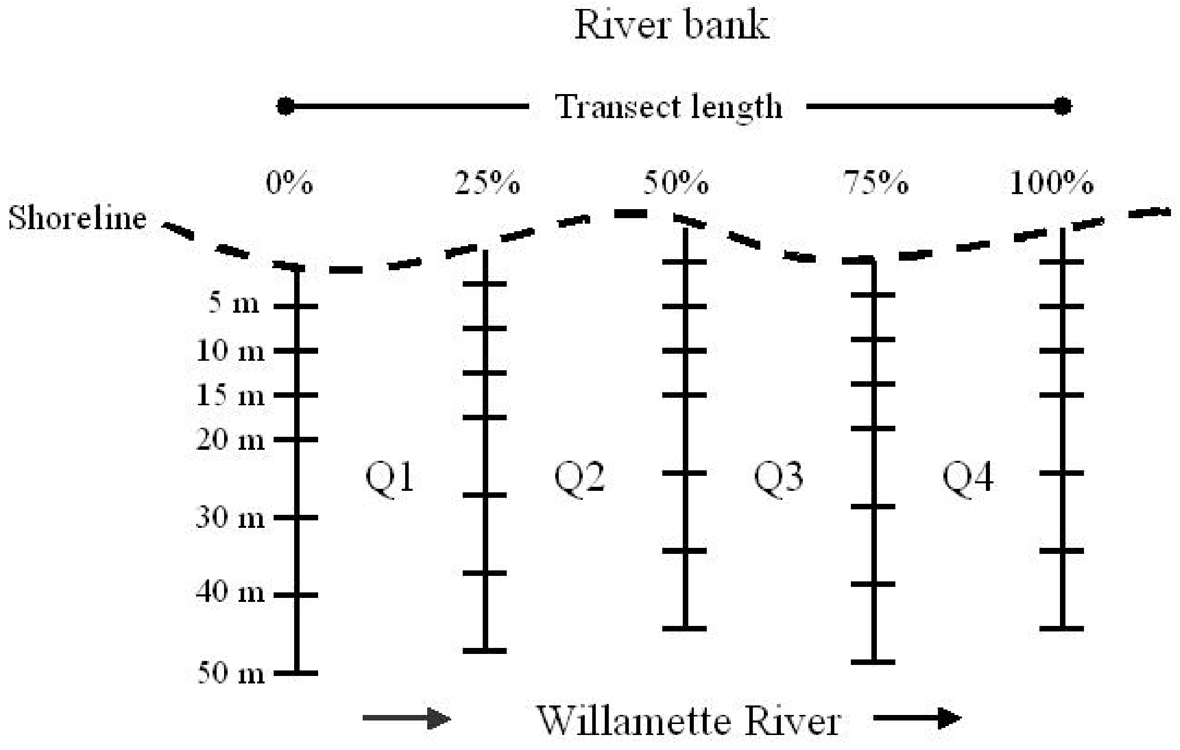

Figure 2. Schematic of sampling transects for habitat and water quality measurements in the lower Willamette River. Vertical bars perpendicular to the shoreline (at 25% increments) are percentiles; spaces between percentiles (Q1 – Q4) are quartiles.

Substrate Grain Size

In spring 2003, we used a standard ponar dredge (525 cm^2) to characterize sediment size (percent sand, silt, and clay) within the nearshore area. Using GIS, a polygon grid was created to randomly select sample locations within the nearshore habitat area of each sample transect. A GPS unit was used to navigate to the coordinates and a single grab sample was collected, placed in a plastic bag, and frozen for laboratory analysis. We collected samples from the 6 alcove sites and 15 standard sites; riprap, rock outcrop, and hardpan substrates at several standard sites precluded the collection of a substrate sample. The size-frequency distribution of sediment particles was analyzed at the U.S. Environmental Protection Agency field office Newport, Oregon. A Coulter LS 100Q laser diffraction particle size analyzer was used to measure the size distribution of particles in the range of 0.4 to 948 µm.

Distance to Thalweg

Using GIS, we made a series of 3 to 5 measurements along the percentile transect of each site. Distances were calculated by measuring the shortest distance from the water-shoreline interface to the thalweg for each site. A shapefile containing the lower Willamette River thalweg was provided by the City of Portland.

Seasonal Analysis of Habitat Groups

To provide a more quantitative approach to categorizing habitat types, we analyzed habitats based on surveyed parameters; the objective of this analysis was to group sample sites by season according to their physical and chemical attributes. Two multivariate techniques were used to analyze habitat data: cluster analysis and principal components analysis (PCA). Cluster analysis groups treatments (the sample sites) into clusters according to similarities in parameter measurements (the habitat parameters). The Ward hierarchal cluster analysis is commonly used and appeared to be the most appropriate data classification method for this study. Like other clustering techniques, Ward's method follows a series of clustering steps that begins with many clusters, each containing one object (e.g. a sampling site) and ends with one cluster containing all of the objects. The method successively merges clusters with the smallest variance, producing closely related groups of objects (Romesburg 1984).

We then applied PCA using SYSTAT software (SSI 2003) to determine which instream and onshore parameters were important in grouping sample sites and explaining variation among sites. Prior to this analysis, the data were separated by season and transformed to achieve a more normal distribution (Romesburg 1984; Neill et al. 1995; Goldstein et al. 1996).

As nearshore habitat use by fish is the focus of the study, we used only nearshore surface water quality measurements in the multivariate investigation, thus eliminating redundant parameters (Goldstein et al. 2002). River bottom slope was calculated using only nearshore depths (5, 10, and 20 m from shore) and the depth 20 m from shore was selected as the single nearshore depth included in multivariate analyses. Habitat data measured as percentages were arcsine transformed, the number of nearshore pilings, nearshore slope, and total outfalls categories were log (x + 1) transformed, and the remaining instream habitat parameters were log transformed. Data were then standardized to a mean of 0 and a standard deviation of 1 prior to cluster analysis and PCA (Zitko 1995; Goldstein et al. 2002; SSI 2003).

Data for each season were also separated into instream and onshore measurements to determine which parameters from each set of measurements explained the majority of the variation among clusters. As a result of similar measurements among sites, buffer width was not included in PCA for any season. Using the methods described by Jolliffe (1972), we selected the variable with the highest absolute value loading from each successive axis until 75% of the overall variance was explained (Goldstein et al. 2002).

RESULTS

Study Area Habitat Evaluation

The majority (59.2%) of the riverbank habitat available in the study area was classified as undeveloped, and had not been modified by an obvious treatment or nearshore development (Table 8, Figure 3). Beach was the most abundant habitat type in both the upper (above Ross Island Bridge) and lower (below Ross Island Bridge) sections of the study area, but the

Table 8. Summary of habitat types and nearshore structures by area in the lower Willamette River, January - August 2001.

Habitat and nearshore structure type	Habitat below Ross Island Bridge (rm 0.0-13.9) Length (m)	Habitat below Ross Island Bridge (rm 0.0-13.9) % of total	Habitat above Ross Island Bridge (rm 14.0-26.5) Length (m)	Habitat above Ross Island Bridge (rm 14.0-26.5) % of total	Total habitat (rm 0.0-26.5) Length (m)	Total habitat (rm 0.0-26.5) % of total	Total nearshore structures (rm 0.0-26.5) Length (m)	Total nearshore structures (rm 0.0-26.5) % of total	Total habitat and nearshore structures (rm 0.0-26.5) Length (m)	Total habitat and nearshore structures (rm 0.0-26.5) % of total
Beach	13,471	29.1	21,826	38.8	35,297	34.4	0	0.0	35,297	29.0
Rock outcrop	0	0.0	14,763	26.3	14,763	14.4	0	0.0	14,763	12.1
Rock	1,687	3.7	8,974	16.0	10,661	10.4	0	0.0	10,661	8.7
Seawall	3,036	6.6	467	0.8	3,503	3.4	0	0.0	3,503	2.9
Vegetated riprap	11,358	24.5	6,773	12.0	18,131	17.7	0	0.0	18,131	14.9
Non-vegetated riprap	3,482	7.5	445	0.8	3,927	3.8	0	0.0	3,927	3.2
Bio-engineered	389	0.8	0	0.0	389	0.4	0	0.0	389	0.3
Unclassified fill	9,421	20.4	2,980	5.3	12,401	12.1	0	0.0	12,401	10.2
Pilings-allowing light[a]	1,315	2.8	0	0.0	1,315	1.3	6,793	35.0	8,108	6.6
Pilings-limiting light[a]	2,127	4.6	0	0.0	2,127	2.1	2,734	14.1	4,861	4.0
Floating-allowing light	0	0.0	0	0.0	0	0.0	7,659	39.5	7,659	6.3
Floating- limiting light	0	0.0	0	0.0	0	0.0	2,202	11.4	2,202	1.8
Total	46,286	100	56,228	100	102,514	100	19,388	100	121,902	100

[a] Classified as bank habitat instead of a nearshore structure type when highly incorporated into the bank and no separate bank habitat classification could be determined.

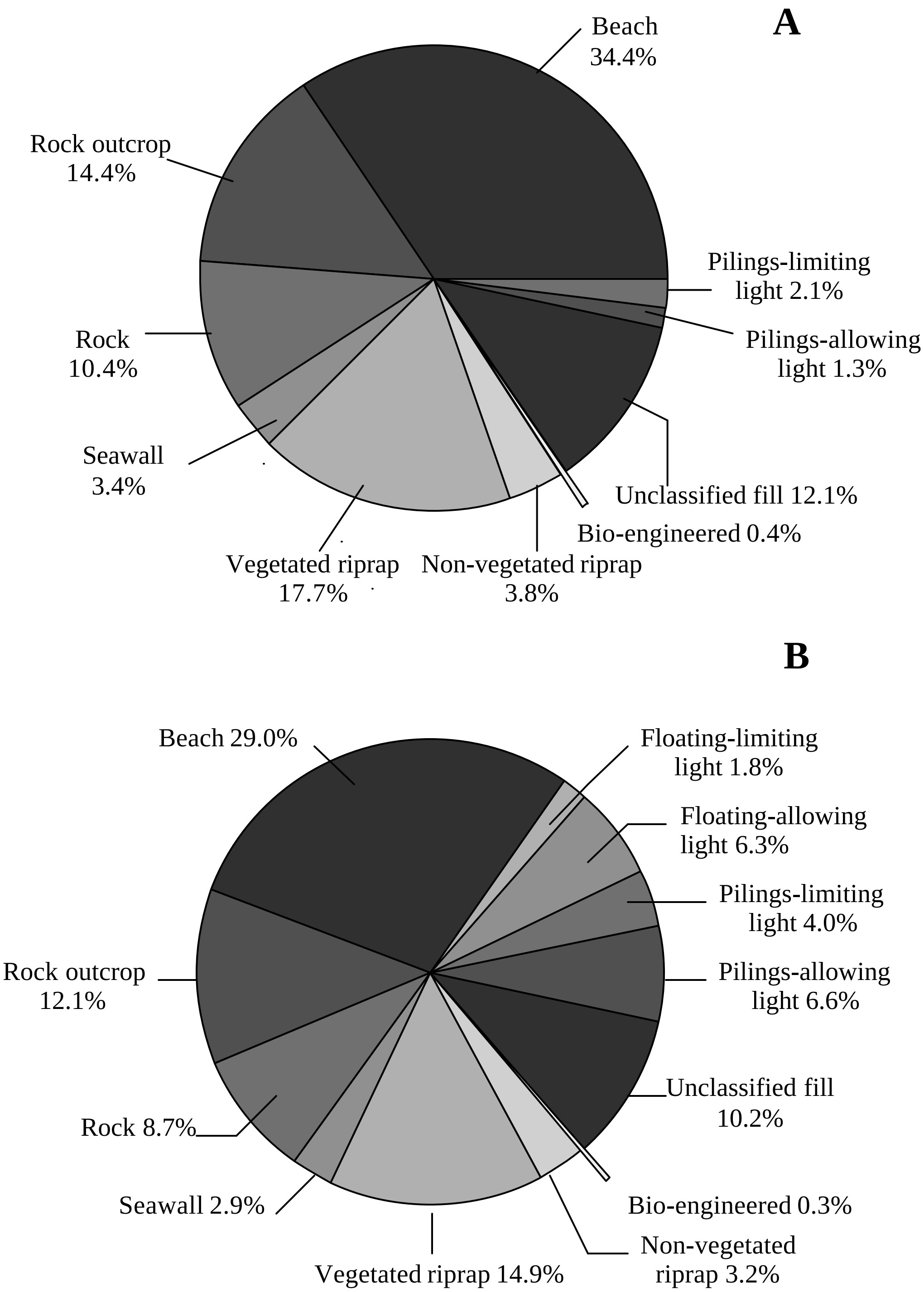

Figure 3. Percent of available (A) habitat types and (B) habitat and nearshore structure types in the lower Willamette River, January – August 2001. Piling structures in (A) were classified as bank habitat instead of a nearshore structure type because they were highly incorporated into the bank and no separate classification could be determined.

distribution of other habitat types was quite different (Table 8; Figure 4). Undeveloped or "natural" bank habitat occurred throughout 81.1% of the upper section but only 32.8 % of the lower section. Riprap and unclassified fill were two and four times more abundant in the lower section than the in upper section. Nearshore structures were found adjacent to 18.7% of the study area shoreline. About 75% of these structures were classified as allowing light and 25% limited light penetration.

Habitat Transition

During the three-year study period, several sites transitioned from one bank substrate to another or had mixed habitat (no predominant bank habitat). During year 1 (summer 2000-spring 2001), only three sites (051E, 064W and 079W) transitioned from one bank substrate (riprap) to another (sand)(Table 9). One additional site (112E) had mixed habitat throughout all sampling seasons and was not included in bank habitat analyses. During year 2 (summer 2001-spring 2002), four sites (012W, 051E, 064W and 079W) transitioned from one bank substrate to another (Table 10). Two additional sites (133W and 136E) transitioned from one bank substrate to mixed habitat. During year 3 (summer 2002-summer 2003), water levels were higher than the previous year and only three sites (051E, 064W and 079W) transitioned between two different bank substrates (Table 11). One additional site (133W) transitioned from beach to mixed habitat. Undeveloped sites and seawalls remained consistent regardless of river stage.

Habitat Surveys

Field Measurements

Physical and chemical parameters are summarized for quantitative habitat types in Table 12 and are described below.

Beach: Eight sampling sites were characterized as beach treatments (006E, 010E, 031W, 040W, 069W, 097E, 167W, 243W). These sites tended to have a shallow shelving shoreline consisting mainly of sand, silt, or fine gravel, and had few pilings or outfalls. Nearshore depths tended to be shallow, as 20 m (from shore) depths were significantly ($P<0.05$) shallower than rock outcrop, seawall, and riprap sites. Bank slopes were gentle and there was little vegetation on the first 10 m of shoreline. The buffers at beach sites generally extended a large distance from the shoreline and were significantly wider than seawall buffers ($P < 0.05$).

Alcove / off-channel: Six sampling sites were characterized as alcoves (067EA, 076WA, 107WA, 148WA, 232WA, 239EA). We included one additional site (148E) in this group because it likely provided off-channel habitat similar to the alcoves. These sites were often surrounded by river bank on three sides. Shoreline substrates were most often beach or a mix of beach and riprap or fill. The river bottom tended to be uniform and shallow; the average slope was significantly lower than rock outcrop and riprap sites ($P < 0.05$). There were also a large number of pilings associated with these sites.

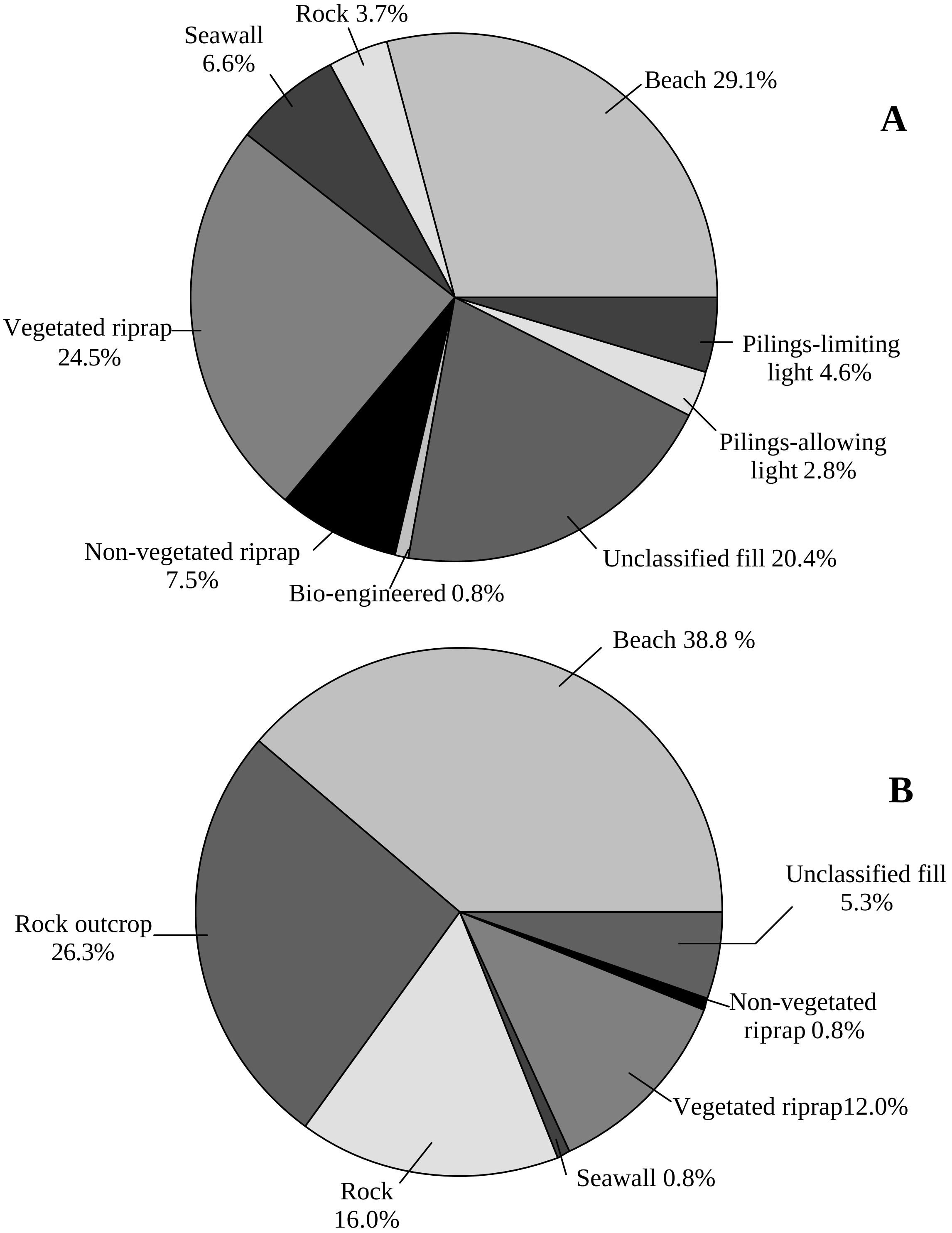

Figure 4. Percent of available habitat types downstream (A) and upstream (B) of Ross Island Bridge in the lower Willamette River, January – August 2001.

Table 9. Bank substrate of sampling sites in the lower Willamette River by season and year, May 2000 - June 2001. Classifications are based on a minimum of 80% similar substrate existing within –3 ft. of the sampling period mean river stage (MRS). N/A = not available.

	Sampling season and mean river stage				
	Spring 2000	Summer 2000	Autumn 2000	Winter 2001	Spring 2001
Site	MRS 6.2	MRS 3.1	MRS 3.2	MRS 3.4	MRS 3.5
006E	N/A	Beach	Beach	Beach	Beach
010E	Beach	Beach	Beach	Beach	Beach
012W	N/A	Beach	Beach	Beach	Beach
031W	Beach	Beach	Beach	Beach	Beach
040W	Beach	Beach	Beach	Beach	Beach
048E	Seawall	Seawall	Seawall	Seawall	Seawall
051E	Riprap	Beach	Beach	Beach	Beach
064W	Riprap	Beach	Beach	Beach	Beach
079W	Riprap	Beach	Beach	Beach	Beach
097E	Beach	Beach	Beach	Beach	Beach
100W[a]	Riprap	Riprap	Riprap	Riprap	Riprap
112E[b]	Mixed	Mixed	Mixed	Mixed	Mixed
118W	Riprap	Riprap	Riprap	Riprap	Riprap
121W	Seawall	Seawall	Seawall	Seawall	Seawall
133W	N/A	N/A	Beach	Beach	Beach
136E	Riprap	Riprap	Riprap	Riprap	Riprap
148E	Beach	Beach	Beach	Beach	Beach
167W	Beach	Beach	Beach	Beach	Beach
200E	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop
219W	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop
243W	Beach	Beach	Beach	Beach	Beach

[a] Site classified as riprap although bank substrate was not positively identified below MRS 3.0. Likely riprap or cement.

[b] No predominant bank substrate existed at any river stage.

Table 10. Bank substrate of sampling sites in the lower Willamette River by season and year, July 2001 through June 2002. Classifications are based on a minimum of 80% similar substrate existing within –3 ft. of the sampling period mean river stage (MRS).

	Sampling season and mean river stage			
	Summer 2001	Autumn 2001	Winter 2002	Spring 2002
Site	MRS 2.3	MRS 3.8	MRS 5.6	MRS 7.0
006E	Beach	Beach	Beach	Beach
010E	Beach	Beach	Beach	Beach
012W	Beach	Riprap	Riprap	Riprap
048E	Seawall	Seawall	Seawall	Seawall
051E	Beach	Beach	Riprap	Riprap
064W	Beach	Beach	Mixed	Riprap
079W	Beach	Mixed	Riprap	Riprap
100W[a]	Riprap	Riprap	Riprap	Riprap
116E	Riprap	Riprap	Riprap	Riprap
121W	Seawall	Seawall	Seawall	Seawall
133W	Beach	Beach	Mixed	Mixed
136E	Mixed	Riprap	Riprap	Riprap
148E	Beach	Beach	Beach	Beach
167W	Beach	Beach	Beach	Beach
200E	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop
219W	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop

[a] Site classified as riprap although bank substrate was not positively identified below MRS 3.0.

Riprap: Six sampling sites were characterized as riprap (012W, 079W, 100W, 116E, 118W, and 136E). Continuous stone revetments mechanically placed to curtail erosion and prevent alterations to the main channel characterized these sites. The river bottom was relatively steep, resulting in a significantly greater slope than at alcove sites ($P < 0.05$). In addition, depths at 5, 10, and 20 m from shore were significantly greater than those at beach sites ($P < 0.05$).

Mixed (riprap/beach/unclassified fill): Four sampling sites were characterized as a mixture of riprap, beach, or unclassified fill depending on river levels (051E, 064W, 112E, and 133W). These sites typically contained stone revetments down to the water line, which then transitioned to beach or fill. Mixed sites had an intermediate bottom slope and bank slope and a narrow buffer width (mean 22.7 m).

Table 11. Bank substrate of sampling sites in the lower Willamette River by season and year, July 2002 through September 2003. Classifications are based on a minimum of 80% similar substrate existing within –3 ft. of the sampling period mean river stage (MRS).

	Sampling season and mean river stage				
	Summer 2002	Autumn 2002	Winter 2003	Spring 2003	Summer 2003
Site	MRS 4.8	MRS 3.2	MRS 5.6	MRS 7.2	MRS 3.2
006E	Beach	Beach	Beach	Beach	Beach
010E	Beach	Beach	Beach	Beach	Beach
012W	Riprap	Riprap	Riprap	Riprap	Riprap
048E	Seawall	Seawall	Seawall	Seawall	Seawall
051E	Mixed	Beach	Riprap	Riprap	Beach
064W	Mixed	Beach	Mixed	Riprap	Beach
079W	Mixed	Beach	Riprap	Riprap	Beach
100W[a]	Riprap	Riprap	Riprap	Riprap	Riprap
116E	Riprap	Riprap	Riprap	Riprap	Riprap
121W	Seawall	Seawall	Seawall	Seawall	Seawall
133W	Beach	Beach	Mixed	Mixed	Beach
136E	Riprap	Riprap	Riprap	Riprap	Riprap
148E	Beach	Beach	Beach	Beach	Beach
167W	Beach	Beach	Beach	Beach	Beach
200E	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop
219W	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop	Rock outcrop

[a] Site classified as riprap although bank substrate was not positively identified below MRS 3.0.

Seawall: There were two seawall sites (048E, 121W). These treatments are impervious vertical retaining walls, generally composed of concrete or sheet pile, that extend beyond ordinary low water. These habitats were uniformly deep and homogenous with a bottom slope significantly less than rock outcrop sites ($P < 0.05$). Because the bank is a vertical wall, the bank slope was 90°, and there was no buffer. These treatments contained large numbers of pilings and outfalls.

Rock Outcrop: There were two rock outcrop sites (200E, 219W), which both were found in the upper portion of the study area. This habitat contains natural bedrock formations consisting of angular ledges, protrusions, and sheer rock faces. Bank slopes were steep and buffer distances were large. The bottom slope was significantly steeper than beach, seawall, and alcove sites ($P < 0.05$). These were the deepest sites sampled with a mean depth of 21 m at a distance of 50 m from shore and were significantly deeper at 50 m from shore than all other habitat types except

Table 12. Mean measurements of instream and onshore parameters for each habitat type in the lower Willamette River, 2000 – 2003. Values differed significantly among types where $P \leq 0.05$.

Parameter	Beach	Riprap	Mixed	Alcove	Seawall	Rock outcrop	*P*
Depth 5m from shore (m)	0.5	1.9	1.3	1.1	11.4	3.8	<0.05
Depth 10m from shore (m)	1.1	3.9	2.7	2.4	12.1	9.0	<0.05
Depth 20m from shore (m)	2.3	7.5	6.0	3.6	13.7	15.2	<0.05
Depth 30m from shore (m)	3.4	9.9	7.9	4.2	15.0	18.8	<0.05
Depth 40m from shore (m)	4.6	11.4	9.5	4.6	15.8	21.0	<0.05
Depth 50 m from shore (m)	6.1	12.1	10.9	5.0	16.6	21.0	<0.05
Bottom slope (degrees)	0.1	0.2	0.2	0.1	0.1	0.4	<0.05
% Overhead cover	1.5	9.9	6.8	1.2	3.7	0.0	0.31
% No vegetation –10 m	9.7	24.3	10.5	17.6	100.0	29.0	0.07
% No vegetation – 20 m	36.8	46.5	41.5	38.7	100.0	60.5	0.17
Bank slope (degrees)	8.9	21.2	22.5	12.5	90.0	23.4	<0.05
Buffer width (m)	159.3	53.9	22.7	100.9	0.0	141.0	<0.05
Water temperature (^{o}C)	12.2	11.3	11.6	12.3	12.7	13.7	0.82
Conductivity (µS)	84.4	74.8	78.4	69.1	74.6	69.2	0.05
Dissolved O_2 (mg/L)	9.9	10.2	10.1	10.0	9.8	9.6	0.84
Transparency-nearshore	94.5	97.2	105.4	82.9	100.4	131.4	0.40
Transparency-offshore	109.9	99.2	111.1	86.3	104.8	141.0	0.06
Number of pilings	17.0	54.7	68.4	94.0	100.0	2.0	0.41
Number of outfalls	1.0	7.8	4.2	0.0	70.0	1.0	<0.05

the two seawall sites ($P < 0.05$). Although these sites have substantial ground vegetation up to 20 m from the waterline, there was no overhanging cover. Transparency values were higher at rock outcrop habitats than at any other habitat type.

Substrate Grain Size

Several sites (100W, 116E, 121W, 200E, and 219W) had riprap, rock, or hardpan substrates and could not be sampled for sediment size. Mean sediment size among sites sampled ranged from 26.2 to 437.5 µm (Table 13). Fine sediments (silt and clay) dominated 12 of 21 sites and site 232WA had the highest composition (92%) of fine sediments. Most (5 of 6) off-channel sites had substrates comprised mainly of silt or clay. Eight sites had substrates dominated by sand; sites classified as beach typically had the highest composition of sand and the largest mean grain size.

Table 13. Sediment size and percent composition of bottom substrates from sampling sites in the lower Willamette River, spring 2003.

Transect	Mean substrate size (μm)	% Sand	% Silt	% Clay
006E	201.33	82.78	14.84	2.38
010E	95.39	49.86	41.38	8.77
012W	65.53	39.80	50.23	9.97
040W	98.07	42.95	47.22	9.83
048E	44.28	16.20	71.81	11.99
051E	65.57	28.60	56.60	14.80
064W	88.70	35.01	53.51	11.49
067EA	38.60	16.21	72.92	10.87
069W	437.53	98.24	1.56	0.20
076WA	50.31	15.95	72.33	11.72
079W	152.34	46.22	44.68	9.10
097E	60.79	32.72	56.50	10.78
107WA	398.54	89.51	8.25	2.24
133W	94.41	50.47	40.38	9.15
136E	129.33	63.01	31.03	5.96
148E	136.65	82.53	13.84	3.62
148WA	76.84	41.31	51.61	7.08
167W	119.58	51.40	41.25	7.35
232WA	26.22	7.88	77.00	15.12
239EA	77.03	39.05	52.02	8.93
243W	206.97	83.02	14.12	2.85

Distance to Thalweg

Standard transects in the lower portion of the river, below rm 14.0, had a lower mean distance to the thalweg (223 m) than standard sites in the upper portion of the river (325 m) (Table 14). Off-channel sites were a mean distance of 277 m from the thalweg and distances among sites were comparable to those of standard transects. The beach transect 148E, located on the east of Ross Island, was the farthest site from the thalweg at a mean distance of 1,094 m, and was therefore grouped as an off-channel site. The rock outcrop site (219W) on Hog Island was closer to the

Table 14. Mean distance to the thalweg for each sample site in the lower Willamette River.

Transect	Thalweg distance (m)	Transect	Thalweg distance (m)	Transect	Thalweg distance (m)
Lower river		Upper river		Alcove	
006E	194	148E	1,094	067EA	338
010E	206	167W	189	076WA	423
012W	260	200E	80	107WA	249
031W	489	219W	51	148WA	211
040W	384	243W	211	232WA	198
048E	175			239EA	241
051E	123				
064W	185				
069W	299				
079W	446				
097E	213				
100W	308				
112E	83				
116E	93				
118W	151				
121W	106				
133W	221				
136E	80				
Mean distance	223		325		277

thalweg (51 m) than any other site. Both rock outcrop sites were located in the upper portion of the study area, which tended to be narrower than the lower portion. As a result, the distance to thalweg was significantly shorter for these sites compared to beaches and alcoves ($P < 0.05$).

Seasonal Analysis of Habitat Groups

Winter

Cluster analysis separated sampling sites into five distinct groups based on instream and onshore habitat measurements (Figure 5). Groups 1 and 3 consisted of sites of the same habitat type: Group 1 included the two rock outcrop sites (200E and 219W) in the upper portion of the river, whereas Group 3 contained the two seawall sites (121W and 048E) (Table 15). Group 2 consisted of riprap and mixed habitats (051E, 064W, 079W, 100WN, 116E, 133W, 136E); Group 5 consisted of mainly beach habitats (010E, 040W, 097E, 167W, 243W), with a single riprap site (012W), and several off-channel sites (067EA, 076WA, 148WA, 148E, 239EA). Two beach sites (069W and 006E) and an off-channel site (107WA) comprised Group 4.

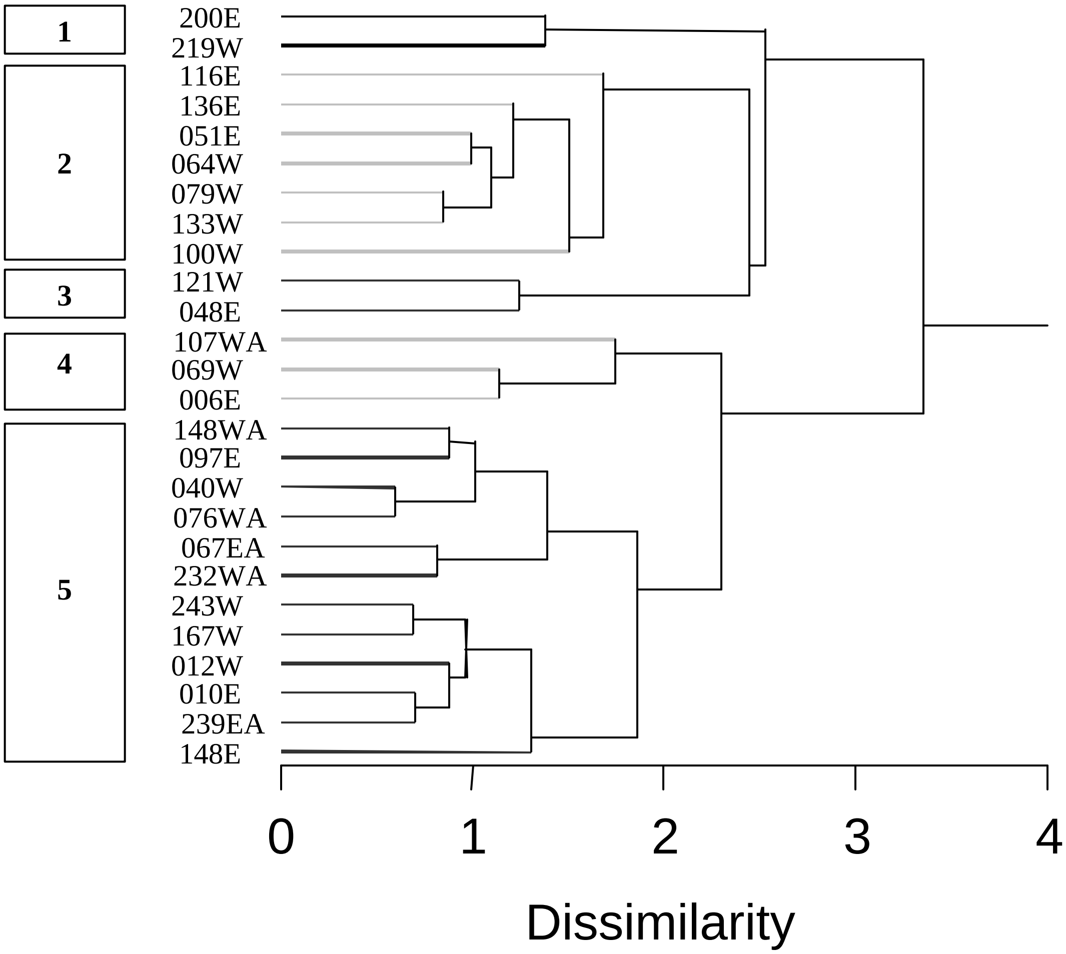

Figure 5. Cluster analysis dendrograph of lower Willamette River sample sites grouped by winter instream and onshore habitat parameters.

Table 15. Cluster analysis summary for sampling sites in the lower Willamette River, winter 2001-2003.

Cluster	Transect	Habitat type (qualitative)
Group 1	200E	Rock outcrop
	219W	Rock outcrop
Group 2	116E	Riprap
	136E	Riprap
	051E	Mixed
	064W	Mixed
	079W	Riprap
	133W	Mixed
	100W	Riprap
Group 3	121W	Seawall
	048E	Seawall
Group 4	107WA	Alcove (mixed)
	069W	Beach
	006E	Beach
Group 5	148WA	Alcove (mixed)
	097E	Beach
	040W	Beach
	076WA	Alcove (beach)
	067EA	Alcove (mixed)
	232WA	Alcove (beach)
	243W	Beach
	167W	Beach
	012W	Riprap
	010E	Beach
	239EA	Alcove (beach)
	148E	Off-channel (beach)

The overall eigenvalues (absolute value) for each instream axis were relatively high, with maximum values > 0.70 for each of the first three axes (Table 16). The cumulative variance explained by the first four axes was over 82%, with the first axis explaining 33% of the total variance. The highest loadings from the first axis described substrate grain size and composition: percent sand, silt, and clay and mean grain size. The second and third axes are related to the hydrology of the river; mean gauge height and mean depth at 20 m from shore explained much of the variability in these axes. The overall eigenvalues for the fourth axis were much lower, with a maximum loading of 0.57. The major components of this axis described water quality and the distance to the thalweg as sources of variation among sites.

The amount of variability explained by each axis for onshore habitat measurements was much lower, with the first six axes explaining just over 75% of the variance (Table 17). The first two axes, which explained over 41% of the variance, described onshore vegetation (lack of vegetation and presence of grass within 20 m of the waterline). The third, fourth, and fifth axes described bank substrate composition. The sixth axis explained just 6.6% of the overall variance; overhead cover (densitometer), with an eigenvalue of 0.75, was the major component.

Spring

Cluster analysis of spring habitat measurements divided sampling transects into five distinct groups (Figure 6). As river levels increased in the spring, sample site groupings changed (Table 18). Group 1 contained the two seawall sites (048E and 121W) and the riprapped site 100W. Group 2 was dominated by sites containing riprap and mixed (riprap/beach) habitat types (067EA, 051E, 064W, 136E, 079W, and 133W). The Multnomah County Sheriff's alcove (107WA), consisting mainly of pilings, and the beach site just upstream of the Sellwood Bridge (167W) were also assembled in the second cluster. The remaining beach sites (069W, 006E, 097E, 040W, 076WA, 010E, and 243W) and off-channel sites (148E, 148WA, and 239EA) composed the third group. Group 4 contained two riprap sites (012W and 116E) and Cedar Oak alcove (232WA), which has a rocky shoreline substrate. The two rock outcrop sites (200E and 219W) were grouped in the final cluster.

The first four axes of the instream PCA explained 78% of the variability among spring habitat data (Table 19). Eigenvalues for each axis were high and the maximum absolute value was greater than 0.68 for each of the first four axes. The first axis, which explained over 32% of the variation among sampling sites, described substrate composition and size; percent sand, with a loading value of 0.96, was the representative category for the first axis. The nearshore river slope was the only category with a relatively high eigenvalue in the second axis. The third category represented water quality parameters, with nearshore transparency explaining the most variance in this axis. Mean river level explained the most variation in the fourth axis.

Onshore habitat PCA resulted in the selection of six axes to explain more than 75% of the variability among sites (Table 20). The overall eigenvalues were much lower for onshore measurements, as the maximum absolute value loadings were less than 0.70 for four of the six axes. The first axis described the lack of bank vegetation, with the 20-m no vegetation category

Table 16. Summary of principal components analysis of instream habitat in the lower Willamette River, winter 2001-2003. Shaded numbers indicate the highest eigenvalue in each axis.

Variable	Axis 1	2	3	4
%SAND	-0.962	0.034	0.235	0.036
%SILT	0.950	0.092	-0.253	0.001
%CLAY	0.948	-0.102	-0.140	-0.100
SUBSIZE	-0.927	0.003	0.271	0.011
DEPTH20M	0.580	-0.113	0.725	0.119
PORTGAGE	0.028	-0.888	0.106	-0.281
TRANSPN	0.380	0.833	0.116	0.191
SURFO_2N	-0.094	-0.769	-0.148	0.480
SCONDN	-0.225	0.636	0.171	-0.567
STEMPN	0.167	-0.623	0.324	-0.513
PILINGN	0.202	0.358	0.697	0.221
SLOPEN	0.243	-0.285	0.624	0.359
DISTHAL	-0.225	0.048	-0.270	0.549
% Total variance explained	33.1	23.9	14.4	11.0

Table 17. Summary of principal components analysis of onshore habitat in the lower Willamette River, winter 2001-2003. Shaded numbers indicate the highest eigenvalue in each axis.

Variable	Axis 1	2	3	4	5	6
%20MNOVEG	-0.945	0.152	-0.101	0.080	-0.029	0.032
%10MNOVEG	-0.916	0.250	-0.220	-0.078	0.019	0.004
%20MFORB	0.676	0.208	0.276	0.286	-0.427	-0.215
%10MFORB	0.671	0.239	0.456	0.188	-0.293	-0.25
%SEAWALL	-0.632	-0.174	0.363	0.507	0.184	-0.127
%10MTREES	0.583	0.293	-0.043	0.535	0.033	0.301
%20MGRASS	0.570	-0.758	0.027	-0.122	0.077	0.079
%10MGRASS	0.564	-0.758	-0.097	0.033	0.103	0.095
BANKSLOPE	-0.553	-0.188	0.680	0.249	0.129	-0.102
%20MSHRUBS	0.373	0.563	0.148	-0.332	0.541	0.025
%20MTREES	0.429	0.532	-0.191	0.306	0.371	0.273
%ROCK	0.381	-0.507	-0.090	0.203	0.015	-0.005
%BEACH	0.078	0.395	-0.768	0.219	-0.054	-0.151
%LGRIPRAP	0.049	0.319	0.567	-0.351	0.049	-0.007
%SMRIPRAP	-0.079	-0.086	0.191	-0.562	-0.288	0.463
%BEDROCK	0.185	-0.319	-0.01	-0.093	0.603	0.045
DENSITOM	-0.192	0.055	0.142	0.135	-0.301	0.752
%ARTFILL	-0.135	-0.11	-0.044	-0.277	-0.093	-0.422
OUTFALLS	-0.459	-0.182	0.413	0.359	0.183	0.112
%10MSHRUBS	0.446	0.497	0.453	-0.17	0.121	-0.023
% Total variance explained	26.6	15	11.8	8.7	6.8	6.6

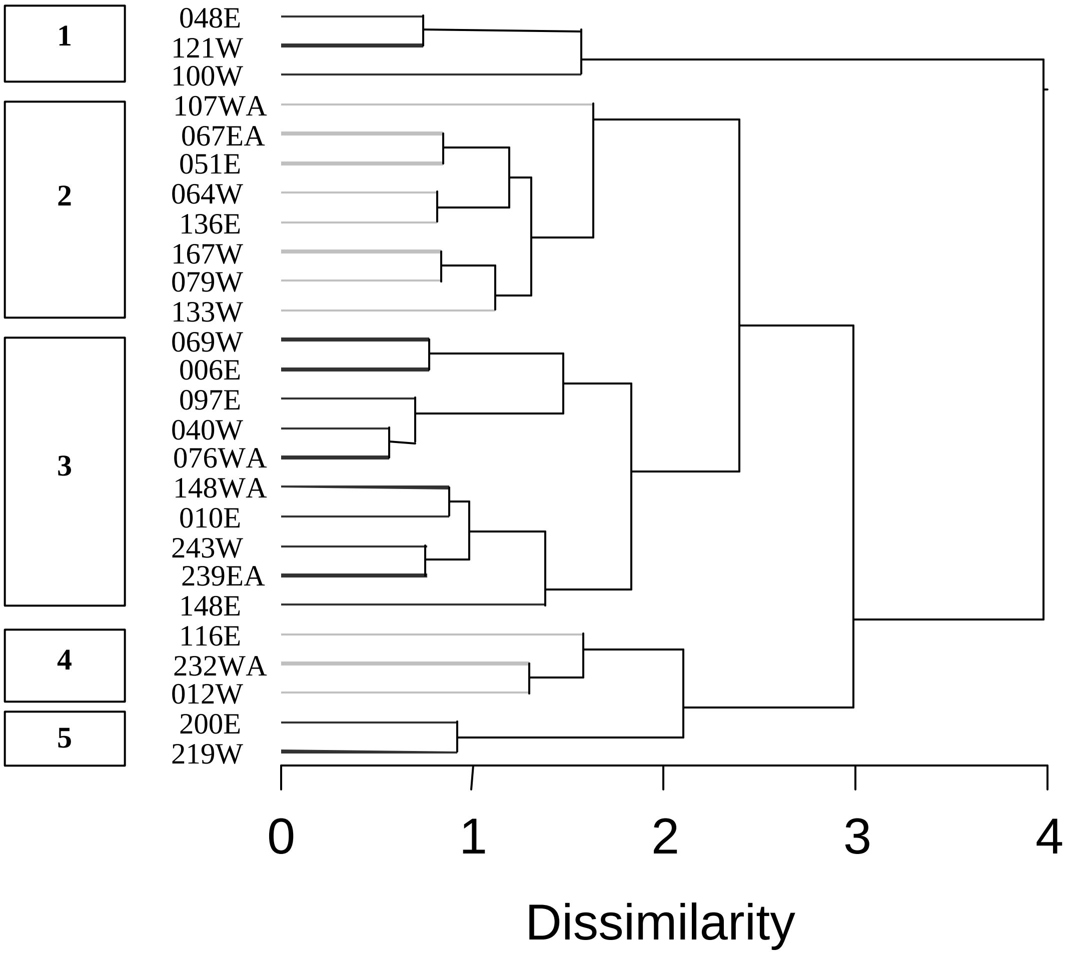

Figure 6. Cluster analysis dendrograph of lower Willamette River sample sites grouped by spring instream and onshore habitat parameters.

Table 18. Cluster analysis summary for sampling sites in the lower Willamette River, spring 2001-2003.

Cluster	Transect	Habitat type (qualitative)
Group 1	048E	Seawall
	121W	Seawall
	100W	Riprap
Group 2	107WA	Alcove (mixed)
	067EA	Alcove (mixed)
	051E	Mixed
	064W	Mixed
	136E	Riprap
	167W	Beach
	079W	Riprap
	133W	Mixed
Group 3	069W	Beach
	006E	Beach
	097E	Beach
	040W	Beach
	076WA	Alcove (beach)
	148WA	Alcove (mixed)
	010E	Beach
	243W	Beach
	239EA	Alcove (beach)
	148E	Off-channel (beach)
Group 4	116E	Riprap
	232WA	Alcove (beach)
	012W	Riprap
Group 5	200E	Rock outcrop
	219W	Rock outcrop

Table 19. Summary of principal components analysis of instream habitat in the lower Willamette River, spring 2001 – 2003. Shaded numbers indicate the highest eigenvalue in each axis.

Variable	Axis			
	1	2	3	4
%SAND	-0.959	0.132	0.096	0.154
%SILT	0.951	-0.200	-0.102	-0.077
%CLAY	0.944	-0.094	-0.084	-0.155
SUBSIZE	-0.938	0.270	0.011	0.037
DEPTH20M	0.559	0.558	0.251	0.272
SLOPEN	0.224	0.737	0.144	-0.196
SURFO$_2$N	0.050	-0.531	0.362	0.619
SCONDN	-0.151	0.512	-0.513	0.260
TRANSPN	0.153	0.316	-0.683	0.370
STEMPN	-0.356	-0.394	-0.622	-0.114
PORTGAGE	0.165	-0.398	-0.366	0.751
PILINGN	0.146	0.440	0.397	0.660
DISTHAL	-0.237	-0.416	0.445	0.064
% Total variance explained	32.6	17.8	14.2	13.6

Table 20. Summary of principal components analysis of onshore habitat in the lower Willamette River, spring 2001-2003. Shaded numbers indicate the highest eigenvalue in each axis.

Variable	Axis					
	1	2	3	4	5	6
%20MNOVEG	-0.931	0.074	-0.016	-0.155	0.167	-0.137
%10MNOVEG	-0.865	0.020	-0.388	-0.222	-0.054	-0.066
OUTFALLS	-0.757	-0.028	0.217	0.207	0.374	-0.116
BANKSLOPE	-0.655	0.136	0.355	0.362	0.130	0.440
%SEAWALL	-0.635	0.016	-0.025	0.187	0.445	0.421
%10MGRASS	0.585	-0.603	0.022	0.207	0.357	-0.145
%20MFORB	0.559	0.624	0.236	0.173	-0.060	0.284
%20MGRASS	0.509	-0.713	-0.171	0.335	-0.079	0.052
%10MTREES	0.505	0.431	0.058	0.284	0.354	-0.398
%10MSHRUBS	0.503	-0.055	0.440	-0.448	0.211	-0.071
%BEDROCK	0.308	-0.729	-0.095	0.167	0.342	0.179
%20MTREES	0.476	0.637	-0.208	0.183	0.298	-0.248
%LGRIPRAP	-0.122	-0.021	0.620	-0.181	-0.365	0.042
%10MFORB	0.396	0.437	0.575	0.183	-0.100	0.323
%BEACH	0.305	0.490	-0.514	-0.512	0.145	0.060
%ARTFILL	-0.018	-0.164	-0.182	0.286	-0.571	0.092
%SMRIPRAP	-0.148	-0.175	0.452	0.087	-0.237	-0.692
DENSITOM	-0.400	0.154	0.318	0.225	0.210	-0.327
%20MSHRUBS	0.485	-0.252	0.312	-0.465	0.251	0.225
%ROCK	0.270	0.346	-0.386	0.469	-0.145	0.004
% Total variance explained	27.6	15.5	11.1	8.6	7.9	7.6

having the highest loading. The remaining axes described onshore bank substrates and included percent composition of bedrock, large riprap, beach, artificial fill, and small riprap.

Summer

Low river levels during summer 2003 resulted in the clustering of five distinct groups that segregated by habitat type (Figure 7; Table 21). Several beach sites (243W, 167W, 097E), and four off-channel sites (148WA, 148E, 239EA, 232WA) composed the first group. Group 2 consisted of a single riprap site (012W) and the remaining five beach transects (076WA, 040W, 069W, 006E, 010E). Habitat types in the third group included riprap (136E, 067EA, 116E, 079W) and mixed habitats (107WA, 133W, 064W, and 051E). The two remaining clusters were a seawall group (048E, 121W) and a rock outcrop group (219W, 200E).

Principal components analysis of summer instream measurements resulted in five axes explaining 82% of the variation between transects (Table 22). The first axis described substrate composition and size; percent sand explained the most variance (0.97). The mean depth 20 m

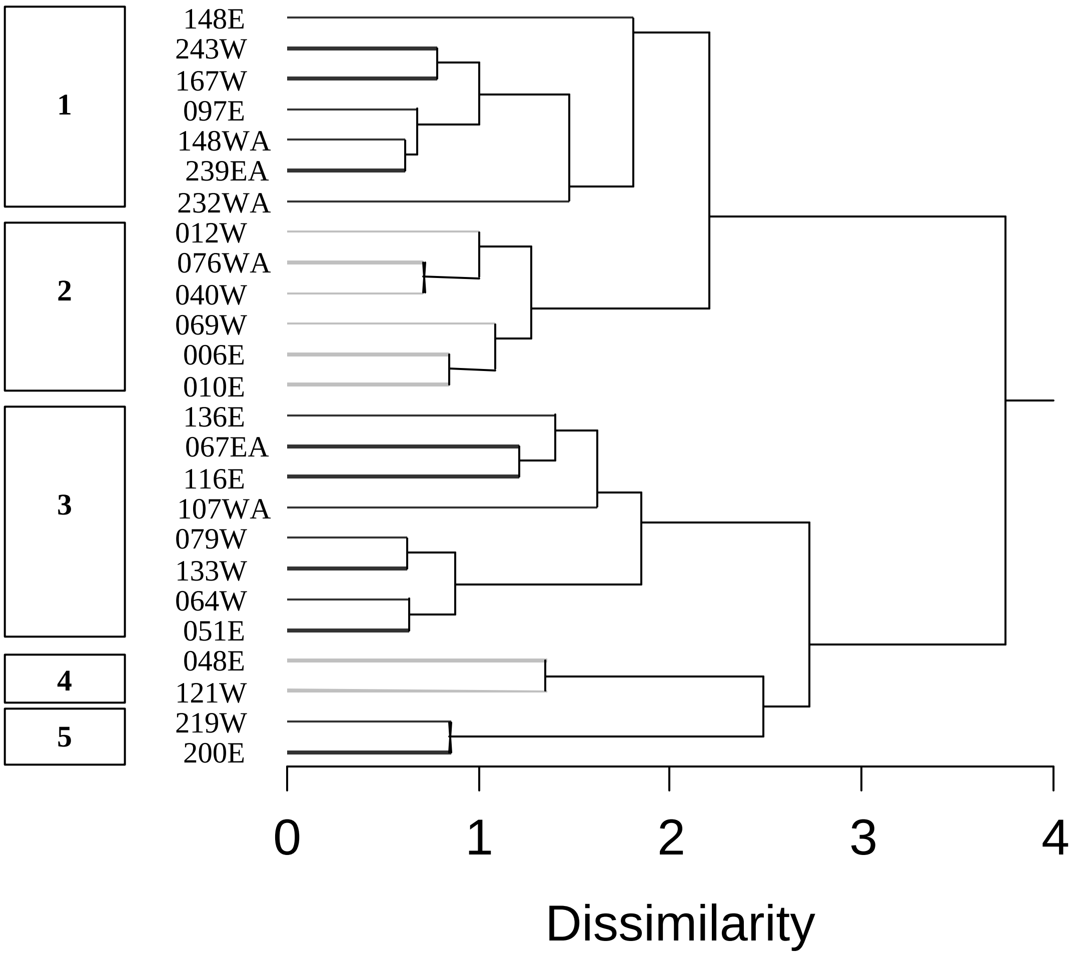

Figure 7. Cluster analysis dendrograph of lower Willamette River sample sites grouped by summer instream and onshore habitat parameters.

Table 21. Cluster analysis summary for sampling sites in the lower Willamette River, summer 2003.

Cluster	Transect	Habitat type (qualitative)
Group 1	148E*	Beach
	243W	Beach
	167W	Beach
	097E	Beach
	148WA	Alcove (mixed)
	239EA	Alcove (beach)
	232WA	Alcove (beach)
Group 2	012W	Riprap
	076WA	Alcove (beach)
	040W	Beach
	069W	Beach
	006E	Beach
	010E	Beach
Group 3	136E	Riprap
	067EA	Alcove (mixed)
	116E	Riprap
	107WA	Alcove (mixed)
	079W	Riprap
	133W	Mixed
	064W	Mixed
	051E	Mixed
Group 4	048E	Seawall
	121W	Seawall
Group 5	219W	Rock outcrop
	200E	Rock outcrop

Table 22. Summary of principal components analysis of instream habitat in the lower Willamette River, summer 2003. Shaded numbers indicate the highest eigenvalue in each axis.

Variable	Axis 1	2	3	4	5
%SAND	-0.971	0.044	0.006	-0.115	-0.138
%SILT	0.969	-0.085	-0.029	0.148	0.047
SUBSIZE	-0.960	0.103	0.031	-0.065	0.023
%CLAY	0.959	0.022	-0.029	0.095	0.093
DEPTH20M	0.382	0.824	0.229	-0.104	-0.108
TRANSPN	-0.268	0.788	0.035	0.185	0.104
SLOPEN	0.058	0.743	0.081	-0.118	0.185
PILINGN	0.023	0.682	0.214	0.339	-0.299
STEMPN	0.080	0.105	-0.896	-0.120	-0.078
PORTDGAGE	-0.025	0.256	-0.601	0.378	0.214
SCONDN	-0.072	-0.356	0.594	0.571	0.088
DISTHAL	-0.216	-0.101	-0.328	0.689	-0.457
SURFO$_2$N	0.352	-0.024	0.092	-0.317	-0.745
% Total variance explained	31.7	19.6	13.4	9.9	7.7

from shore had the highest loading in the second axis. The remaining axes identified nearshore surface temperature (0.90), distance to thalweg (0.69), and nearshore surface dissolved oxygen (0.75) as important variables.

The first axis of the onshore PCA explained 23.7% of the variance and the lack of vegetation on the banks described this axis (Table 23). The category that measured the lack of bank vegetation at 10 m had a loading value of 0.94, and was the representative parameter for this first axis. Bank slope, with an eigenvalue of 0.76, explained the most variance in the second axis. Bank substrate composed of bedrock described axis 3, while the fourth and fifth axes described bank vegetation (percent trees and shrubs at 20 m from shore).

Autumn

Cluster analysis of autumn nearshore instream and onshore parameters identified six groups of sites that were generally grouped according to their qualitative habitat type (Figure 8; Table 24). All sites composed of beach habitat (167W, 243W, 069W, 006E, 010E, 031W, 040W, 097E) along with a single off-channel site (148E) were grouped in the first cluster. Group 2 consisted of three riprap sites (136E, 012W, 079W) and three mixed habitat sites (133W, 064W, 051E). The seawall (048E and 121W) and rock outcrop sites (200E and 219W) were again clustered as separate groups. Two riprap sites (100W and 118W) and a single mixed habitat site (112E) composed cluster Group 4. Group 6 consisted of a single riprap site (116E).

Four PCA axes explained over 81% of the instream variability among sites (Table 25). The first axis explained 38.5% of the overall variance and described substrate grain size and composition. Percent sand was the representative parameter with a loading value of 0.99, the highest value of

Table 23. Summary of principal components analysis of onshore habitat in the lower Willamette River, summer 2003. Shaded numbers indicate the highest eigenvalue in each axis.

Variable	Axis				
	1	2	3	4	5
%10MNOVEG	-0.937	-0.015	0.127	-0.253	0.014
%20MNOVEG	-0.861	0.349	0.028	-0.202	0.074
%10MFORB	0.673	0.440	0.249	0.114	-0.336
%20MFORB	0.658	0.132	0.429	0.355	-0.031
LGRIPRAP	0.611	0.540	0.336	-0.196	0.103
%10MSHRUBS	0.592	0.228	0.307	-0.200	0.585
BANKSLOPE	0.045	0.756	-0.365	0.291	0.172
%SEAWALL	-0.499	0.588	-0.236	0.299	0.243
%BEACH	-0.473	-0.561	0.358	-0.173	0.072
OUTFALLS	-0.437	0.549	-0.207	0.294	0.167
DENSITOM	-0.218	0.524	0.049	0.657	-0.043
%ROCK	0.001	-0.509	0.066	0.238	0.103
%BEDROCK	0.322	-0.225	-0.792	0.089	0.251
%10MGRASS	0.430	-0.267	-0.761	0.073	0.174
%20MGRASS	0.437	-0.245	-0.717	-0.072	-0.137
%20MTREES	0.045	-0.477	0.339	0.715	0.016
%10MTREES	-0.003	-0.403	0.297	0.706	0.035
%20MSHRUBS	0.445	-0.044	0.362	-0.287	0.609
%ARTFILL	0.210	0.033	-0.102	-0.025	-0.562
%SMRIPRAP	0.283	0.405	0.134	-0.296	-0.435
% Total variance explained	23.7	17.4	14.6	11.5	8.0

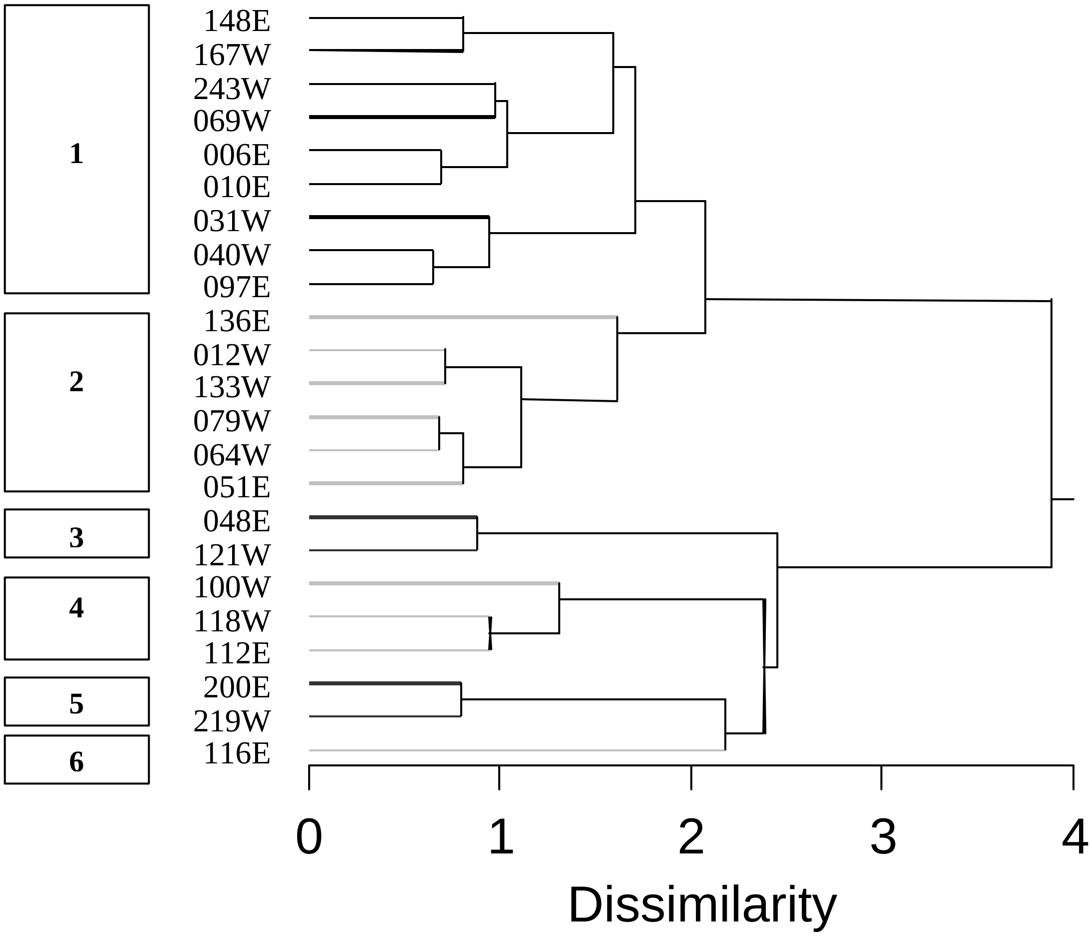

Figure 8. Cluster analysis dendrograph of lower Willamette River sample sites grouped by autumn instream and onshore habitat parameters.

Table 24. Cluster analysis summary for sampling sites in the lower Willamette River, autumn 2001-2002.

Cluster	Transect	Habitat type (qualitative)
Group 1	148E	Off-channel (beach)
	167W	Beach
	243W	Beach
	069W	Beach
	006E	Beach
	010E	Beach
	031W	Beach
	040W	Beach
	097E	Beach
Group 2	136E	Riprap
	012W	Riprap
	133W	Mixed
	079W	Riprap
	064W	Mixed
	051E	Mixed
Group 3	048E	Seawall
	121W	Seawall
Group 4	100W	Riprap
	118W	Riprap
	112E	Mixed
Group 5	200E	Rock outcrop
	219W	Rock outcrop
Group 6	116E	Riprap

Table 25. Summary of principal components analysis of instream habitat in the lower Willamette River, autumn 2001-2002. Shaded numbers indicate the highest eigenvalue in each axis.

Variable	Axis 1	2	3	4
%SAND	-0.990	0.009	0.020	0.043
%SILT	0.971	-0.012	0.144	0.000
SUBSIZE	-0.951	0.022	-0.006	-0.035
%CLAY	0.943	-0.013	0.016	-0.038
SURFO_2N	0.568	-0.428	-0.596	-0.074
PILINGN	0.543	0.054	0.353	0.450
DEPTH20M	0.516	0.779	0.110	0.060
TRANSPN	0.075	0.889	-0.271	0.262
STEMPN	-0.450	0.687	0.510	0.007
SLOPEN	0.099	0.686	-0.294	-0.313
PORTGAGE	-0.337	0.161	-0.704	-0.053
SCONDN	0.012	-0.232	0.572	-0.544
DISTHAL	-0.274	-0.359	0.057	0.678
% Total variance explained	38.5	21.0	13.5	8.8

any parameter in any season. Nearshore transparency had the highest eigenvalue in the second axis. The third and fourth axes were related to river hydrology; mean river level and mean distance to the thalweg were the most important parameters in these axes.

The first five axes of the onshore PCA explained over 76% of the variability (Table 26). Vegetative ground cover 10 m from the waterline was important in describing axis 1 and 3; percent no vegetation and percent grass at 10 m from the waterline had the highest loadings. Bank slope was selected from the second axis, and the fourth and fifth axes described bank composition (seawall and rock).

DISCUSSION

Identifying habitat parameters that influence fish abundance and diversity can be important in guiding future restoration and management efforts, but is often complex. Juvenile salmonid habitat preferences change throughout the year as environmental conditions fluctuate (Allen 2000; Orsi et al. 2000). Habitat use may also change with other factors, such as growth. Chinook salmon fry in the Wenatchee River, for example, occupied slow-moving, shallow stream margins whereas larger subyearling fish used faster, deeper water (Hillman et al. 1989). In addition, physical habitat attributes are rarely static, changing throughout the year as environmental conditions fluctuate.

Table 26. Summary of principal components analysis of onshore habitat in the lower Willamette River, autumn 2001-2002. Shaded numbers indicate the highest eigenvalue in each axis.

Variable	Axis 1	2	3	4	5
%10MNOVEG	-0.950	-0.032	-0.088	-0.002	-0.031
%10MFORB	0.825	0.296	-0.287	0.141	-0.105
%20MFORB	0.746	0.132	-0.364	0.168	-0.249
%LGRIPRAP	0.703	0.381	-0.296	-0.059	0.196
%10MTREES	0.687	0.047	-0.581	0.203	0.254
%20MNOVEG	-0.620	0.110	-0.286	0.475	-0.231
BANKSLOPE	0.210	0.782	0.339	0.431	0.005
OUTFALLS	-0.449	0.700	0.080	0.418	0.005
%BEACH	-0.388	-0.690	-0.533	-0.128	0.007
%SEAWALL	-0.428	0.606	0.000	0.568	-0.052
%10MGRASS	0.228	-0.389	0.696	0.271	0.395
%BEDROCK	0.213	-0.255	0.602	0.402	0.196
%20MGRASS	0.218	-0.412	0.595	0.379	0.376
DENSITOM	-0.103	0.387	0.118	-0.526	0.268
%10MSHRUBS	0.299	0.235	0.500	-0.522	-0.305
%ARTFILL	0.102	0.257	0.293	-0.517	-0.019
%ROCK	0.283	-0.310	0.210	0.146	-0.740
%20MSHRUBS	0.341	-0.275	0.340	0.179	-0.674
%SMRIPRAP	0.034	0.409	0.233	-0.469	0.060
%20MTREES	0.414	-0.287	-0.372	0.196	0.273
% Total variance explained	23.5	16.4	15.2	12.6	9.1

Waite and Carpenter (2003) indicated fish assemblages were greatly influenced by physical habitat diversity and quality in Willamette basin streams. Critical fish habitat parameters such as habitat complexity, vegetative cover, and large woody debris are severely limited in the lower Willamette River, especially near Portland, making the recognition of important habitat types essential for the protection of listed species. Much of the natural bank habitat below the Ross Island Bridge has been replaced by artificial habitats, which previous studies have shown to decrease aquatic species richness and diversity in the middle Willamette River (Hjort et al. 1984). In addition, Li et al. (1984) concluded larval and juvenile salmonid densities were lower at some sites in the Willamette River as a result of unfavorable conditions created by riprapped banks.

In our study, data reduction procedures and PCA reduced the number of habitat parameters from 60 to just 9 or 10 measurements for each season, eliminating redundant and homogeneous data. Vegetation (or lack of vegetation), substrate type, hydrology, and bank substrate explained the majority of the variation in our habitat data. Similar PCA results were noted for several rivers in British Columbia; water velocity, substrate size, water depth, and distance to cover explained most of variation in habitats (Taylor 1991). In our study, percent sand composition in bottom substrates was identified by PCA as an important source of variation among habitat types in every season. This parameter was always present in the first PCA axis and had very high eigenvalues (0.96 - 0.99). Onshore vegetation also appeared to be an important explanatory variable. The proportion of the riverbank that lacked vegetation at 10 m (summer and autumn) and 20 m (winter and spring) from the waterline also had high eigenvalues in the first PCA axis during every season. Other parameters identified in at least two seasons included: river level (gauge height), water depth 20 m from shore, distance to the thalweg, nearshore transparency, % beach, % small riprap, % bedrock, and bank slope. Bank substrates appeared to be especially important during spring. Additional surveys of bottom substrates should be conducted, as we were able to collect samples only during one season of one year. Percent sand appeared to be a highly important variable in explaining variation among sites, and is likely related to other parameters (e.g. bottom slope, % beach, depth).

Instream habitat measurements were more important in explaining variation among sites than onshore parameters, as eigenvalues were typically higher for these variables in each season. Water quality data indicated river chemistry varied little among sites; nearshore transparency was the only water quality measurement identified as an important component by PCA in more than one season.

Artificial and natural habitats tended to segregate, and although the upper portion of the study area (above Ross Island) contained more natural habitat, there was little evidence to suggest separation of upstream and downstream sites. Summer 2003 was the only period in which sites separated longitudinally; cluster group 1 consisted of natural habitats in the upper river (rkm 15.6 and above), whereas cluster group 2 consisted largely of natural habitats in the lower portion of the river (rkm 12.2 and below). Groups of sites identified with cluster analysis tended to correspond with the subjective (qualitative) habitat categories defined early in the study. For example, sites subjectively labeled as seawall and rock outcrop segregated into distinct groups during every season. Similar results were observed for beach sites, which were often grouped together. Riprap, rock, and mixed habitat types often appeared in multiple groups. These patterns increased our confidence that qualitative descriptions of habitats based on appearance were not wholly inaccurate, and the multivariate analyses were reliable in determining differences among habitats based on measured parameters.

Analyses conducted in the early years of this study identified little variation in fish community structure and abundance among habitats, particularly for ESA-listed salmonids (North et al. 2002; Friesen et al. 2002). However, the analyses were based solely on the subjective habitat classifications. We expect the habitat groups and variables identified in this report will be useful in further characterizing habitat use by fishes of the lower Willamette River, and may result in the development of scientifically valid management recommendations (see Friesen et al. 2004 and Pribyl et al. 2004).

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Migratory Behavior, Timing, Rearing, and Habitat Use of Juvenile Salmonids in the Lower Willamette River

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INTRODUCTION

The lower Willamette River, Oregon, is unique in providing a major fishery for Pacific salmon *Oncorhynchus* spp. near a large metropolitan area, Portland (Figure 1). In 2001, anglers harvested approximately 47,600 salmon from the Willamette River and its tributaries (Oregon Department of Fish and Wildlife, unpublished data). Salmonids produced in the Willamette basin are also caught by commercial fishers in the Pacific Ocean and the nearby Columbia River, provide ceremonial and consumptive fisheries to Northwest Indian tribes, and contribute to the identity of the region.

In the late 90s, four evolutionarily significant units (ESUs) of naturally propagated anadromous salmonids were listed as threatened species under the federal Endangered Species Act (ESA): lower Columbia River and upper Willamette River Chinook salmon *O. tshawytscha* (NOAA 1999a), upper Willamette River steelhead *O. mykiss* (NOAA 1999b), and lower Columbia River steelhead (NOAA 1998). Lower Columbia River coho salmon *O. kisutch* were also listed as endangered under the Oregon Endangered Species Act (Chilcote 1999). The lower Columbia River ESU includes the Willamette River from the mouth to Willamette Falls at river kilometer (rkm) 42.6.

The lower Willamette River has been heavily modified, especially near Portland. The channel has been dredged to accommodate commercial shipping, and docks, piers, bulkheads (seawalls), and rock revetment (riprap) have replaced much of the natural bank habitat. Pollution from industrial sources, especially in the river sediments, is a serious concern. A section of the reach, from rkm 5.6 to 15.3, was added to the U. S. Environmental Protection Agency (USEPA) “Superfund” list in December 2000. Primary contaminants include mercury, polychlorinated biphenyls, polynuclear aromatic hydrocarbons, dioxins, furans, and pesticides (USEPA 2000).

In the mid-1980s, concerns about the effects of waterway development on juvenile salmonids led to a cooperative study between the Port of Portland and the Oregon Department of Fish and Wildlife (ODFW; ODFW 1992). The study focused primarily on the Portland Harbor area (rkm 0.0 – 19.0) and concluded that (1) with the exception of habitat losses caused by seawall construction, development posed little risk to salmonids; (2) the location of developments in the harbor area did not need to be weighed heavily when considering risks to salmonids; and (3) predation on juvenile salmonids by northern pikeminnow *Ptychocheilus oregonensis* was not enhanced by development (Ward et al. 1994). The study also recommended further research to better characterize fish-habitat relationships.

In 2000, following the ESA listings and consultations with regional fisheries managers, the City of Portland funded a new study directed at describing the relationships of nearshore development and bank treatments on both resident and anadromous fish species. The study was intended specifically to help the City of Portland protect listed species and support their recovery.

In this report, we examine in detail the migratory characteristics of juvenile Chinook salmon, coho salmon, and steelhead in relation to nearshore habitat in the lower Willamette River. Where possible, we assessed both hatchery and naturally propagated (unmarked) groups of all three species.

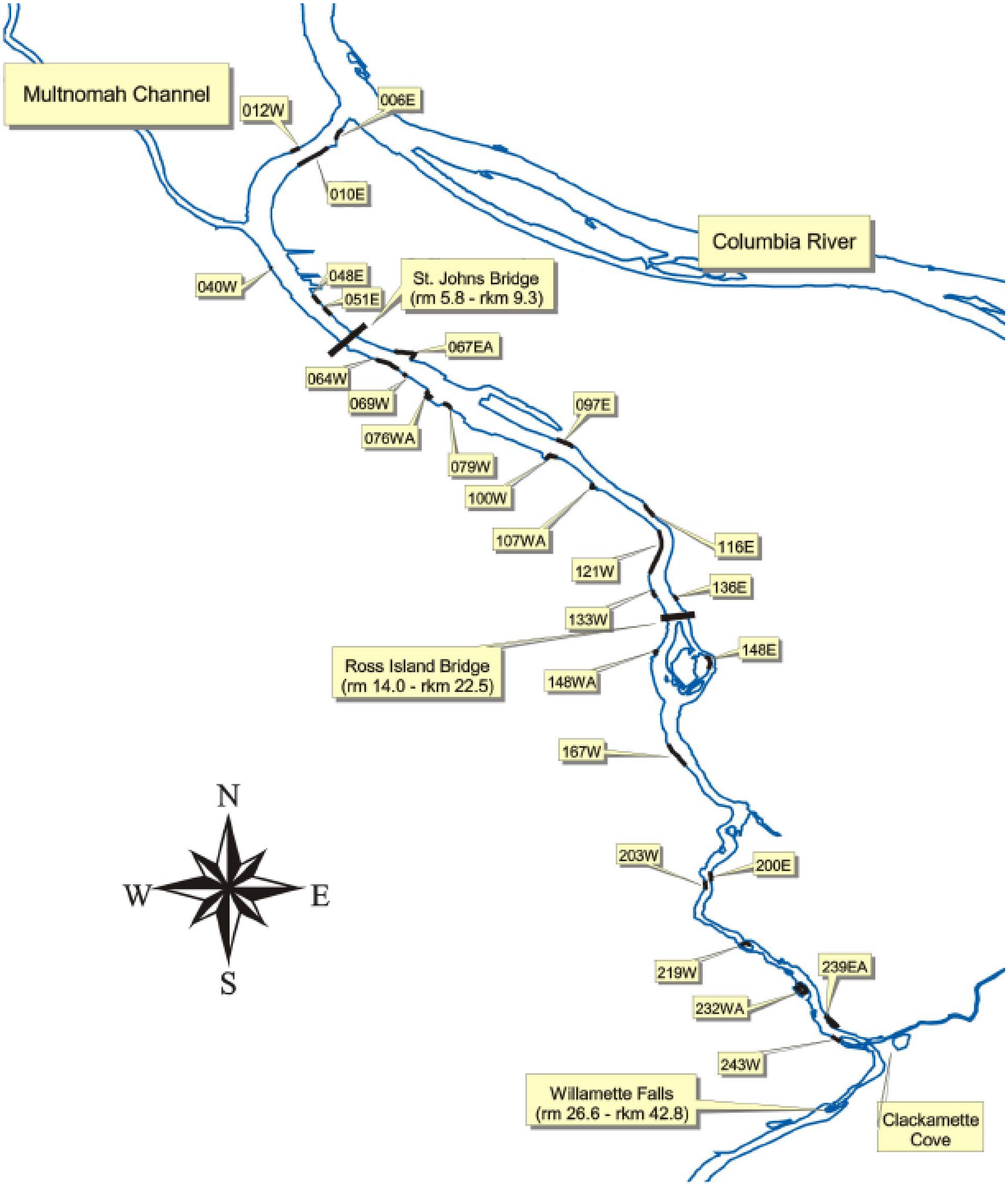

Figure 1. The lower Willamette River study area and associated features. Sampling site labels denote river mile (rm; xx.x) and east (E) or west (W) shore. A = alcove site; rkm = river kilometer.

We tested three null hypotheses:

1) *The density of juvenile salmonids does not vary among bank treatment and nearshore development types.*

2) *Juvenile salmonids do not exhibit changes in size (length or weight) during migration through the study area.*

3) *The distribution of radio-tagged juvenile salmonids among nearshore habitat types does not differ from the distribution of habitat types.*

We also documented other facets of juvenile salmonid biology that would lead to a better understanding of their behavior in the lower Willamette River. These included: species composition, outmigration timing, size structure, growth, migration rate, and residence time. We provided general comments on resident salmonids but focused our efforts on ESA-listed species and races.

METHODS

Field Sampling

Electrofishing and Beach Seining

We used beach seining and electrofishing to determine species composition, origin, size, run timing, and growth of juvenile salmonids. Repeated sampling was conducted at 27 sampling stations. Of these, 21 were sampled with electrofishing, 4 were sampled with beach seines, and 2 were sampled using both gears. Sampling sites are described in Vile and Friesen (2004). Prior to winter 2001, sampling was conducted during a 4-6 week period in each season (spring, summer, autumn, and winter), resulting in some temporal gaps (i.e., sampling did not occur in some months). We corrected this by redesigning the sampling scheme so all months were sampled equally. Beginning in December 2001, electrofishing was conducted four days per month (each site sampled twice), and beach seining was performed once per week (each site sampled once). Our level of effort varied somewhat due to other priorities (primarily radio telemetry) and weather conditions.

Boat electrofishing was conducted after sunset. Because the primary goal of the study was to characterize the effects of nearshore development on juvenile salmonids, we sampled as close to shore as possible. Navigation was difficult in water < 1 m deep, and sampling effectiveness was probably reduced at depths of > 3 m. We therefore adopted a target depth of 1-3 m, though some sites (loading docks, seawalls) were considerably deeper even very close to shore. We sampled for a maximum of 750 s (continuous energized direct current) at each sample site. Voltage regulator settings were changed frequently early in the study to avoid harming ESA-listed salmonids. Beginning in December 2000, we used 30 pulses/s at 50-100% of the low range, which appeared to maximize taxis (involuntary attraction to the anodes) and minimize tetany (immobilization). These settings resulted in an electrofisher output of <1.0 – 2.0 amperes, depending on conductivity. The conservative settings we used sometimes prevented us from collecting all observed juvenile salmonids when densities were highest. We counted juvenile salmonids we did not collect (± 10 fish) and identified individuals to species when possible.

We conducted daytime beach seining at five sites; a sixth was added in spring 2002. While shoreline habitat varied greatly for electrofishing efforts, beach seine sites were relatively consistent, defined by shallow areas with gentle slope, little or no structure, and small substrate (fines, sand, or gravel). We used a 2.4 x 45.7 m straight-wall, buntless net constructed of 4.8-mm Delta-style nylon mesh with a weighted line at the bottom and a floating line at the top. The seines were deployed from a boat in a semi-circular fashion and pulled to shore.

Juvenile salmonids collected by electrofishing and beach seining were identified to species when possible; small individuals could not always be identified readily and were recorded as unidentified salmonids. We examined all salmonids for the presence of clipped fins, indicating they were of hatchery origin. Non-finmarked fish were assumed to be naturally propagated and are hereafter referred to as “unmarked”. We measured fork length (FL) to the nearest mm and weighed (g) a maximum of 30 individuals of each species and origin during each sampling effort.

Radio Telemetry

Radio telemetry was used to monitor actively migrating juvenile salmonids. We used telemetry data to calculate migration rates and residence times, describe the distribution of fish across the river channel, and explore habitat associations.

We collected juvenile Chinook salmon, coho salmon, and steelhead each spring (2001-2003) for radio tagging. Salmonids were collected by beach seining or electrofishing within the study area, or were obtained from the juvenile fish trap at the Portland General Electric Sullivan Plant at Willamette Falls. Fish between 100 and 230 mm FL were kept for tagging if they were in good physical condition.

We held salmonids for 16-48 hours following collection to allow for the evacuation of stomach contents. During 2001 and 2002, the fish were held in 125-L containers suspended by floating frames in Clackamette Cove, located near the confluence of the Clackamas and Willamette Rivers (Figure 1). The containers were perforated to allow water to circulate freely. Due to poor conditions (stagnant water and high temperatures) in this area during 2003, the fish were held at the ODFW Clackamas Regional office in large spring-fed tanks with continuous water circulation.

Radio tags were coded microprocessor transmitters (NTC-2-1 NanoTags®) manufactured by Lotek Engineering. We programmed all tags with a continuous 4 s burst rate, and the minimum estimated battery life was 11 d. Tag size was 4.5 x 6.3 x 14.5 mm and averaged 0.8 g (air weight) including antennae. During 2001, some fish were also tagged with MCFT-3KM tags measuring 7.3 x 18 mm with an air weight of 1.4 g. Adams et al. (1998a) and Brown et al. (1999) recommended tag weight should not exceed 5.0% of the weight of the fish. Due to difficulties in obtaining fish of the proper weight, our tags occasionally composed up to 6.5% of the weight of the fish during 2001 and 2002.

Prior to implantation, each tag was activated and checked with a receiver to ensure proper working condition. We surgically implanted the tags into the ventral body cavity following techniques described in Adams et al. (1998b). Following the procedure, we retained the fish for 12-36 hours to ensure complete recovery.

We released radio-tagged fish between 14 April and 27 June of each year. Releases occurred pre-dawn in the upper portion of the study area; between rkm 27.0 and 39.1 in 2001, rkm 32.5 and 39.6 in 2002, and rkm 39.4 and 39.6 in 2003. Only fish that appeared to be in good physical condition were released. We matched water temperatures in the holding containers as closely as possible to river temperatures, and released the fish via a water-to-water transfer.

We tracked radio-tagged fish in 5.5 - 6.7 m boats, traveling at approximately 8.0 km/h, using a six-element yagi-style antenna and Lotek receiver. Tracking was conducted in an upstream to downstream direction. Upstream of Elk Rock Island (rkm 30.6) we tracked mid-channel because signals from either shore could be detected. A zigzag tracking pattern was used downstream of Elk Rock Island, where the river becomes wider, to maximize the amount of surface area covered and to ensure random recoveries of fish between nearshore and offshore habitats. Total tracking time conducted offshore and nearshore was recorded for each shift to maintain an approximate 50:50 ratio.

We began tracking the fish about one hour after their release, 1.6 km above the release site. On non-release days, tracking began near the mid-point of fish relocations from the previous shift. If no fish were located after two hours of tracking, we employed a search pattern until signals were detected. Tracking was conducted twice per day (day and night) for eight to ten hours per shift, and for at least five consecutive days following a release.

Once a signal was audible on the receiver, we discontinued the tracking pattern and directed the boat towards the signal. The location of the fish was determined by lowering the gain and using the aerial antenna to locate the direction of the strongest power signal. When the power signal was sufficiently strong, a coaxial antenna was lowered 1 – 2 m underwater to pinpoint the location of the fish. Whether we pinpointed the fish or not, we stopped the boat where the signal was strongest and recorded the tag channel and code, time, latitude and longitude, river mile, distance to shore, channel width, final gain and signal power readings, and the quality of the signal. We defined nearshore recoveries as those occurring within 10% of the measured channel width of either shore. We recorded general habitat types for all nearshore recoveries; categories included beach, riprap, rock outcrop, other natural rock, seawall, artificial fill, and pilings (North et al. 2002; Friesen et al. 2003; Vile and Friesen 2004).

We also employed a number of fixed telemetry sites to monitor fish passage through the study area. These included a six-element yagi-style antenna attached to a fixed object, a Lotek receiver, and a power supply. The receiver was programmed to continuously monitor the tag frequencies and to record the date, time, tag code, and signal strength of passing tagged fish. Each week, data was downloaded to a laptop computer and the battery was replaced.

We employed eight fixed telemetry sites in 2001. At several locations, a station was set up on both sides of the river to ensure coverage of the entire channel. These included: 1) Sellwood Bridge (rkm 26.7), 2) Albers Mill Building (rkm 18.7), 3) Cargill Inc. Irving Elevator (rkm 18.7), 4) City of Portland Water Pollution Control Laboratory (rkm 9.5), 5) U. S. Army Corp of Engineers Portland District (rkm 9.5), 6) U. S. Coast Guard (USCG) navigation aid for Multnomah Channel (rkm 4.8), 7) USCG navigation aid #3 (rkm 1.1), and 8) USCG navigation aid #4 (rkm 1.1). In 2002 the number of fixed telemetry sites was reduced to four because of USCG restrictions on navigation aids and difficulties in setting up and maintaining the station on the Sellwood Bridge. Stations for 2002 included 1) the Albers Mill Building, 2) the Cargill Inc. Irving Elevator, 3) the City of Portland Water Pollution Control Laboratory, and 4) a private residence in Multnomah Channel 2.4 rkm downstream from the head of the channel. In 2003 the number of fixed telemetry sites was reduced to one because of difficulties in obtaining valid data from several of the receivers, due primarily to interference from automobile traffic. The remaining site was located at the private residence in Multnomah Channel.

Data Analysis

Density and timing

To assess run timing, we calculated the relative density of juvenile salmonids using an index based on the proportion of zero-fish catches. Although catch per unit effort (CPUE) is the most commonly used index of fish density, Bannerot and Austin (1983) recommended the use of the square root of the relative frequency of zero-fish catches. Zimmerman and Parker (1995) modified the index by using its reciprocal (1/square root of the proportion of zero catches) so the index value would be directly proportional to density.

For both electrofishing and beach seining, we calculated monthly density index values for Chinook salmon, coho salmon, and steelhead to provide information on their relative temporal distribution. Separate indices were calculated for unmarked and hatchery-origin Chinook salmon. Because the catch and relative density of both coho salmon and steelhead was low, we combined hatchery and unmarked fish to provide indices for these species.

Growth

Growth of juvenile salmonids implies active feeding and the existence of suitable rearing habitat. We used the Mann-Whitney rank sum test (a nonparametric equivalent of the T-test; Jandel Scientific Corporation 1995) to compare fork length and body weight of juvenile salmonids among sampling sites in the upstream and downstream portions of the study area (null hypothesis 2). As with other analyses, we examined only Chinook salmon because sample sizes of coho salmon and steelhead were small. Catches varied substantially with gear type; we divided this analysis into two components to maximize statistical power: hatchery fish captured by electrofishing and unmarked fish captured in beach seines. For beach seine catches, we compared downstream sites 006EN and 040WN to upstream sites 167WN and 243WN (Figure 1). Electrofishing sites were 006EN, 010EN, and 012WN (downstream) and 167WN, 200EN, and 219WN (upstream).

Habitat Use (electrofishing)

To supplement and verify radio telemetry results, we explored salmonid habitat associations using electrofishing data (null hypothesis #1). We used CPUE standardized to the mean electrofishing effort as our index of fish density among habitat types. Habitat use was evaluated among seasons, as bank habitats change throughout the year with fluctuations of river levels and other environmental conditions (Vile and Friesen 2004). Because electrofishing catches were biased towards larger fish, we restricted these analyses to individuals > 100 mm FL. We omitted analyses for some species and seasons where catches were very low (coho salmon in autumn and winter, and steelhead in summer and winter).

The electrofishing data included a large number of zero catches, resulting in a non-normal distribution; we therefore used median values and nonparametric statistical tests. Box plots represented the data and provided the median CPUE for each habitat classification, 25th and 75th percentiles, and 10th and 90th percentiles (Figure 2). The Mann-Whitney rank sum test, the Kruskal-Wallis one-way analysis of variance (ANOVA) and Dunn's multiple comparison test were used to identify significant differences among habitats. For all analyses, comparisons were considered significant where $P<0.05$.

Generalized Habitat Categories

We compared mean standardized CPUE of juvenile salmonids among generalized habitat categories. To increase sample sizes and improve our ability to describe differences among types, we combined similar habitat types (Vile and Friesen 2004). In addition, habitat types initially categorized in North et al. (2002) often did not accurately describe the actual riverbank treatment. For example, a site classified as "floating structure" could also have a riprap bank treatment. Our final categories included beach, riprap, rock outcrop, seawall, and mixed habitats.

Clustered Habitat Categories

Vile and Friesen (2004) reported bank habitats in the lower Willamette River clustered into groups based on physical and chemical parameters, and subjective characterizations of habitat types (i.e., the general habitat categories) often accurately described differences in bank treatments. Therefore, we also compared median standardized CPUE to habitat clusters identified by Vile and Friesen (2004). For clarity, we identified the corresponding general habitat types (e.g., beach, riprap, seawall) in each analysis.

Off-channel Habitats

To assess the use of refuge-type habitats away from the main river channel, we compared the median CPUE for all species between off-channel (alcove, backwater, or secondary channel) and "main-channel" sites. Off-channel sites included 067EA, 076WA, 107WA, 148WA, 148EN,

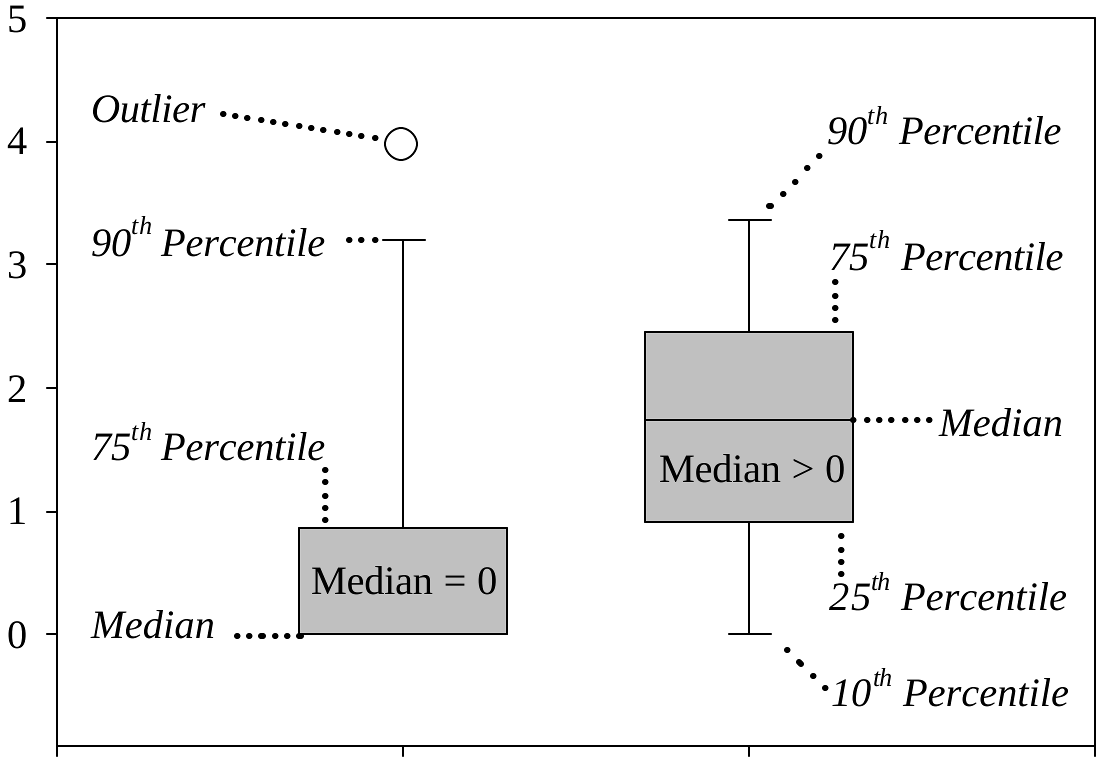

Figure 2. Key to box-and-whisker plots used in this report.

232WA, and 239EA (Figure 1). We used the Mann-Whitney rank sum test to determine if catches at off-channel and main-channel habitats differed significantly, and omitted species-specific results for some seasons with very low catches.

Habitat Parameters

Vile and Friesen (2004) also identified the onshore and instream parameters that contributed most to the separation of sampling sites into clusters. To provide information on the importance of individual habitat parameters, we compared median CPUE of juvenile Chinook salmon (hatchery, unmarked, and combined) to categorized values from the parameters using the Kruskal-Wallis one-way ANOVA and the Mann-Whitney rank sum test. Dunn's pairwise multiple comparison method was used to determine where differences occurred. We restricted the analysis to winter and spring, when most salmonids were captured, and again included only fish > 100 mm FL. Because habitat and fish surveys did not occur simultaneously, we eliminated parameters likely to change appreciably within a season (river level, transparency, conductivity). Winter habitat measurements included: (1) percent of the bottom substrate consisting of fines, sand, rock, and bedrock, (2) water depth 20 m from shore, (3) percent vegetative cover on the bank 10 and 20 m from the waterline, (4) percent vegetation composed of grass 10 and 20 m from the waterline, and (5) percent of the bank habitat consisting of beach.

Spring habitat parameters were: (1) percent of the bottom substrate consisting of fines, sand, rock, and bedrock, (2) slope of the river bottom 0-50 m from shore, (3) nearshore transparency (cm), (4) percent vegetative cover on the bank 10 and 20 m from the waterline, (5) percent of the bank habitat consisting of bedrock, (6) percent of the bank habitat consisting of large riprap, and (7) percent of the bank habitat consisting of beach (Vile and Friesen 2004).

Radio Telemetry

Migration rates and residence times

We calculated migration rates (km/d) of juvenile salmonids based on travel time from the initial release point to subsequent downstream relocation points. Mobile telemetry and fixed telemetry data were combined into one dataset and sorted by tag channel and code, allowing us to examine the data for individual fish and identify peculiarities that required editing. Criteria we established for radio telemetry data included: 1) fish that were pinpointed multiple times in the same location for over 24 hours were presumed dead and were not included in subsequent analyses; 2) fish that moved upstream with no subsequent downstream movement were not actively migrating, or may have been a victim of predation; migration rates were calculated using only downstream movements of the fish to the point at which the fish began to move upstream; 3) if the signal strength was of low quality (unable to obtain good signal strength on the aerial antenna and/or unable to pinpoint the fish using the underwater antenna), the data was not included in calculations of migration rate. In addition, we verified river mile estimates for relocations by plotting the GPS waypoints onto an Oregon Lambert-projected ortho-photo (2' resolution) using ArcView 3.2a.

To calculate residence time, we multiplied the overall migration rate for each fish by the study area distance (42.6 rkm). We compared migration rates and residence times among species using the Kruskal-Wallis one-way ANOVA on ranks and Dunn's nonparametric multiple comparison test. Migration rates and residence times between unmarked and hatchery fish, and the upper study area (rkm 22.6 – 42.6) and the lower study area (rkm 0.0 – 22.5) were compared for each species using the Mann-Whitney rank sum test. Factors that could influence migration rates, including river flow, temperature, release day, and fish size (fork length) were assessed using simple and multiple linear regressions.

Habitat use

We used distributions of radio telemetry relocations across the river channel to determine if salmonids were closely associated with nearshore areas, and are therefore likely to encounter different bank habitats. For each relocation, we divided the measured river width into 10% increments and assigned the relocation a category (e.g., 0-10%, 11-20%). We analyzed distributions using the chi-square test; samples with expected values of < 5 for a single category were not included (Zar 1999).

We used the same analysis to determine if nearshore relocations among general habitat types were distributed differently than the habitat types (null hypothesis #3), which could indicate selection or avoidance of specific habitats. Survey data from North et al. (2002) were used to determine proportions of each habitat type present throughout the study area (rkm 0.0 to 42.6). Because the release timing of radio-tagged fish varied from year to year, there was some potential for environmental conditions, primarily river flow, to affect telemetry results. To explore this factor, we plotted hydrographs of daily flow values for spring (April – June) and for periods we were tracking radio-tagged fish. Differences among years were identified using the Kruskal-Wallis one-way ANOVA on ranks and Dunn's nonparametric multiple comparison test. We also calculated median, minimum, and maximum flow values for each period, and qualitatively characterized differences among years. We used U. S. Geological Survey (USGS) river flow data collected at the Morrison Bridge gauging station (USGS 2004; Suzanne Miller, USGS, personal communication).

RESULTS

We collected 5,030 juvenile salmonids identifiable to species (Figure 3). Over 87% were Chinook salmon, 9% were coho salmon, and 3% were steelhead. A small number of other salmonids were collected, including 40 mountain whitefish *Prosopium transmontanus*, five sockeye salmon *O. nerka*, and two cutthroat trout *O. clarki*. Hatchery fish predominated, comprising 54% of the Chinook salmon, 66% of the coho salmon, and 91% of the steelhead. Differences in catch between gears were pronounced. The electrofishing catch consisted primarily (68%) of hatchery Chinook salmon, while unmarked Chinook salmon dominated (85%) the beach seine catch. The majority of steelhead (91%) and coho salmon (81%) were captured by electrofishing.

The mean fork length of hatchery Chinook salmon captured by electrofishing (155 mm) was considerably greater than that of unmarked fish (115 mm), though the unmarked component exhibited greater variance (Figure 4). Few hatchery Chinook salmon were captured with beach seines, and were similar in size to those captured with electrofishing gear. Unmarked fish observed in beach seine catches were generally much smaller than those captured by electrofishing, and exhibited a bimodal length distribution, with peak numbers of fish occurring at about 45 and 75 mm FL.

Steelhead, observed infrequently in both beach seine and electrofishing catches, were usually larger (>150 mm FL) than Chinook or coho salmon, and ranged from 58-250 mm FL (Figure 5). Coho salmon captured by electrofishing were slightly larger than those observed in beach seine catches, and had a bimodal length distribution, with peaks occurring at about 75 and 150 mm FL (Figure 5).

Density and Timing

From May 2000 to July 2003, density values of both hatchery and unmarked juvenile Chinook salmon captured by electrofishing generally increased beginning in November and declined to near zero by June (Figure 6). Peak densities varied, occurring between January and April. Hatchery Chinook salmon were present at higher densities than unmarked fish during most months, and both hatchery and unmarked fish were present at low densities in August, September, and October of some years.

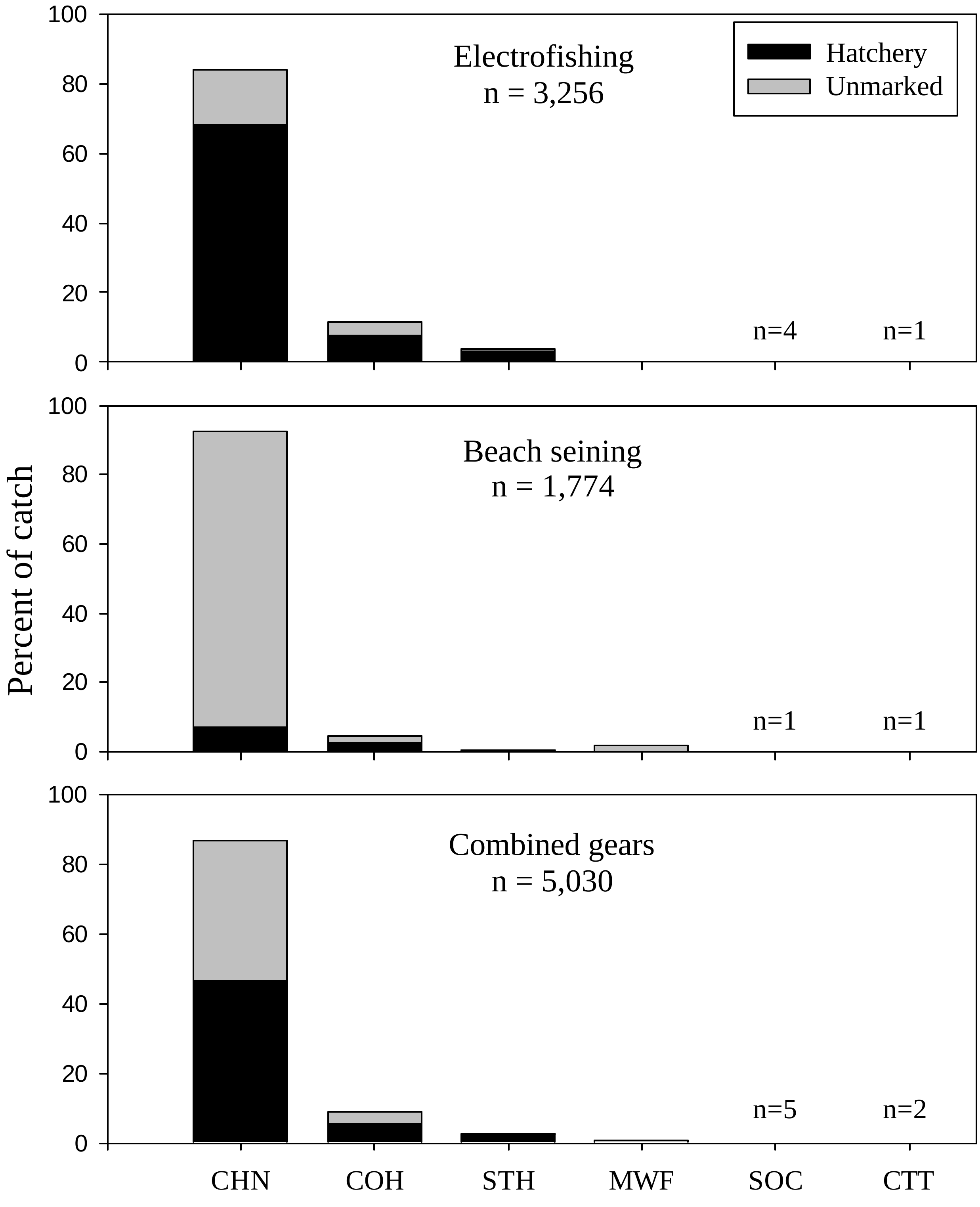

Figure 3. Juvenile salmonids captured by electrofishing and beach seining in the lower Willamette River, 2000-2003. CHN = Chinook salmon, COH = coho salmon, STH = steelhead, MWF = mountain whitefish, SOC = sockeye salmon, CTT = cutthroat trout.

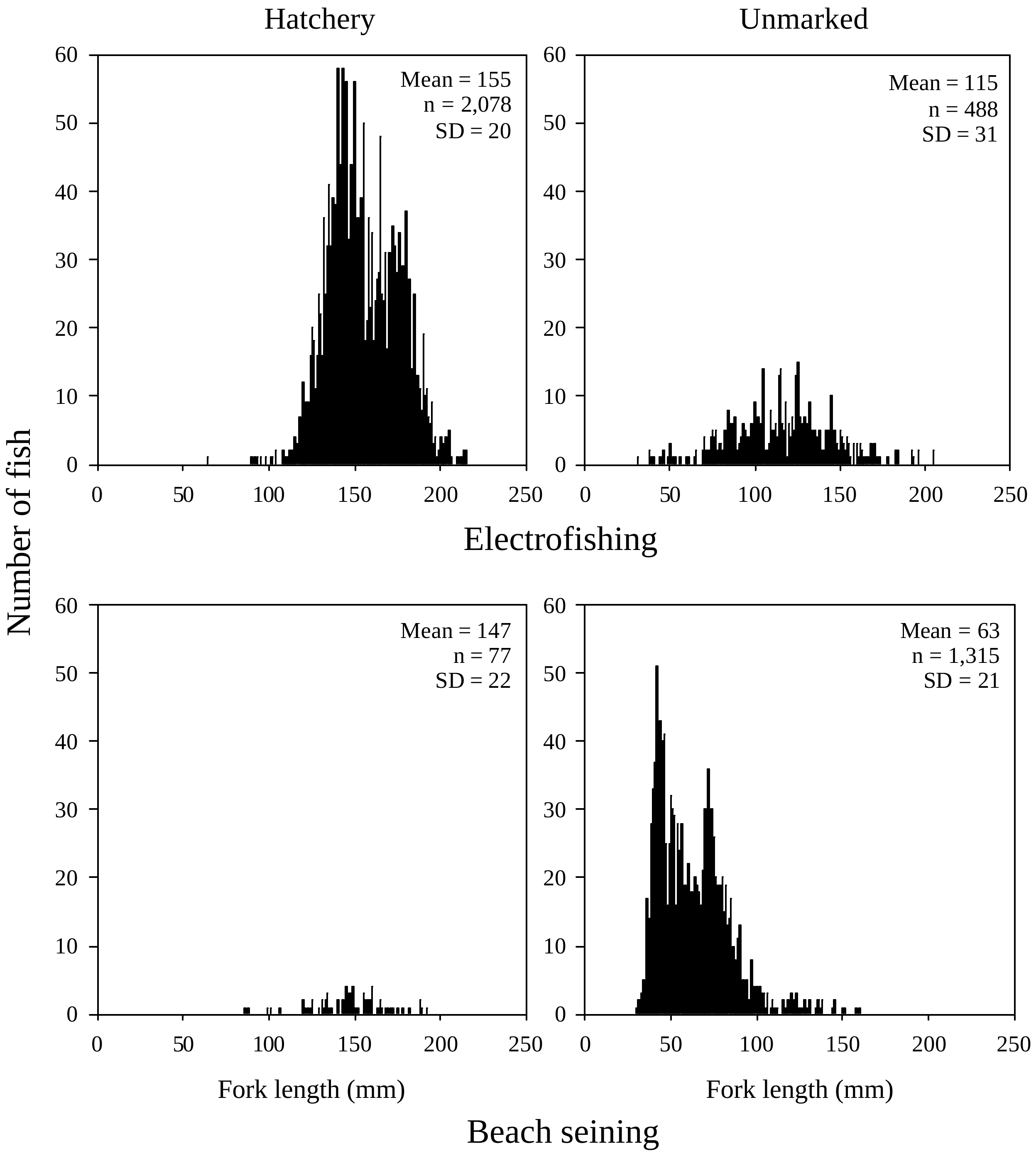

Figure 4. Fork length distributions for hatchery and unmarked juvenile Chinook salmon captured by electrofishing (top panels) and beach seining (lower panels) in the lower Willamette River, 2000-2003. SD = standard deviation.

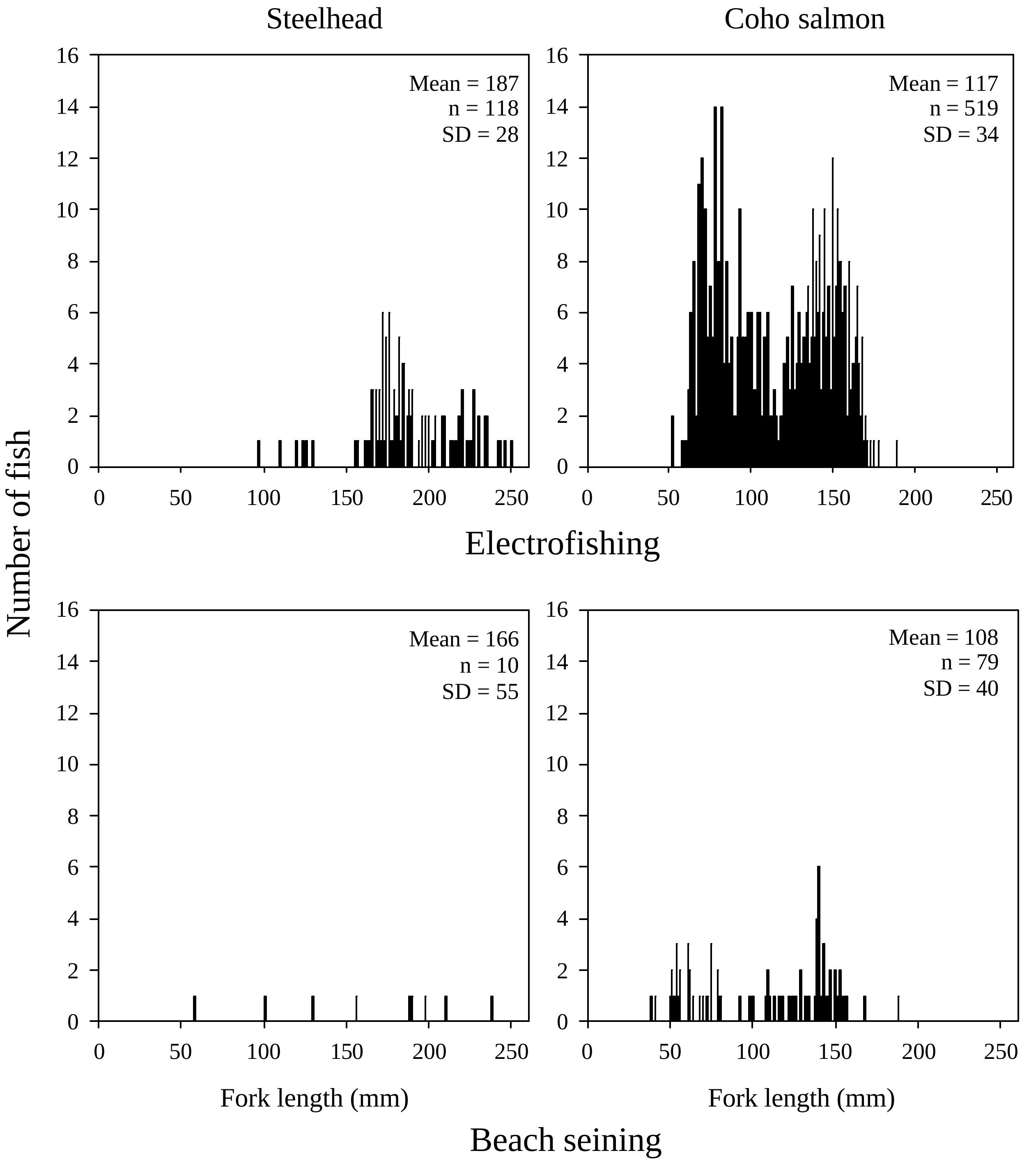

Figure 5. Fork length distributions for juvenile steelhead and juvenile coho salmon captured by electrofishing (top panels) and beach seining (bottom panels) in the lower Willamette River, 2000-2003. SD = standard deviation.

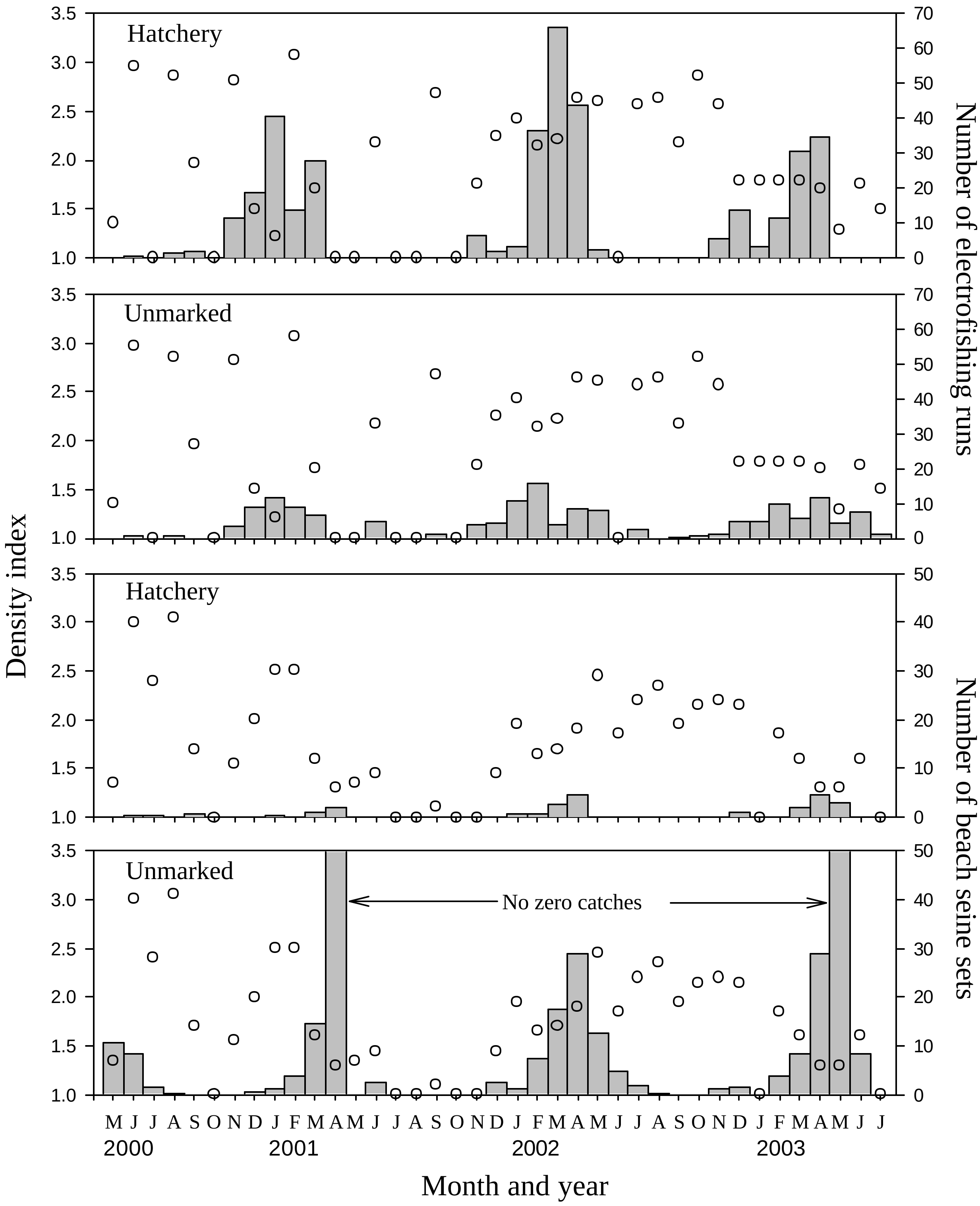

Figure 6. Monthly relative density for juvenile Chinook salmon (hatchery and unmarked) captured by electrofishing (top panels) and beach seining (lower panels) in the lower Willamette River, 2000-2003. Open circles indicate sampling effort (Z-axis).

Juvenile Chinook salmon observed in beach seine catches exhibited similar timing, except peak catches of both hatchery and unmarked fish occurred later (usually one month) than those from electrofishing (Figure 6). Densities of unmarked fish increased sharply in February and declined to near zero in July. Densities of unmarked fish were much higher than those of hatchery fish, and peak catches of unmarked fish occurred in April or May. We captured unmarked juvenile Chinook salmon in every beach seine set in April 2001 and May 2003, resulting in infinite density index values.

Due to the small number of coho salmon and steelhead collected, we did not separate these species into hatchery and unmarked groups. Relative densities for both species, derived from the electrofishing catch, were generally lower than those of Chinook salmon, and their temporal distribution varied widely (Figure 7). Densities of coho salmon in electrofishing surveys peaked during spring (April or May) in 2000, 2002, and 2003. Electrofishing effort was greatly reduced in 2001, and we observed coho salmon only during June. We captured coho salmon in every month except October. Juvenile steelhead were observed from November through June; peak densities occurred in November (2000) or May (2002 and 2003).

Densities of juvenile coho salmon and steelhead from beach seine catches were relatively low, with variable timing (Figure 7). No juvenile coho salmon were observed in 2000, but were present at low densities in December or January and May-June during 2001-2003. Steelhead were absent from beach seine catches in 2000 and 2001, but were present at low densities in 2002 (April-July and December) and 2003 (March).

Growth

Median fork lengths of hatchery Chinook salmon were significantly greater at downstream sampling sites than at upstream sites during winter, spring, and for both seasons combined (Figure 8). Differences were more pronounced during winter, when the median fork length was 14 mm greater at downstream sites than at upstream sites (compared to 9 mm greater during spring). Weight comparisons followed the same pattern; fish captured at downstream sites were significantly heavier ($P<0.01$) than those captured at upstream sites.

Length and weight differences for unmarked subyearling Chinook salmon among upper and lower sampling sites were less distinct (Figure 9). Median fork lengths were always greater (1 – 6 mm) at downstream sites but significantly different ($P=0.01$) from upstream sites only where winter and spring data were combined. Median weights were significantly greater at downstream sites during spring and both seasons combined, but not during winter ($P=0.85$).

Habitat Use (electrofishing)

Generalized Habitat Categories

We completed 898 electrofishing runs to assess habitat use. Median electrofishing catch rates of juvenile salmonids >100 mm FL were often zero, and we identified few significant differences among generalized habitat types. For all juvenile Chinook salmon (hatchery and unmarked;

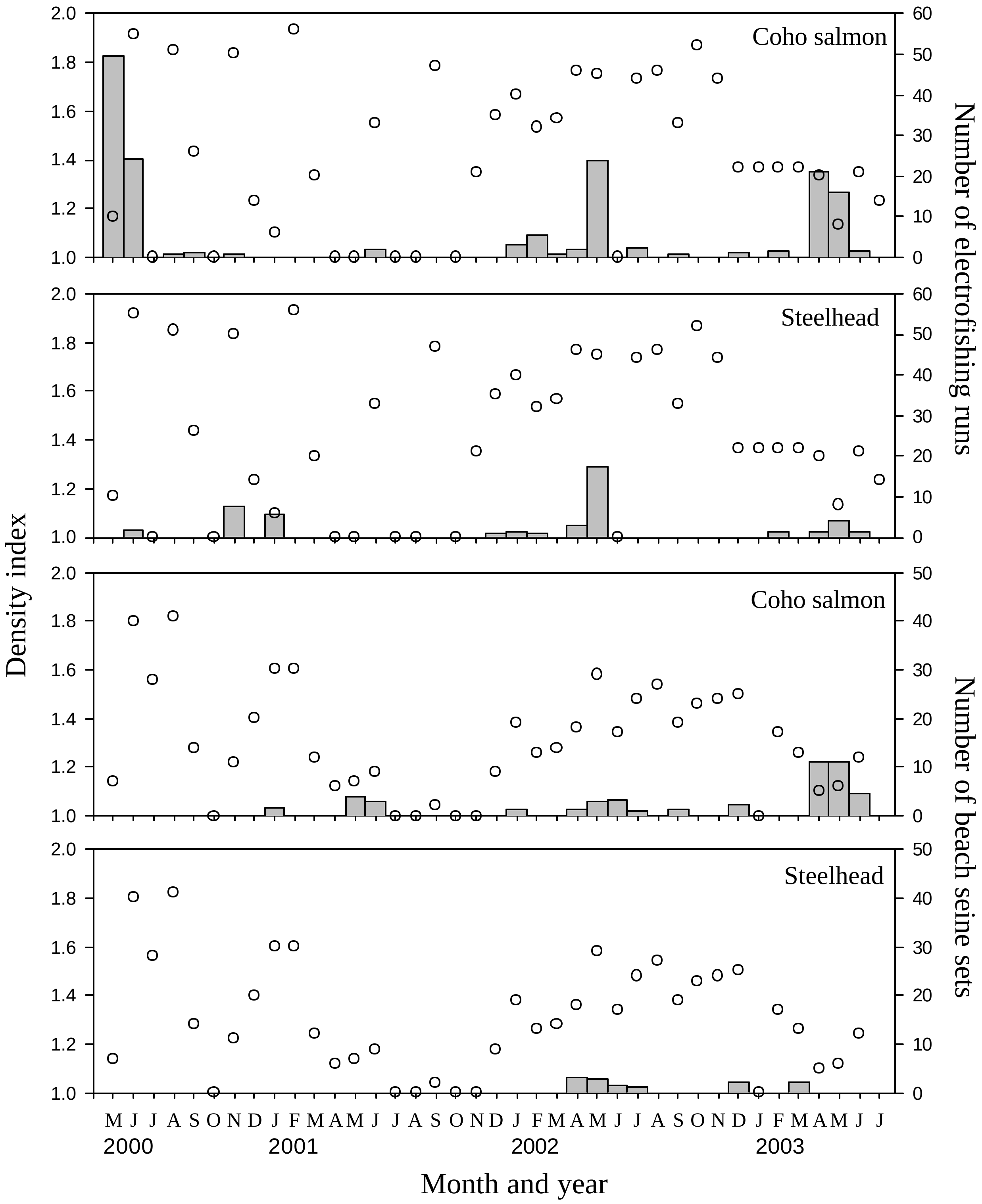

Figure 7. Monthly relative density for juvenile coho salmon and steelhead captured by electrofishing (top panels) and beach seining (lower panels) in the lower Willamette River, 2000-2003. Open circles indicate sampling effort (Z-axis).

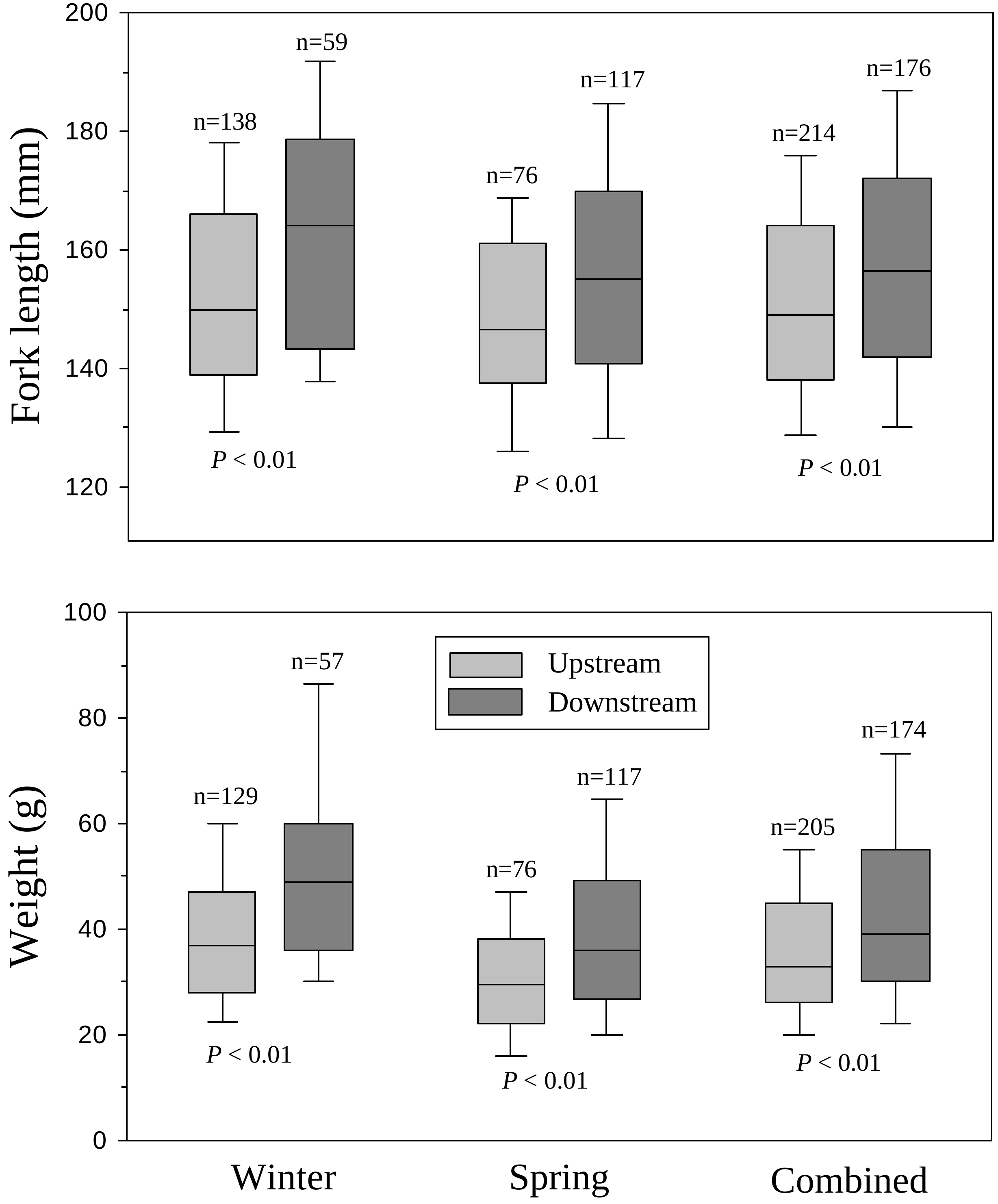

Figure 8. Seasonal fork length and weight of juvenile hatchery Chinook salmon at upstream (rkm 26.9, 32.2, and 35.2) and downstream (rkm 1.0, 1.6, and 1.9) sampling sites in the lower Willamette River, 2000 – 2003.

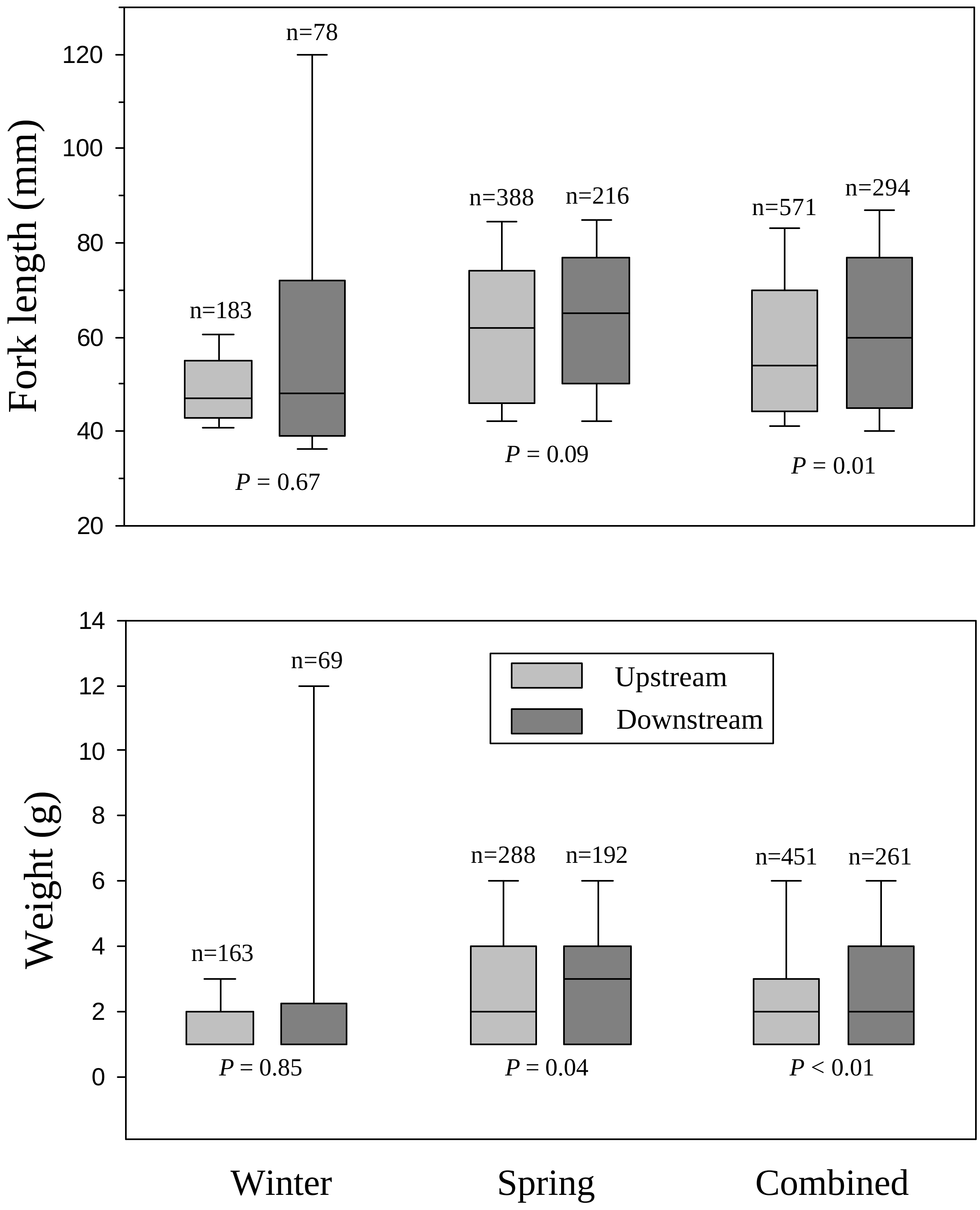

Figure 9. Seasonal fork length and weight of unmarked juvenile Chinook salmon at upstream (rkm 26.9 and 39.1) and downstream (rkm 1.0 and 6.4) sampling sites in the lower Willamette River, 2000 – 2003.

Figure 10), winter catch rates were significantly lower at seawall sites than at beach, mixed, and riprap habitats (*P*<0.01). In summer, catch rates were significantly (*P*=0.04) lower at seawall sites than at mixed-habitat sites. No significant differences were observed in spring or autumn.

We captured a relatively small number (n = 244) of unmarked Chinook salmon >100 mm FL, and observed few differences in median catch rates among habitat types (Figure 11). Catch rates were significantly higher at mixed-habitat sites than at seawalls in both winter and autumn (*P* < 0.01 and *P* = 0.04).

Hatchery Chinook salmon >100 mm FL were far more numerous (n = 1,419), and differences among habitat types were significant only during winter (*P* < 0.01); median catch rates were significantly higher at riprap and mixed habitats than at seawalls (Figure 12). Though no significant differences were evident in spring, high catches tended to occur more frequently at mixed habitats than at other habitat types. Only 22 fish were captured during summer, and no differences among habitat types were evident. Autumn catch rates did not vary significantly among habitats, but some very high catches occurred at beaches.

Most coho salmon were captured in spring (n=347) and summer (n = 23). Median catch rates at rock outcrops during spring were significantly higher than at beach, riprap, and seawall sites (*P* < 0.01; Figure 13). Catch rates at mixed habitats during spring were relatively high, but not significantly different from other habitats. No differences among habitat types were observed in summer.

Steelhead were present in low numbers, and catches were highest in spring (n = 54) and summer (n = 58). Differences in median CPUE for steelhead among habitat types were not significant in either season, though higher catches tended to occur more frequently at rock outcrops (spring and autumn) and mixed habitats (spring; Figure 13).

Clustered Habitat Categories

Differences in median catch rates among habitat groups defined by cluster analysis were similar to those of generalized habitat types. The median CPUE of juvenile Chinook salmon > 100 mm FL was significantly different among clustered groups during winter (*P* < 0.01; Figure 14). Group 3 (seawalls) catches were significantly lower than group 2 (riprap and mixed habitats) and group 5 (primarily off-channel habitats). Catch rates were significantly higher for group 2 than group 1 (rock outcrops). No significant differences among habitats were present in spring (*P* = 0.09) or summer (*P* = 0.51). Though not significantly different (*P* = 0.06), autumn catch rates for groups dominated by riprap (4 and 6) were higher than other groups

The median catch of unmarked Chinook salmon >100 mm FL in winter was greater for group 2 (riprapped and mixed habitats) than any other group, but was significantly different (*P* = 0.01) only from group 3 (seawalls; Figure 15). Catch rates in autumn differed significantly (*P* < 0.05) among habitats, but the multiple comparison procedure (Dunn's test) could not identify which pairs differed. Low catches occurred more frequently at groups 1 (primarily beaches), 3 (beach and off-channel habitats) and 5 (rock outcrops). No significant differences existed among

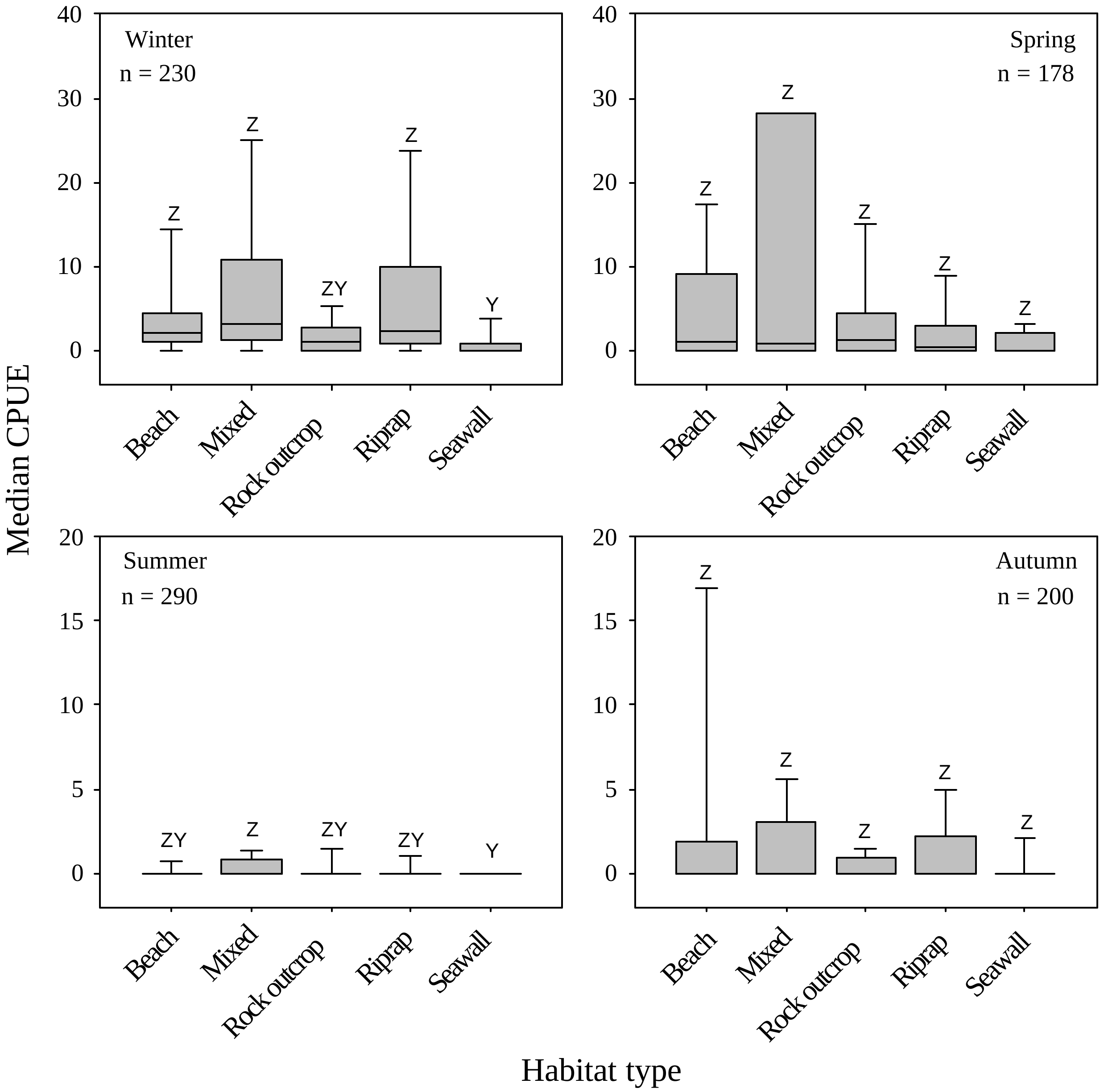

Figure 10. Median catch per unit effort (CPUE) of juvenile Chinook salmon >100 mm FL among seasons and generalized habitat types in the lower Willamette River, 2000-2003. In each chart, bars without a letter in common are significantly different (*P*<0.05). n = number of electrofishing runs.

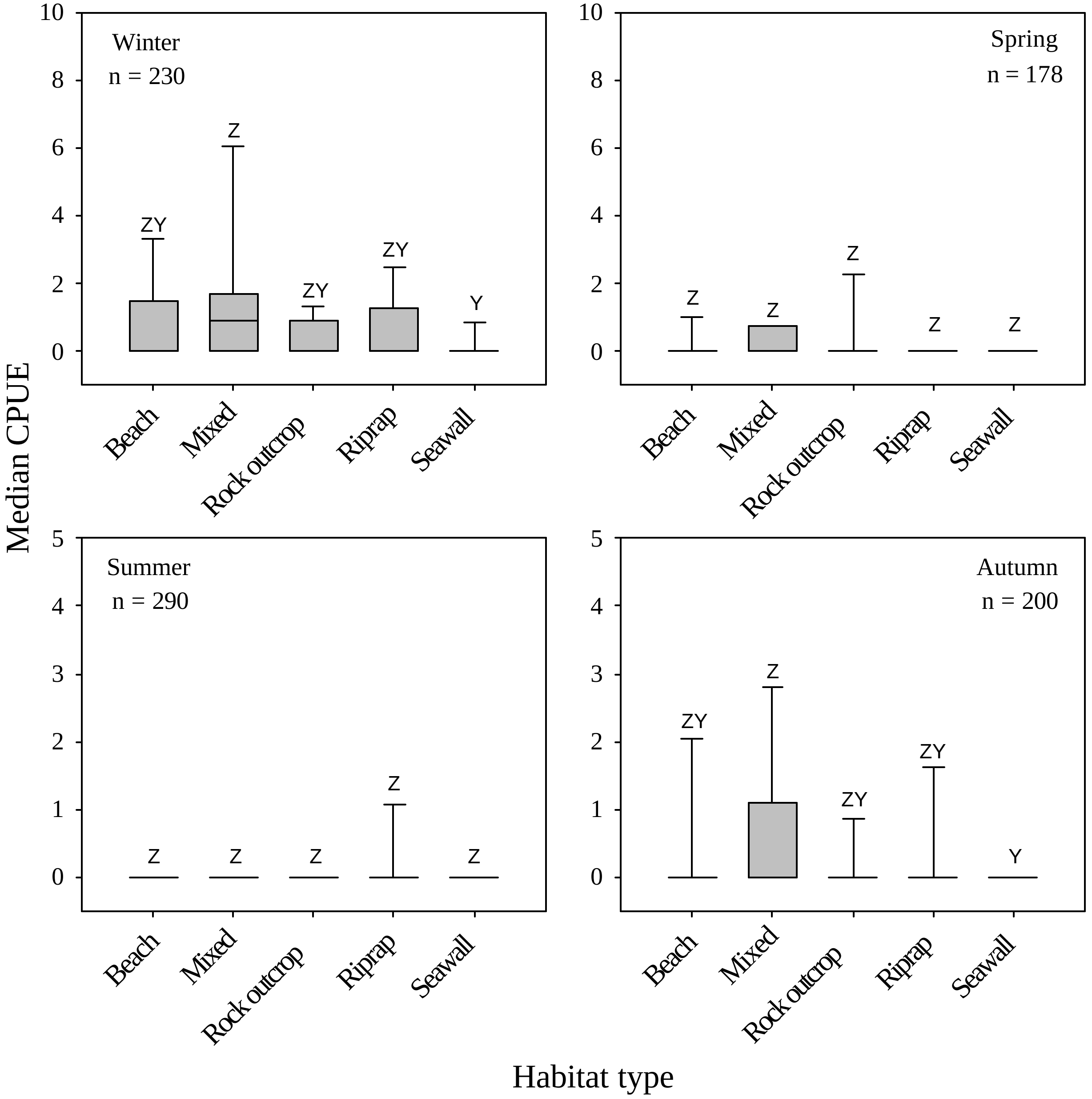

Figure 11. Median catch per unit effort (CPUE) of unmarked juvenile Chinook salmon >100 mm FL among seasons and generalized habitat types in the lower Willamette River, 2000-2003. In each chart, bars without a letter in common are significantly different (*P*<0.05). n = number of electrofishing runs.

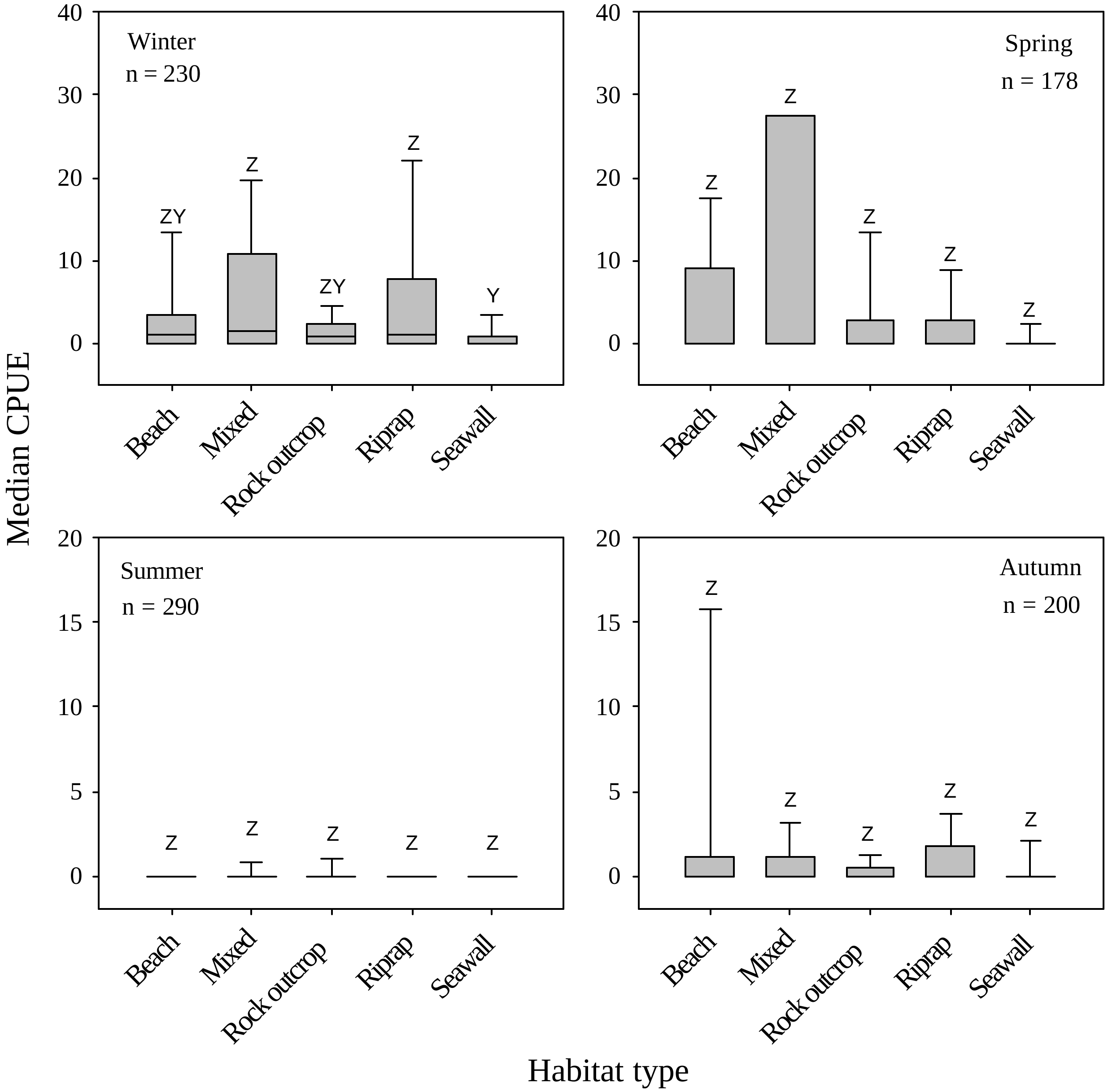

Figure 12. Median catch per unit effort (CPUE) of hatchery juvenile Chinook salmon >100 mm FL among seasons and generalized habitat types in the lower Willamette River, 2000-2003. In each chart, bars without a letter in common are significantly different (*P*<0.05). n = number of electrofishing runs.

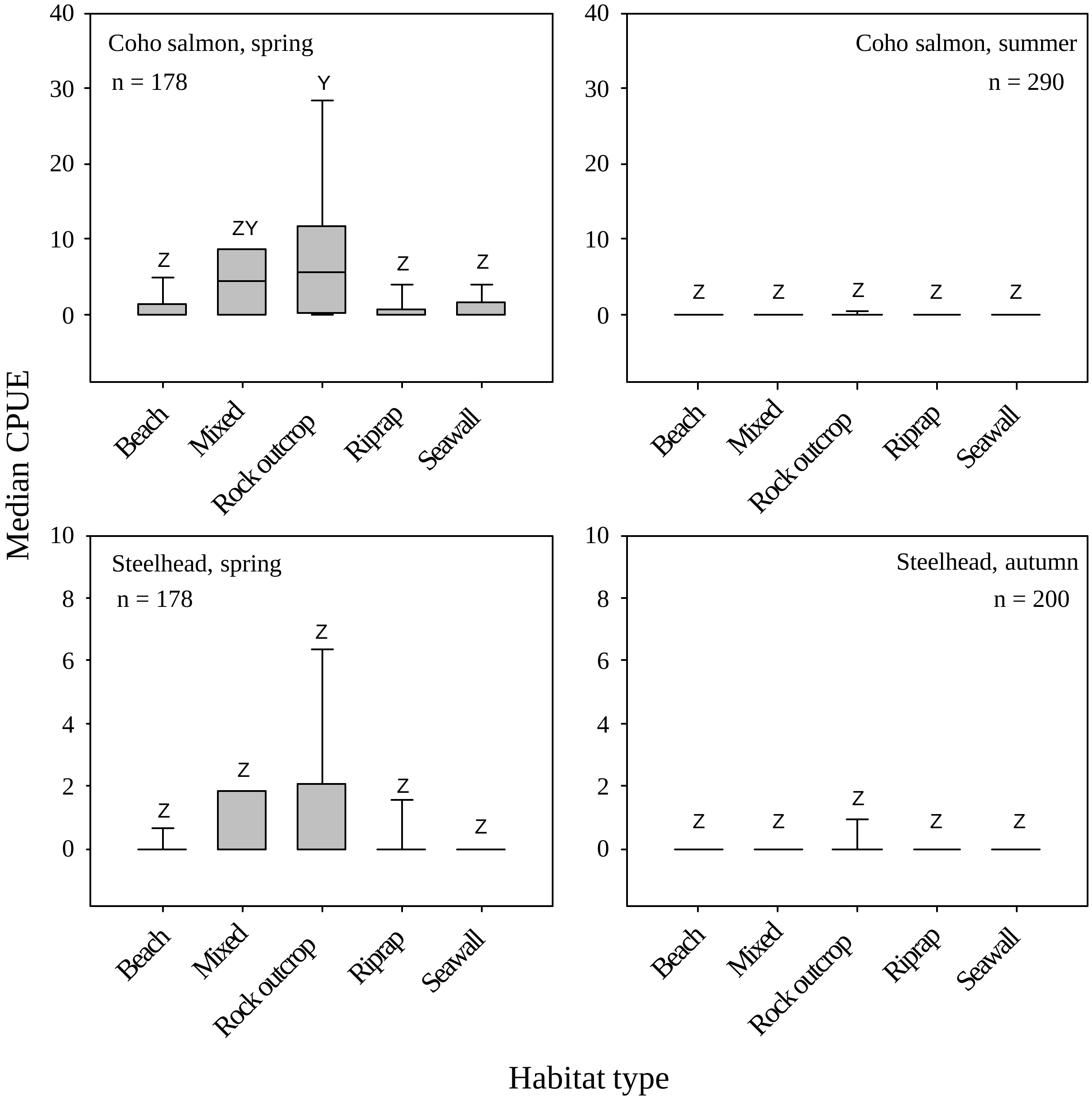

Figure 13. Median catch per unit effort (CPUE) of coho salmon and steelhead >100 mm FL among seasons and generalized habitat types in the lower Willamette River, 2000-2003. In each chart, bars without a letter in common are significantly different (*P*<0.05). n = number of electrofishing runs.

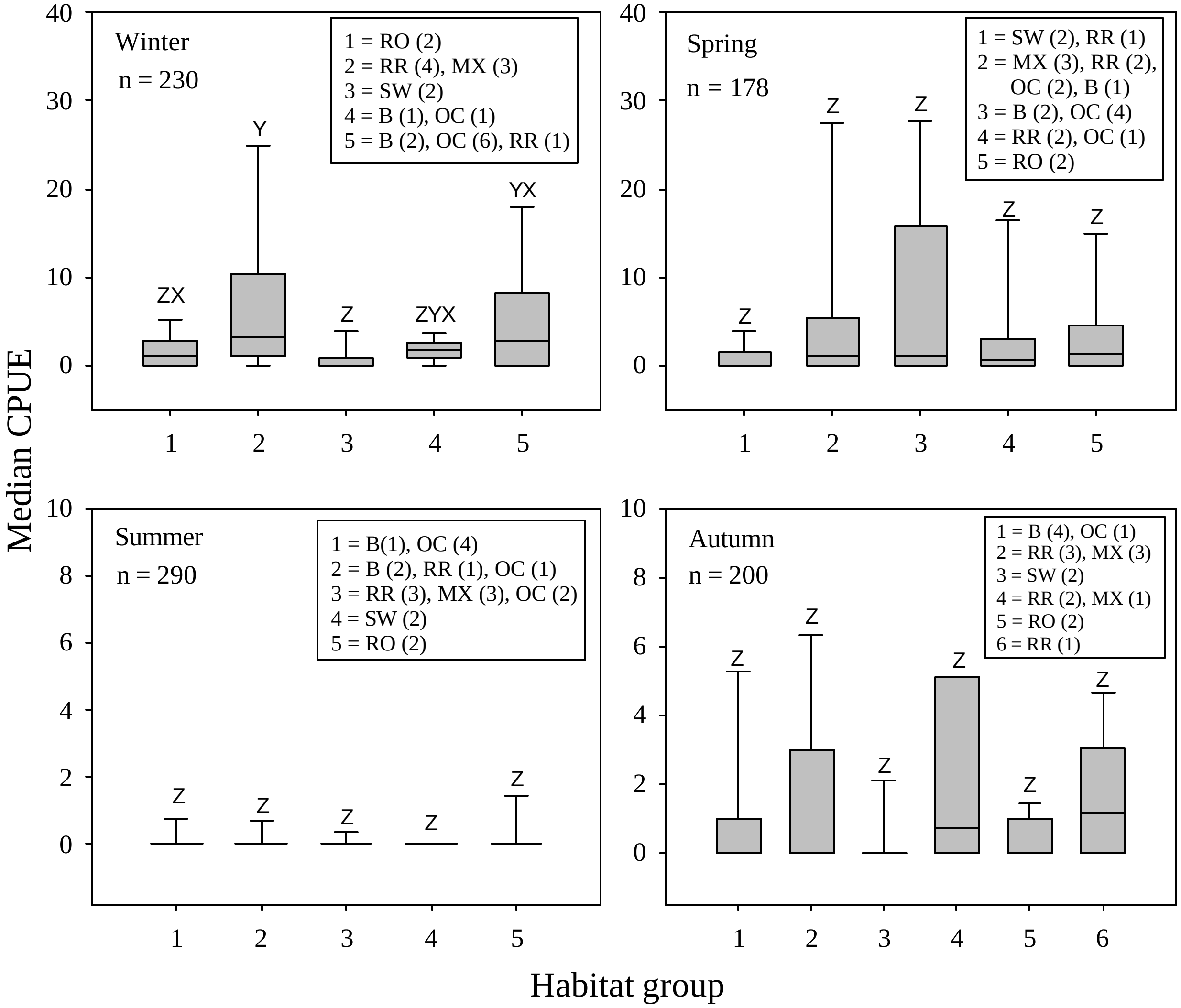

Figure 14. Median catch per unit effort (CPUE) of juvenile Chinook salmon >100 mm FL among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) present in each group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall and OC = off channel. In each chart, habitat groups without a letter in common are significantly different (*P*<0.05). n = number of electrofishing runs.

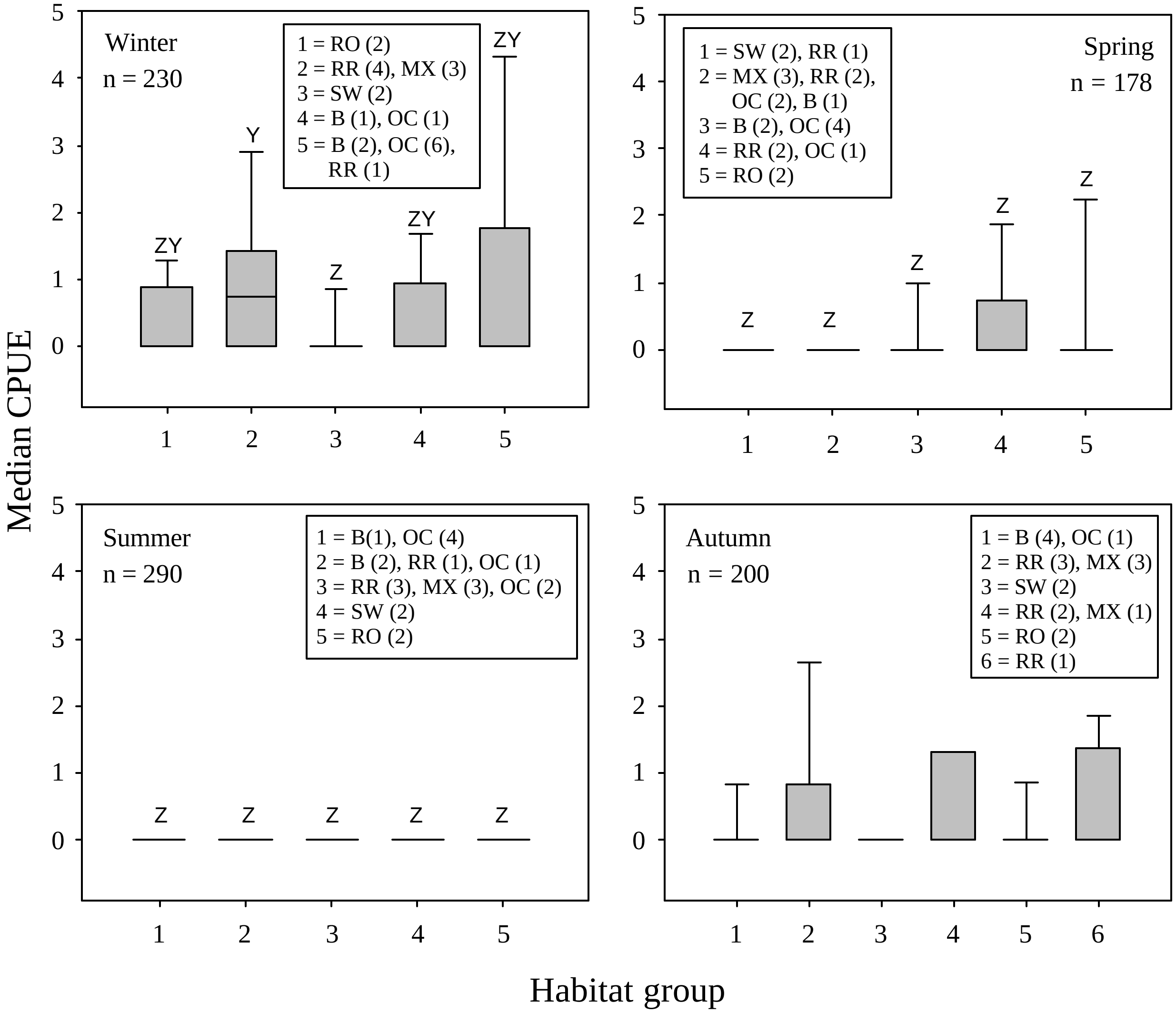

Figure 15. Median catch per unit effort (CPUE) of unmarked juvenile Chinook salmon >100 mm FL among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) present in each group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall and OC = off channel. In each chart, habitat groups without a letter in common are significantly different (*P*<0.05). n = number of electrofishing runs.

groups in spring or summer. The median, 75th percentile, and 90th percentile of catch rates were consistently low at seawalls in all seasons.

Among hatchery Chinook salmon >100 mm FL captured in winter, median catch rates were significantly lower for group 3 (seawalls) than group 2 (riprap and mixed habitats) and group 5 (primarily off-channel habitats) ($P < 0.01$; Figure 16). Results for spring were similar; median CPUE was significantly lower for group 1 (seawalls) than group 2 (mixed, riprap, and off-channel sites) and group 3 (beach and off-channel sites; $P = 0.01$). Summer and autumn catch rates were not significantly different among groups.

Differences in spring catch rates of coho salmon among clustered habitat groups were nearly identical to those for generalized habitat types (Figure 17). Group 5, consisting of two rock outcrop sites, had significantly ($P < 0.01$) higher catches of coho salmon (median CPUE = 5.8) than the other four groups (all median CPUEs = 0.0). Catches of coho salmon during summer were sparse, and no differences among groups were apparent.

No significant differences in median CPUE for steelhead among clustered habitat groups were evident, though higher catches occurred frequently at group 5 (rock outcrop) sites during spring, and the relatively low P-value (0.06) may indicate some biological significance (Figure 17).

Off-channel Habitats

Median catch rates of juvenile Chinook salmon >100 mm FL tended to be slightly higher (and high catches occurred more frequently) at off-channel sites during winter and spring, but were not significantly different from main-channel sites. For all Chinook salmon combined (unmarked and hatchery), catches were significantly ($P = 0.04$) higher at main channel sites during autumn (Figure 18). Patterns for unmarked (Figure 19) and hatchery fish (Figure 20) were similar; high catches occurred more frequently at off-channel sites during winter and spring, and at main channel sites during autumn, though none of the relationships were statistically significant. Catches of coho salmon and steelhead were generally low and did not differ significantly between off-channel and main-channel sites, though higher catches of coho salmon occurred more frequently in off-channel areas (Figure 21).

Habitat Parameters

We observed few significant differences in median CPUE among categorical habitat parameter values during spring; catches of juvenile Chinook salmon did not vary with dominant substrate type, bottom slope, transparency, or the percent of bank habitat consisting of large riprap. (Appendix Tables 1-3). Catches among bank vegetation categories (the percent of onshore habitat covered by living plants within 20 m of the waterline) differed significantly.
The median catch rate for all Chinook salmon (hatchery and unmarked) was significantly higher at sites having 21-30% vegetative coverage than at sites with 0-10% ($P = 0.05$) (Appendix Table 1). Results for unmarked fish were similar; median CPUE was highest at sites with 71-80% coverage (Appendix Table 2). Catch rates for marked fish were relatively high at sites with both large (71 – 80%) and small (21 – 30%) amounts of vegetation, and the only pairwise significant

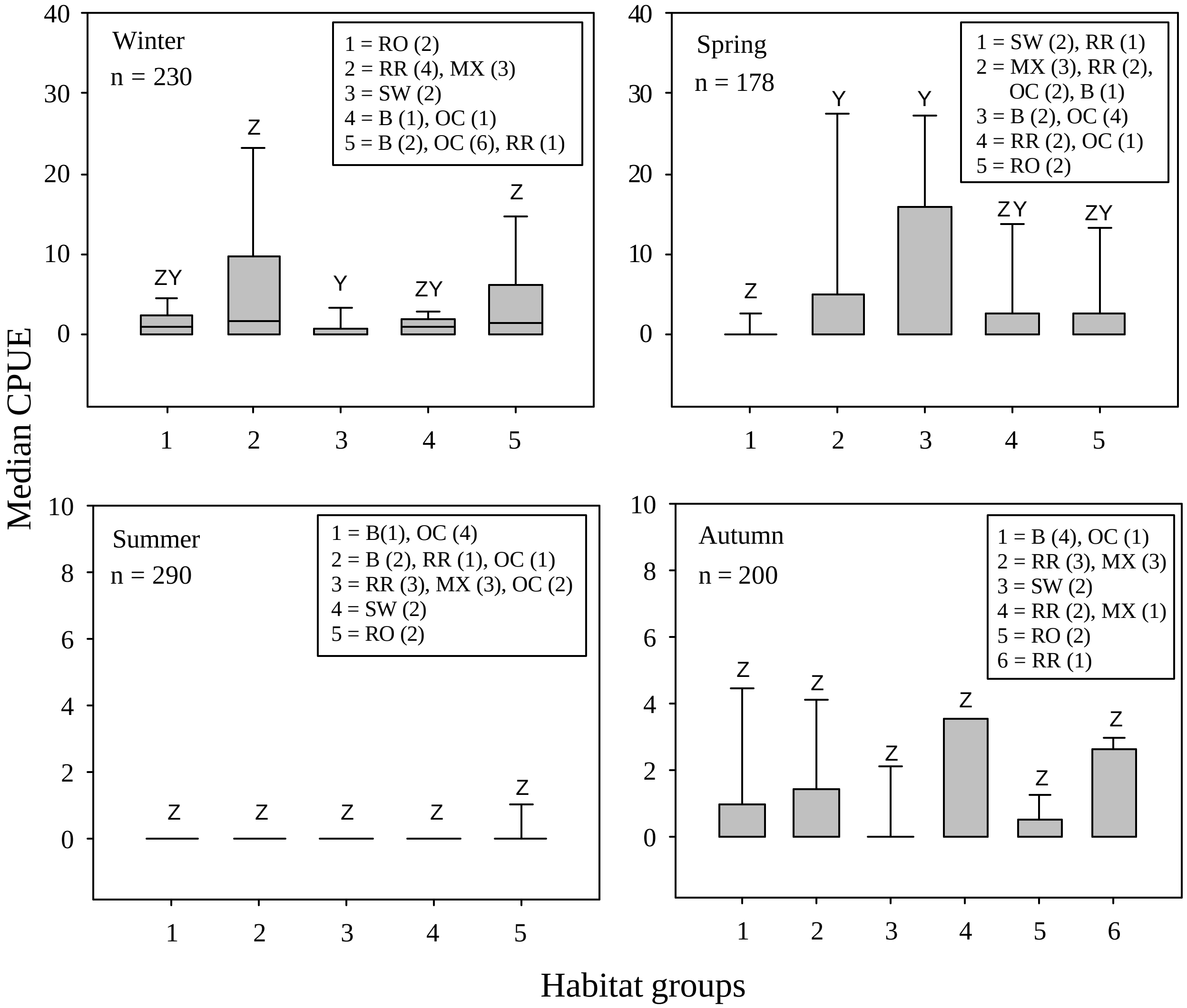

Figure 16. Median catch per unit effort (CPUE) of hatchery juvenile Chinook salmon >100 mm FL among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) present in each group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall and OC = off channel. In each chart, habitat groups without a letter in common are significantly different (*P*<0.05). n = number of electrofishing runs.

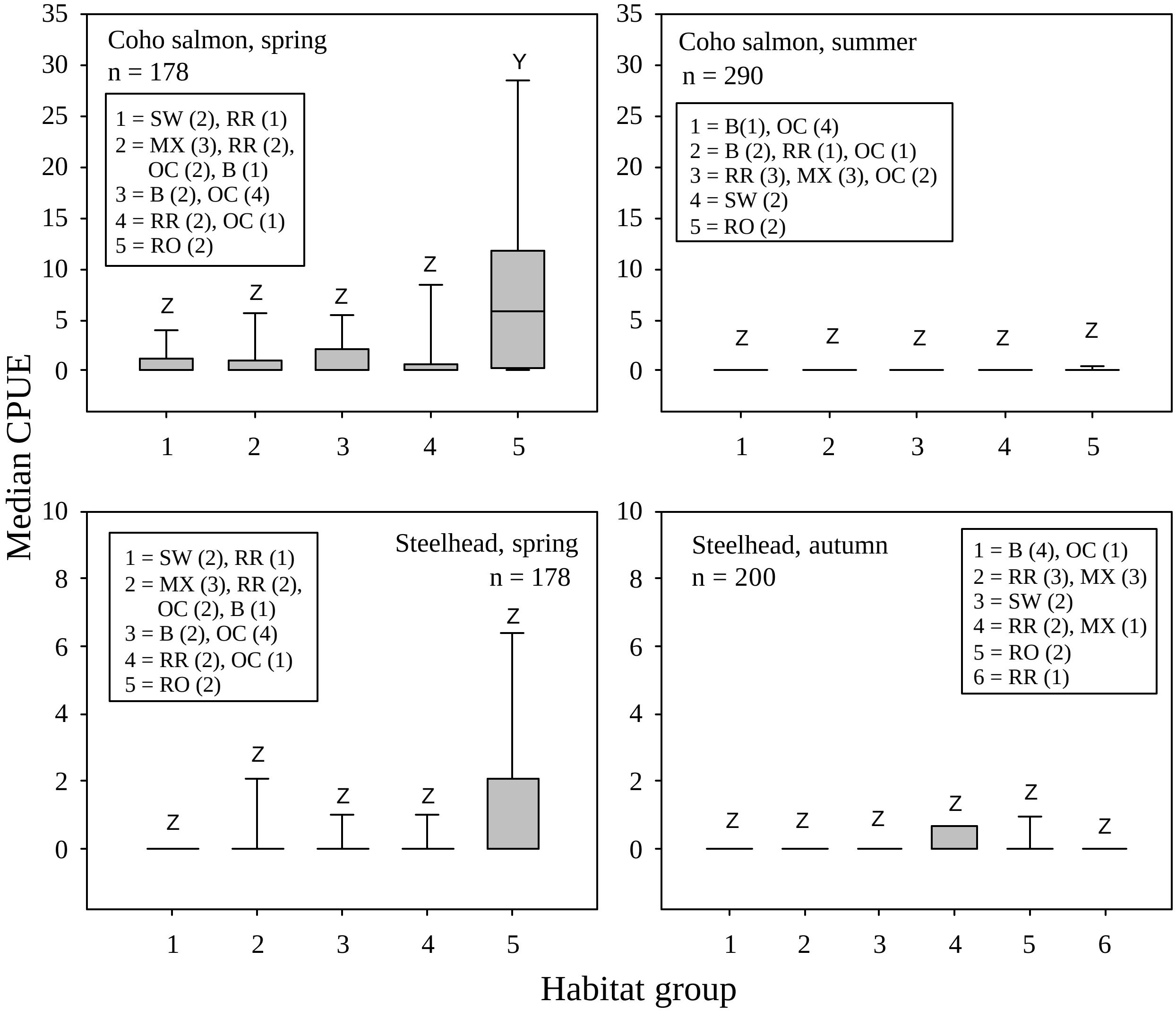

Figure 17. Median catch per unit effort (CPUE) of juvenile coho salmon and steelhead >100 mm FL among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) present in each group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall and OC = off channel. In each chart, habitat groups without a letter in common are significantly different (*P*<0.05). n = number of electrofishing runs.

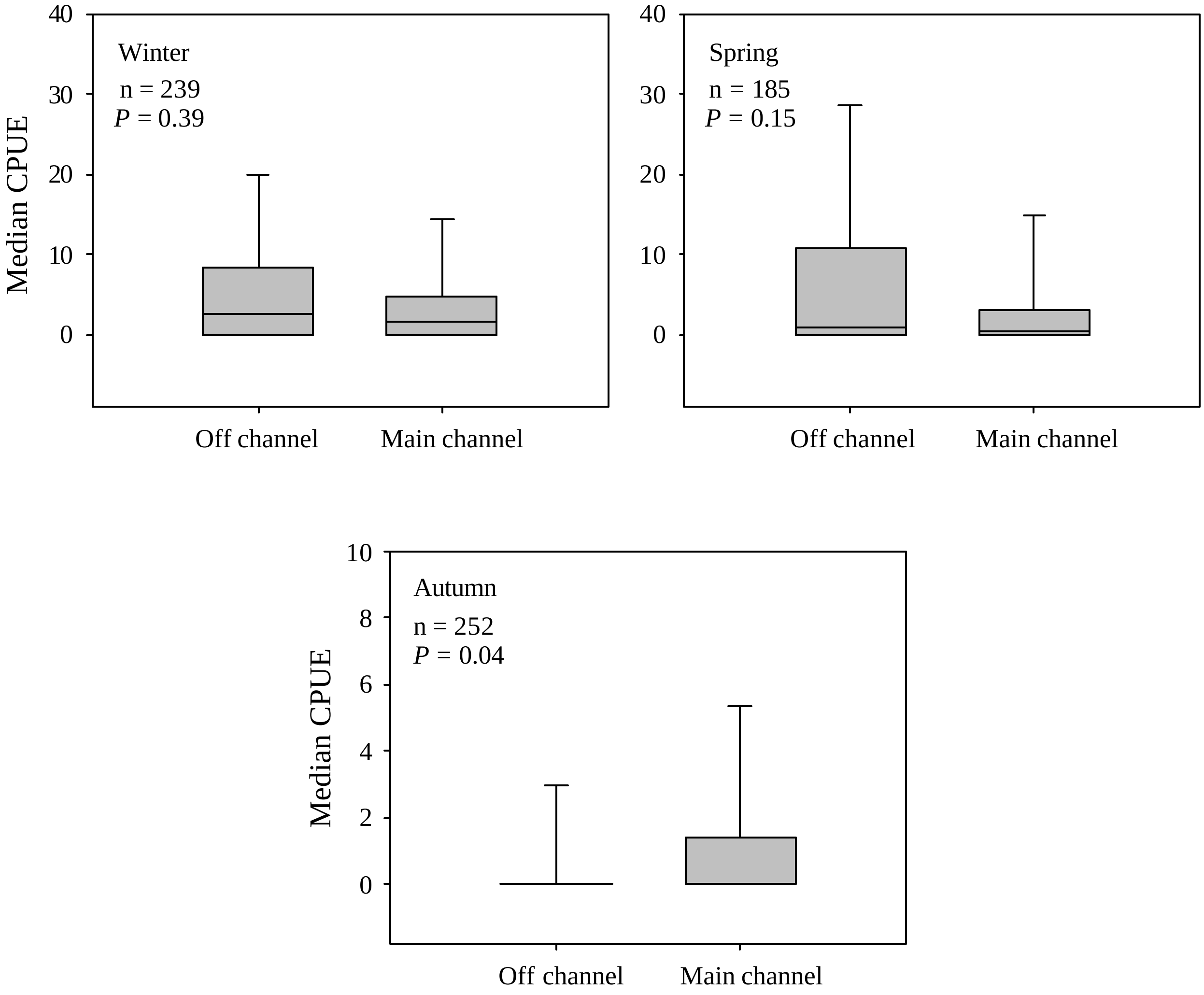

Figure 18. Median catch per unit effort (CPUE) of juvenile Chinook salmon >100 mm fork length at off-channel (alcoves, backwaters, and secondary channels) and main-channel sampling sites among seasons in the lower Willamette River, 2000-2003. n = number of electrofishing runs.

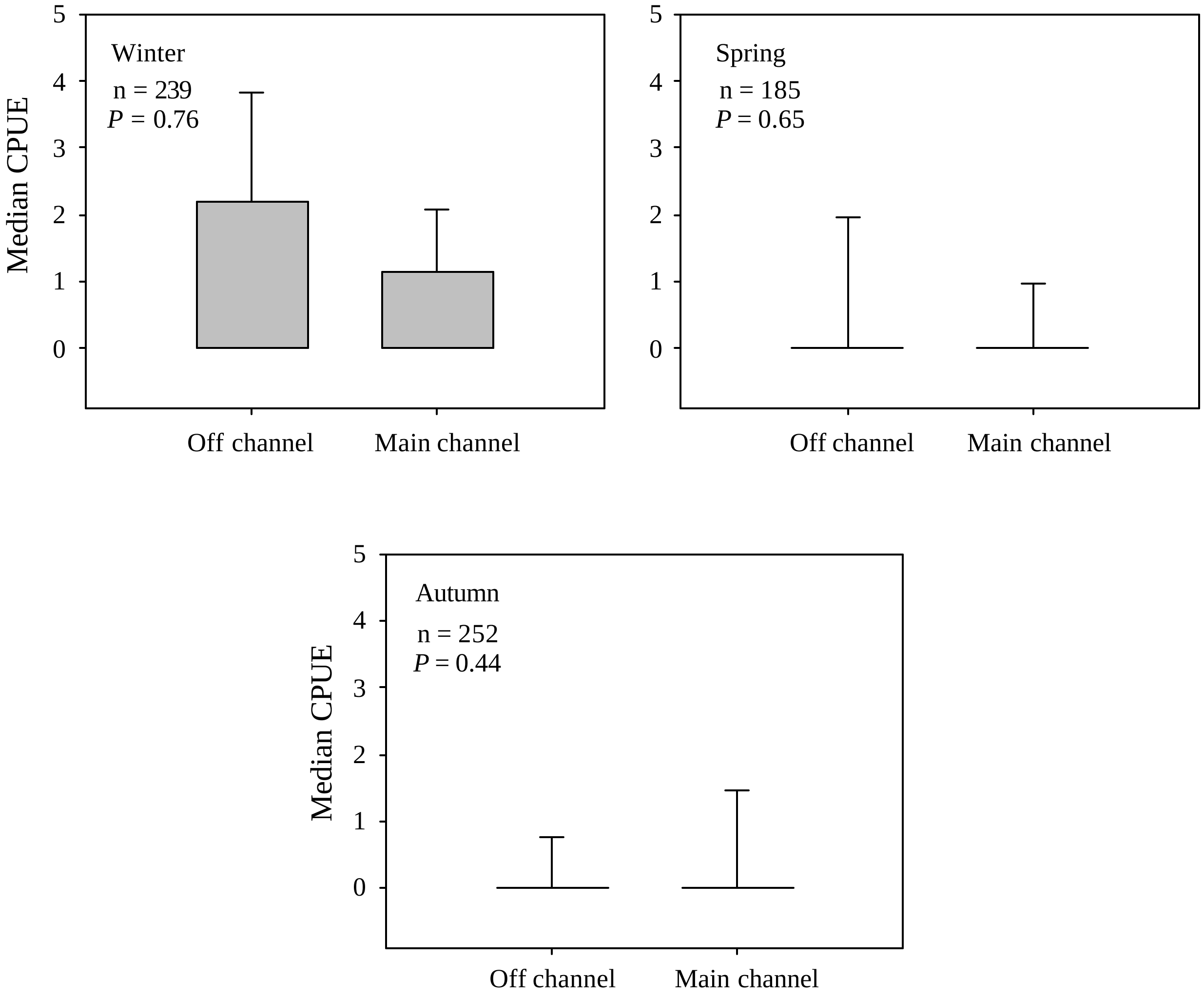

Figure 19. Median catch per unit effort (CPUE) of unmarked juvenile Chinook salmon >100 mm fork length at off-channel (alcoves, backwaters, and secondary channels) and main-channel sampling sites among seasons in the lower Willamette River, 2000-2003. n = number of electrofishing runs.

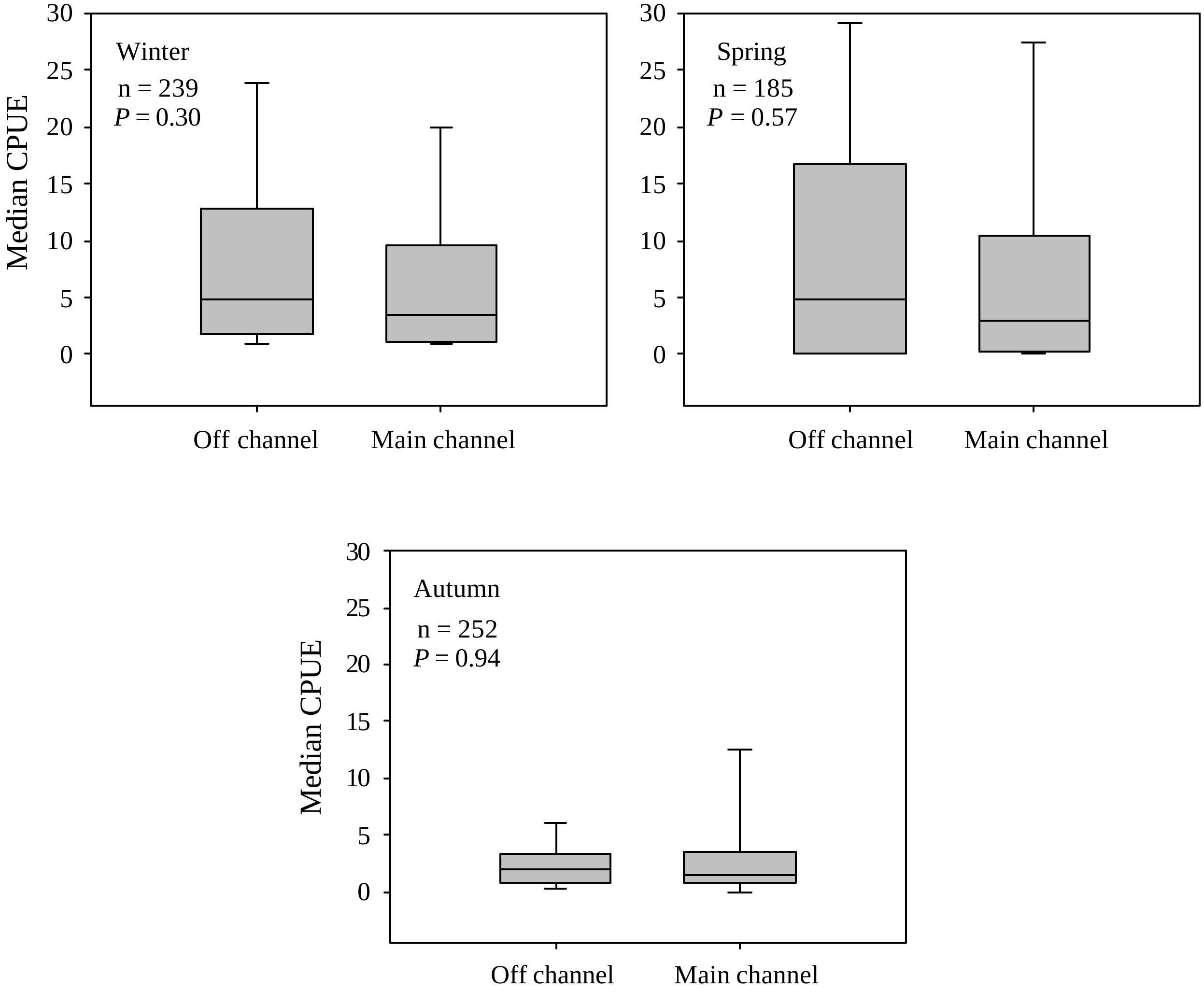

Figure 20. Median catch per unit effort (CPUE) of hatchery juvenile Chinook salmon >100 mm fork length at off-channel (alcoves, backwaters, and secondary channels) and main-channel sampling sites among seasons in the lower Willamette River, 2000-2003. n = number of electrofishing runs.

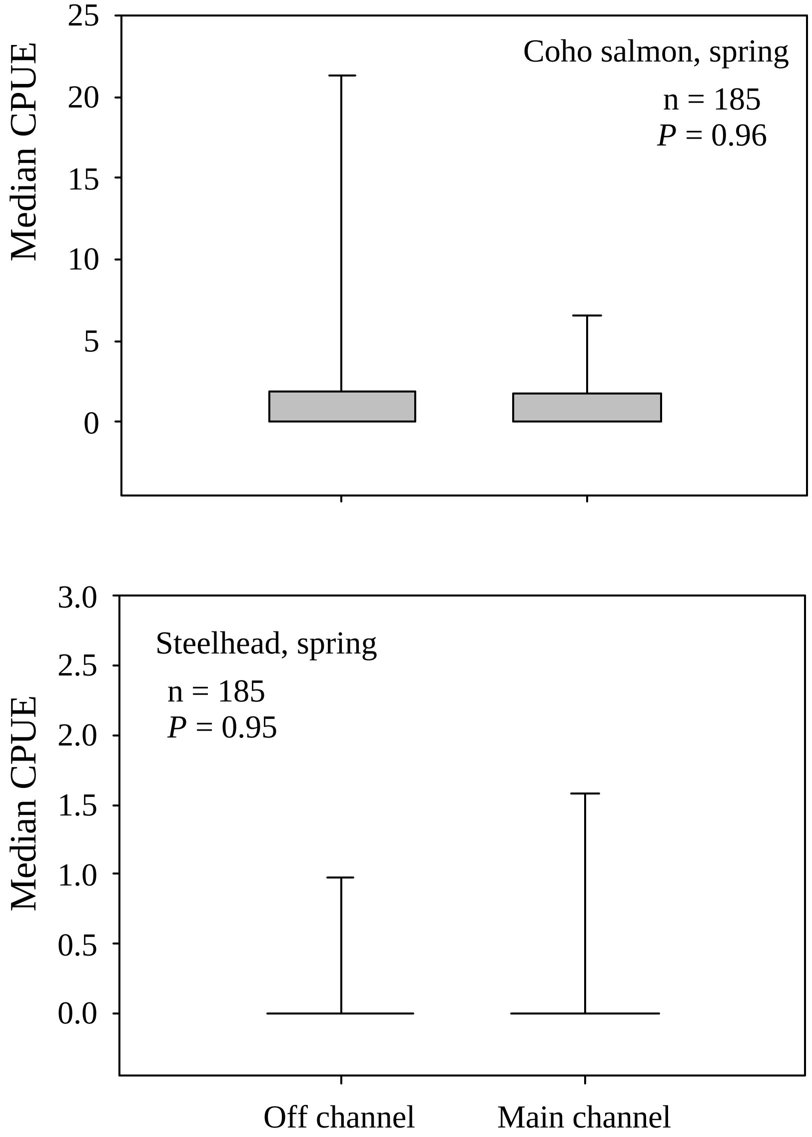

Figure 21. Median catch per unit effort (CPUE) of juvenile coho salmon and juvenile steelhead >100 mm fork length during spring at off-channel (alcoves, backwaters, and secondary channels) and main-channel sampling sites in the lower Willamette River, 2000-2003. n = number of electrofishing runs.

difference was between the 21-30% and 0 – 10% categories (Appendix Table 3). In all cases, catches were low when vegetation was sparse (<11% bank coverage). Catches did not vary significantly with the proportion of bank habitat composed of beach, except for unmarked fish during spring. Catches were significantly higher at sites consisting of 90-100% beach than at sites that were 80-89% beach (P=0.05; Appendix Table 2).

In contrast to spring, nearly every habitat parameter during winter had some statistically significant differences for catch rate among categories. For hatchery and unmarked fish combined (Appendix Table 4), median CPUE was highest at sites where sand was the major substrate type, and catches at sand-dominated sites differed significantly (P<0.01) from sites dominated by fines and bedrock. Catches were generally higher at sites having shallow depths (20 m from shore), and CPUE was significantly lower at depths of >10 m than at depths of 0.0 – 3.0 m (P<0.01). Sites that were 21-60% vegetated had significantly higher catches than sites with little or no bank vegetation (0-10%, P<0.01). Median CPUE tended to be higher where grass composed moderate proportions (11-40%) of the bank vegetation. Catches did not vary with the proportion of bank habitat consisting of beach, except the 11-20% category had the highest median CPUE and varied significantly (P<0.01) from sites consisting of 31-40% beach.

Patterns were similar for unmarked Chinook salmon captured in winter (Appendix Table 5). Catches of unmarked fish were significantly higher at sand-dominated sites than where riprap was the major substrate (P<0.01). Sites that were relatively deep (8.1->10 m) had a significantly lower median CPUE than sites where the average depth was 2.1-3.0 m. As with hatchery and unmarked fish combined, catches were lowest at sites with little or no bank vegetation (0-10%), and were significantly higher at sites that were 21-60% vegetated (P<0.01). Catches did not vary significantly with the proportion of bank vegetation composed of grass (P=0.11). Median CPUE was highest at sites composed of 51-60% beach habitat, but this category varied significantly only from sites with 31-40% beach habitat (P=0.01).

For hatchery Chinook salmon captured in winter (Appendix Table 6), variations among categories of dominant substrate, bank vegetation, and percent grass were nearly identical to those for hatchery and unmarked fish combined, and patterns for depth and percent beach followed those of unmarked fish.

Radio Telemetry

From 2001 to 2003, we released 186 radio-tagged juvenile salmonids, including 95 Chinook salmon, 63 coho salmon, and 28 steelhead (Table 1). No steelhead were tagged in 2003. More than half (57%) of all fish were of hatchery origin; the remainder were unmarked. Tagged steelhead were typically larger (mean FL 186 mm) than tagged Chinook or coho salmon (141 and 145 mm FL).

Tracking effort for the three years of telemetry totaled 401 hours (Table 2). Nearshore (53%) and offshore (47%) efforts were similar, and 66% of the effort occurred during daylight hours. We logged 591 total recoveries, and relocated 92% of the fish at least once, including 94% of the Chinook salmon, 86% of the coho salmon, and all of the steelhead (Table 1).

Table 1. Summary of radio-tagged juvenile salmonids released in the lower Willamette River, 2001-2003. H = hatchery; U = unmarked.

					Fork length (mm)			Weight (g)		
Species	Year	Number released	Number recovered	Number of relocations	Min.	Mean	Max.	Min.	Mean	Max.
Chinook salmon (U)	2001	14	13	61	108	115	125	13	15	19
Chinook salmon (H)	2001	18	18	67	118	140	150	17	25	32
Chinook salmon (U)	2002	14	12	36	112	125	166	15	22	51
Chinook salmon (H)	2002	4	3	0	160	178	186	52	63	77
Chinook salmon (U)	2003	13	13	38	123	141	156	16	27	33
Chinook salmon (H)	2003	32	30	77	131	154	180	21	35	55
Chinook salmon, total		95	89	279	108	141	186	13	28	77
Coho salmon (U)	2001	1	1	2	129	129	129	21	21	21
Coho salmon (H)	2001	17	9	18	132	144	153	21	28	34
Coho salmon (U)	2002	16	15	53	112	130	152	17	24	31
Coho salmon (H)	2002	5	5	10	140	153	161	28	39	48
Coho salmon (U)	2003	16	16	104	136	154	173	16	34	49
Coho salmon (H)	2003	8	8	60	146	157	180	27	33	41
Coho salmon, total		63	54	247	112	145	180	16	30	49
Steelhead (U)	2001	5	5	18	157	182	215	38	55	85
Steelhead (H)	2001	11	11	36	186	210	227	56	79	97
Steelhead (U)	2002	1	1	0	156	156	156	33	33	33
Steelhead (H)	2002	11	11	11	120	165	193	17	42	68
Steelhead (U)	2003	0	-	-	-	-	-	-	-	-
Steelhead (H)	2003	0	-	-	-	-	-	-	-	-
Steelhead, total		28	28	65	120	186	227	17	59	97
Total		186	171	591	108	149	227	13	33	97

Table 2. Tracking effort (h) for radio-tagged juvenile salmonids in the lower Willamette River, 2001-2003. Areas were considered nearshore if they were within 10% of the measured channel width of either riverbank. Off-channel habitats include alcoves, lagoons, side channels, and other areas not associated with the primary river channel.

Tracking category	2001	2002	2003	Total
Nearshore	54.3	57.1	75.9	187.3
Offshore	63.7	49.5	100.6	213.8
Off-channel	8.2	8.3	14.3	30.8
Day	84.8	72.4	106.2	263.4
Night	33.2	34.2	70.3	137.7
All locations	118.0	106.6	176.5	401.1

About 89% of the telemetry recoveries occurred in the main river channel. Off-channel recoveries occurred primarily in Multnomah Channel, the Swan Island lagoon, the east channel and lagoon at Ross Island, the alcove at Cedar Oak Island, and the west channel / alcove at Goat Island. Among fish we relocated, 23% were observed at an off-channel site at least once, including 29% of the Chinook salmon, 28% of the coho salmon, and 4% of the steelhead. Multnomah Channel was the most frequently used off-channel area (55% of off-channel recoveries), followed by the east channel and lagoon at Ross Island (21%).

Multnomah Channel terminates in the Columbia River, providing an alternative passage route for fish leaving the Willamette River. Overall, 12% of our radio-tagged fish used Multnomah Channel, including 16 of 89 (18%) Chinook salmon, 7 of 54 (13%) coho salmon, and 0 of 28 (0%) steelhead. However, many fish (71%) were never relocated downstream of the head of Multnomah Channel; their passage route remains undetermined.

River Flow

Flow regimes and the timing of radio telemetry efforts varied among years (Figure 22). In general, the timing of radio tracking corresponded to a period of moderate, relatively stable flows in 2001, relatively low, stable flows in 2002, and higher, more variable flows in 2003. Median daily April – June flows ranged from 21 kcfs (2001 and 2003) to 24 kcfs (2002), but differed significantly ($P < 0.01$) only between 2001 and 2002.

Statistical differences in river flow among years during the radio tracking periods were more pronounced. In 2001, median flow during the tracking period (April 25 – June 13) was 20 kcfs (range 13-34). Median flow during the 2002 tracking period (June 1 – June 27) was 17 kcfs (range 12–25) kcfs, and was 33 kcfs (range 18-63) during 2003 (April 14 – May 23). All pairwise comparisons differed significantly ($P<0.01$)

Migration Rates and Residence Times

Median migration rates were significantly higher for Chinook salmon (11.3 km/d) and steelhead (12.5 km/d) than for coho salmon (4.6 km/d; Figure 23). Hatchery Chinook salmon migrated

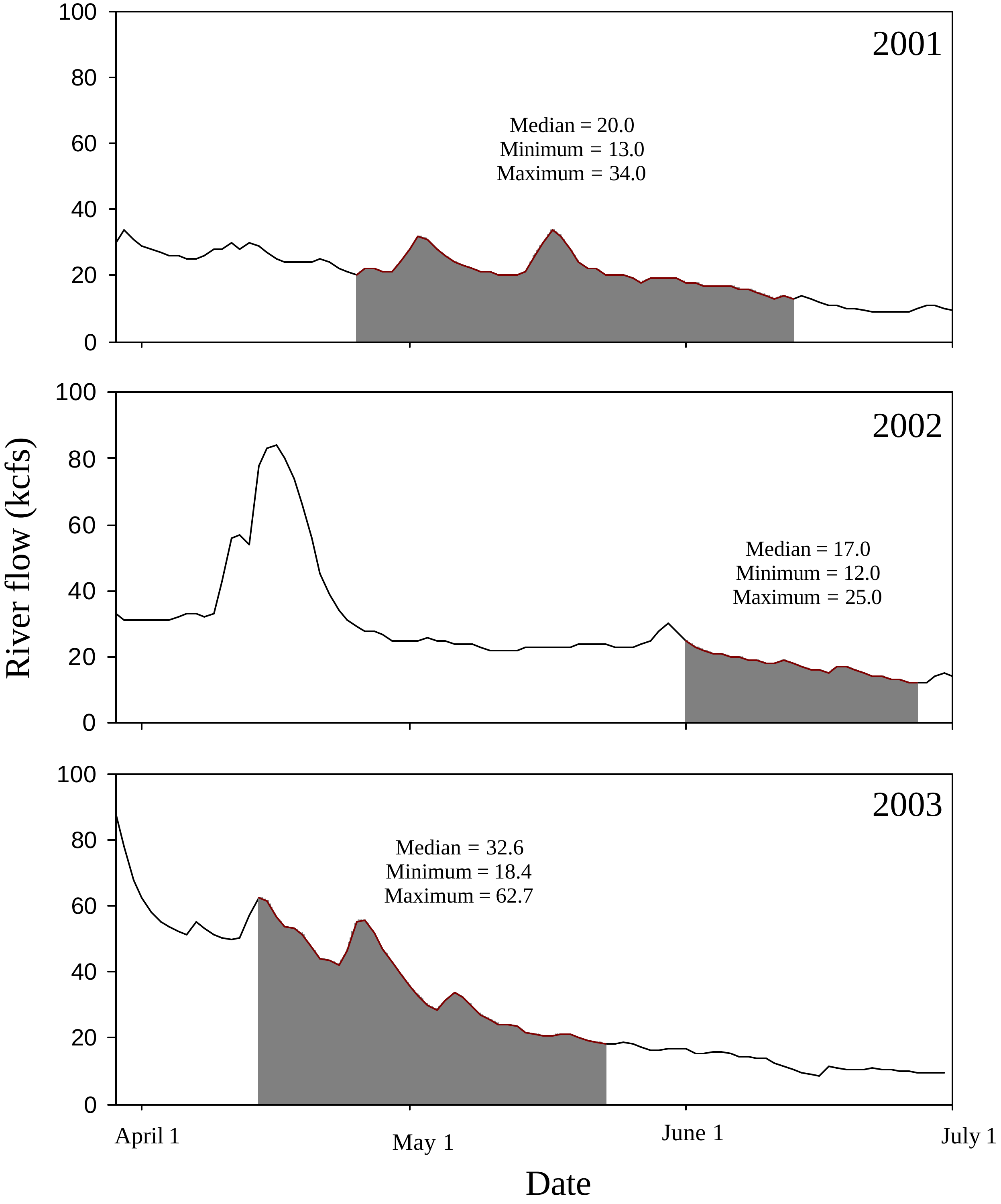

Figure 22. April – June hydrographs for the lower Willamette River, 2001 – 2003. Shaded areas represent the period of juvenile salmonid radio tracking efforts. Median, minimum, and maximum daily flows were calculated for the tracking period only.

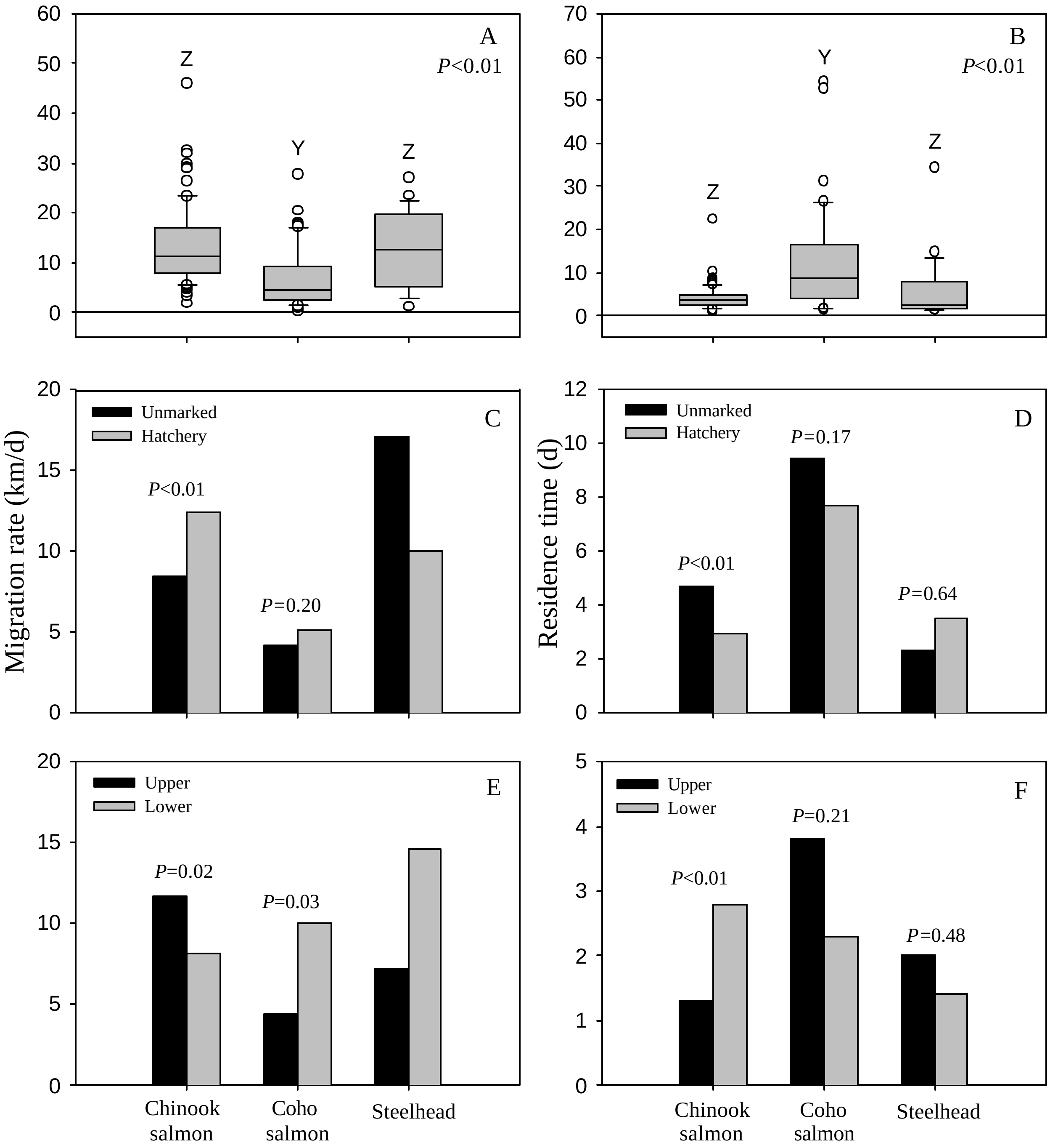

Figure 23. Median migration rates and residence times for juvenile Chinook salmon (n = 77), coho salmon (n = 46), and steelhead (n = 19) in the lower Willamette River, 2001 - 2003. Charts A-B are overall values, charts C-D compare unmarked vs. hatchery fish, and charts E-F compare upper (rkm 22.6 – 42.6) and lower (rkm 0.0 – 22.5) sections of the study area. In charts A and B, species without a letter in common are significantly different, and open circles denote outliers. *P*-values are not shown where the test power was low (<0.80).

significantly faster (12.4 km/d) than unmarked fish (8.4 km/d); coho salmon and steelhead migration rates were not significantly different between hatchery and unmarked fish. Chinook salmon traveled significantly faster (11.7 km/d) in the upper portion of the study area than in the lower portion (8.1 km/d); conversely, coho salmon traveled significantly faster in the lower portion (10.0 km/d) than in the upper portion (4.4 km/d). Steelhead appeared to travel faster in the lower portion than in the upper portion, but the sample size was small (n=19), and statistical power was low (<0.8).

Residence times, inversely related to migration rate, varied similarly (Figure 23). Coho salmon residence times were more variable (range 1.4 – 54.1 d) than those of Chinook salmon (0.9 – 22.3) or steelhead (1.2 – 34.2), and their median residence time was significantly longer (8.7 days) than Chinook salmon (3.4 days) or steelhead (2.5 days). Unmarked Chinook salmon had significantly longer residence times (4.7 days) than hatchery fish (2.9 days). Residence times were not significantly different between marked and unmarked coho salmon and marked and unmarked steelhead. Chinook salmon spent significantly more time in the lower study area (2.8 days) than in the upper portion (1.3 days). Median residence times for coho salmon were considerably longer in the upper portion (3.8 days) than in the lower portion (2.3 days), but did not differ significantly. Again, statistical power was low (<0.8) for steelhead comparisons (hatchery vs. unmarked and upper vs. lower study area).

Migration rates and residence times also varied among years (Figure 24). The median migration rate for Chinook salmon was significantly faster in 2003 (15.7 km/d) than in 2002 (7.3 km/d) or 2001 (8.6 km/d). Coho salmon migrated at a significantly faster rate in 2001 (17.1 km/d) than in 2002 (4.8 km/d) or 2003 (2.6 km/d). The sample size for steelhead was too small to analyze statistically, but median migration rates in 2001 (16.3 km/d) was considerably higher than in 2002 (4.7 km/d). Patterns for median residence time were identical but inverse; Chinook salmon remained in the study area for a significantly shorter period of time in 2003 (2.5 d) than in 2002 (5.4 d) or 2001 (4.5 d). Median residence time was significantly longer for coho salmon in 2003 (15 d) than in 2002 (8.3 d) or 2001 (1.7 d).

Factors Influencing Migration Rate

Simple linear regressions identified several variables that helped explain variation in migration rates, especially for Chinook salmon. Migration rates for both Chinook and coho salmon tended to increase linearly with flow (Figure 25), and these regressions had the highest r^2 values among any of the relationships we examined (0.385 for Chinook salmon and 0.476 for coho salmon). River flow was not a significant predictor of steelhead migration rates ($P = 0.23$).

Migration rate was positively related to fork length for Chinook salmon, and explained a considerable amount of the variation ($r^2 = 0.332$; Figure 26). For coho salmon, the relationship between fork length and migration rate was weak ($r^2 = 0.091$), and unlike Chinook salmon, migration rate tended to decrease with increasing fork length. In addition, the power of this regression was low (0.53). There was no significant relationship between migration rate and fork length for steelhead.

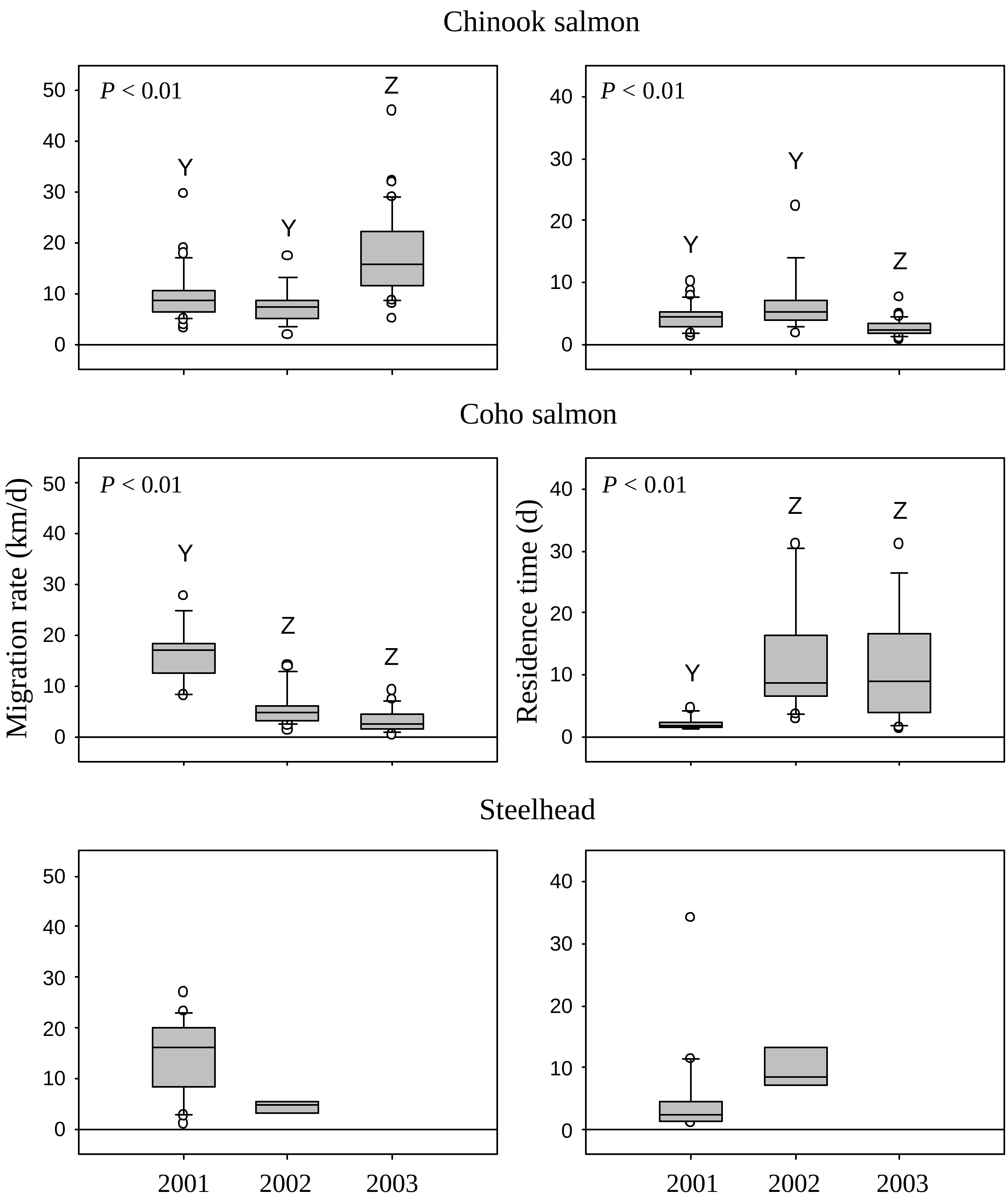

Figure 24. Migration rates and residence times by year (2001-2003) for radio tagged juvenile Chinook salmon, coho salmon, and steelhead in the lower Willamette River. No steelhead were tagged in 2003. In each chart, bars without a letter in common are significantly different (*P*<0.05); open circles denote outliers.

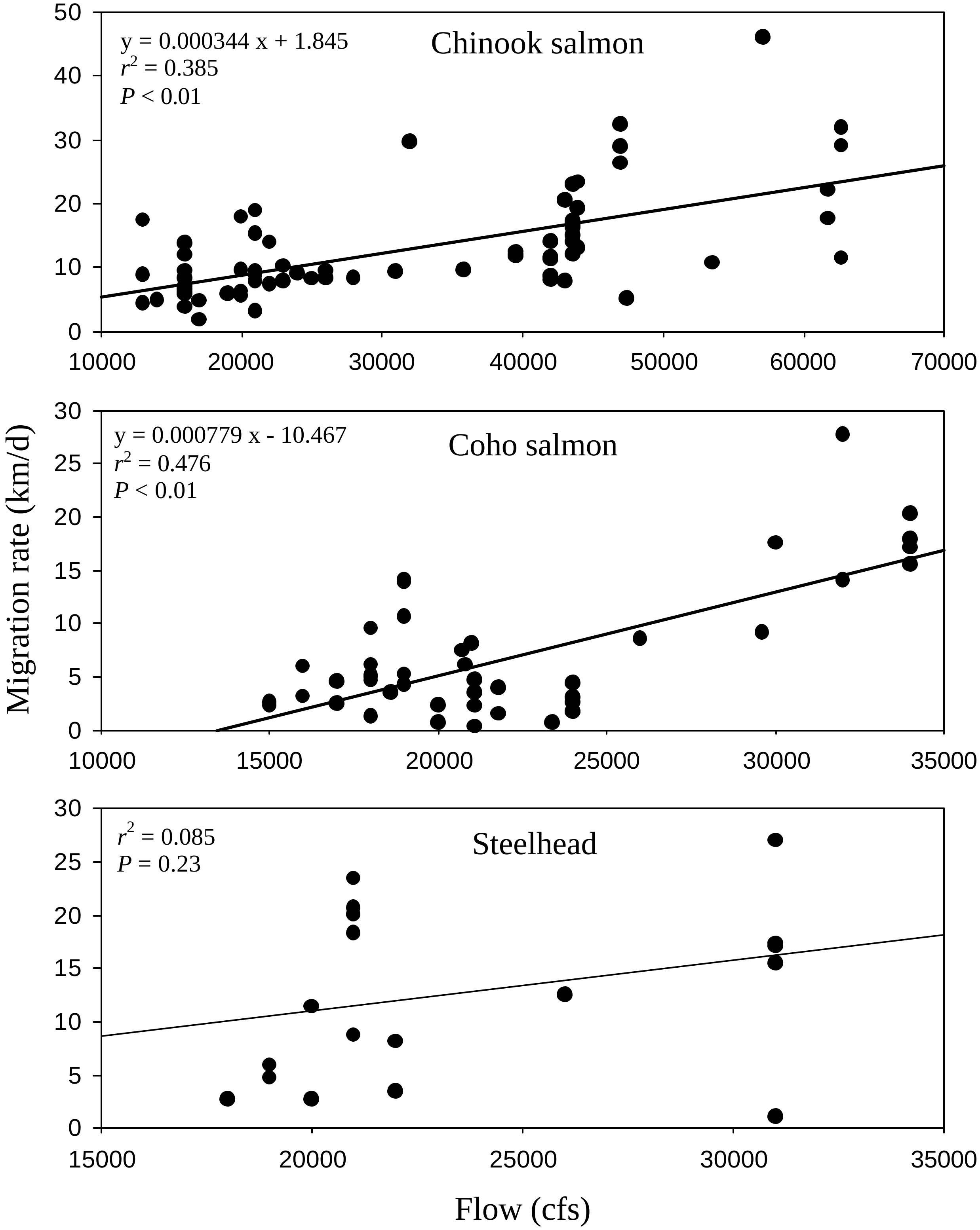

Figure 25. Linear regressions of migration rate on river flow (on last recovery date) for juvenile Chinook salmon, coho salmon, and steelhead in the lower Willamette River, 2001-2003.

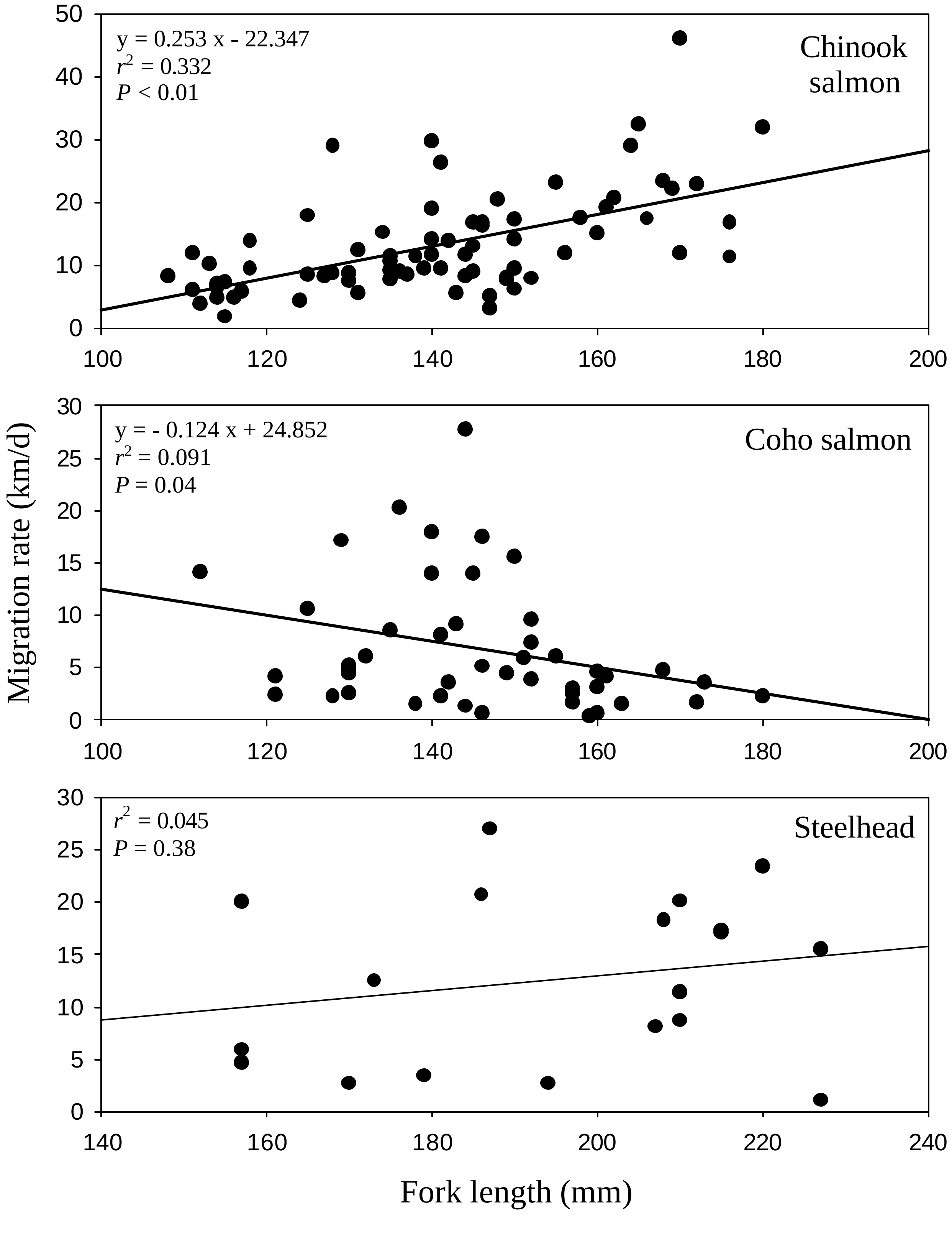

Figure 26. Linear regressions of migration rate on fork length for juvenile Chinook salmon, coho salmon, and steelhead in the lower Willamette River, 2001 – 2003.

Release day was negatively related to migration rate (Figure 27) for Chinook salmon (r^2 = 0.232); fish released earlier in the year tended to migrate faster. We detected no relationship between release day and migration rates of coho salmon and steelhead.

Temperature was a significant predictor of migration rates (Figure 28) for Chinook salmon but explained a relatively small amount of variation (r^2 = 0.159). Temperature and migration rate appeared to be positively related to coho salmon migration rates, though the test power (0.50) and r^2 (0.088) values were low.

We performed multiple linear regression on migration rate data, with river flow, fork length and release day as independent variables. Temperature was not included because it was a strong covariate of release day. For Chinook salmon, the three variables explained 44.5% of the variation in migration rate, though only river flow and fork length were statistically significant (Table 3). For coho salmon, river flow, fork length, and release day explained 67% of the variation in migration rate; river flow and release day were significant variables. No significant relationships were observed for steelhead.

Habitat Use (radio telemetry)

The majority of radio telemetry relocations occurred offshore (>10% of the measured channel width). Offshore relocation rates were 76.3% for Chinook salmon, 57.1% for coho salmon, and 75.4% for steelhead. Nearshore relocations of Chinook salmon (P=0.01) and coho salmon (P<0.01) varied significantly with the relative availability of habitat types (Figure 29). Radio-tagged Chinook salmon were recovered at lower-than-expected rates at rock and riprap habitats and at a slightly higher-than-expected rate near pilings. Juvenile coho salmon were recovered at a much higher rate than expected at beaches and appeared to under-utilize artificial habitats such as riprap and fill. We relocated a small number of steelhead (n=16) near shore; these were often associated with beaches and rock outcrops, but the sample size was too small to discern differences among habitats.

Relocation frequencies of radio tagged juvenile salmonids across the river channel indicated Chinook salmon and steelhead were distributed relatively evenly from the west bank to the east bank (Figure 30). Coho salmon were not distributed evenly across the river channel (P < 0.01) and showed an affinity for areas close to shore.

Day and night channel distributions were similar for Chinook salmon and coho salmon, but steelhead appeared to move closer to shore (especially the west bank) at night (Figure 31). Again, the sample size of steelhead was too small to determine if this pattern was statistically significant.

In the upper portion of the study area, Chinook salmon and steelhead were evenly distributed across the river channel, but coho salmon appeared to favor nearshore areas (P < 0.01; Figure 31). Relocations in the lower portion of the study area were evenly distributed across the river channel for all three species.

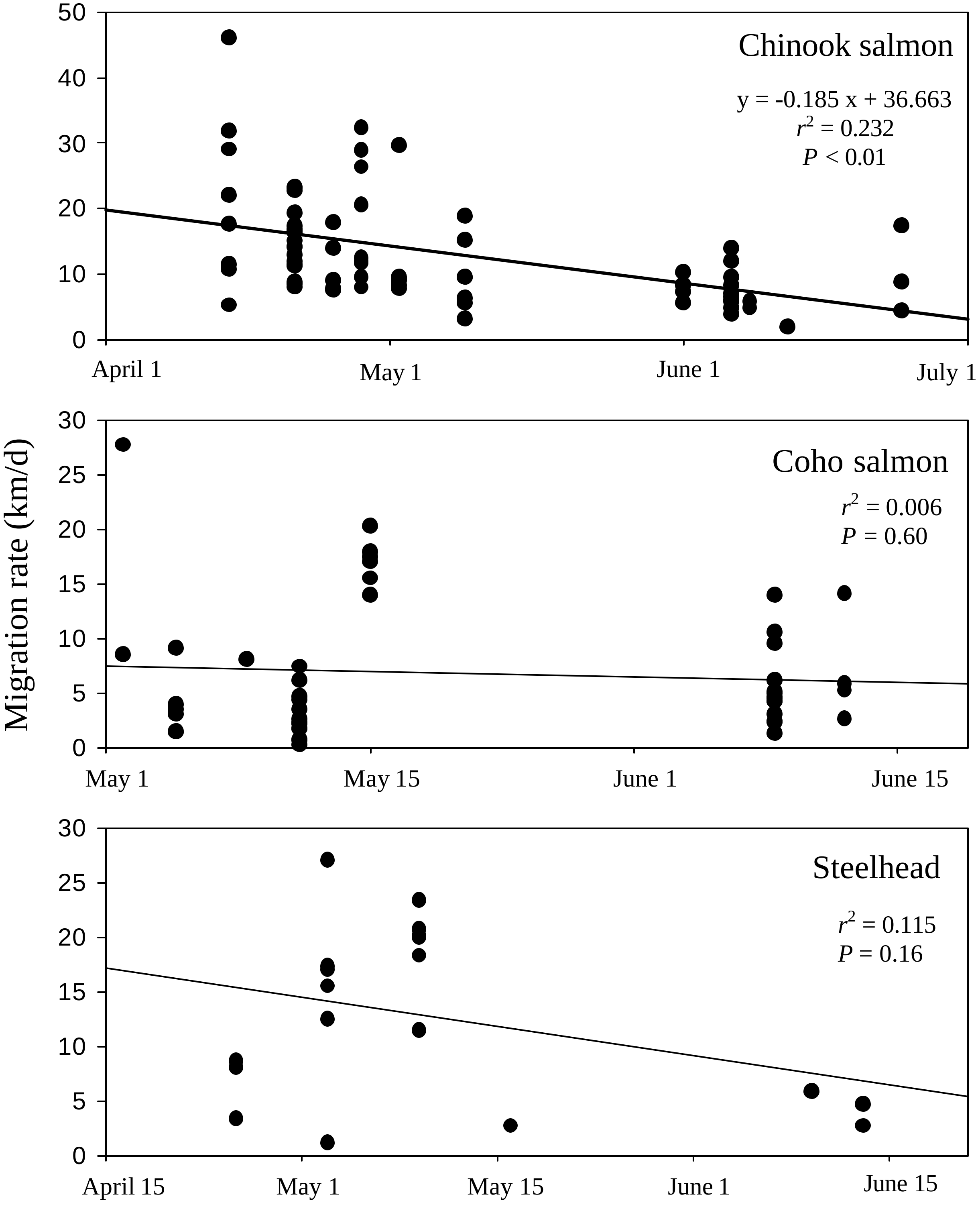

Figure 27. Linear regressions of migration rate on release date for juvenile Chinook salmon, coho salmon, and steelhead in the lower Willamette River, 2001-2003.

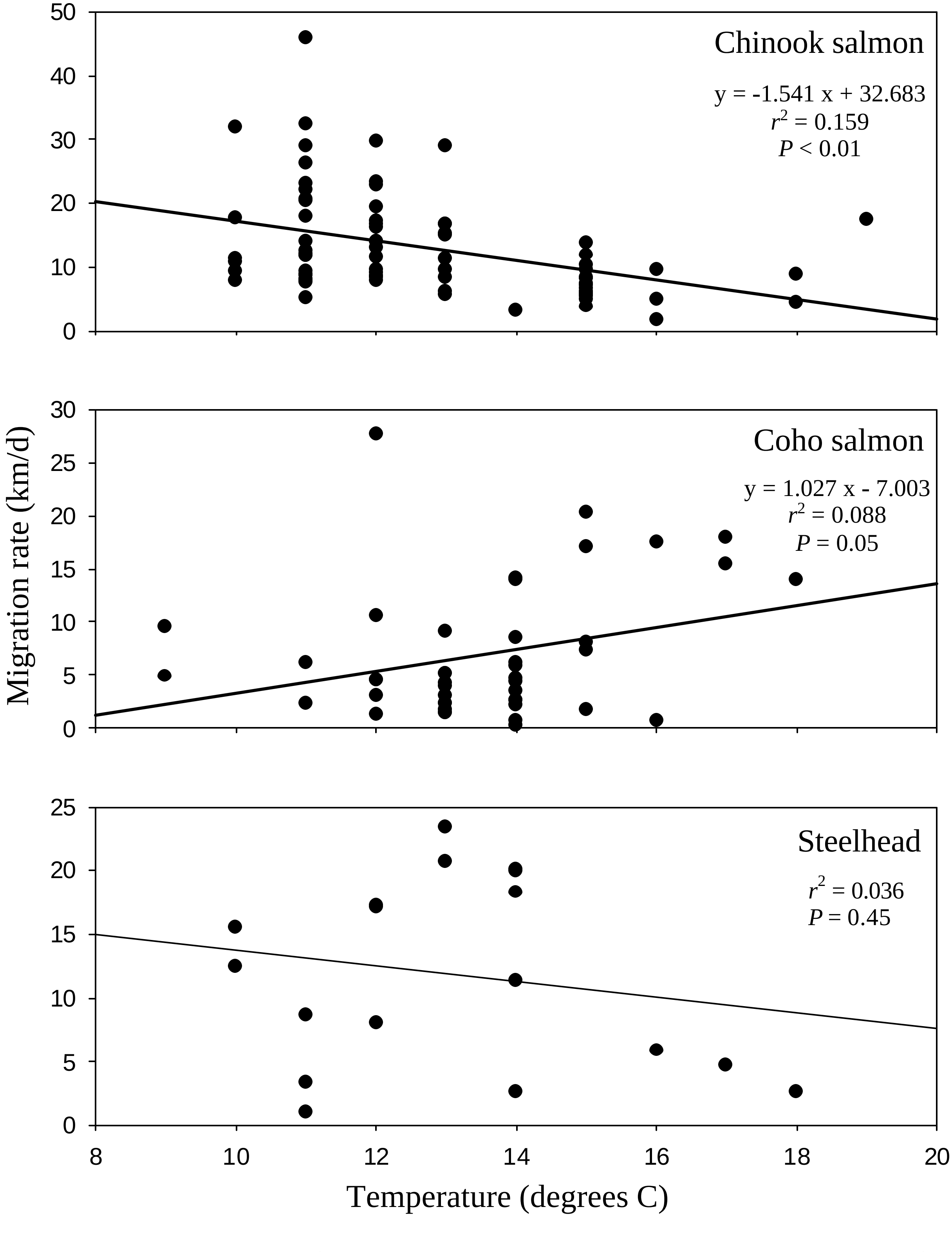

Figure 28. Linear regressions of migration rate on river temperature (on last recovery date) for juvenile Chinook salmon, coho salmon, and steelhead in the lower Willamette River, 2001 – 2003.

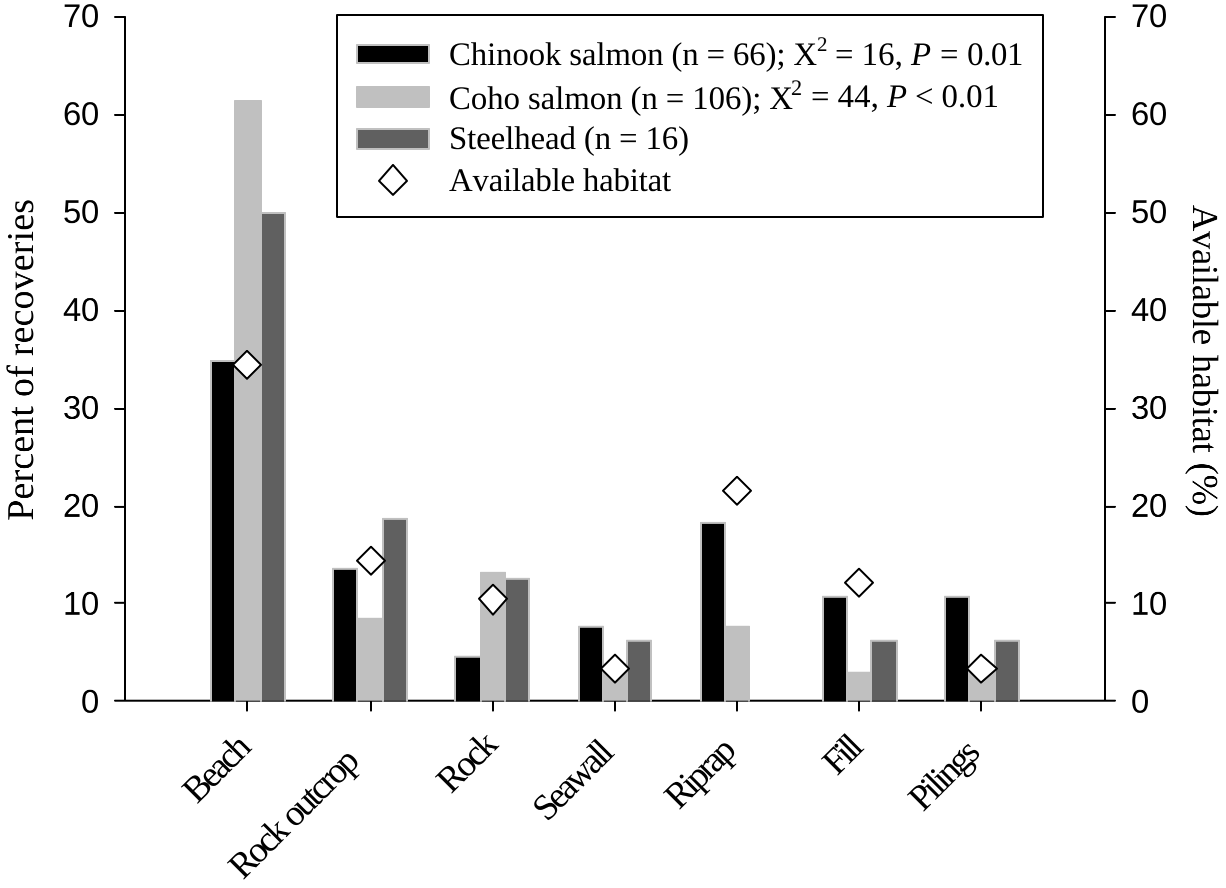

Figure 29. Proportional distribution of radio telemetry recoveries for juvenile Chinook salmon, coho salmon, and steelhead among nearshore habitat types in the lower Willamette River, 2001-2003. Chi-square statistics are included where the expected n (number of recoveries) was ≥ 5 for each habitat type (Zar 1999).

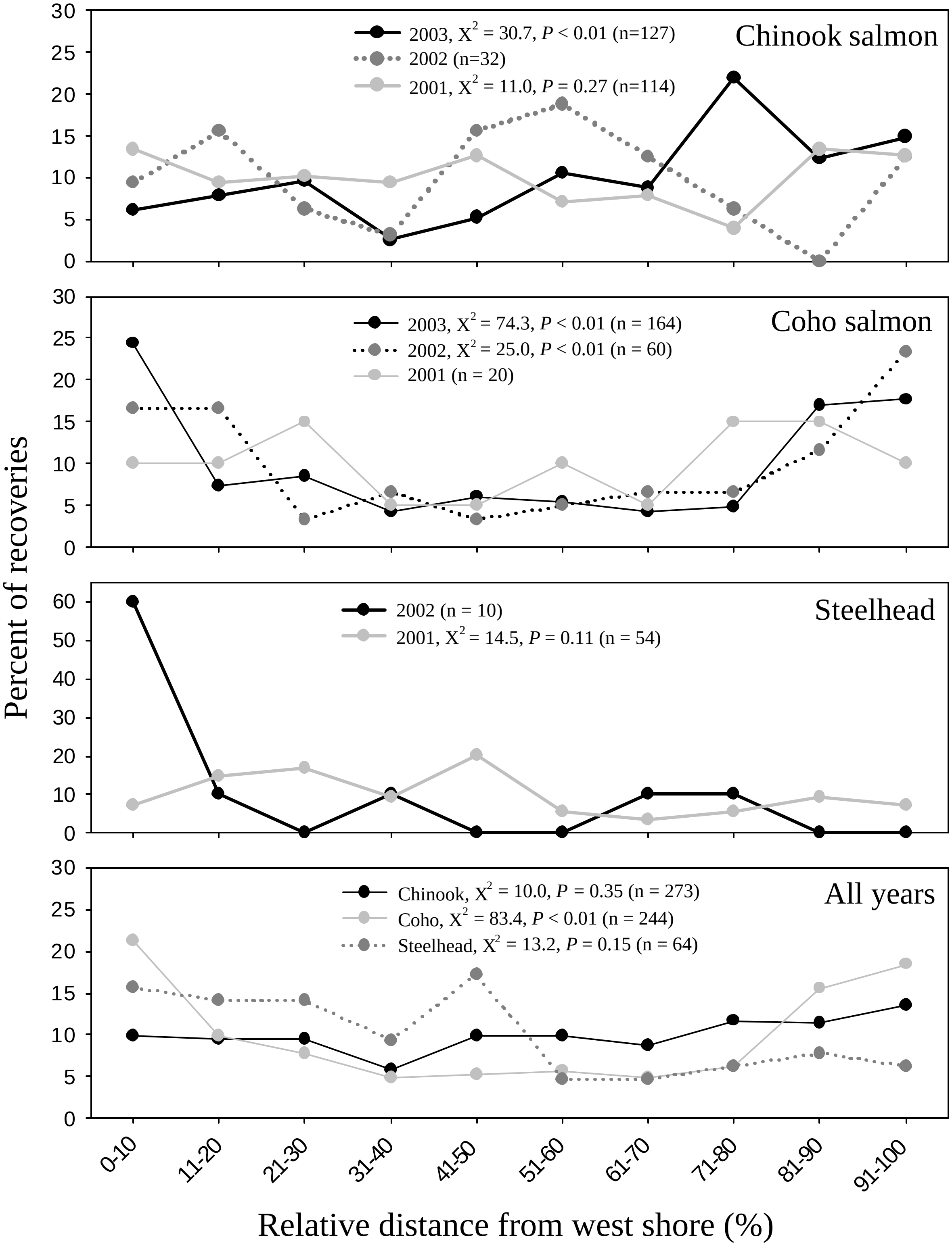

Figure 30. River channel distributions for radio-tagged Chinook salmon, coho salmon, and steelhead in the lower Willamette River, 2001–2003. West bank of river = 0%, east bank of river = 100% (X axis). Chi square statistics are included where expected n ≥ 5 for each category.

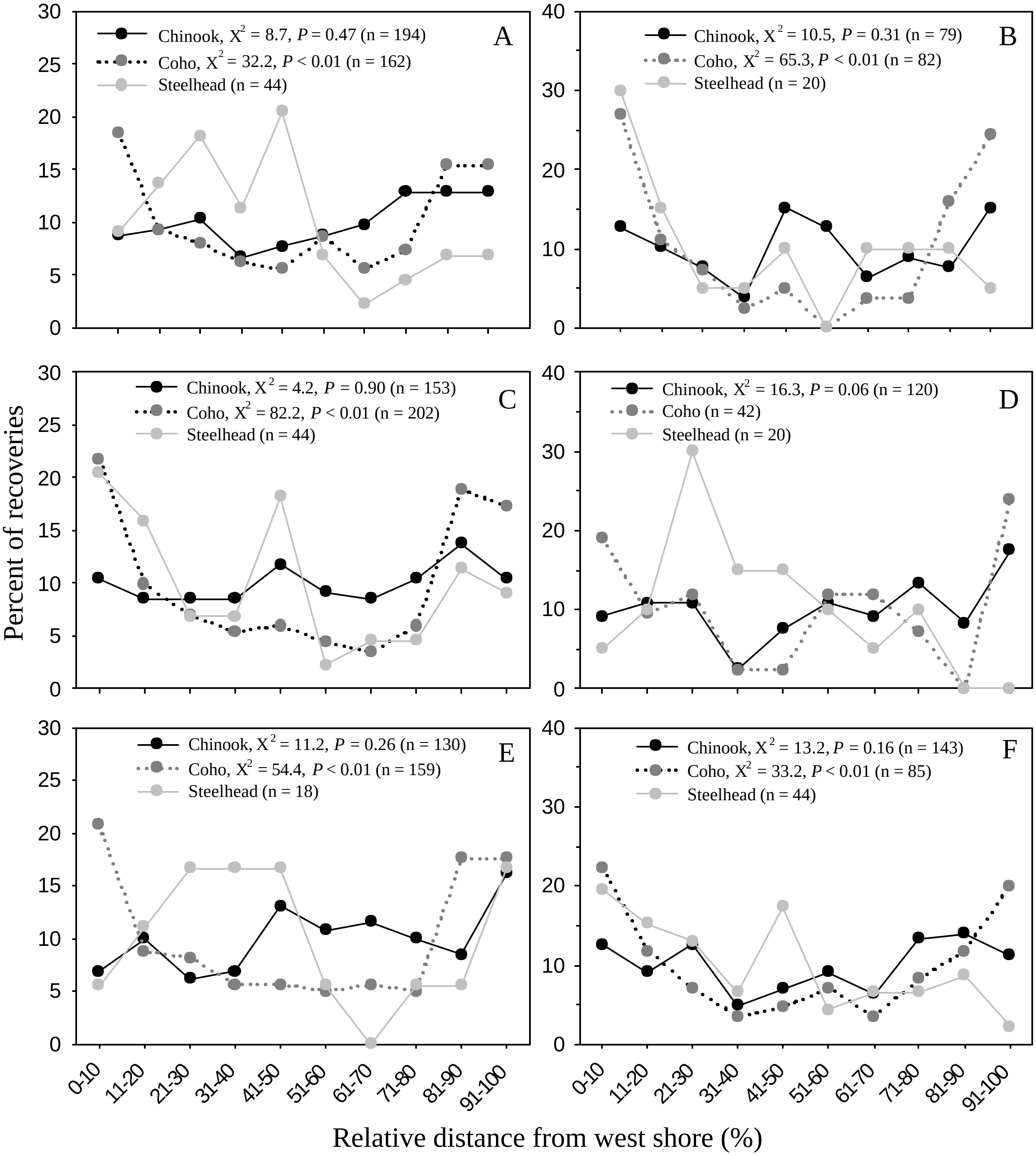

Figure 31. River channel distributions of radio-tagged Chinook salmon, coho salmon, and steelhead in the lower Willamette River, 2001 – 2003. West bank of river = 0%, east bank of river = 100% (X axis). Chart categories are: A) day, B) night, C) upper study area (rkm 22.6-42.6), D) lower study area (rkm 0.0-22.5), E) unmarked salmonids, and F) hatchery salmonids. Chi-square statistics are included where expected n ≥ 5 for each category.

We detected no differences in channel distribution patterns between hatchery and unmarked groups for any species (Figure 31). Relocations of both unmarked and hatchery Chinook salmon and unmarked and hatchery steelhead were evenly distributed across the river channel, while unmarked and hatchery coho salmon both appeared to prefer areas close to shore ($P < 0.01$).

DISCUSSION

Population Structure

Most juvenile salmonids we collected were Chinook salmon. We assumed these were largely spring-run stocks, as fall Chinook salmon are not indigenous to the upper Willamette River basin and wild fall Chinook in the lower Willamette River (primarily from the Clackamas River) were extirpated by 1934 (WRI 2004). A small number of introduced fall Chinook salmon persist; adults are observed annually at Willamette Falls. In 2002, 763 adult fall Chinook salmon were counted, compared to 82,111 adult spring Chinook salmon (ODFW 2002). Some production of fall Chinook salmon occurs in the upper watershed; Schroeder et al. (2003) estimated 6% of subyearling Chinook salmon seined in the Willamette River during 2002 were fall-run fish.

Chinook salmon captured in our study were approximately half hatchery fish and half unmarked fish, though there was a clear dichotomy between gear types. Large (>100 mm FL) hatchery fish dominated the electrofishing catch; small (<100 mm FL) unmarked fish were prevalent in beach seine catches. Lacking a means to accurately age these fish (most are intrusive and would have resulted in unacceptable mortality), we assumed that fish >100 mm FL were generally yearlings (age 1) and smaller fish were subyearlings (age 0). Spring Chinook salmon are generally regarded as “stream type” fish; they rear in fresh water for a year or more before migrating to the ocean, where fall Chinook salmon are considered “ocean type”, rearing for only a few months before migrating (Wydoski and Whitney 2003). Considering the large number of small Chinook salmon we collected, and the apparent low abundance of fall Chinook salmon, we concluded that most small Chinook salmon in the lower Willamette River are spring-run fish that outmigrate as subyearlings. The bimodal distribution of length frequencies in beach seine catches also suggested several age-classes were present; these could include older subyearlings from upper basin tributaries (e.g., Santiam River) and younger subyearlings from lower basin tributaries (e.g., Clackamas River). Future studies should address the origin and race of these fish.

Hatchery coho salmon are no longer stocked above Willamette Falls, and remaining runs are confined primarily to the Clackamas River, helping explain their low abundance in our surveys relative to Chinook salmon. Like Chinook salmon, they exhibited a bimodal distribution of length frequencies (in the electrofishing catch) with a natural break at about 100 mm FL. This again suggested several age classes were present; the habitat requirements of all ages should be considered when implementing fish management strategies.

Juvenile steelhead were quite rare; we captured less than 150 over four years of intensive sampling in the lower Willamette River, and most were large (>150 mm FL). As steelhead spend one to three (usually two) years in fresh water (Wydoski and Whitney 2003), and we observed relatively rapid migration rates for our radio-tagged steelhead, we concluded these fish reared primarily in their natal streams and larger tributaries, and passed quickly through our study area.

The relative abundance of other salmonids in the lower Willamette River is low; for example, we observed very few mountain whitefish in our study. Like most salmonids, they are considered to be intolerant of habitat and water quality perturbations (Zaroban et al. 1999), and are therefore an important species for assessing stream health.

Sockeye salmon are not indigenous to the Willamette basin, though the landlocked form (kokanee) are stocked at lakes in the upper watershed. A small number of large, mature fish are observed each year passing Willamette Falls; these are presumably kokanee that have escaped the reservoirs and residualized or reared in the ocean (C. Foster, ODFW, personal communication).

Cutthroat trout persist in many Willamette River tributaries (Friesen and Ward 1996; Friesen and Zimmerman 1999; Graham and Ward 2002) but are apparently very rare in nearshore areas of the lower mainstem.

Timing

The outmigration period for Chinook salmon, both hatchery and unmarked, was surprisingly long. The presence of juvenile fish often increased in late autumn and persisted into the next summer, and juvenile salmonids were present in every month we sampled from May 2000 to July 2003. Winter and spring were clearly the periods of greatest abundance, though the presence of different races (spring and fall), size classes, and stocks undoubtedly confounded our ability to completely assess timing. Coho salmon and steelhead were generally present only during winter and spring.

Growth

The increases in size we observed in juvenile Chinook salmon from upper to lower sampling sites were generally greater than the range described in the literature, especially for hatchery fish. For example, we observed a median fork length increase of 9 mm for hatchery Chinook salmon from upper to lower sampling sites, where the mean distance between upper and lower sites was 29.9 km. Radio-tagged Chinook salmon traveled at a median rate of 12.4 km/d, so their residence time between the upper and lower sites was about 2.4 d. Fisher and Pearcy (1995) documented growth rates of 0.75 – 1.05 mm/d for juvenile (hatchery) Chinook salmon in the lower Columbia River; applying their results to our estimated residence time would result in observed growth of 1.8 – 2.5 mm. However, due to technical limitations (e.g., weight and battery life of radio transmitters) our telemetry efforts focused on larger, actively migrating fish, which may have biased our migration rate estimates (high). We eliminated some fish from migration rate calculations because they stopped moving or moved upstream. Even among fish that consistently moved downstream, we estimated individual migration rates as low as 1.8 km/d. Considering these factors, it is plausible that some juvenile Chinook salmon spend extended amounts of time in the study area, and the growth we observed is realistic.

Fork length and weight of small, unmarked juvenile salmonids, while not always statistically significant, were consistently larger at downstream sites, again suggesting growth occurs. We observed increases from one to six mm FL. As with hatchery fish, this amount of growth was generally greater than observed in other areas. Published growth rates for subyearling Chinook salmon (including ocean-type fish) range from 0.48 mm/d (Sommer et al. 2001) to 1.2 mm/d (Conner and Burge 2003). We did not radiotag subyearling juvenile Chinook salmon, but Giorgi et al. (1997) estimated age-0 Chinook salmon migrated at 15.6 km/d in the mid-Columbia River (Rock Island Dam to McNary Dam). Applying these figures to the mean distance between our upper and lower sites (29.3 km) yielded growth estimates of 0.9 – 2.3 mm from upper to lower sites. This calculation is largely speculative, lacking migration and growth studies specific to the Willamette or lower Columbia rivers, but provides a general reference. Future studies in the lower Willamette River should determine migration rates and residence times of age-0 fish.

Differential mortality resulting from size-selective predation or other factors may have contributed to the size changes we observed; higher mortality rates for smaller fish would result in larger observed sizes at downstream locations. In the Columbia River, smallmouth bass preyed on relatively small juvenile Chinook salmon, and consumed far more subyearling fish in spring than yearling fish in summer (Zimmerman 1999). However, predation on juvenile salmonids by resident fish in the lower Willamette River appears to be minimal (Pribyl et al. 2004), and we observed no other mechanisms for (or evidence of) differential mortality. Survival estimates for various size classes and life stages of juvenile salmonids in our area would help clarify this issue and improve analyses of growth.

Other fish entering the study area (from a tributary or the Columbia River) could have biased the observed lengths and weights of fish in our study. However, no major streams enter the Willamette River below rkm 39.9 (the Clackamas River; Figure 1). All of the sampling sites used in the analysis were downstream of this point, though one (rkm 39.1, site 243W) was relatively close and on the opposite shore, so some influence from the Clackamas River is possible. Fish entering from the Columbia River would have to exhibit an odd behavior – migrating about 2-10 km in an upstream direction. Considering also the large sample size, consistent pattern, and statistical strength of the length and weight analyses, we felt there was sufficient evidence to reject the null hypothesis that juvenile salmonids do not exhibit changes in size during migration through the lower Willamette River. Some amount of growth undoubtedly occurs, as Vile et al. (2004) documented extensive feeding by juvenile salmonids on *Daphnia* spp. and other invertebrates in our study area. Schreck et al. (1994) also documented feeding by hatchery Chinook salmon in the Willamette River above Willamette Falls.

Migration Rates and Residence Times

Our observed migration rates for juvenile Chinook salmon >100 mm FL (presumably yearlings) were very similar to those reported in the Port of Portland study (ODFW 1992, Ward et al. 1994). Ward et al. (1994) documented median migration rates of 9.8 (1990), 8.7 (1989), and 11.0 km/d (1988) during spring in the lower Willamette River; we estimated a median rate of 11.3 km/d from 2001-2003. Similarly, our estimate of median migration rate for steelhead was 12.5 km/d over the course of the study, compared to 17.9 km/d (1989) and 11.9 km/d (1990) in Ward et al. (1994).

In general, spring migration rates for juvenile Chinook salmon are generally higher (19.6 – 43.0 km/d) in Columbia and Snake river impoundments (Giorgi et al. 1997; Adams et al. 1998c; Hockersmith et al. 2003; Smith et al. 2003) and lower (4.1 km/d) in the Columbia River below rkm 75.0 (Fisher and Pearcy 1995). Juvenile steelhead also tend to move slowly in impoundments (30.4 km/d; Giorgi et al. 1997), and Dawley et al. (1986) observed that tagged coho salmon in the Columbia River traveled faster when they were released farther upstream. This pattern of slower migration rates as juvenile salmonids move downstream in the Columbia basin suggests the lower Willamette River may play a role in rearing as the fish prepare to transition to salt water.

In a pattern repeated over several of our analyses, coho salmon behaved differently than Chinook salmon or steelhead, exhibiting much slower migration rates and longer residence times. Conditions and resources in the lower Willamette River may therefore be of particular importance to coho salmon.

The implications of migration rates and residence times are uncertain. Delayed migration due to dams, low river flows, and other factors have been cited as causing serious impacts to salmonids in the Columbia and Snake rivers (Bentley and Raymond 1976; Raymond 1979). Rapid travel through watersheds altered by human activity presumably increases survival, as juvenile salmonids spend less time exposed to degraded or sub-optimal habitat, predation, poor water conditions, and toxins. Schreck et al. (1994), noting many resting and feeding areas in the Willamette River have been eliminated by channelization, speculated that quick downstream movement is the most successful evolutionary strategy for juvenile Chinook salmon. However, observations from our study, including the growth of juvenile salmonids, their presence throughout much of the year, extensive feeding (Vile et al. 2004), and low predation rates and predator densities (Pribyl et al. 2004) suggest the lower Willamette River has value as rearing habitat and does not present a particular danger to juvenile salmonids. If this is the case, the importance of rapid migration rates may be negligible. However, uptake of contaminants remains a potential risk for juvenile salmonids in the lower Willamette River, and a full assessment is planned (Windward Environmental 2004).

Factors Influencing Migration Rate

Recent evidence strongly suggests river flow and migration rate are positively correlated. Schreck et al. (1994) showed migration rates of hatchery Chinook salmon that traveled 280 km from the upper Willamette basin to Willamette Falls were strongly correlated ($r^2 = 0.66$) with river flow. Dawley et al. (1986) observed migration rates for both juvenile Chinook and coho salmon in the Columbia River estuary increased with river flow, and Giorgi et al. (1997) found that flow in the mid-Columbia River basin explained 42, 36, and 31% of the variation in migration rates of sockeye salmon, hatchery steelhead, and wild steelhead. In our study, positive significant relationships were observed for both juvenile Chinook salmon and juvenile coho salmon.

We also observed a relatively strong linear relationship between fish size (fork length) and migration rate. The relationship was relatively strong and positive for Chinook salmon, weaker and negative for coho salmon. Our results were similar to those of Giorgi et al. (1997), who noted a positive relationship between migration rate and fish length for ocean-type Chinook salmon juveniles (r^2=0.59). We also observed that hatchery Chinook salmon migrated significantly faster than unmarked fish. This was undoubtedly an effect of the size of the fish, as migration rate increased with size and the hatchery fish we radio tagged were significantly larger than unmarked fish.

Temperature (Chinook and coho salmon) and release date (Chinook salmon only) were weakly related to migration rate, and both are related to river flow. Combining river flow, fork length, and release day as independent variables in multiple linear regressions generally helped explain more of the variation in migration rates than the simple univariate regressions. River flow and release day accounted for 67% of the variation in coho salmon migration rate; river flow and fork length explained 45% of the variation in Chinook salmon migration rate.

Management implications of migration rates and factors affecting them are uncertain. The ability of the City of Portland to affect migration through manipulations of river flow and temperature is obviously quite limited, and the benefits of more rapid passage are uncertain. Flow in the Willamette River is controlled largely by reservoirs in the middle and upper watershed; managers should cooperate to maintain flows approaching historic levels and reduce temperatures during outmigrations of juvenile salmonids.

Habitat Use (telemetry)

Radio-tagged Chinook salmon were not highly associated with nearshore areas; they were distributed evenly across the river channel regardless of year, time of day (day or night), origin (hatchery or unmarked), or area (upper or lower study area). Very few studies have addressed the cross-sectional distribution of juvenile salmonids in lotic systems. Dauble et al. (1989) examined spatial distributions in the Hanford Reach of the Columbia River and reached conclusions similar to ours: yearling spring Chinook salmon (and steelhead) were found primarily in mid-channel areas; smaller fish (age-0 Chinook salmon) were most abundant at nearshore sites.

Chinook salmon located near shore were distributed unevenly with respect to the availability of different habitat types; we rejected the null hypothesis (*the distribution of radio-tagged juvenile salmonids among nearshore habitat types does not differ from the distribution of habitat types*). However, these fish did not show clear selection for, or avoidance of, particular habitat types. Associations with specific habitats (e.g., pilings) were weak, and the distribution of telemetry recoveries appeared to closely follow the proportional availability of habitat types. Also, a relatively small proportion (about 24%) of radio-tagged Chinook salmon were recovered near shore; the influences of different habitat types are likely minimal. We also rejected the null hypothesis for coho salmon. These fish were often located near shore and showed a clear preference for beaches; they also appeared to avoid riprap and artificial fill. Steelhead were rarely associated with nearshore areas and the small number of fish located near shore was insufficient to address the null hypothesis.

Habitat Use (electrofishing)

Electrofishing CPUE varied significantly among habitat types; we rejected the null hypothesis *(the density of juvenile salmonids does not vary among bank treatment and nearshore development types*) on the basis of the statistical tests. However, these differences were almost always associated with low catches of fish at seawall habitats. Sampling efficiency was probably compromised in these areas, which were typically much deeper than other habitats. Our electrofishing gear did not sample the entire water column, likely contributing to the low catches relative to other sites. We concluded these fish did not use the upper portion of the water column at seawall sites, or tended to avoid them altogether.

Aside from seawalls, we found no indication that juvenile salmonids >100 mm FL were associated with specific habitats or groups of habitats, with one exception. During spring, electrofishing catches of coho salmon were significantly higher at the clustered group consisting of two rock outcrops (group 5) than at any other group. Similar results were observed for the qualitative habitat types; the catch was highest at rock outcrops and significantly greater than catches at beaches, seawalls, or riprapped habitats. However, the telemetry analyses did not indicate a preference for rock outcrops; radio-tagged coho salmon were recovered at somewhat lower-than-expected rates at this habitat type. Considering the magnitude of the relationship in the electrofishing data, and the relatively small number of nearshore telemetry relocations, we felt rock outcrops clearly have a particular value for coho salmon during spring. We were unable to find any citations documenting the use of habitats similar to our rock outcrops by coho salmon.

Electrofishing CPUE for juvenile salmonids in off-channel areas was not significantly greater than in main-channel areas. However, all off-channel types were clearly utilized, and some (Multnomah Channel and the east channel at Ross Island) provide alternative passage routes. Off-channel sites provide refuge from extremely high flow events, and may be important foraging areas.

Individual habitat parameters (those that contributed to the separation of clustered habitat groups; Vile and Friesen 2004) appeared to have little or no relationship to juvenile Chinook salmon density during spring, with the exception of bank vegetation. Habitat parameters appeared to be much more important during winter; higher catches were generally associated with sand substrates, shallow water, and moderate amounts of bank vegetation. Some relationships were confused; CPUE in similar parameter categories occasionally varied significantly (e.g., 11-20% and 21-30% bank vegetation). For other parameters, CPUE varied significantly only between the highest and lowest proportional categories. We suggest future studies use a more rigorous approach to identify important habitat variables, such as multivariate logistic regression modeling (e.g., Garland et al. 2002).

A final important observation in our study was the large number of subyearling Chinook salmon present. Because we did not often capture these fish with electrofishing gear, and beach seining efforts occurred at a single bank habitat type, we could not effectively analyze their habitat preferences. However, based on the high numbers of fish and their extended temporal distribution in seine catches, beaches were clearly an important habitat type for small Chinook salmon. These observations are supported by numerous citations, which are virtually unanimous in concluding that younger age classes of juvenile salmonids are highly associated with shallow, nearshore areas in both lotic and lentic environments (e.g., Lister and Genoe 1970, Johnson and Sims 1973, Dauble et al. 1989, Kahler 2000, Tabor and Pioskowski 2002). Recent work also suggests the quality and composition of nearshore habitat is important to subyearling salmonids. Garland et al. (2002), for example, concluded substrate size was the most important factor in determining the presence of subyearling fall Chinook salmon in the Columbia River above McNary Dam; fish were more likely to be present at unaltered shorelines than at riprapped sites.

Overall, we found little evidence to suggest that nearshore habitat as it currently exists is a critical factor affecting yearling salmonids, and we generally agree with Ward et al. (1994), who concluded waterway developments presented few risks to juvenile salmonids. However, we believe the effects of development are incompletely explored, especially with respect to subyearling fish. Clearly, the lower Willamette River is more than a simple migration corridor. Juvenile Chinook salmon feed (Vile et al. 2004) and apparently grow during their outmigration, and unaltered nearshore habitats appear to be important to smaller fish. Coho salmon also feed extensively on aquatic invertebrates (Vile et al. 2004), were associated with nearshore areas, exhibited selection for specific habitat types, and spent relatively long periods in the study area. All off-channel habitats were utilized by juvenile salmonids, and they were present for extended periods in all years. While current conditions appear to adequately support fish populations, future development should be planned carefully to avoid detrimental impacts.

RECOMMENDATIONS

We present several recommendations intended help protect ESA-listed species. These were developed by the principal investigators, and will not necessarily be adopted as policies or guidelines by the Oregon Department of Fish and Wildlife. Recommendations fall into three categories: (1) primary recommendations, which are recommendations regarding in-water or shoreline activities that are supported directly by study findings, (2) secondary recommendations, which are recommendations regarding in-water or shoreline activities that are supported in part by study findings, but may rely in part on general ecological principles and ecosystem functions, and (3) recommendations for additional studies.

Primary Recommendations

1. **The in-water work period for activities such as dredging, bank stabilization, etc., should be restricted to July 1 – October 31.** Primary considerations for recommending in-water work periods are given to important fish species, including anadromous fish and those receiving protection under federal or state ESAs. The existing work period for the lower Willamette River and Multnomah Channel is July 1 – October 31 and December 1 – January 31 (ODFW 2000). Our findings indicate Chinook salmon, coho salmon, and steelhead (including a large number of unmarked fish) are present during December 1 – January 31, and are often abundant during this period; in-water work should be avoided to prevent harming listed stocks.

This recommendation does not necessarily reflect policy of ODFW or the COP. ODFW is responsible for providing guidelines for in-water work periods to minimize impacts to fish, wildlife, and habitat. It is likely that ODFW will recommend the winter work period remain open, but that strict criteria be met to ensure impacts to fish, wildlife, and habitat resources are negligible.

2. **Protect existing beach habitat.** Natural beaches appeared to be an important habitat for younger age classes of salmonids (particularly Chinook salmon), were selected by radio-tagged coho salmon, and were not a preferred habitat of large predator fishes (Pribyl et al. 2004); enhancements directed at creating beaches will likely provide a benefit to salmonids. It is unknown to what extent this habitat type can be enhanced by physical restoration efforts (see recommendation 5). Remaining beaches in the lower Willamette River represent relatively undisturbed habitats, and have important recreational and aesthetic value.

3. **Avoid construction of additional seawalls.** Seawalls represent a loss of natural shoreline conditions, provide little habitat for any fish species, and appeared to be under-utilized by juvenile salmonids. Electrofishing catches were low at seawalls; fish either avoid seawalls or change their behavior (move out of the range of electrofishing gear) upon encountering them. Because juvenile salmonids are generally associated with the upper portion of the water column, it is unlikely that low catches were due primarily to fish utilizing deep water along seawalls.

Secondary Recommendations

4. **Protect existing off-channel sites.** Many of these areas (alcoves, lagoons, backwaters, secondary channels) have been eliminated from the lower Willamette River; remaining areas are likely important for forage and refuge. All off-channel types were used by migrating yearling salmonids, and a proportion of our radio-tagged fish migrated through the Multnomah Channel. Habitat alterations should, at worst, not further eliminate habitat important to juvenile salmonids, and at best, provide additional habitat for juvenile salmonids while discouraging predators, potential competitors, and invasive species. The Multnomah Channel should be included in habitat conservation and enhancement activities.

5. **Determine if bio-engineering and other techniques can restore beach habitat functions and processes.** The City of Portland and ODFW should work with engineers and habitat specialists to determine the feasibility of restoring or creating beach habitats while considering other issues, such as commercial shipping, bank stabilization, and flood control. Though yearling Chinook salmon and other species did not exhibit clear preferences for any habitat type, beaches were clearly important to subyearling fish, and catches of larger fish were sometimes correlated with small substrates (sand), shallow water, and vegetated banks.

Recommendations for Additional Studies

6. **Focus additional studies on subyearling Chinook and coho salmon.** Very little is known about the origin and race, habitat use, residence time, diet, and survival of age-0 Chinook salmon in the lower Willamette River. Our observations indicated these fish were abundant

and used beach sites extensively; however, this study focused largely on yearling salmonids and did not answer critical questions pertaining to smaller age classes (especially habitat use and migration rates). Subyearling fish may be particularly important because nearly all are naturally produced (and therefore federally protected), and unlike older fish, may be associated with specific nearshore habitats (beaches). Investigating subyearling Chinook salmon in the lower Willamette River will greatly improve knowledge of their behavior and habitat requirements, and will enhance the ability of agencies to protect listed races. The habitat requirements of all ages should be considered when implementing fish management strategies.

Small steelhead were rare in our surveys and probably do not use the lower Willamette River to a great degree; most appear to outmigrate quickly after rearing in their natal streams. However, younger age classes of coho salmon were clearly present. Considering the status of coho salmon as a state-listed endangered species (they are also a candidate for federal listing), and their apparent behavioral differences relative to Chinook salmon, we recommend they be considered as a focal species in future studies.

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Appendix

Chinook Salmon CPUE – Habitat Parameter Comparisons

Appendix Table 1. Spring electrofishing catch rates (CPUE; n=178) for juvenile Chinook salmon (unmarked and hatchery) among habitat parameter categories. The parameters analyzed are those that contributed most to the separation of sampling sites into clusters (Vile and Friesen 2004). Where *P*<0.05, category pairs without a letter in common are significantly different.

Parameter, category	Median CPUE	25th percentile	75th percentile	Pairwise comparison
Dominant substrate (*P*=0.28)				
Bedrock	0.41	0.00	2.92	--
Riprap	0.00	0.00	1.90	--
Sand	1.30	0.00	11.68	--
Fines	0.81	0.00	4.03	--
Bottom slope, percent (*P*=0.56)				
<0	0.00	0.00	1.57	--
0-9	1.63	0.00	23.37	--
10-19	0.49	0.00	4.79	--
20-29	0.81	0.00	7.16	--
30-39	0.00	0.00	2.20	--
40-49	--	--	--	--
50-59	0.49	0.00	2.52	--
60-69	1.30	0.00	4.27	--
70-79	1.87	0.00	4.07	--
Transparency, cm (*P*=0.71)				
20-29	0.00	0.00	2.63	--
30-39	0.00	0.00	0.81	--
40-49	0.41	0.00	3.89	--
50-59	0.81	0.00	5.64	--
60-69	0.48	0.00	11.68	--
70-79	0.81	0.00	2.90	--
80-89	0.98	0.00	5.08	--
90-100	0.98	0.20	12.43	--
Bank vegetation, percent coverage (*P*=0.05)				
0-10	0.00	0.00	1.14	z
11-20	0.98	0.00	15.60	zy
21-30	8.77	0.00	10.83	y
31-40	0.00	0.00	6.06	zy
41-50	0.64	0.00	2.90	zy
51-60	0.98	0.00	3.09	zy
61-70	--	--	--	zy
71-80	2.93	0.00	18.06	zy

Appendix Table 1 (continued)

Bank composition, percent large riprap (*P*=0.78)				
0-9	0.813	0.00	4.86	--
10-19	12.62	0.00	29.28	--
20-29	0.41	0.00	3.88	--
30-39	0.98	0.20	12.43	--
40-49	0.00	0.00	4.27	--
50-59	--	--	--	--
60-69	0.48	0.00	2.52	--
70-79	0.41	0.00	1.30	--
80-89	--	--	--	--
90-100	0.00	0.00	28.46	--
Bank composition, percent beach (*P*=0.79)				
0-9	0.40	0.00	3.25	--
10-20	--	--	--	--
20-30	--	--	--	--
30-39	3.37	0.00	4.88	--
40-49	0.98	0.00	10.47	--
50-59	--	--	--	--
60-69	0.98	0.00	4.81	--
70-79	0.00	0.00	22.94	--
80-89	1.79	0.00	3.65	--
90-100	2.28	0.00	16.59	--

Appendix Table 2. Winter electrofishing catch rates (CPUE; n=230) for juvenile Chinook salmon (unmarked and hatchery) among habitat parameter categories. The parameters analyzed are those that contributed most to the separation of sampling sites into clusters (Vile and Friesen 2004). Where *P*<0.05, category pairs without a letter in common are significantly different.

Parameter, category	Median CPUE	25th percentile	75th percentile	Pairwise comparison
Dominant substrate (*P*<0.01)				
Bedrock	0.87	0.00	2.41	z
Riprap	3.16	0.00	11.98	zy
Sand	4.36	1.57	13.08	y
Fines	1.37	0.00	3.49	z
Depth (m), 20 m from shore (*P*<0.01)				
0.0-1.0	2.68	1.74	4.85	z
1.1-2.0	3.43	0.95	10.29	z
2.1-3.0	4.36	0.87	11.34	z
3.1-4.0	1.19	0.00	2.62	zy
4.1-5.0	1.90	0.64	15.03	zy
5.1-6.0	2.83	1.20	5.66	zy
6.1-7.0	--	--	--	--
7.1-8.0	1.44	0.00	7.12	zy
8.1-9.0	--	--	--	--
9.1-10.0	--	--	--	--
>10.0	0.00	0.00	2.32	y
Bank vegetation, percent coverage (*P*<0.01)				
0-10	0.00	0.00	1.30	y
11-20	1.61	0.76	2.19	zy
21-30	3.56	1.10	9.69	z
31-40	--	--	--	--
41-50	4.36	1.10	10.46	z
51-60	2.06	0.00	10.13	z
61-70	1.41	0.00	4.71	zy
Bank vegetation, percent grass (*P*<0.01)				
0-10	1.29	0.00	4.36	zy
11-20	2.99	1.15	9.99	z
21-30	2.11	0.73	9.06	zy
31-40	4.80	2.91	13.95	z
41-50	0.87	0.00	1.52	y
51-60	--	--	--	--
61-70	1.41	0.00	4.71	zy

Appendix Table 2 (continued)

Bank composition, percent beach ($P<0.01$)				
0-10	1.45	0.00	5.23	zy
11-20	6.70	4.50	14.97	z
21-30	0.87	0.00	2.11	zy
31-40	0.00	0.00	0.87	y
41-50	4.38	2.62	19.01	zy
51-60	4.35	0.87	9.29	zy
61-70	0.00	0.00	3.41	zy
71-80	1.30	0.42	4.21	zy
81-90	4.80	2.91	13.95	zy
91-100	1.79	1.60	2.68	zy

Appendix Table 3. Spring electrofishing catch rates (CPUE; n=178) for unmarked juvenile Chinook salmon among habitat parameter categories. The parameters analyzed are those that contributed most to the separation of sampling sites into clusters (Vile and Friesen 2004). Where *P*<0.05, category pairs without a letter in common are significantly different.

Parameter, category	Median CPUE	25th percentile	75th percentile	Pairwise comparison
Dominant substrate (*P*=0.43)				
Bedrock	0.00	0.00	0.00	--
Riprap	0.00	0.00	0.00	--
Sand	0.00	0.00	0.00	--
Fines	0.00	0.00	0.00	--
Bottom slope, percent (*P*=0.67)				
<0	0.00	0.00	0.00	--
0-9	0.00	0.00	0.00	--
10-19	0.00	0.00	0.00	--
20-29	0.00	0.00	0.00	--
30-39	0.00	0.00	0.00	--
40-49	--	--	--	--
50-59	0.00	0.00	0.00	--
60-69	0.00	0.00	0.00	--
70-79	0.00	0.00	0.98	--
Transparency, cm (*P*=0.44)				
20-29	0.00	0.00	0.00	--
30-39	0.00	0.00	0.00	--
40-49	0.00	0.00	0.00	--
50-59	0.00	0.00	0.24	--
60-69	0.00	0.00	0.00	--
70-79	0.00	0.00	0.00	--
80-89	0.00	0.00	0.00	--
90-100	0.00	0.00	0.00	--
Bank vegetation, percent coverage (*P*<0.01)				
0-10	0.00	0.00	0.00	z
11-20	0.00	0.00	0.00	zy
21-30	0.00	0.00	0.00	z
31-40	0.00	0.00	0.00	z
41-50	0.00	0.00	0.00	z
51-60	0.00	0.00	0.00	zy
61-70	--	--	--	--
71-80	0.98	0.00	2.20	y

Appendix Table 3 (continued)

Bank composition, percent large riprap (*P*=0.30)				
0-9	0.00	0.00	0.00	--
10-19	0.00	0.00	0.98	--
20-29	0.00	0.00	0.00	--
30-39	0.00	0.00	0.00	--
40-49	0.00	0.00	0.00	--
50-59	--	--	--	--
60-69	0.00	0.00	0.00	--
70-79	0.00	0.00	0.00	--
80-89	--	--	--	--
90-100	0.00	0.00	0.00	--
Bank composition, percent beach (*P*=0.05)				
0-9	0.00	0.00	0.00	zy
10-19	--	--	--	zy
20-29	--	--	--	zy
30-39	0.00	0.00	0.00	zy
40-49	0.00	0.00	0.73	zy
50-59	--	--	--	zy
60-69	0.00	0.00	0.00	zy
70-79	0.00	0.00	0.00	zy
80-89	0.00	0.00	0.00	z
90-100	0.00	0.00	0.98	y

Appendix Table 4. Winter electrofishing catch rates (CPUE; n=230) for unmarked juvenile Chinook salmon among habitat parameter categories. The parameters analyzed are those that contributed most to the separation of sampling sites into clusters (Vile and Friesen 2004). Where $P<0.05$, category pairs without a letter in common are significantly different.

Parameter, category	Median CPUE	25th percentile	75th percentile	Pairwise comparison
Dominant substrate ($P<0.01$)				
Bedrock	0.00	0.00	0.79	zy
Riprap	0.00	0.00	0.00	y
Sand	0.87	0.00	1.74	z
Fines	0.00	0.00	1.12	zy
Depth (m), 20 m from shore ($P<0.01$)				
0.0-1.0	0.80	0.00	1.71	zy
1.1-2.0	0.00	0.00	1.56	zy
2.1-3.0	1.16	0.00	2.91	z
3.1-4.0	0.00	0.00	1.02	zy
4.1-5.0	--	--	--	--
5.1-6.0	0.00	0.00	1.29	zy
6.1-7.0	0.87	0.00	1.22	zy
7.1-8.0	--	--	--	--
8.1-9.0	0.00	0.00	0.00	y
9.1-10.0	--	--	--	--
>10	0.00	0.00	0.36	y
Bank vegetation, percent coverage ($P<0.01$)				
0-10	0.00	0.00	0.00	y
11-20	0.73	0.00	1.10	zy
21-30	0.00	0.00	1.81	z
31-40	--	--	--	
41-50	0.87	0.00	1.53	z
51-60	0.00	0.00	1.45	z
61-70	0.00	0.00	0.21	zy
Bank vegetation, percent grass ($P=0.11$)				
0-10	0.00	0.00	0.95	--
11-20	0.73	0.00	1.29	--
21-30	0.00	0.00	1.55	--
31-40	0.87	0.00	1.74	--
41-50	0.00	0.00	0.87	--
51-60	--	--	--	--
61-70	0.00	0.00	0.22	--

Appendix Table 4 (continued)

Bank composition, percent beach (*P*=0.01)				
0-10	0.00	0.00	1.00	zy
11-20	1.24	0.00	2.79	zy
21-30	--	--	--	--
31-40	0.00	0.00	0.00	y
41-50	--	--	--	--
51-60	1.74	0.00	2.98	z
61-70	0.00	0.00	0.61	zy
71-80	0.00	0.00	0.42	zy
81-90	--	--	--	--
91-100	0.87	0.00	1.45	zy

Appendix Table 5. Spring electrofishing catch rates (CPUE; n=178) for hatchery juvenile Chinook salmon among habitat parameter categories. The parameters analyzed are those that contributed most to the separation of sampling sites into clusters (Vile and Friesen 2004). Where *P*<0.05, category pairs without a letter in common are significantly different.

Parameter, category	Median CPUE	25th percentile	75th percentile	Pairwise comparison
Dominant substrate (*P*=0.07)				
Bedrock	0.00	0.00	1.95	--
Riprap	0.00	0.00	1.90	--
Sand	0.81	0.00	10.83	--
Fines	0.00	0.00	3.90	--
Bottom slope, percent (*P*=0.13)				
<0	0.00	0.00	0.00	--
0-9	1.63	0.00	23.37	--
10-19	0.49	0.00	4.79	--
20-29	0.81	0.00	7.16	--
30-39	0.00	0.00	1.47	--
40-49	--	--	--	--
50-59	0.49	0.00	2.52	--
60-69	0.00	0.00	1.92	--
70-79	0.00	0.00	2.44	--
Transparency, cm (*P*=0.67)				
20-29	0.00	0.00	2.52	--
30-39	0.00	0.00	0.00	--
40-49	0.00	0.00	2.93	--
50-59	0.00	0.00	5.64	--
60-69	0.00	0.00	9.73	--
70-79	0.00	0.00	1.95	--
80-89	0.00	0.00	4.88	--
90-100	0.98	0.00	12.14	--
Bank vegetation, percent coverage (*P*<0.01)				
0-10	0.00	0.00	0.00	y
11-20	0.98	0.00	15.58	z
21-30	8.77	0.00	10.83	z
31-40	0.00	0.00	6.06	zy
41-50	0.00	0.00	2.90	zy
51-60	0.00	0.00	2.52	zy
61-70	--	--	--	--
71-80	1.95	0.00	15.37	zy

Appendix Table 5 (continued)

Bank composition, percent large riprap (*P*=0.72)				
0-9	0.00	0.00	3.65	--
10-19	12.62	0.00	28.30	--
20-29	0.00	0.00	3.88	--
30-39	0.98	0.00	12.14	--
40-49	0.00	0.00	4.27	--
50-59	--	--	--	--
60-69	0.49	0.00	2.52	--
70-79	0.00	0.00	0.96	--
80-89	--	--	--	--
90-100	0.00	0.00	28.46	--
Bank composition, percent beach (*P*=0.44)				
0-9	0.00	0.00	2.83	--
10-19	--	--	--	--
20-29	--	--	--	--
30-39	3.37	0.00	4.88	--
40-49	0.00	0.00	9.01	--
50-59	--	--	--	--
60-69	0.98	0.00	4.81	--
70-79	0.00	0.00	22.45	--
80-89	1.79	0.00	3.65	--
90-100	1.79	0.00	14.64	--

Appendix Table 6. Winter electrofishing catch rates (CPUE; n=230) for hatchery juvenile Chinook salmon among habitat parameter categories. The parameters analyzed are those that contributed most to the separation of sampling sites into clusters (Vile and Friesen 2004). Where *P*<0.05, category pairs without a letter in common are significantly different.

Parameter, category	Median CPUE	25th percentile	75th percentile	Pairwise comparison
Dominant substrate (*P*<0.01)				
Bedrock	0.73	0.00	2.39	z
Riprap	3.14	0.00	10.71	zy
Sand	2.91	0.00	12.00	y
Fines	0.00	0.00	2.56	z
Depth (m), 20 m from shore (*P*=0.02)				
0.0-1.0	1.79	0.00	3.66	zy
1.1-2.0	1.98	0.00	8.93	zy
2.1-3.0	2.00	0.00	11.37	z
3.1-4.0	0.00	0.00	1.45	zy
4.1-5.0	1.74	0.00	12.75	zy
5.1-6.0	--	--	--	--
6.1-7.0	1.02	0.36	4.63	zy
7.1-8.0	1.44	0.00	7.12	zy
8.1-9.0	--	--	--	--
9.1-10.0	--	--	--	--
>10.0	0.00	0.00	1.91	y
Bank vegetation, percent coverage (*P*<0.01)				
0-10	0.00	0.00	0.84	yx
11-20	0.00	0.00	1.67	x
21-30	1.98	0.00	9.59	z
31-40	--	--	--	--
41-50	2.62	0.87	9.28	z
51-60	0.94	0.00	6.84	z
61-70	1.41	0.00	3.58	zyx
Bank vegetation, percent grass (*P*=0.02)				
0-10	0.00	0.00	2.54	zy
11-20	1.67	0.00	8.10	zy
21-30	1.30	0.00	6.68	zy
31-40	4.80	0.00	12.21	z
41-50	0.00	0.00	1.05	y
51-60	--	--	--	--
61-70	1.41	0.00	3.58	zy

Appendix Table 6 (continued)

Bank composition, percent beach (*P*=0.01)				
0-10	0.87	0.00	4.34	zy
11-20	6.36	1.28	13.72	zy
21-30	--	--	--	--
31-40	0.00	0.00	0.73	y
41-50	--	--	--	--
51-60	2.62	1.09	11.55	z
61-70	0.00	0.00	2.03	zy
71-80	1.30	0.00	4.21	zy
81-90	--	--	--	--
91-100	1.85	0.00	5.23	zy

Population Structure, Movement, Habitat Use, and Diet of Resident Piscivorous Fishes in the Lower Willamette River

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INTRODUCTION

The lower Willamette River provides habitat for several species of salmon and steelhead *Oncorhynchus* spp. listed as threatened under the federal Endangered Species Act. These include stocks from several evolutionarily significant units: lower Columbia River and upper Willamette River Chinook salmon *O. tshawytscha*, and lower Columbia River and upper Willamette River steelhead *O. mykiss* (NOAA 1998, NOAA 1999a, NOAA 1999b). In addition, lower Columbia River coho salmon *O. kisutch* were listed as an endangered species under Oregon's Endangered Species Act in 1999 (Chilcote 1999). Piscivorous fish known to reside in the lower Willamette River, such as northern pikeminnow *Ptychocheilus oregonensis*, walleye *Sander vitreus*, smallmouth bass *Micropterus dolomieu*, and largemouth bass *M. salmoides*, prey on juvenile salmonids as a part of their diet (Stein 1970, Rieman et al. 1991, Farr and Ward 1993, Shrader and Moody 1997, Zimmerman 1999). As part of a long-term study to investigate the effect of riverbank development on juvenile salmonids, we investigated these species to determine if they pose a particular risk to threatened and endangered salmonids.

Piscivores prefer low-light environments and overhanging structures that provide cover (Mesing and Wicker 1986, Probst et al. 1984). For example, largemouth bass monitored in lakes were found most frequently near vegetation or piers (Mesing and Wicker 1986, Colle et al. 1989) and smallmouth bass showed a high affinity for nearshore cover and woody debris in both lakes and streams (Probst et al. 1984, Bevelhimer 1990, Lobb and Orth 1991). Low-light environments are generally preferred by piscivores, as many utilize a lie-in-wait strategy to capture prey (Gerking 1994). Nearshore structures that provide cover may increase the risk of predation on prey fish, such as juvenile salmonids. Much of the natural bank habitat of the lower Willamette River has been transformed to control flooding, prevent erosion, and accommodate commercial shipping. The numerous piers, docks, seawalls, and armored banks (e.g. riprap) may provide an advantage to piscivores. In a previous study, Ward et al. (1994) found no difference in northern pikeminnow predation between developed and undeveloped sites in this area.

In this study, we examined the movement patterns, habitat preferences, and diet composition of northern pikeminnow, smallmouth bass, largemouth bass and walleye in the Willamette River from its confluence with the Columbia River at river kilometer (rkm) 0.0 to Willamette Falls (rkm 42.6; Figure 1). We used radio telemetry to characterize movements and habitat associations of these species, and electrofishing, gillnetting, and beach seining to determine predator distribution and diet associated with specific bank treatment types.

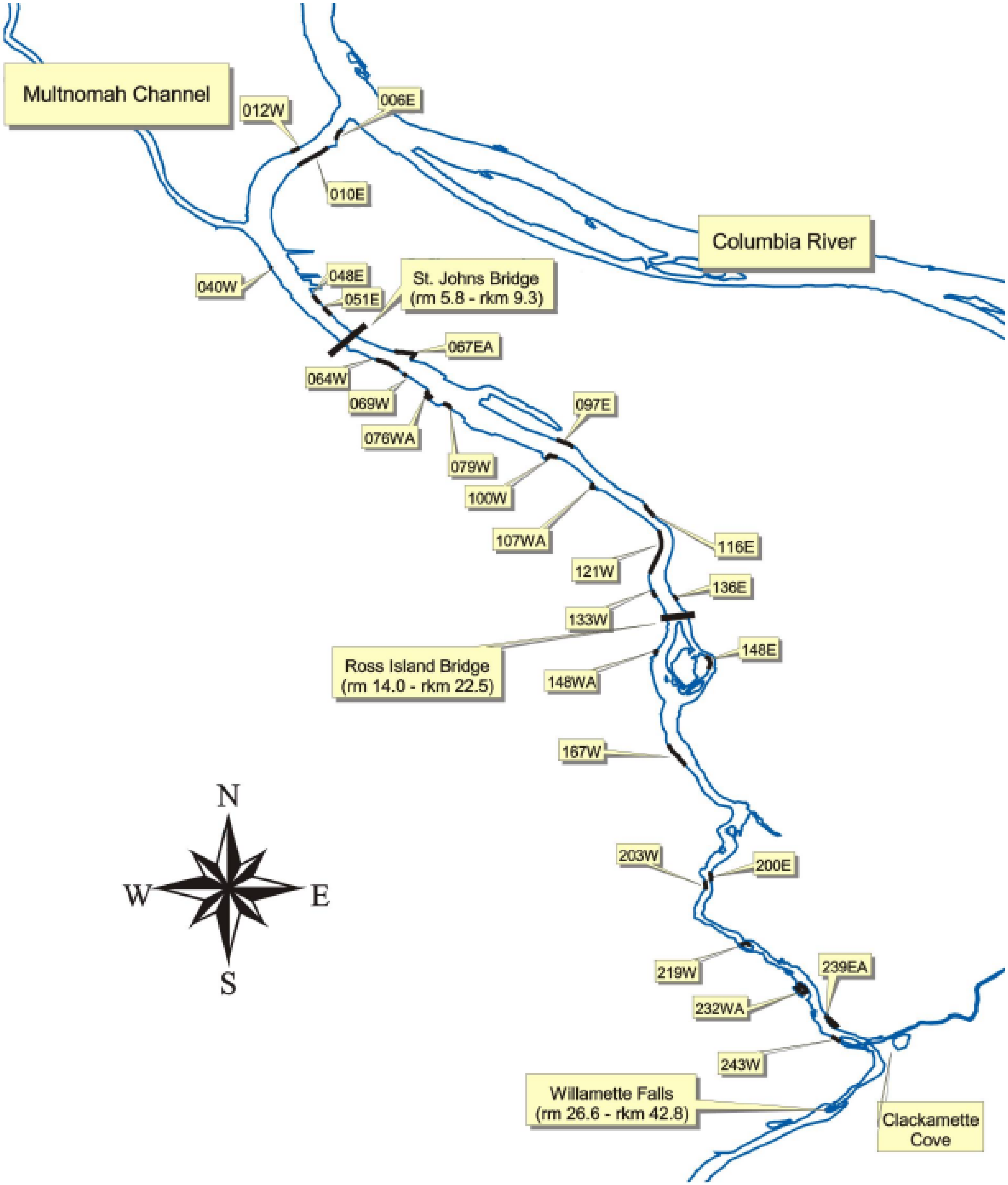

Figure 1. The lower Willamette River and associated features. Sampling site labels denote river mile (rm; xx.x) and east (E) or west (W) shore. A = alcove site, rkm = river kilometer.

METHODS

Field Sampling

Fish Collection

We used electrofishing and gillnetting to collect walleye, northern pikeminnow, smallmouth bass and largemouth bass at standardized sampling sites in the lower Willamette River between rkm 1.0 and 39.4 (Figure 1) from May 2000 to July 2003. Sampling sites were chosen to represent various bank treatment types found in the study reach (Vile and Friesen 2004). Sites were sampled by boat electrofishing and gillnetting after sunset. Boat electrofishing was conducted nearshore, at a target depth of 1 – 3 m (although some sites were much deeper), for a maximum of 750 s of continuous output. Gill nets were deployed both nearshore and offshore for approximately 40 minutes. Six sites were sampled with beach seines, which were deployed from a boat in a semi-circular fashion and pulled to shore. We recorded fork length (FL; mm) and weight (g) of all predator species captured, with the date, time, surface temperature, conductivity, duration of sampling effort (except beach seines), and minimum and maximum sampling depth for each effort. Sampling methodologies are described in detail in Friesen et al. (2003) and Friesen et al. (2004).

Radio Telemetry

Fish larger than 250 mm FL and in good physical condition were retained for radio tagging. We used 3.0-volt coded microprocessor transmitters manufactured by Lotek Engineering (models MCFT-3B and MCFT-3EM). All tags were coded with a continuous 4-s burst rate, and the minimum estimated battery life was 238 d for the MCFT-3B tags and 439 d for the MCTFT-3EM tags. The MCFT-3B tags were 14 x 43 mm and weighed 10.5 g (air weight) including antennae. The MCFT-3EM tags were 11 x 49 mm and weighed 8.9 g (air weight) including antennae. Tags did not exceed 6.2% of the fish's body weight.

Fish were either tagged onsite and immediately released, or tagged offsite and held overnight (12 - 18 hours) prior to release. Each tag was activated and checked with a Lotek receiver to ensure proper working condition. We surgically implanted tags into the ventral body cavity using methods described by Adams et al. (1998) for salmonids. After implanting tags, we inspected all fish to ensure they were actively swimming and in good condition. We released all tagged fish at their original capture site.

Tracking was conducted by boat, on an irregular basis, about one to ten days per month from 2000 - 2003. We tracked resident fish in both upstream and downstream directions. We typically began at one end of the study reach and proceeded upstream or downstream until the shift ended. Subsequent tracking began where previous tracking ended.

Upstream of Elk Rock Island (rkm 30.6) the river was relatively narrow; we attempted to locate radio-tagged fish by driving the boat roughly in the middle of the river channel. We employed a zigzag (from one shoreline to the other) tracking pattern downstream of the island to ensure we located as many fish as possible in this wider river section. Tracking effort was monitored to maintain an approximate 50:50 ratio between the east and west shorelines.

After a radio signal was detected, we attempted to pinpoint the location of the fish as described in Friesen et al. (2004). Date, time, tag frequency, tag code, GPS coordinates, estimated river mile, water depth, distance to the east and west shorelines, water temperature, and signal strength were recorded for each recovery. Recoveries were considered nearshore if they were within 10% of the measured channel width to either bank, and offshore if they were within 11 - 90%. For nearshore recoveries, we also recorded the bank treatment type. These were qualitative (based on the appearance of the shore habitat above the waterline) and included beach, rock outcrop, rock, riprap, fill (e.g. concrete or asphalt rubble), pilings, floating structures, and seawall (impervious vertical walls or bulkheads). Recoveries were considered off-channel if they were behind islands, in secondary channels, or in tributaries.

Diet

We collected diet samples from walleye, northern pikeminnow, smallmouth bass, and largemouth bass from January 2002 – July 2003 during standardized electrofishing and gillnetting. Prior to sample collection, all fish were measured and weighed. To ensure we sampled only fish capable of consuming juvenile salmonids, we adhered to minimum fork lengths: ≥ 200 mm FL for smallmouth bass and walleye (Zimmerman 1999), and ≥ 250 mm FL for northern pikeminnow and largemouth bass (Zimmerman 1999, Wanjala et al. 1986).

We extracted stomach contents from walleye, smallmouth bass, and largemouth bass using a modified Seaburg sampler (Seaburg 1957). Stomachs were flushed with a strong stream of water from the sampler and the contents were deposited into a sieve. Walleye, smallmouth bass and largemouth bass were released alive after sampling. Northern pikeminnow do not have a true stomach; we sacrificed these fish and removed the entire digestive tract. All diet samples were sealed in plastic bags and frozen until they could be processed. Samples were analyzed using methods described by Zimmerman (1999). We used diagnostic bones (dentaries, cleithra, and pharyngeal arches) to identify prey fish to the lowest possible taxa, usually genus (Frost 2000).

Data Analysis

Population Structure

We created length-frequency histograms for walleye, northern pikeminnow, smallmouth bass, and largemouth bass for each type of sampling effort (electrofishing, gillnetting, and beach seining). Differences among species and gear types were analyzed using a Kruskal-Wallis one-way analysis of variance (ANOVA) and Dunn’s method for pairwise comparisons. We log-transformed ($\log_{10} + 1$) length and weight data, and used simple linear regressions to describe length-weight relationships for all predator species.

Movement

We calculated observed movement of resident predators (upstream + downstream movement) and maximum displacement from their initial release point. We used a Kruskal-Wallis one-way ANOVA and Dunn's method for pairwise comparisons to compare total movement and maximum displacement from the release point among species. To analyze factors affecting fish movement, we performed linear regressions with water temperature, river flow, and fork length as the independent variables; relationships were considered significant if $P \leq 0.05$. We first identified candidate variables with simple linear regressions, then combined significant variables in multiple linear regressions.

To characterize the affinity of predator fishes for nearshore areas, we calculated the distribution of telemetry relocations across the river channel, represented as a percentage of the total river width (from the west shore):

$$\% \text{ relocation distance from west shore} = D_W / (D_E + D_W)*100, \text{ where}$$

D_W = relocation distance (m) from the west shore, and
D_E = relocation distance (m) from the east shore.

We then used the chi-square goodness-of-fit test to determine if telemetry relocations were evenly distributed across the river channel. Samples with expected values of less than 5 were not included (Zar 1999).

For other analyses of channel distribution, we calculated the percent relocation distance from the shoreline the fish was located nearest (west or east shore). Distributions were compared among species using a Kruskal -Wallis one-way ANOVA and Dunn's method for pairwise comparisons. Distributions across the river channel were also compared between daytime and nighttime relocations using a Mann-Whitney rank sum test. Because Vile and Friesen (2004) noted differences in general habitat types between the lower (rkm 0.0 – 22.5) upper (rkm 22.6 – 42.6) sections of the study area, we also compared channel distributions between these areas.

To determine if radio-tagged predators selected or avoided specific nearshore habitats, we used a chi-square goodness-of-fit test to determine if the frequency of telemetry relocations among habitat types was different from the availability of each habitat type. The proportional availability of each habitat type was determined from habitat inventories conducted in the lower Willamette River during 2001 (Vile and Friesen 2004).

Density – Habitat Comparisons

To supplement and verify radio telemetry results, we explored predator habitat associations using electrofishing data. We used both catch per unit effort (CPUE) and the proportion of non-zero catches as indices of fish density. Habitat use was evaluated among seasons, as bank habitats change throughout the year with fluctuations of river levels and other environmental conditions (Vile and Friesen 2004). As with other analyses, investigations of habitat use were restricted to predator-sized smallmouth bass, walleye, northern pikeminnow, and largemouth bass.

We used CPUE as one basis for evaluation. Because catch data was not normally distributed (many zero catches), we used median values and nonparametric statistical tests. Box plots represented the data and provided the median CPUE for each habitat classification, 25th and 75th percentiles, and 10th and 90th percentiles. The Kruskal-Wallis one-way ANOVA and Dunn's multiple comparison method were used to test for significant differences among habitat groupings. Because seasonal densities of individual predator species were often low, sample sizes were too small to perform statistical comparisons (with the exception of smallmouth bass catches during summer). We therefore combined all species to provide meaningful comparisons among seasons.

We also calculated the relative density of predators using an index based on the proportion of zero-fish catches. Although CPUE is the most commonly used index of fish density, Bannerot and Austin (1983) suggested the use of the square root of the relative frequency of zero-fish catches as an alternative. Zimmerman and Parker (1995) modified the index by using its reciprocal (1/square root of the proportion of zero catches) so the index value would be directly proportional to density. We compared seasonal density index values among seasons and bank habitats for individual species and all predators combined. Because the calculation of density indices resulted in a single value for each species/season, statistical comparisons were not possible. We visually interpreted density index results and compared them to results of the CPUE analysis.

Vile and Friesen (2004) reported bank habitats in the lower Willamette River clustered into groups based on physical and chemical parameters, and subjective characterizations of habitat types often accurately described differences in bank treatments. We therefore compared CPUE and density index values to habitat clusters identified by Vile and Friesen (2004), and identified the corresponding general habitat types (e.g. beach, riprap, seawall) in each analysis.

Diet

Predator diets were categorized as fish, crayfish, shrimp, and other prey. We determined the proportional wet weight of prey items found in predators and the proportion of predators containing prey items. Diets were compared among species, seasons, and habitat types, and between the upper and lower study reaches. We interpreted this data qualitatively, as small sample sizes precluded statistical comparisons.

RESULTS

Population Structure

We captured a total of 1,589 predators during standardized sampling. Slightly over half (51%) of the fish were captured by electrofishing, followed by beach seining (34%) and gillnetting (15%). Fork lengths of predator species were significantly different among the three gears. Median fork lengths were 302 mm for gill nets, 140 mm for electrofishing, and 58 mm for beach seines. Length-weight relationships (for all gears combined) are provided in Figure 2.

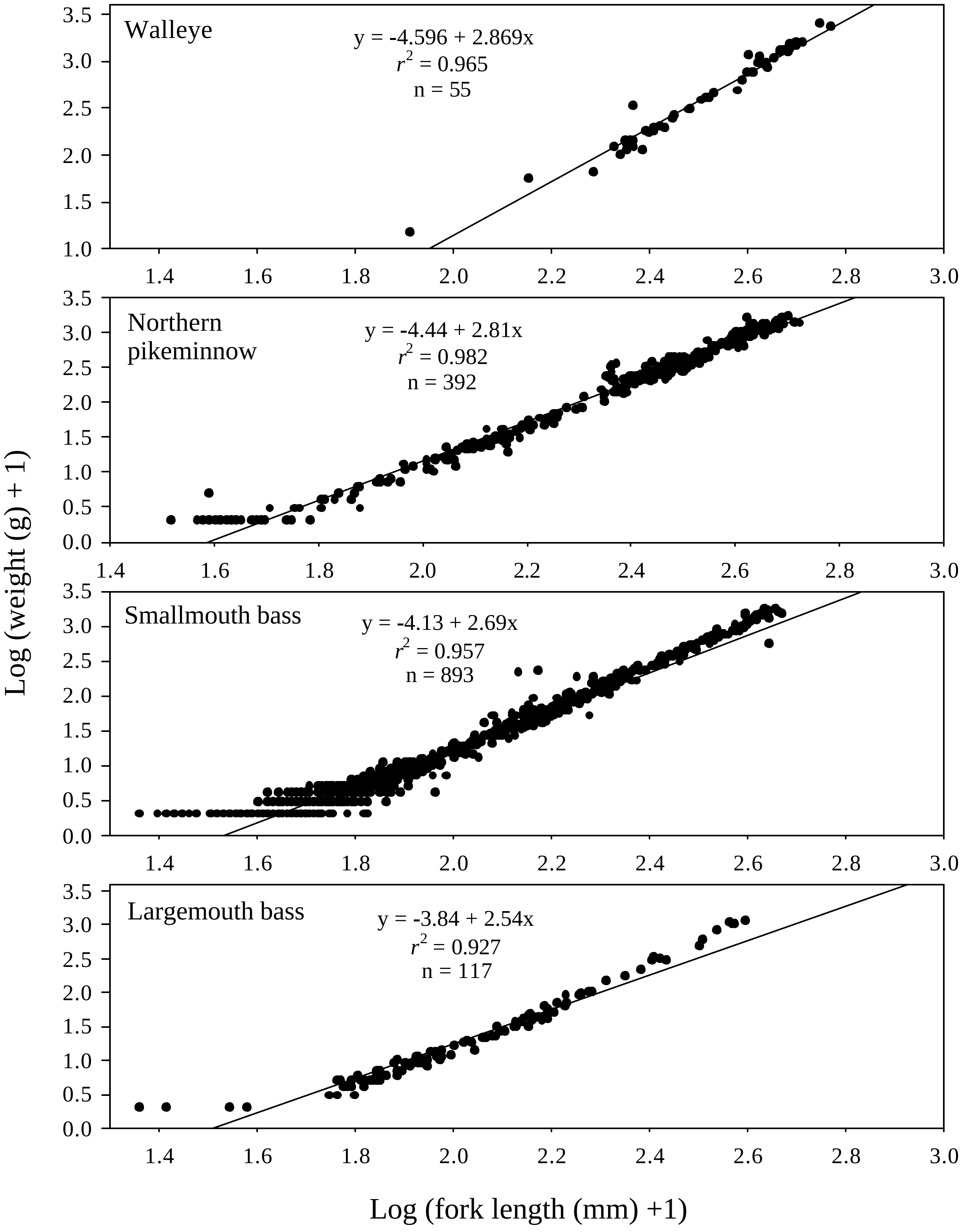

Figure 2. Length-weight relationships for predator species (all sampling gears combined) in the lower Willamette River, 2000-2003.

Smallmouth bass were the most abundant predator species captured by electrofishing (67% of the total catch; Figure 3). Median fork lengths ranged from 120 mm for smallmouth bass to 331 mm for walleye. Walleye were significantly larger than all other species ($P < 0.05$), and northern pikeminnow were significantly larger than both smallmouth and largemouth bass ($P < 0.05$). Length frequency distributions were skewed towards fish < 250 mm FL for all species except walleye.

Most fish captured by gillnetting were northern pikeminnow (89% of the total catch; Figure 4). No largemouth bass were captured. Fork lengths of predators captured with gill nets ranged from 298 mm for northern pikeminnow to 387 mm for walleye.

All predator species were present in beach seine catches, but smallmouth bass <100 mm FL were the most abundant (77% of the total catch; Figure 5). Median fork lengths ranged from 50 mm for northern pikeminnow to 86 mm for walleye. Walleye and largemouth bass captured in beach seines tended to be larger than northern pikeminnow and smallmouth bass.

Movement

From 2000 – 2003, we released a total of 73 radio-tagged predators, including 8 walleye, 37 northern pikeminnow, 23 smallmouth bass, and 5 largemouth bass (Table 1). We relocated 53 of the 73 fish, including 50% of the walleye, 59% of the northern pikeminnow, 96% of the smallmouth bass, and all of the largemouth bass. Anglers captured four radio-tagged fish, though each of these had been relocated at least once. We recorded a total of 264 predator relocations.

Radio-tagged predators did not travel far and tended to stay near their initial release points. The median total distance traveled ranged from 1.6 km for northern pikeminnow and largemouth bass to 9.0 km for walleye (Table 2). The median of the maximum distance traveled from the initial release point ranged from 1.0 km for largemouth bass to 4.7 km for walleye. Total distance traveled and maximum displacement from the release point did not vary significantly among species.

Simple linear regressions of river flow, water temperature, and fork length against the movement of predators identified only two significant relationships: the downstream movement of walleye increased weakly with flow ($r^2 = 0.213$), and the total movement of smallmouth bass was related weakly to temperature ($r^2 = 0.081$). However, river flow and fork length combined in a multiple linear regression explained a considerable amount of variation ($R^2 = 0.515$) in the downstream movement of walleye (Table 3). River flow was also positively related to the downstream movement of largemouth bass ($R^2 = 0.339$). Temperature appeared to be related to the total movement of smallmouth bass, but the multiple regression explained little of the overall variation ($R^2 = 0.087$).

The majority of predator relocations occurred offshore, though offshore relocations were often adjacent to a structure. For example, walleye were relocated offshore 93% of the time, but 49% of the offshore relocations were near pilings. Similarly, 62% of northern pikeminnow

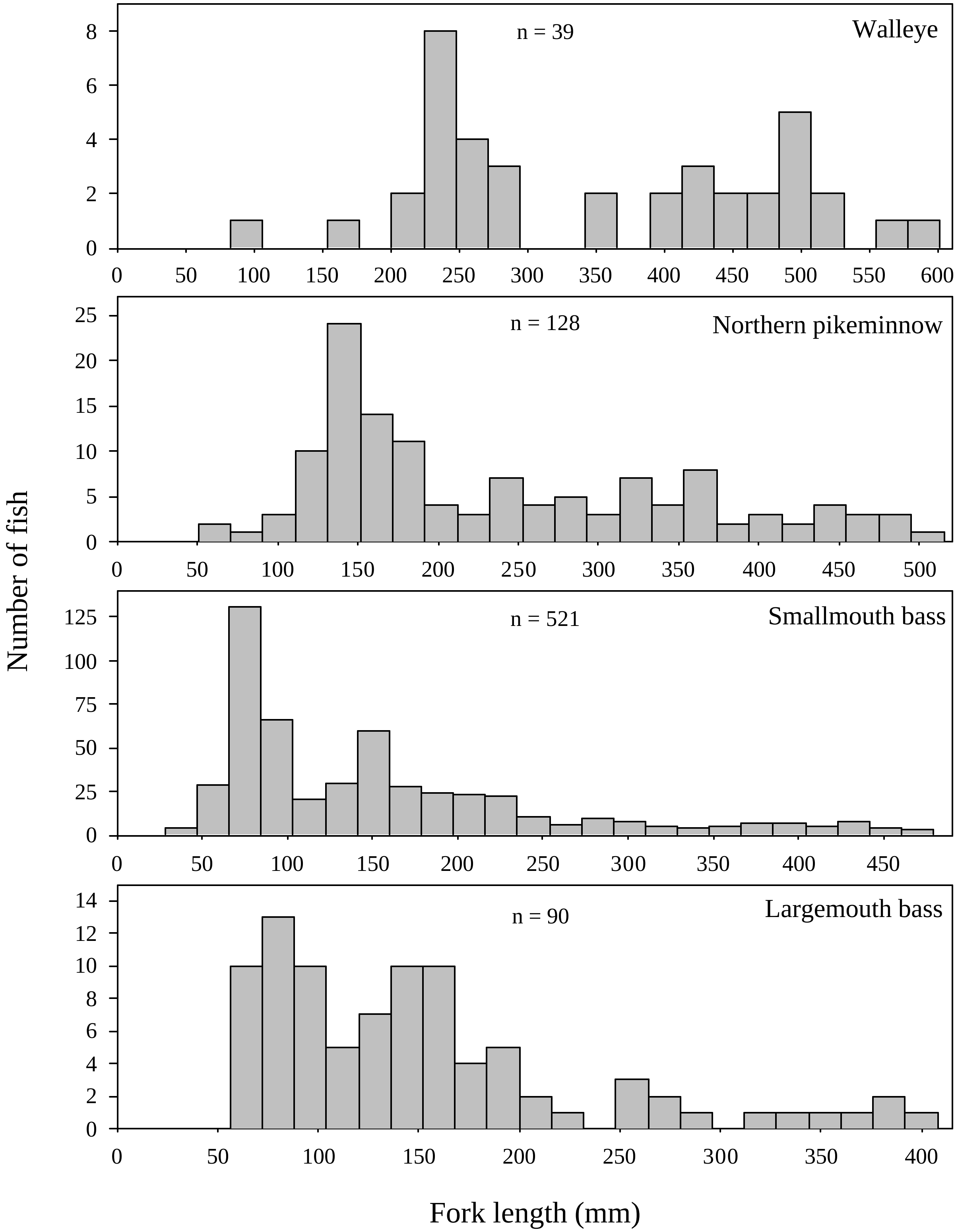

Figure 3. Length – frequency distribution of predator species captured by electrofishing in the lower Willamette River, 2000 – 2003.

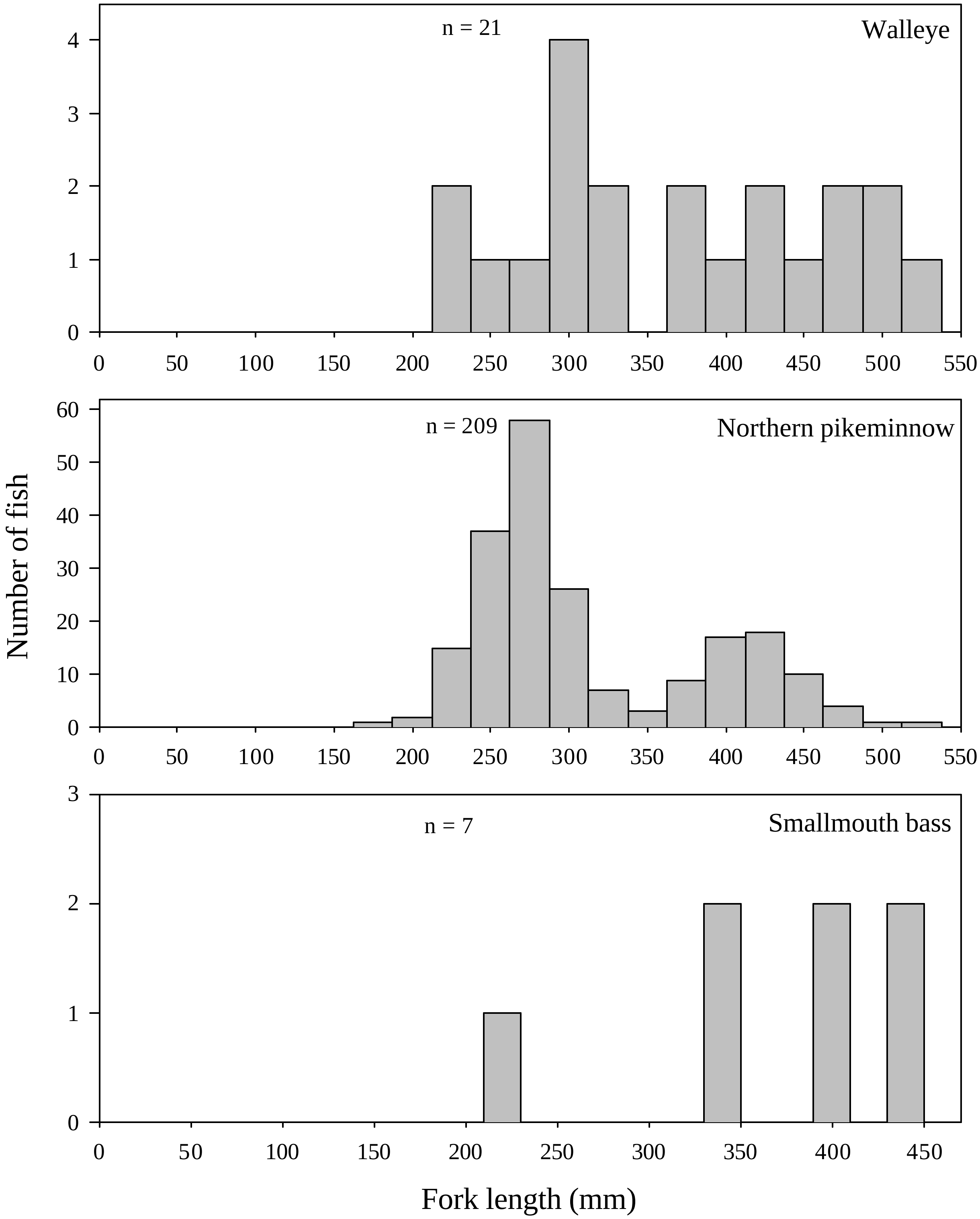

Figure 4. Length – frequency distributions of predator species captured with gill nets in the lower Willamette River, 2000 – 2003.

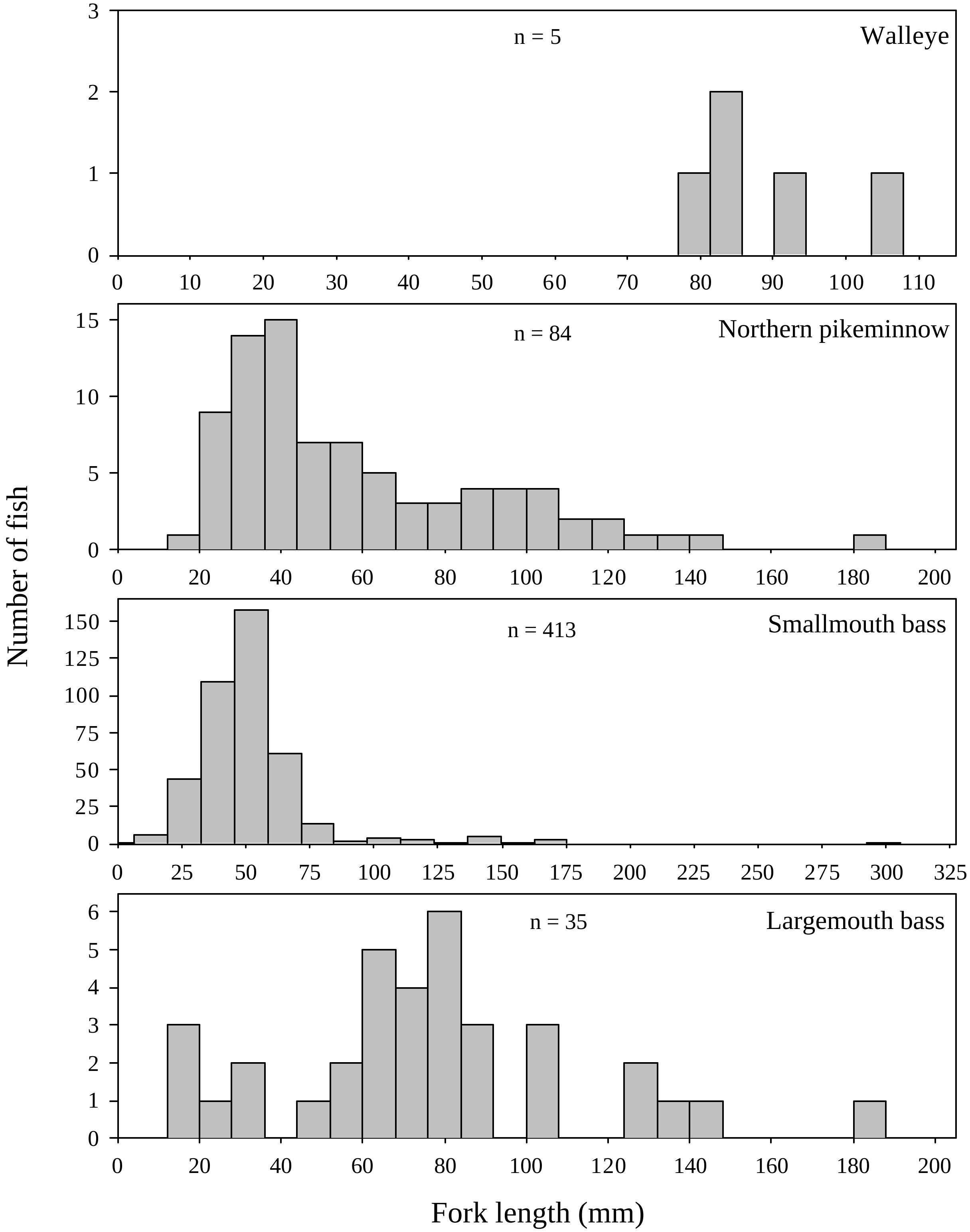

Figure 5. Length – frequency distributions of predator species captured with beach seines in the lower Willamette River, 2000 – 2003.

Table 1. Summary of releases, recoveries, lengths, and weights for radio-tagged walleye, northern pikeminnow, smallmouth bass, and largemouth bass in the lower Willamette River, 2000-2003. No fish were tagged in 2001. The number of relocations may include fish tagged in previous years. WAL = walleye; NPM = northern pikeminnow; SMB = smallmouth bass; LMB = largemouth bass.

		Number	Number	Number of	Fork length (mm)			Weight (g)		
Species	Year	released	recovered	relocations	Min.	Max.	Mean	Min.	Max.	Mean
WAL	2000	4	1	2	328	396	361	405	750	548
	2001	0	0	3	-	-	-	-	-	-
	2002	1	0	0	282	282	282	260	260	260
	2003	3	3	23	250	269	258	170	190	183
	All	8	4	28	250	396	312	170	750	375
NPM	2000	30	17	25	253	492	395	340	1650	852
	2001	0	0	15	-	-	-	-	-	-
	2002	6	4	3	268	469	341	469	1200	567
	2003	1	1	9	340	340	340	470	470	470
	All	37	22	52	253	492	385	340	1650	796
SMB	2000	11	11	65	298	398	364	440	1040	747
	2001	0	0	11	-	-	-	-	-	-
	2002	9	8	9	260	453	369	280	1740	954
	2003	3	3	65	346	404	376	720	1160	910
	All	23	22	150	260	453	368	280	1740	849
LMB	2000	0	0	0	-	-	-	-	-	-
	2001	0	0	0	-	-	-	-	-	-
	2002	4	4	28	255	394	319	310	1160	715
	2003	1	1	6	322	322	322	590	590	590
	All	5	5	34	255	394	320	310	1160	690
Total	All	73	53	264	250	492	367	170	1740	759

Table 2. Summary of total distance traveled (upstream + downstream movement), maximum displacement from initial release point, and duration of the monitoring period for walleye, northern pikeminnow, smallmouth bass, and largemouth bass in the lower Willamette River, 2000-2003. WAL = walleye; NPM = northern pikeminnow; SMB = smallmouth bass; LMB = largemouth bass. n = number of fish tagged.

		Total distance traveled (km)			Maximum displacement (km)			Monitoring period (d)		
Species	n	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile	25th percentile	Median	75th percentile
WAL	4	5.1	9.0	14.6	2.4	4.7	8.2	86	107	164
NPM	22	0.3	1.6	4.5	0.3	1.4	3.4	28	82	170
SMB	22	0.8	4.3	8.0	0.5	2.3	4.3	83	147	180
LMB	5	1.0	1.6	5.8	0.5	1.0	3.5	81	120	151

Table 3. Summary of multiple linear regressions for the movement of resident predator fish in the lower Willamette River, 2000 – 2003. Models with significant relationships for one or more independent variables are shown. n = number of relocations.

Species	Direction of travel	n	Independent variable	Regression coefficient	*P*	Power	R^2
Walleye	Downstream	22	Constant	-10.546	< 0.05	0.976	0.515
			Flow	9.56×10^{-5}	< 0.05		
			Temperature	0.132	0.14		
			Fork length	0.027	< 0.05		
Largemouth bass	Downstream	31	Constant	-0.340	0.14	0.941	0.339
			Flow	6.12×10^{-6}	< 0.05		
			Temperature	-0.002	0.91		
			Fork length	6.58×10^{-4}	0.30		
Smallmouth bass	Upstream and downstream	90	Constant	-0.516	0.59	0.811	0.087
			Flow	3.82×10^{-6}	0.46		
			Temperature	0.056	< 0.05		
			Fork length	-8.46×10^{-5}	0.97		

relocations were offshore; 19% of these were near pilings or floating structures. Smallmouth bass were located offshore 58% of the time, with 17% of the relocations occurring near pilings or floating structures. Largemouth bass were located offshore 48% of the time, with 10% of the relocations near pilings or floating structures.

Nearshore relocations of radio-tagged predators tended to vary from the relative availability of nearshore bank treatment types (Figure 6), though small sample sizes precluded the use of statistical comparisons for all species except smallmouth bass. The observed recoveries of smallmouth bass differed significantly ($P < 0.05$) from expected recoveries based on the proportional distribution of habitat types. Smallmouth bass over-utilized pilings, floating structures, and to a lesser degree, riprap. We visually interpreted habitat use patterns for other species. Northern pikeminnow appeared to have an affinity for pilings, and appeared to avoid beaches. Largemouth bass appeared to over-utilize pilings and rock habitats, but avoided rock outcrops. We relocated only two walleye near shore. All species appeared to share two habitat associations: over-utilization of pilings, and under-utilization of artificial fill and seawalls.

We observed several differences in nearshore habitat associations between summer/autumn and winter/spring (Figure 7). There were no nearshore relocations in the summer and autumn for walleye, and only two nearshore relocations in the winter and spring, one adjacent to riprap and one adjacent to pilings. Nearshore relocations of northern pikeminnow in the summer and autumn were primarily near pilings (40%) and riprap (30%), and in the winter and spring near pilings (55%). Smallmouth bass were relocated primarily near riprap (30%) and pilings (23%) in the summer and autumn, and near beach (33%) and rock outcrop (18%) in the winter and spring. Smallmouth bass habitat associations indicated significant differences between utilized habitat and available habitat in the summer and autumn, but not in the winter and spring ($P = 0.30$). Seasonal patterns of habitat use were similar between northern pikeminnow and smallmouth bass; both species were found at beaches and rock outcrops more frequently in the winter and spring, though these habitats were not always over-utilized. Both species were highly associated with pilings, regardless of season. Largemouth bass were relocated near pilings (71%) and beach sites (29%) in summer and autumn, and were evenly distributed among pilings (31%), rock (31%), and beach (31%), during winter and spring. As with northern pikeminnow and smallmouth bass, largemouth bass were often found near pilings.

About 23% of all telemetry recoveries were made away from the main river channel (Table 4). The majority of off-channel relocations occurred behind islands (Ross Island, Goat Island, Hog Island, or Swan Island; 44% of off-channel recoveries) or in the large alcove behind Cedar Oak Island (43% of off-channel recoveries). Predators relocated in the Cedar Oak alcove tended to remain there for long periods of time (median 80 days), as opposed to predators relocated behind other islands (median 17 days). Among all fish, 18% of the northern pikeminnow, 25% of the walleye, 41% of the smallmouth bass, and 60% of the largemouth bass were relocated in off-channel habitat at least once.

The distribution of radio-tagged fish across the river channel indicated a consistent preference for areas within 20% of either shoreline (Figure 8). Walleye were relocated within 20% of both riverbanks 68% of the time, northern pikeminnow 75% of the time, smallmouth bass 73% of the time, and largemouth bass 81% of the time. Smallmouth bass and northern pikeminnow were

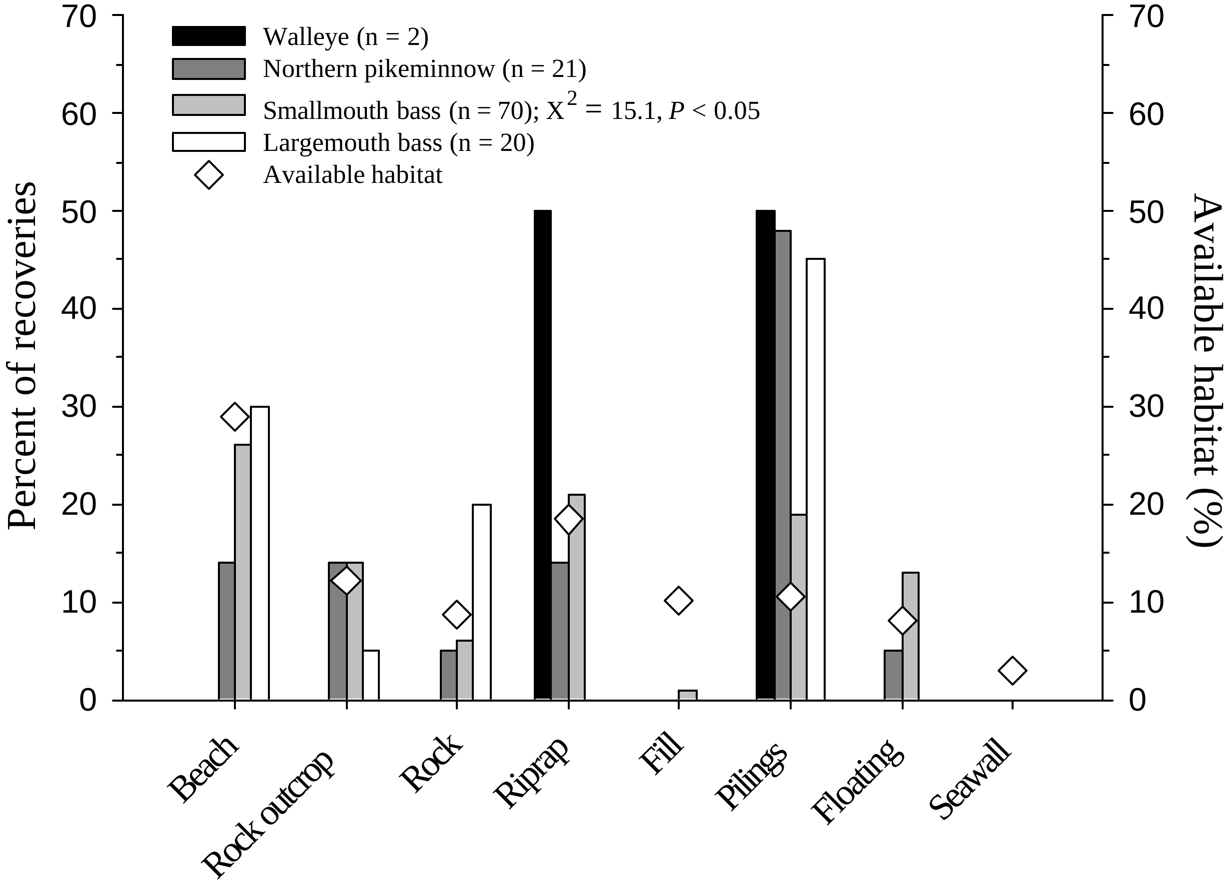

Figure 6. Nearshore recoveries of radio-tagged predator species compared to the proportional availability of general bank habitat types in the Willamette River, 2001-2003. Chi square statistics are included where the expected n ≥ 5 for each category. n = number of recoveries.

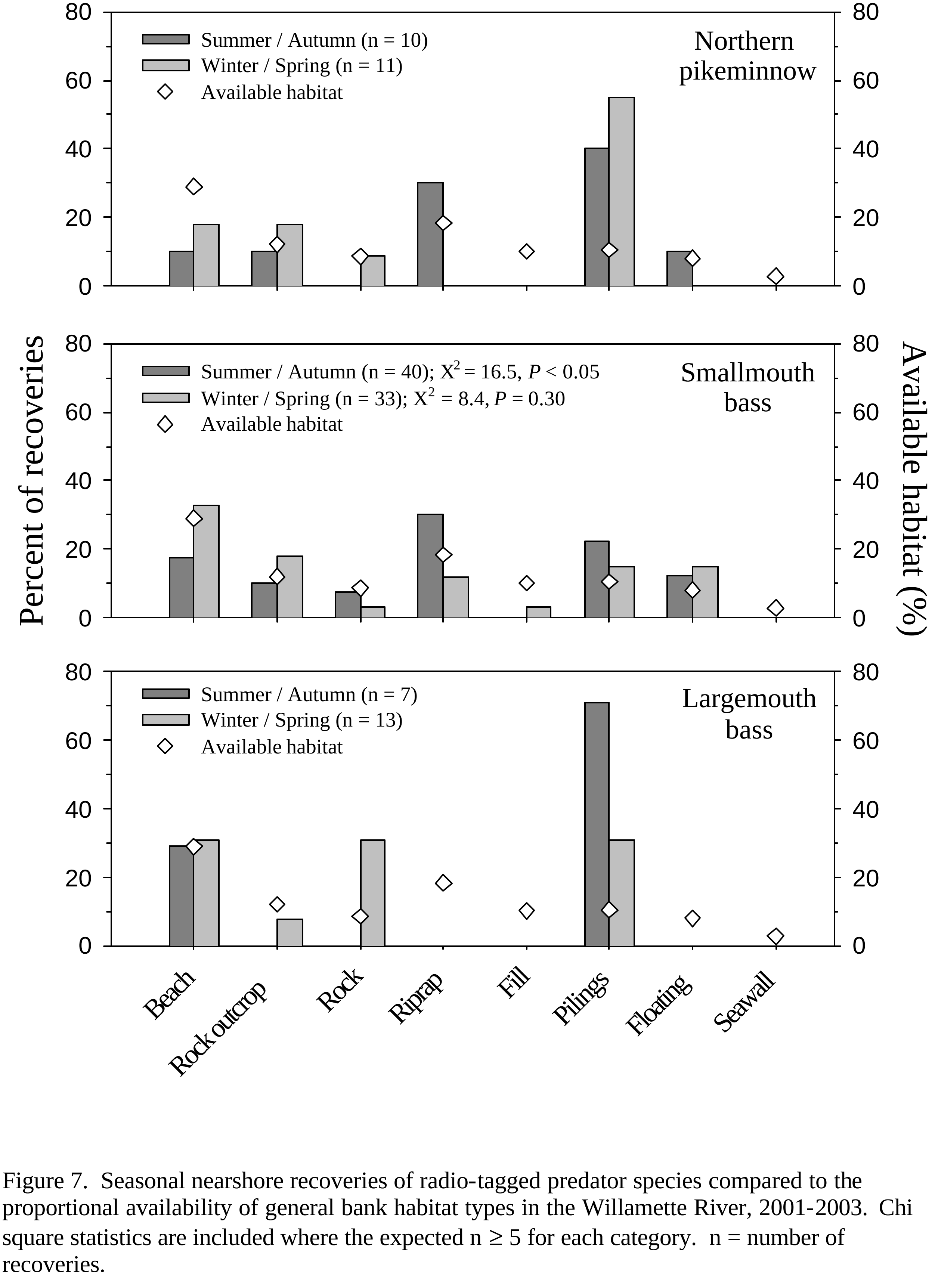

Figure 7. Seasonal nearshore recoveries of radio-tagged predator species compared to the proportional availability of general bank habitat types in the Willamette River, 2001-2003. Chi square statistics are included where the expected n ≥ 5 for each category. n = number of recoveries.

Table 4. Summary of individual off-channel radio telemetry relocations of walleye, northern pikeminnow, smallmouth bass, and largemouth bass in the lower Willamette River, 2000-2003. Asterisks indicate fish caught by anglers. WAL = walleye; NPM = northern pikeminnow; SMB = smallmouth bass; LMB = largemouth bass.

Species	Off-channel location	Percent off-channel relocations (n)	Total distance traveled (km)	Median distance from release (km)	Time spent off-channel (d)	Total tracking time (d)
WAL	Behind Ross Island	78 (9)	6.1	1.4	16.9	125.8
NPM	Multnomah channel	83 (6)	7.2	3.4	99.0	169.7
NPM	Multnomah channel	67 (3)	0.3	0.0	14.0	82.9
NPM	Multnomah channel	33 (3)	1.6	0.3	-	203.5
NPM	Swan Island	100 (1)	0.6	0.6	-	70.0
SMB	Behind Hog Island	100 (2)	0.0	0.0	16.7	39.1
SMB	Swan Island	14 (7)	6.4	0.5	-	192.1
SMB*	Cedar Oak alcove	17 (12)	3.1	0.5	34.1	196.9
SMB	Cedar Oak alcove	8 (12)	8.0	5.0	-	254.3
SMB	Behind Ross Island	60 (5)	4.7	1.0	53.5	76.9
SMB	Behind Hog Island	60 (5)	2.4	0.2	15.0	128.4
SMB	Behind Ross Island	17 (6)	0.8	0.2	-	83.0
SMB	Cedar Oak alcove	88 (8)	0.8	0.0	97.0	138.9
SMB	Behind Hog Island	60 (5)	8.4	0.3	6.9	106.5
LMB	Behind Goat Island	83 (6)	1.1	0.8	81.0	137.1
LMB	Cedar Oak alcove	100 (11)	1.6	0.0	191.0	191.0
LMB*	Cedar Oak alcove	100 (6)	0.6	0.0	62.9	62.9

not evenly distributed across the river channel ($P < 0.01$). Sample sizes were too small to analyze the distribution of walleye and largemouth bass, but visual interpretation indicated these species had distributions similar to those of smallmouth bass and northern pikeminnow.

The median percentage and the median distance from shore that radio-tagged fish were located also varied among species. Walleye were located a median percentage of 16% from either shore (median distance 75 m), northern pikeminnow were located a median percentage of 12% from either shore (median distance 44 m), smallmouth bass were located a median percentage of 12% from either shore (median distance 33 m), and largemouth bass were located a median percentage of 10% from either shore (median distance 20 m). Walleye were relocated significantly farther (by percent of river width) from shore than largemouth bass, and significantly farther (by distance) from shore than any other species. Largemouth bass relocations were significantly closer to shore, by percent and distance, than any other species.

The distribution of radio-tagged predators across the river channel did not vary between day and night (Figure 9, Table 5). The median distributions of all species were within 10 - 15% of either shoreline during the day, and 11 – 17% at night.

The distribution of all species across the river channel varied significantly between the upper and lower portions of the study area. Predators tended to stay farther from shore in the upstream section and closer to shore in the lower section (Figure 10, Table 6). For example, the median distribution of walleye in the upper portion of the study reach was within 31% of either shore

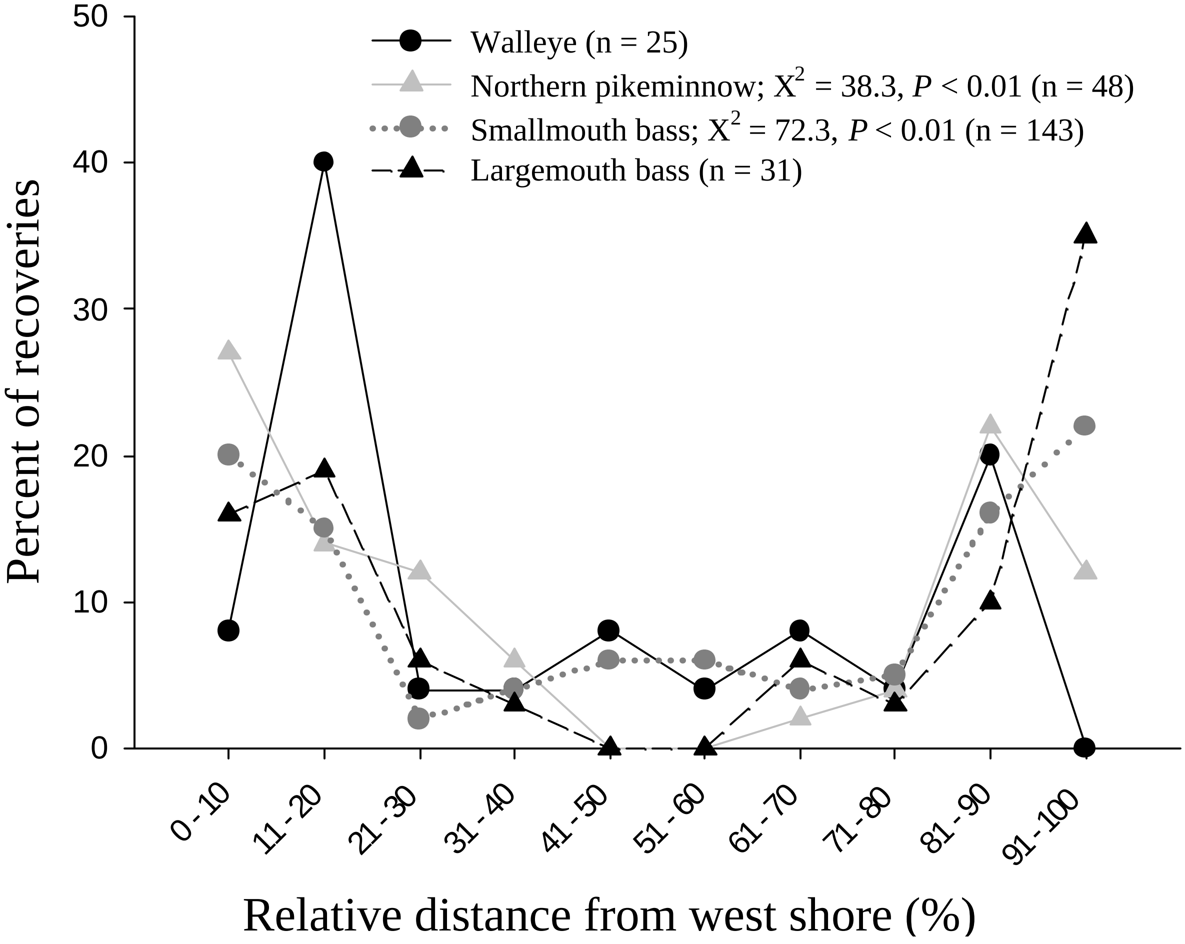

Figure 8. Recovery frequencies of radio-tagged predator species by relative distance from the west shore in the lower Willamette River, 2000-2003. Chi square statistics are included where the expected n ≥ 5 for each category. West shore = 0%; east shore = 100%; n = number of recoveries.

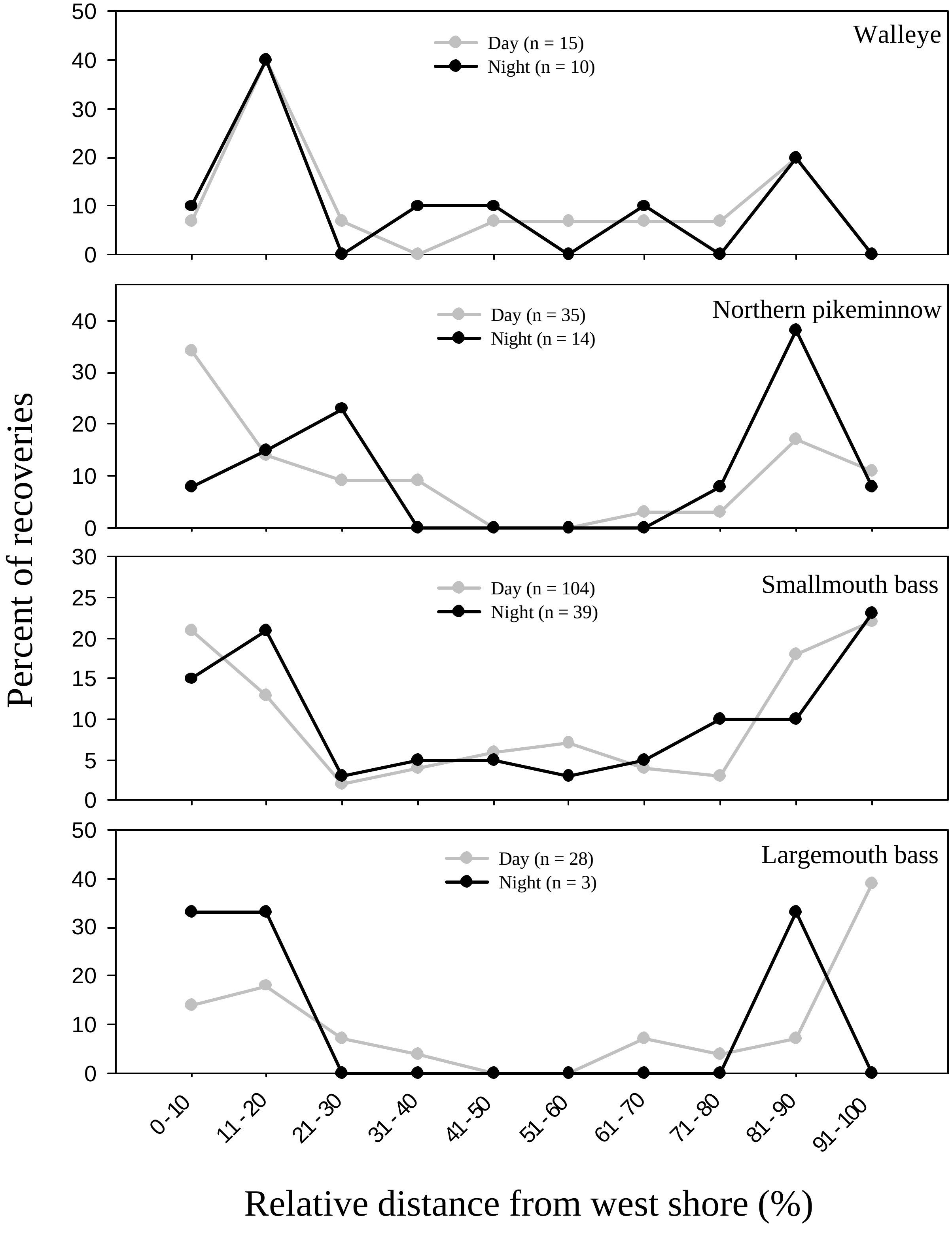

Figure 9. Day and night recovery frequencies of radio-tagged predator species by relative distance from the west shore in the lower Willamette River, 2000-2003. West shore = 0%; east shore = 100%; n = number of recoveries.

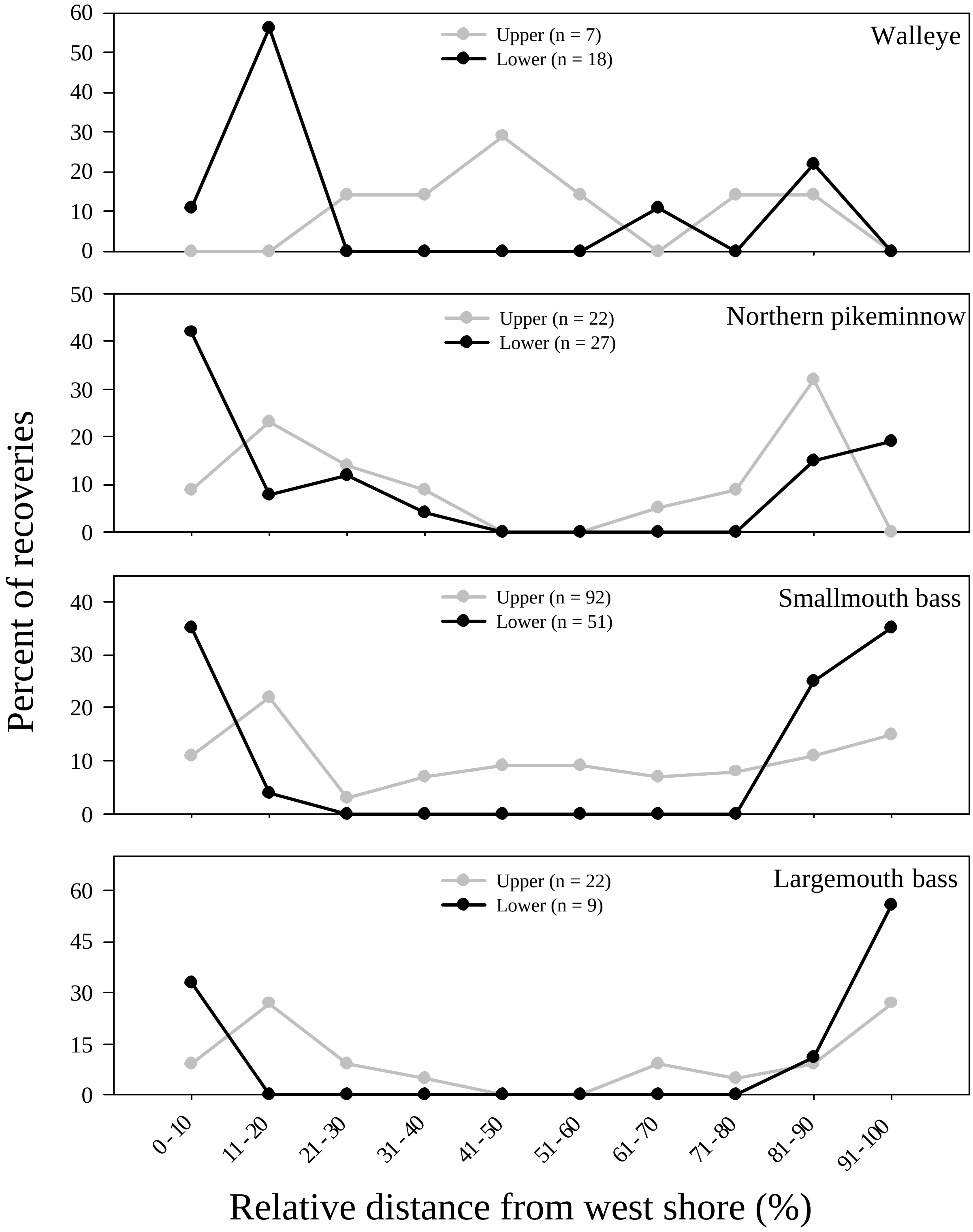

Figure 10. Recovery frequencies of radio-tagged predator species by relative distance from the west shore in the upper (rkm 22.6 - 42.6) and lower (rkm 0.0 – 22.5) Willamette River, 2000-2003. West shore = 0%, east shore = 100%; n = number of recoveries.

Table 5. Summary statistics of distribution across the river channel (percent of the river width) for radio-tagged walleye, northern pikeminnow, smallmouth bass, and largemouth bass during the day and night in the lower Willamette River, 2000-2003. n = number of recoveries.

Species	n	Median	25th percentile	75th percentile	*P*
Walleye – day	15	15.0	12.5	28.5	0.70
Walleye – night	10	17.0	13.0	31.0	
Northern pikeminnow – day	35	10.0	6.0	18.8	0.19
Northern pikeminnow – night	13	16.0	10.0	21.5	
Smallmouth bass – day	104	12.0	7.0	20.0	0.89
Smallmouth bass – night	39	11.0	8.3	24.3	
Largemouth bass – day	28	9.5	6.5	19.5	0.79
Largemouth bass - night	3	11.0	8.8	14.8	

Table 6. Summary statistics of distribution across the river channel (percent of the river width) for walleye, northern pikeminnow, smallmouth bass, and largemouth bass in upper (rkm 0.0 – 22.5) and lower (rkm 22.6 – 42.6) sections of the lower Willamette River, 2000-2003. n = number of recoveries.

Species	n	Median	25th percentile	75th percentile	*P*
Walleye – upper	7	31.0	27.5	42.5	< 0.05
Walleye – lower	18	14.0	12.0	17.0	
Northern pikeminnow – upper	22	15.5	12.0	24.0	< 0.05
Northern pikeminnow – lower	26	8.5	6.0	18.0	
Smallmouth bass – upper	92	18.0	9.5	35.5	< 0.05
Smallmouth bass – lower	51	9.0	5.0	11.0	
Largemouth bass – upper	22	11.5	8.0	20.0	< 0.05
Largemouth bass - lower	9	6.0	4.0	8.3	

and the median distribution of walleye in the lower portion of the study reach was within 14% of either shore. Similar patterns were observed for northern pikeminnow, smallmouth bass, and largemouth bass.

Density – Habitat Comparisons

Large predator fishes were present at very low densities during all seasons; median catch rates (all species combined) were always 0.0 (Figure 11). Catches were highest during spring and summer. Sample sizes were large enough during these seasons to conduct statistical analyses, and we identified several significant differences in median CPUE among clustered habitat groups. Spring predator catches were significantly higher ($P = 0.02$) for group 4 (two riprapped sites and one off-channel site dominated by rock) than for group 1 (two seawall sites and one riprapped site). Catch rates were also relatively high, but not significantly different, for group 5 (two rock outcrop sites). In summer, CPUE for group 3 (three riprapped sites and five mixed habitat / off-channel sites dominated by rock) was significantly ($P < 0.01$) higher than all other groups except group 5 (two rock outcrop sites). Winter and autumn catches were very low, but slightly higher catch rates occurred at habitat groups dominated by riprap or rock outcrop.

We were unable to provide statistical CPUE comparisons among habitat groups for most individual species and seasons due to small sample sizes, with the exception of smallmouth bass captured during summer (Figure 12). The median smallmouth bass CPUE for group 3 (three riprapped sites and five mixed or off-channel sites dominated by rock) was significantly higher ($P < 0.01$) than catch rates for any group except group 5 (two rock outcrop sites). In addition, group 1 (three beach sites and one off-channel site) catch rates, while relatively low, were significantly higher than group 2 catch rates (four beach sites, one riprapped site, and one off-channel site).

Comparisons of relative density among habitat groups, visually interpreted, were similar to the CPUE analyses. For all species combined, predator densities were relatively high at rock outcrop sites during every season except winter (Figure 13). Density indices were highest in spring, with the bulk of predators collected at sites dominated by riprap, rock outcrop, or mixed habitat. Peak summer density occurred in groups 3 (primarily riprap and other rock) and 5 (rock outcrop); autumn densities were highest at rock outcrop sites (group 5). Beach and seawall sites had low density indices in all seasons.

Density index – habitat comparisons varied somewhat among species, though relative densities tended to be highest at habitat groups dominated by riprap, mixed habitat (primarily riprap and beach), and rock outcrop. Smallmouth bass densities were relatively high at rock outcrop sites in all seasons except winter (Figure 14). Smallmouth bass density was also high at group 3 (primarily riprap and other rock) sites during summer. The highest relative density of northern pikeminnow occurred during spring at group 4 (two riprap sites and one off-channel site; Figure 15). High densities of northern pikeminnow were also collected from rock outcrop sites in winter (group 1) and autumn (group 5). Although the overall largemouth bass catch was relatively low throughout the year, densities were highest in spring at cluster group 4 composed of two riprap sites and an alcove (Figure 16). Walleye density indices, while also low, were

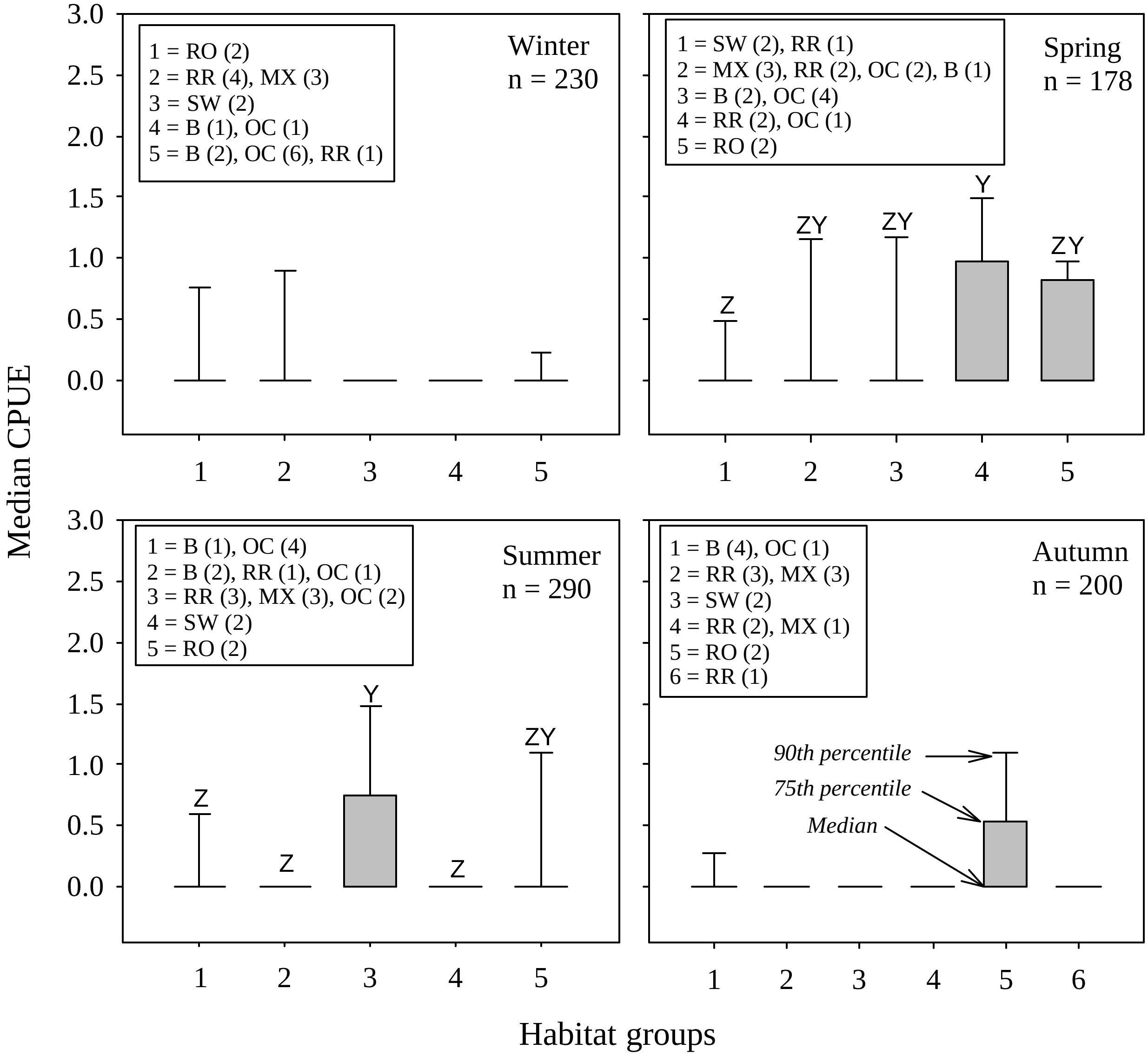

Figure 11. Median catch per unit effort (CPUE) of predator fishes (all species combined) among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites that were grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) that were included in each habitat group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall, and OC = off channel. n = number of electrofishing runs. Habitat groups without a letter in common differed significantly ($P<0.05$).

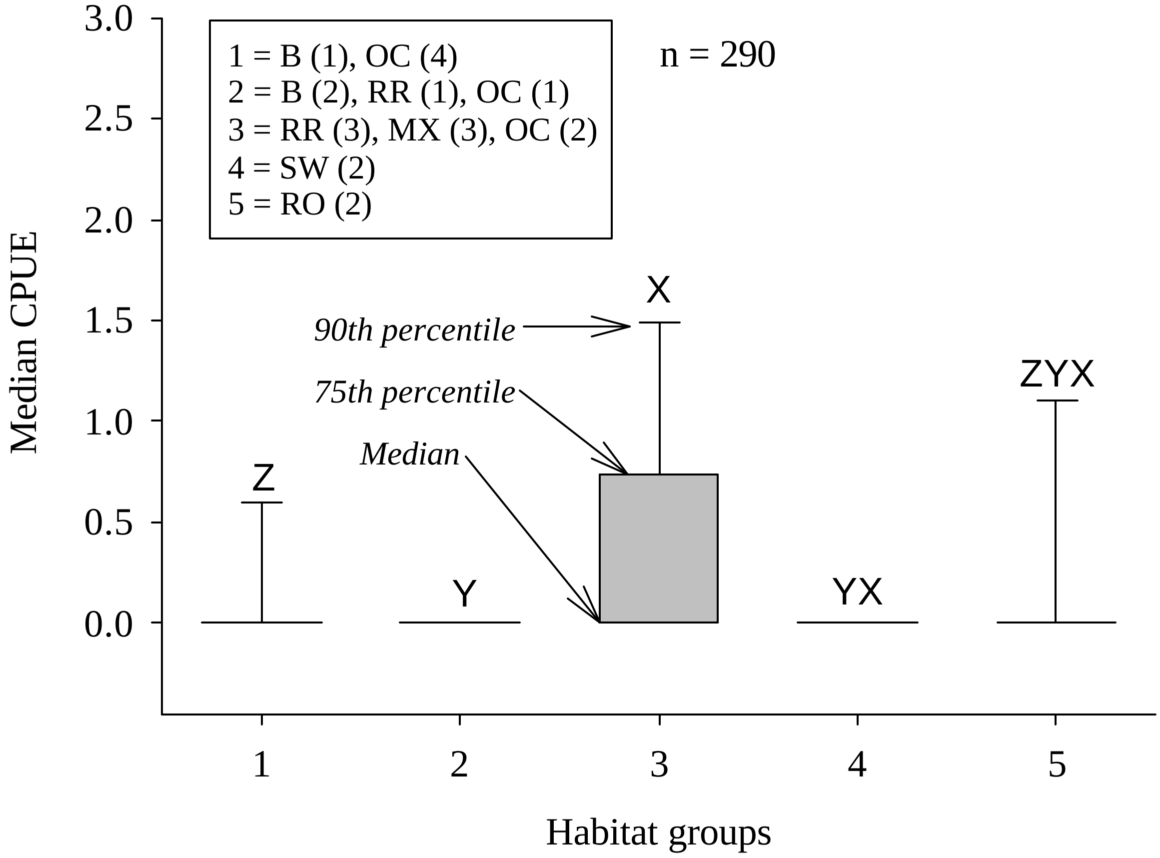

Figure 12. Median catch per unit effort (CPUE) during summer for predator-sized (>199 mm FL) smallmouth bass among habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites that were grouped by cluster analysis (Vile and Friesen 2004). The legend indicates generalized habitat types (number of sites in parentheses) included in each habitat group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall, and OC = off channel. n = number of electrofishing runs. Habitat groups without a letter in common differed significantly (*P*<0.05).

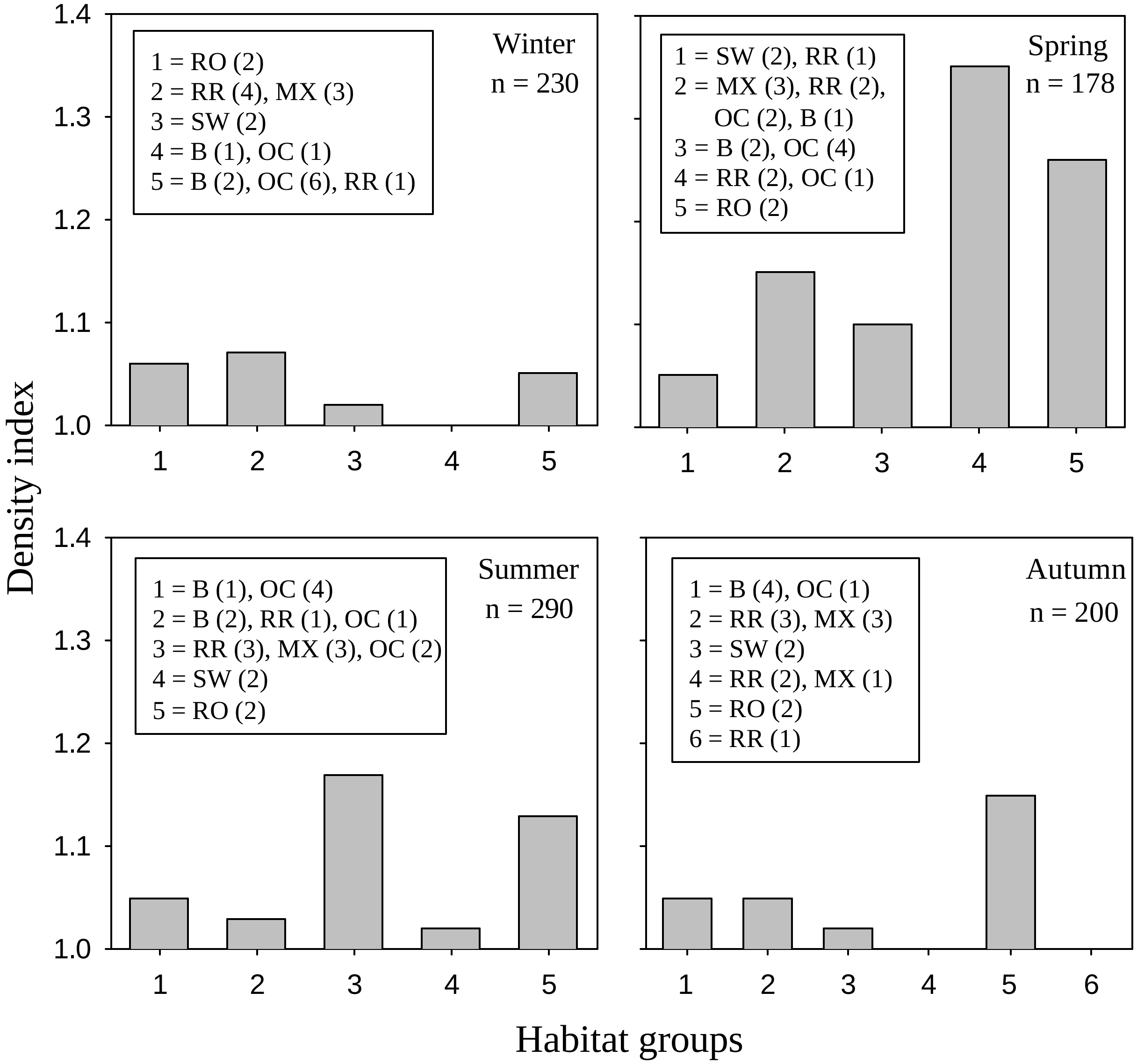

Figure 13. Density indices of predator fishes (all species combined) among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites that were grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) that were included in each habitat group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall, and OC = off channel. n = number of electrofishing runs.

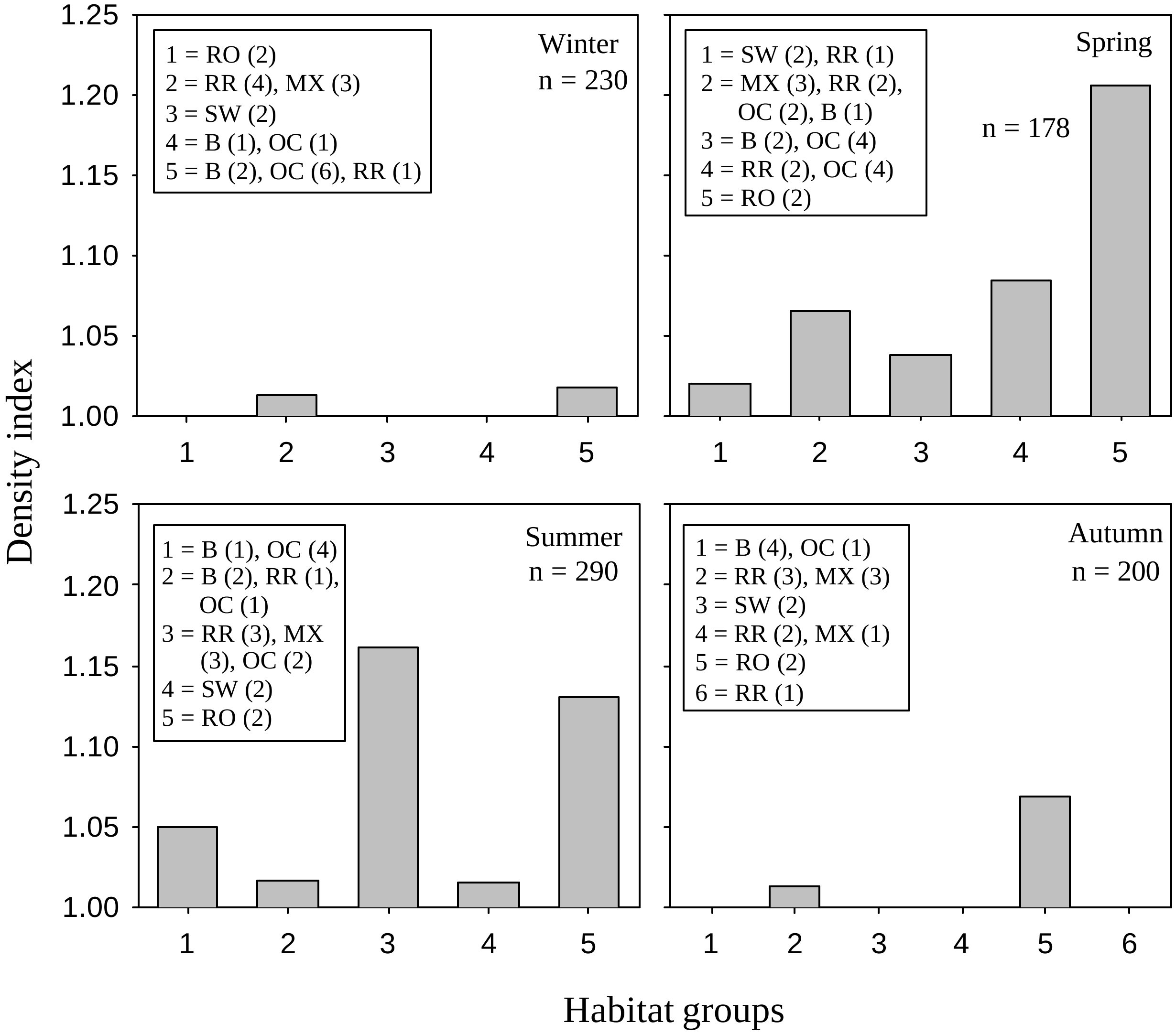

Figure 14. Density indices of predator-sized (>199 mm FL) smallmouth bass among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites that were grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) that were included in each habitat group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall, and OC = off channel. n = number of electrofishing runs.

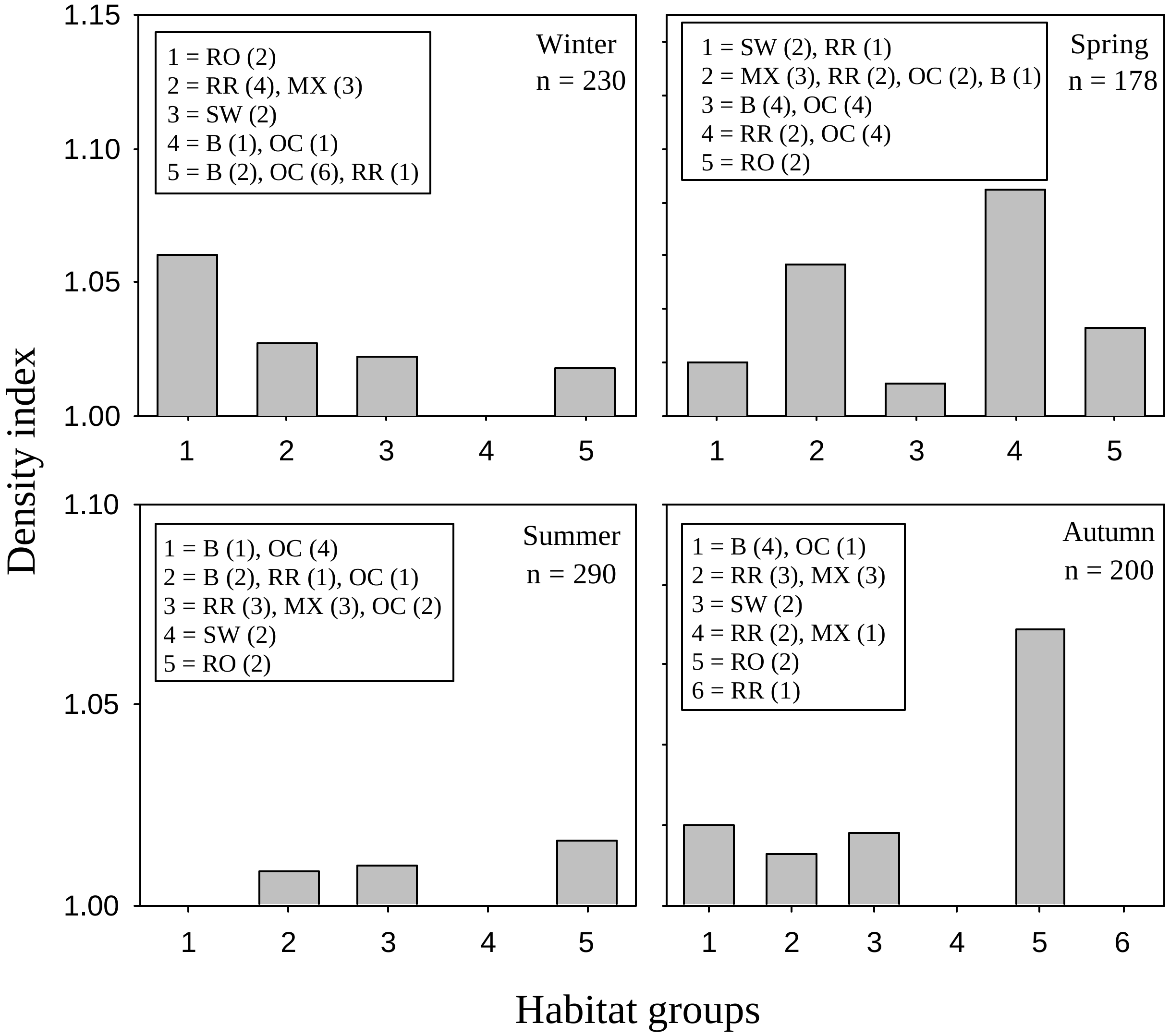

Figure 15. Density indices of predator-sized (>249 mm FL) northern pikeminnow among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites that were grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) that were included in each habitat group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall, and OC = off channel. n = number of electrofishing runs.

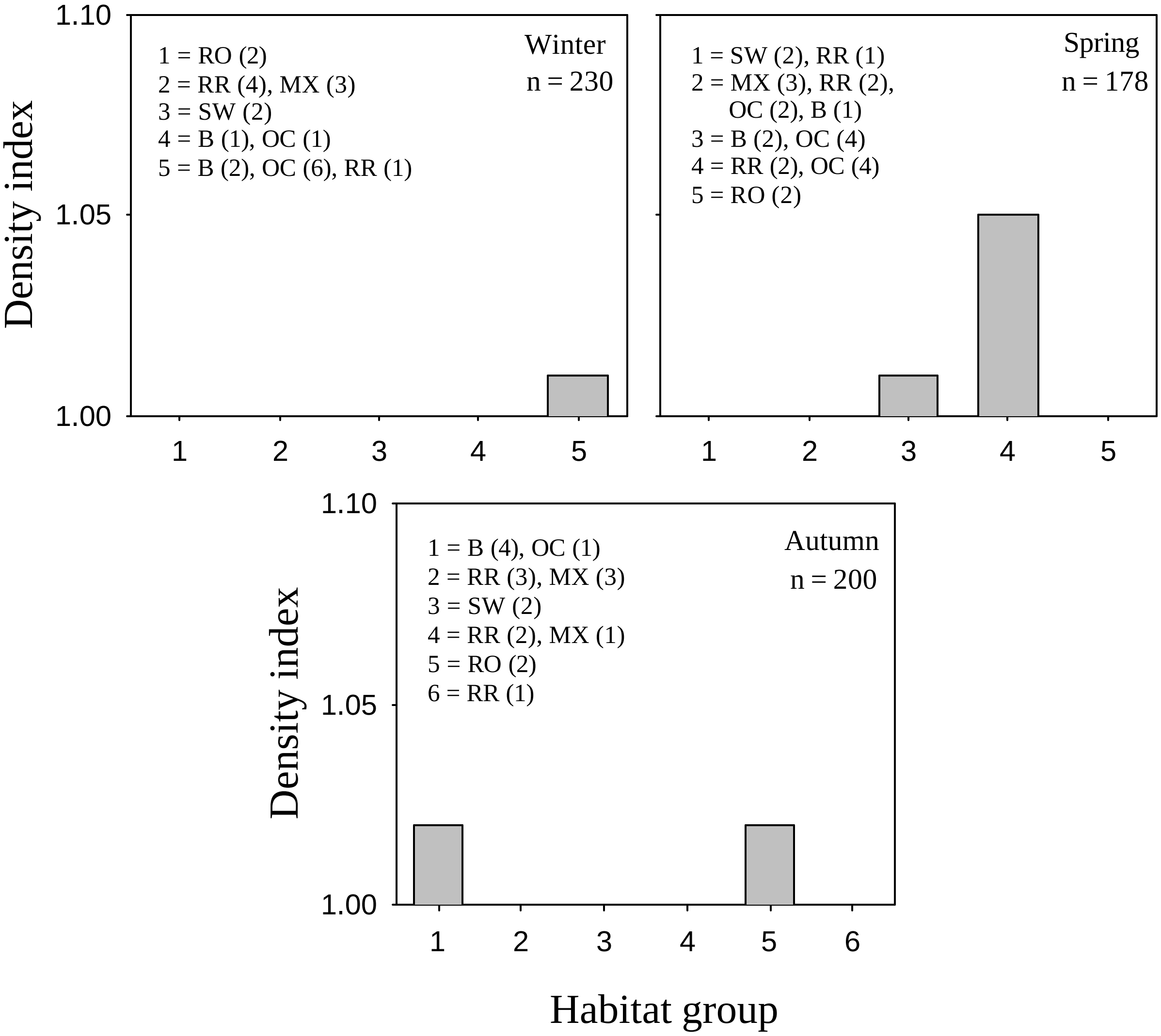

Figure 16. Density indices of predator-sized (>249 mm FL) largemouth bass among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites that were grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) that were included in each habitat group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall, and OC = off channel. n = number of electrofishing runs. No predator-sized largemouth bass were observed during summer.

highest at sites composed mainly of riprap and mixed bank habitats in winter, spring, and autumn (Figure 17). No predator-sized walleye or largemouth bass were observed during summer.

Diet

We obtained 121 diet samples from walleye, northern pikeminnow, smallmouth bass, and largemouth bass during 2002-2003. Proportionally, 6% of the samples were from walleye, 50% were from northern pikeminnow, 38% were from smallmouth bass, and 6% were from largemouth bass. Only 46 (38%) of the stomachs or digestive tracts contained food items. Walleye samples contained the highest occurrence of food items (71.4%), followed by largemouth bass (62.5%), northern pikeminnow (35.0%), and smallmouth bass (32.6%).

By wet weight, walleye and smallmouth bass consumed primarily fish; northern pikeminnow and largemouth bass consumed primarily crayfish (Figure 18). By count, crayfish were the most frequently occurring food item in northern pikeminnow, smallmouth bass, and largemouth bass (Figure 19).

The highest numbers of diet samples containing food were found at riprap and alcove sites (Figure 20). Crayfish were found more frequently than other prey items in samples collected at riprap, alcove, and rock outcrop sites, and prey fish were found most frequently in samples from riprap and alcove sites. All identifiable prey fish were sculpins, except for one juvenile salmonid recovered from a smallmouth bass stomach.

Seasonally, predator diet samples contained food most frequently in the autumn (50%), and least frequently in the winter (24%). Fish made up the highest proportional wet weight of food items in winter and spring, and crayfish made up the highest proportional wet weight in summer and autumn (Figure 21). Crayfish were found in a greater number of samples than any other prey item in the spring, summer and autumn (Figure 22).

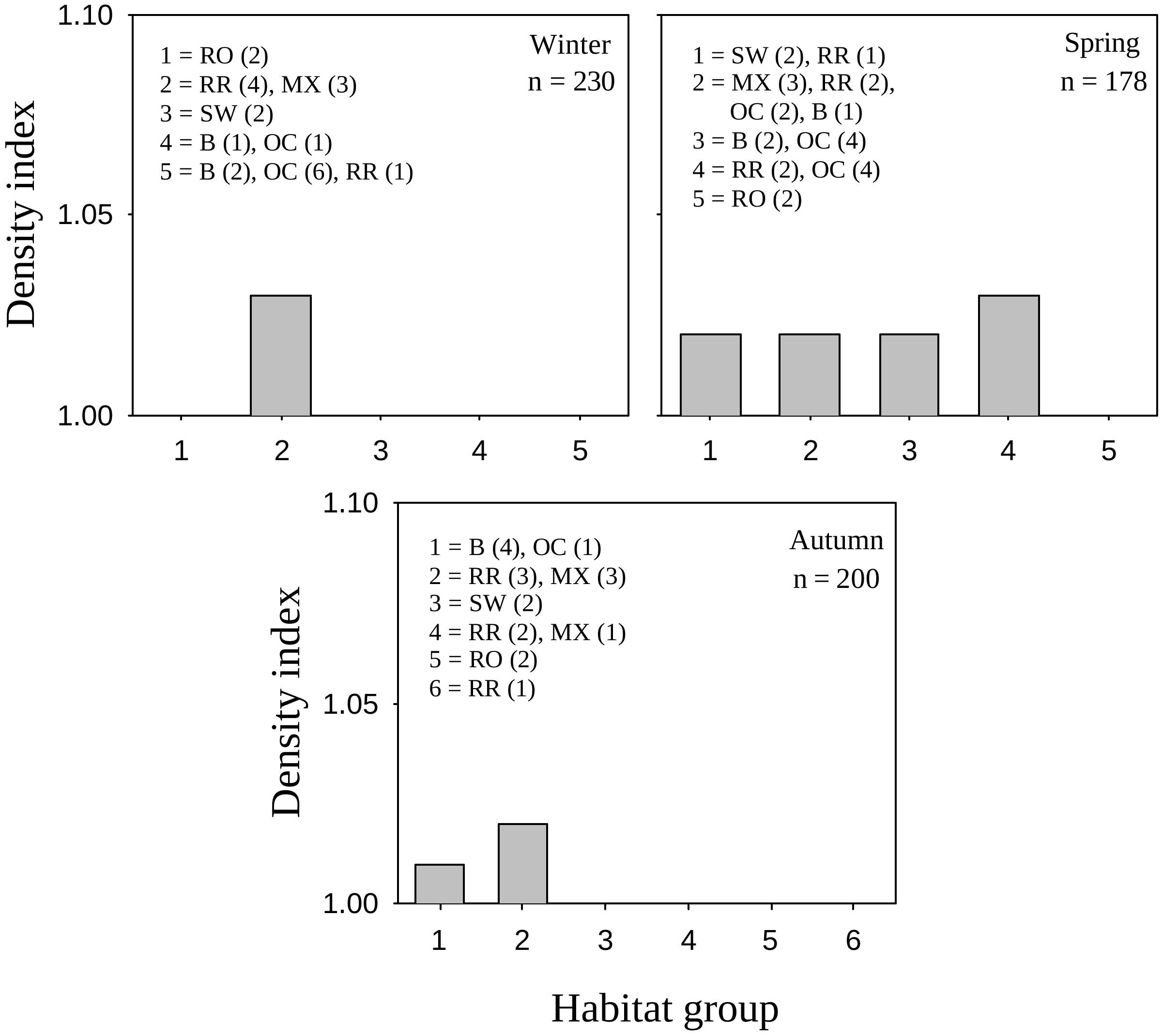

Figure 17. Density indices of predator-sized (>199 mm FL) walleye among seasons and habitat groups in the lower Willamette River, 2000-2003. Habitat groups represent sampling sites that were grouped by cluster analysis (Vile and Friesen 2004). Legends indicate generalized habitat types (number of sites in parentheses) that were included in each habitat group: RO = rock outcrop, RR = riprap, B = beach, MX = mixed (usually RR and B), SW = seawall, and OC = off channel. n = number of electrofishing runs. No predator-sized walleye were observed during summer.

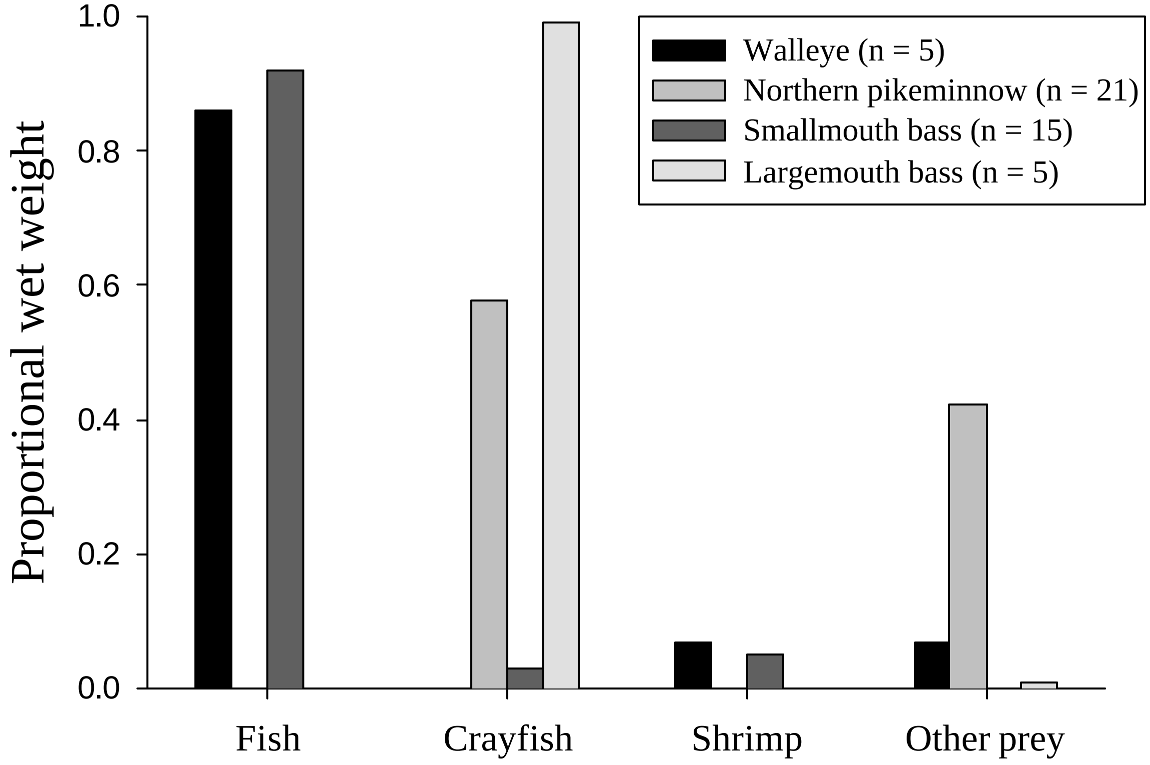

Figure 18. Proportional wet weight of prey items from the digestive tracts of predator species collected in the lower Willamette River, 2002-2003. n = number of samples containing prey items.

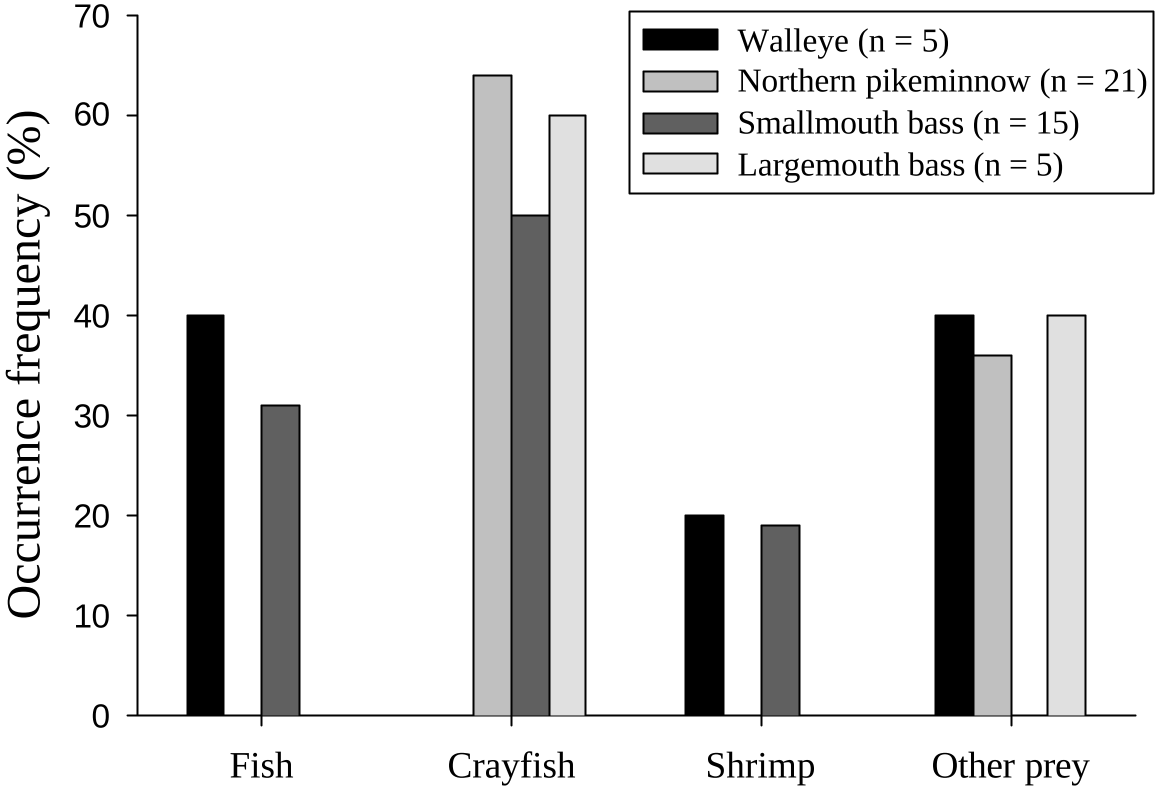

Figure 19. Percent of digestive tract samples from predator species collected in the lower Willamette River (2002-2003) containing fish, crayfish, shrimp, and other prey. n = number of samples containing prey items.

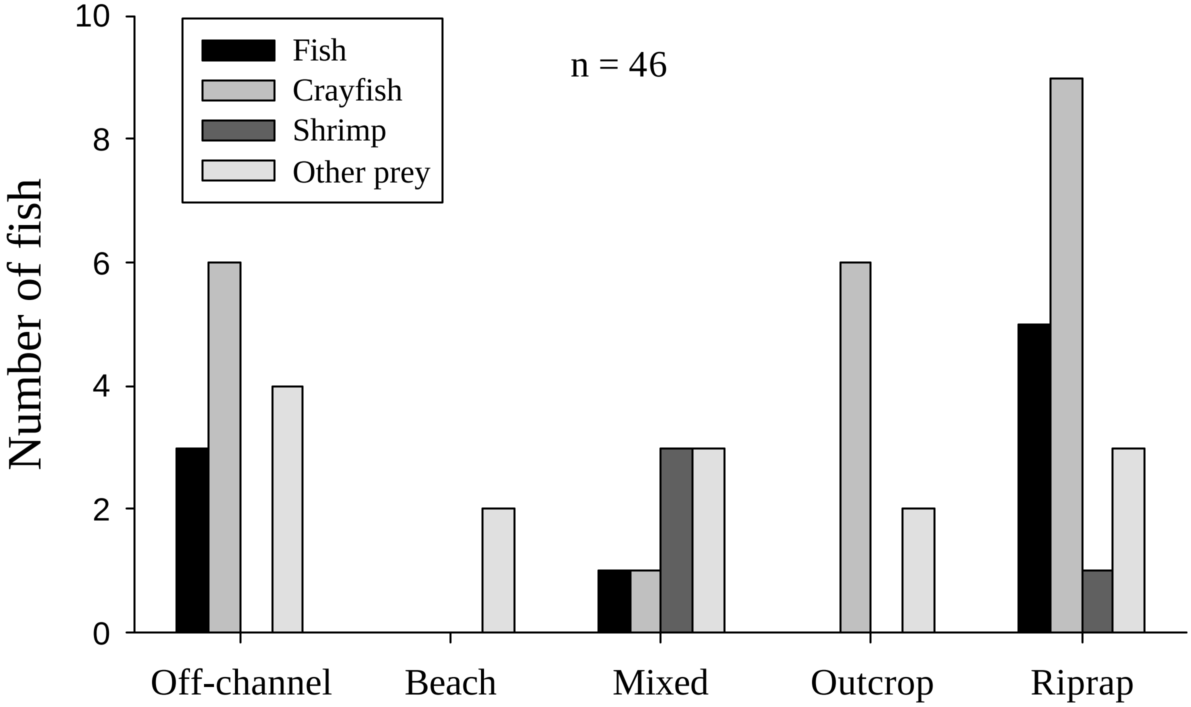

Figure 20. Number of predator fishes (northern pikeminnow, smallmouth bass, largemouth bass, and walleye) containing fish, crayfish, shrimp, and other prey items among general bank habitat types in the lower Willamette River, 2002-2003.

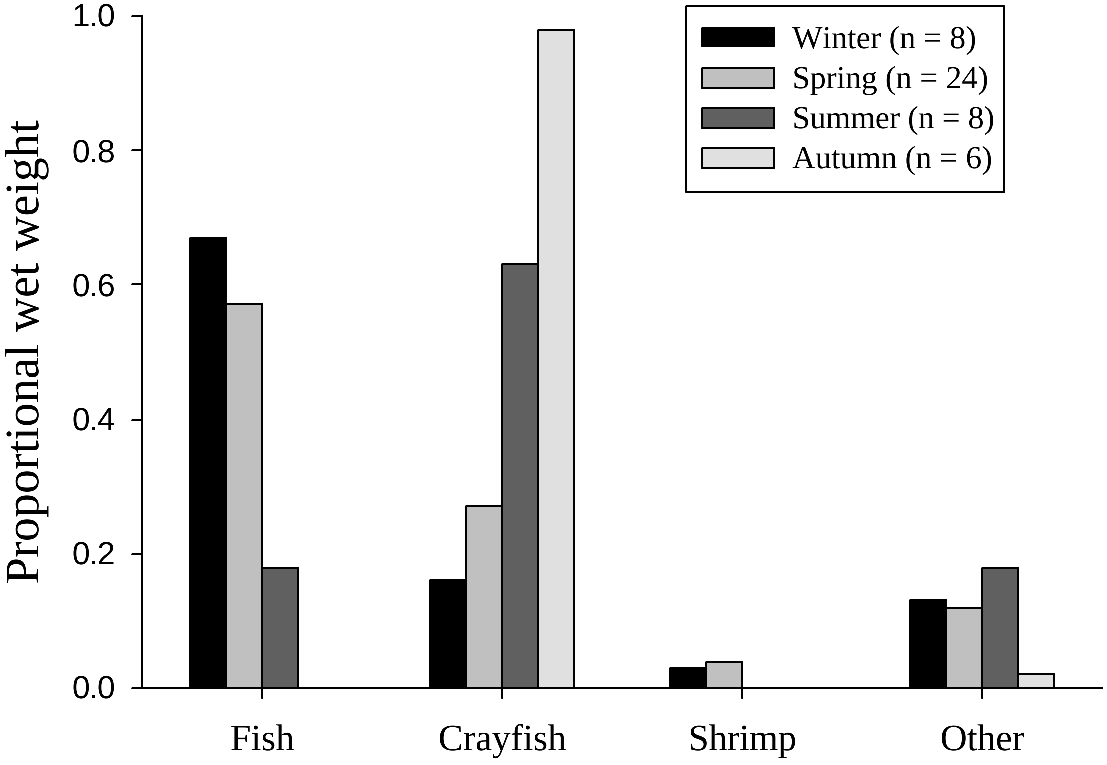

Figure 21. Proportional wet weight of prey items in digestive tract samples from northern pikeminnow, smallmouth bass, largemouth bass, and walleye in the lower Willamette River, 2002-2003. n = number of samples.

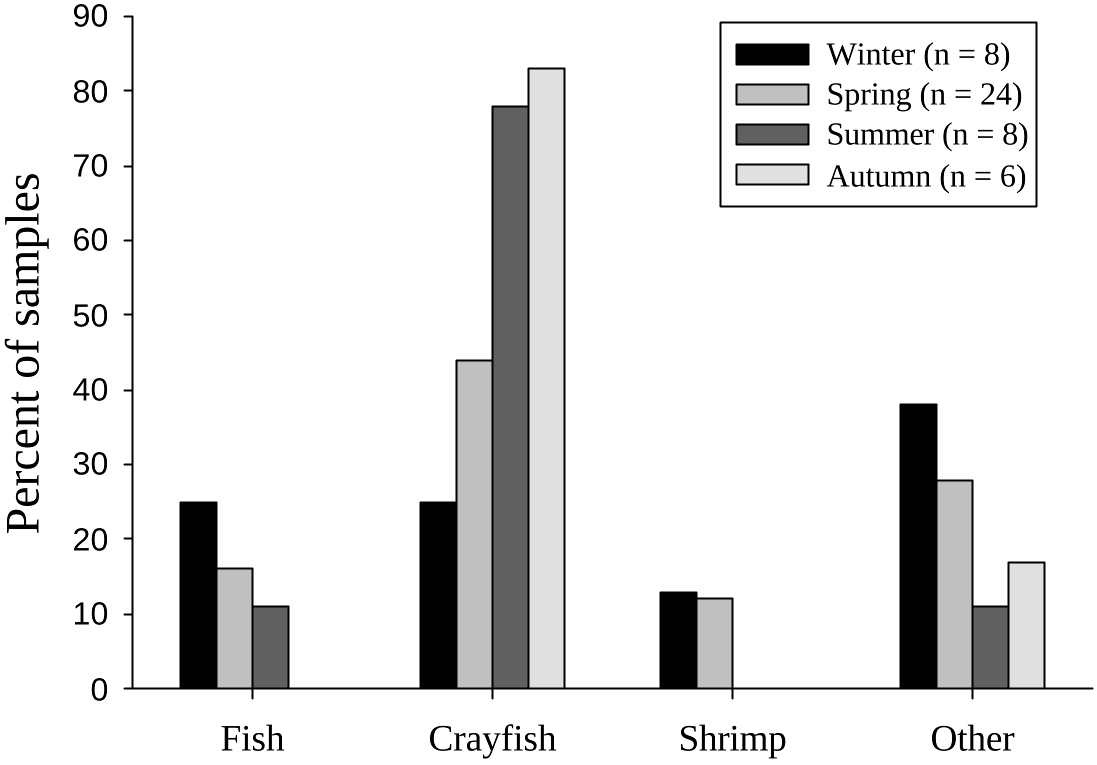

Figure 22. Seasonal composition of prey items from northern pikeminnow, smallmouth bass, largemouth bass, and walleye digestive tracts collected in the lower Willamette River, 2002-2003.

DISCUSSION

Predator-sized northern pikeminnow, smallmouth bass, largemouth bass, and walleye were relatively rare in our survey of the lower Willamette River, making analyses of habitat use and diet difficult. However, length-frequency analyses indicated these species, with the exception of walleye, are quite numerous when all size classes are considered. Poor survival to older age classes probably helps to minimize predation on juvenile salmonids. Angling pressure may contribute to the relatively small numbers of large fish; the lower Willamette River supports a popular bass fishery, and anglers captured four (14%) of our radio-tagged bass.

Predators generally did not travel long distances, and our observations of movements were similar to those in other studies. Walleye appeared to be the most active species, but we observed no significant differences in total distance traveled among species. Walleye in riverine habitats exhibit minimal movement in winter but can travel long distances (35 km in 3-4 days) during late spring and early summer for spawning (Paragamian 1989). We never observed or relocated walleye during summer, suggesting they may move out of the study reach to spawn. Paragamian (1989) also corroborated our observation that the downstream movement of walleye increased with river flow.

Northern pikeminnow moved considerably less than walleye, and we observed varying seasonal recovery rates. Martinelli and Shively (1997) found northern pikeminnow released near dams tended to remain near their release sites, where northern pikeminnow released in reservoirs made long-range movements. They suggested the difference in movement patterns was due to the proximity of spawning and foraging habitats. Most (73%) of our northern pikeminnow telemetry recoveries occurred during autumn and winter, suggesting seasonal movements to more optimal habitats during spring and summer.

Smallmouth bass in rivers spend most of their time in a home pool and only move between 0.1 – 1.2 km from it (Munther 1970, Gerardi 1983, Todd and Rabeni 1989). We found smallmouth bass to be somewhat more active, moving 2.3 km (median of the maximum distances) from the release site. However, several of our smallmouth bass moved considerably in the first month after release, then stayed close to the same location for the rest of the tracking period. The median of the maximum distance smallmouth bass traveled from their location at least one month after release was only 0.4 km, similar to the reported findings. We also noted a weak response to water temperature. Other researchers (Coble 1975, Todd and Rabeni 1989) have observed smallmouth bass increase their activity when water temperatures increase, and move little when temperatures fall below 6°C.

Largemouth bass moved far less than the other species. This species is known to be relatively sedentary, and like smallmouth bass, spend most of their time within a small home range. Mesing and Wicker (1986) observed largemouth bass had a mean maximum home range of 0.6 – 1.1 km in two Florida lakes, Warden and Lorio (1975) observed a maximum home range of 0.1 km in a Mississippi lake, and Wanjala et al. (1986) observed a largemouth bass did not move more than 0.4 km from their release point in an Arizona lake.

Patterns of habitat use determined by electrofishing and radio telemetry were similar. Most radio-tagged fish were located close to shore (within 20% of the total river width), and were often associated with pilings and rocky banks (rock outcrop, rock, riprap). Fish captured during nearshore electrofishing were similarly associated with riprap and rock outcrop.

Distribution of radio-tagged fish across the river channel showed no diel differences, though our sample size for nighttime relocations was small. Distributions of radio-tagged fish in the upper and lower study reaches were different because the lower study reach is wider than the upper study reach. Predators are located the same physical distance from shore throughout the study area, but are proportionally closer to shore in the lower study reach because it is much wider than the upper study reach.

We relocated radio-tagged walleye offshore most of the time, and they were generally farther from shore than the other species. Most offshore relocations of walleye were near pilings. Ager (1976) found most tagged walleye in a Tennessee reservoir tended to prefer open water year-round; Johnson (1969) also found walleye older than age-0 tended to be located offshore during most of the year. Walleye prefer deep water and avoid strong river currents and light (Johnson 1969, Ager 1976, Paragamian 1989, Wahl 1995); these behaviors were reflected in our observations. Walleye captured nearshore during electrofishing were mostly associated with riprap and mixed-rock bank treatment types, also similar to observations from other studies (Ager 1976, Johnson et al. 1988).

Over half of the radio-tagged northern pikeminnow were located offshore; however, when they were located nearshore they were primarily associated with pilings and riprap in the summer and autumn, and pilings, rock outcrop, and beach in the winter and spring. Northern pikeminnow captured nearshore by electrofishing were most often associated with riprap in the spring and summer and rock outcrop in the autumn and winter. Martinelli and Shively (1997) also found northern pikeminnow were often associated with boulder, bedrock, or cobble, and they prefer rocky substrates for spawning, which typically occurs in the late spring to summer (Beamesderfer 1992, Martinelli and Shively 1997).

Radio-tagged smallmouth bass moved close to shore during summer and farther from shore during winter. Nearshore relocations of radio-tagged smallmouth bass were most often near pilings and riprap in the summer and autumn and near beach and rock outcrop in the winter and spring. Smallmouth bass spawn in shallow water when temperatures increase in late spring and summer, often near benthic structures such as rocks, pilings and logs (Pflug and Pauley 1984). This spawning behavior may explain why we observed smallmouth bass moving closer to shore and associating with rocky substrates and structure to a greater degree during summer. Nearshore electrofishing captures of smallmouth bass were primarily associated with riprap in the summer and rock outcrop sites the rest of the year. Rocky habitats are preferred by smallmouth bass in many regions and selection for these substrates may be related to crayfish density (Munther 1970, Pflug and Pauley 1984, Todd and Rabeni 1989). Crayfish appeared to be a major prey item for smallmouth bass in our study, occurring in 50% of the samples containing food. Smallmouth bass were also located frequently in off-channel areas. They are known to exhibit strong cover-seeking behavior and typically seek out pools or deep areas behind rocks where the current is slack (Edwards et al. 1983, Pflug and Pauley 1984, Probst et al. 1984).

Radio-tagged largemouth bass were located closer to shore than any other species. We also found largemouth bass were located in off-channel habitats most of the time, and when located in the main channel, were most often associated with pilings. Electrofishing results were similar; largemouth bass were often associated with off-channel sites. Largemouth bass are known to prefer low-velocity areas such as pools and backwaters when in riverine environments (Wydoski and Whitney 2003, Wheeler and Allen 2003), corroborating our results.

In the lower Columbia and Snake rivers, high levels of predation by northern pikeminnow, smallmouth bass, and walleye occur during the outmigration of juvenile salmonids (Poe et al. 1991, Vigg et al. 1991). Northern pikeminnow generally consume higher proportions of salmonids than smallmouth bass or walleye (Zimmerman 1999), and a predator-control fishery for northern pikeminnow has been established to improve juvenile salmonid survival (Friesen and Ward 1999). In the lower Willamette River, we found no fish in the digestive tracts of northern pikeminnow; samples containing food consisted primarily of crayfish. Similar results were reported by Buchanan et al. (1981), who concluded northern pikeminnow posed little threat to juvenile salmonids in the Willamette River above Willamette Falls.

Walleye are probably too rare in the lower Willamette River to have an effect on salmonid survival, and largemouth bass (also relatively rare) consumed primarily crayfish. However, fish dominated smallmouth bass diets by wet weight, and we identified one juvenile salmonid from a smallmouth bass stomach sample (many samples were not identifiable). If their numbers increase (or are larger than we could detect), predation by smallmouth bass could potentially become an important source of mortality for juvenile salmonids. Currently, densities of all large predator fishes are low, and effects on juvenile salmonids are likely negligible.

The greatest risk of predation may be for subyearling salmonids. While age 1 salmonids tend to travel offshore in the lower Willamette River, large numbers of subyearling salmonids were observed at nearshore beach sites (Friesen et al. 2004). Subyearling salmonids are known to use nearshore areas with reduced current velocities for rearing (Dauble et al. 1989, Johnson et al. 1994, Key et al. 1994). In the Columbia River, high levels of predation on subyearling salmonids occur in areas with reduced current velocity because of habitat overlap with predators (Poe et al. 1991, Tabor et al. 1993, Zimmerman 1999). Zimmerman (1999) found smallmouth bass consumed 1.1 salmonids/day and northern pikeminnow consumed 1.6 salmonids/day downstream of Bonneville Dam during summer as a result of habitat overlap. Future studies in the lower Willamette River should determine if subyearling salmonids utilize nearshore bank treatment types that overlap with predator habitats (see Friesen et al. 2004).

RECOMMENDATIONS

The recommendations presented here were developed by the principal investigators, and will not necessarily be adopted as policies or guidelines by the Oregon Department of Fish and Wildlife. Recommendations fall into two categories: (1) primary recommendations, which are recommendations regarding in-water or shoreline activities that are supported directly by study findings, (2) secondary recommendations, which are recommendations regarding in-water or shoreline activities that are supported in part by study findings, but may rely in part on general ecological principles and ecosystem functions.

Primary Recommendation

1. **Minimize the use of structures with pilings in the lower Willamette River.** Native and exotic piscivorous fishes were clearly associated with nearshore areas, and all species over-utilized pilings to some degree. We found little evidence of predation by exotic predators on juvenile salmonids; however, effect of exotic fishes extends beyond direct predation on juvenile salmonids. Minimizing the future use of pilings or a net reduction in the overall number of pilings will reduce the amount of habitat favored by exotic species.

Secondary Recommendation

2. **Where possible, consider alternatives to riprap.** Densities of large predators were consistently highest at sampling sites dominated by rocky habitats (both natural and riprap), and radio-tagged predators over-utilized riprap in summer and autumn. We found little evidence of predation by exotic predators on juvenile salmonids; however, the effect of exotic fishes extends beyond direct predation on juvenile salmonids. Occurrence frequencies of fish and crayfish in predator diets were highest for samples collected from riprap, suggesting riprap provides good feeding habitat for predators. Friesen et al. (2004) noted radio-tagged coho salmon, and to a lesser extent Chinook salmon, underutilized riprap. Densities of invertebrates were high at riprapped sites (Friesen et al. 2005), adding uncertainty to the overall effects of riprap on ecosystem functions. Schmetterling et al. (2001) concluded that the practice of riprapping stream banks is counter to current practices and philosophies of stream habitat restoration, and may impede future enhancement work.

   The recommendation to consider alternatives to riprap is consistent with recommendations in Friesen et al. (2004), who suggested (1) protecting existing beach habitat and (2) determining if bio-engineering and other techniques can restore beach habitat functions and processes. Bio-engineered sites are more likely than riprap to facilitate normative ecosystem processes. It is not feasible nor do findings warrant removal of existing riprap; however, the COP and ODFW should work with engineers and habitat specialists to determine the feasibility of using alternatives to riprap in the future while considering other issues such as commercial shipping, bank stabilization, and flood control.

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Diets of Juvenile Salmonids and Introduced Fishes of the Lower Willamette River

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INTRODUCTION

Interest in Pacific salmon *Oncorhynchus* spp. in the lower Willamette River has increased in recent years following the listing of several species as threatened under the federal Endangered Species Act (ESA). These include four races from two evolutionarily significant units (ESUs): lower Columbia River and upper Willamette River Chinook salmon *O. tshawytscha* (NOAA 1999a), upper Willamette River steelhead *O. mykiss* (NOAA 1999b), and lower Columbia River steelhead (NOAA 1998). The lower Columbia River ESU includes the Willamette River up to Willamette Falls (rkm 42.8; Figure 1). In addition, naturally propagated coho salmon *O. kisutch* are listed as endangered under the State of Oregon's Endangered Species Act (Chilcote 1999).

Yearling Chinook salmon spend a short amount of time in the lower Willamette River; radio-tagged fish had a median residence time of 3.4 days (Friesen et al. 2004a). Despite the short migration period, Friesen et al. (2004a) observed body length and weight were significantly greater for fish collected in the downstream portion of the study area than in the upstream portion, suggesting feeding and growth occur. Sub-yearling Chinook salmon are also present in substantial numbers (Friesen et al. 2004a), and their survival is undoubtedly related to available food resources. Species alien to Oregon (e.g. smallmouth bass *Micropterus dolomieu*, yellow perch *Perca flavescens*, and crappie *Pomoxis* spp.) are well established and often abundant (Farr and Ward 1993; Pribyl et al. 2004). Food availability, feeding behavior, and interactions with introduced species may therefore be important components of salmonid production in the Willamette basin.

Dietary overlap and similarity in feeding behavior among juvenile salmonids and introduced fish species can lead to competition through exploitation of a limited resource or feeding interference (Diana 1995). Estuarine studies have reported significant dietary overlap between juvenile salmonids and other species, although competition has not been documented (Emmett 2003). Salmonid diet studies in large rivers are scarce. In the nearby Columbia River, the diet of subyearling Chinook salmon is composed primarily of zooplankton and terrestrial insects in impoundments, and caddisflies and chironomids in the free-flowing riverine sections (Rondorf et al. 1990). As they moved downriver, these fish exhibited a dietary shift from larger midges and trichopterans to smaller daphnia (*Daphnia* spp.) in response to increased zooplankton density in the impounded sections (Rondorf et al. 1990). Craddock et al. (1976) determined juvenile Chinook salmon fed selectively on daphnia in the lower Columbia River. Previous studies addressing juvenile salmonids in the lower Willamette River have focused primarily on habitat use and predation by resident piscivores (Buchanan et al. 1980; Ward et al. 1994; North et al. 2002; Friesen et al. 2003).

Our objectives in this study were to characterize the diets of resident and anadromous fish in the lower Willamette River, and determine if dietary overlap occurs between naturally propagated salmonid stocks and either introduced species or hatchery salmonids. Diet similarities could suggest competition and have management implications for threatened or endangered species. We tested three null hypotheses:

1. *The diet composition of juvenile salmonids does not differ from the diet composition of introduced fish species.*

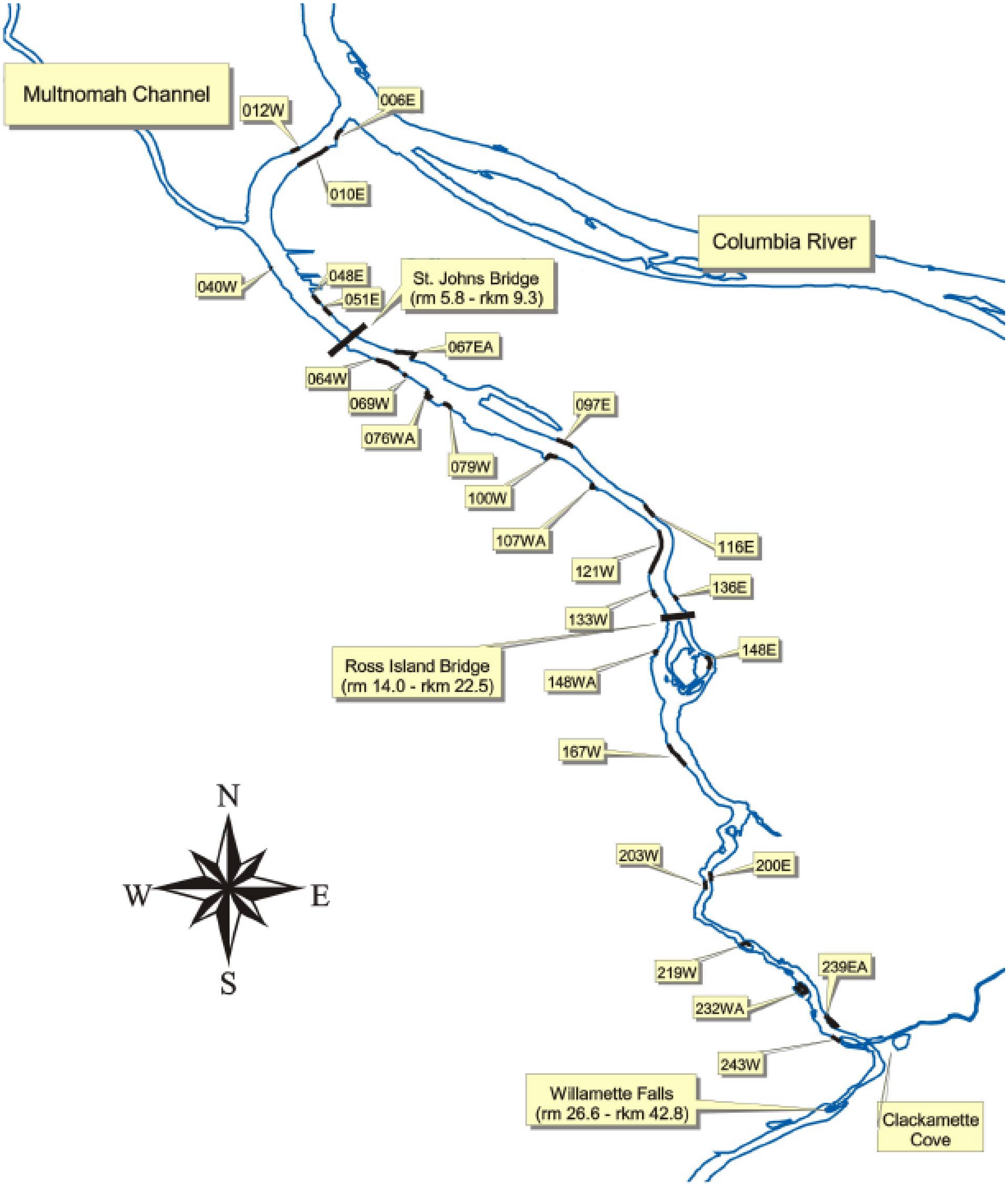


Figure 1. The lower Willamette River and associated features. Sampling site labels denote river mile (rm; xx.x) and east (E) or west (W) shore. A = alcove site; rkm = river kilometer.

2. *The diet composition of juvenile hatchery salmonids does not differ from the diet composition of unmarked juvenile salmonids*

3. *The diet composition of juvenile salmonids does not differ from the composition of food items available in the environment*

To further describe fish diets, we developed feeding strategy plots for abundant species, and compared Chinook salmon diets among nearshore habitat types.

METHODS

Field Sampling and Laboratory Analysis

We compared juvenile salmonid diets with those of similar-sized introduced species. To provide comparable sizes and avoid injuries to the fish, we collected diet samples from juvenile salmonids and yellow perch >99 mm fork length (FL), and from all other species >89 mm FL. We included only Chinook salmon in diet comparisons between hatchery and unmarked juvenile salmonids, as sample sizes for other species (coho salmon and steelhead) were generally small.

We used boat electrofishing to collect fish and diet samples at standardized sampling sites in the lower Willamette River between rkm 1.0 and 39.4 (Figure 1) from August 2002 to July 2003. Sites were chosen to represent various bank treatment types found in the study reach (Vile and Friesen 2004). We conducted sampling after sunset and near shore, at a target depth of 1 – 3 m (although some sites were much deeper), for a maximum of 750 s of continuous electrofishing output. We recorded fork length (mm) and weight (g) of all species captured. For each sampling effort, we also recorded the date, time, location, surface temperature, conductivity, and minimum and maximum sampling depths. Friesen et al. (2003) and Friesen et al. (2004a) describe sampling methods in detail.

We used gastric lavage to remove stomach contents from juvenile fish; Meehan and Miller (1978) reported this method was 99% effective at removing organisms from coho salmon stomachs, with no survival impacts. Lavage was performed using a 30-cc syringe and the contents were flushed into plastic sample bottles. Samples were placed on ice to slow digestion and preserved in 70% ethanol within 8 hours. In the laboratory, we filtered samples through a 500-µm sieve and identified all organisms to the lowest possible level, usually genus (Merritt and Cummins 1996; Smith 2001). Organisms of the same taxonomic group were combined and weighed after excess water was blotted. We used a Mettler PM400 laboratory scale to measure the wet weight of each food item to the nearest 0.1 mg.

Data Analysis

Diet

We calculated several indices to characterize diet diversity and feeding behavior of juvenile salmonids and introduced fish. We determined the number of different taxa consumed as an indicator of diet richness, and used the Shannon diversity index (H') to evaluate dietary diversity. The Shannon index is:

$$H' = -\sum_{i=1} (p_i) \ln(p_i)$$

where

S = total number of taxa consumed, and
p_i = the proportion of S consisting of the *i*th taxa (Ludwig and Reynolds 1988).

Index values increase with increasing diversity of diet.

We also calculated evenness (E), which measures how evenly prey are distributed in the diet. Evenness tracks the abundance of prey taxa and can reflect the changing importance of high-ranked taxa relative to those ranked lower (Nagaoka 2001). The index is calculated as

$$E = H'/\ln(S)$$

where

S = number of taxa consumed (Caillet et al 1986).

Values near one represent populations with a uniform diet distribution (all taxa present in equal numbers); values approaching zero indicate only one group is present (Magurran 1988).

Dietary Overlap

We used the Schoener Index (α) to evaluate dietary overlap between juvenile salmonids and introduced fish species and between hatchery and unmarked salmonids:

$$\alpha = 1 - 0.5 \left(\sum_{i=1}^{n} |P_{xi} - P_{yi}|\right)$$

where

P_{xi} = the proportion of food category i in the diet of fish species x,
P_{yi} = the proportion of food category i in the diet of fish species y, and
n = the number of food categories (Wallace 1981).

We calculated index values using both prey abundance and wet weight. Values greater than 0.60 indicate a significant overlap in diet between two species, which can lead to competition if food resources are limited (Zaret and Rand 1971).

We also calculated the percent body weight index (%BW; Brodeur 1992), a measure of relative stomach fullness, for hatchery and unmarked salmonids:

$$\%BW = [SCW/(BW - SCW)] \times 100,$$

where

SCW = stomach content weight (g)
BW = fish weight (g).

Feeding Strategy

We used modified Costello diagrams (Amundsen et al. 1996) to present species-specific feeding strategies graphically. The two-dimensional diagram uses the percent occurrence of food items and the prey-specific abundance of those organisms. The prey-specific abundance is defined as the proportional abundance of an organism present only in the stomach contents of those fish that preyed on that organism:

$$P_i = (\Sigma S_i / \Sigma S_{ti}) \times 100$$

where

P_i = prey-specific abundance of prey item i,
S_i = number of prey item i in the stomach contents, and
S_{ti} = total number of items in the stomach contents of fish in which prey item i occurs (Amundsen et al. 1996).

The modified Costello diagram represents feeding strategy and prey importance according to the location and distribution of points along diagonals and axes. Points that lie above the 50% prey-specific abundance axis (y-axis) indicate specialized feeding; points below the y-axis are indicative of a generalized feeding strategy. A diagonal line extending from the origin to the upper right corner identifies prey importance, with the dominant organisms found in the upper right and rare organisms in the lower left. The remaining diagonal extending from the upper left to the lower right of the diagram represents the niche contribution of prey items. Prey points located in the upper left indicate a high between-phenotype contribution (BPC) to the niche width; a high BPC indicates different individual fish are specializing on different organisms. Points located in the lower right are indicative of a high within-phenotype contribution (WPC) to the niche width; a high WPC indicates generalized feeding by a population on the same organisms (Amundsen et al. 1996).

Prey Selection

We used Strauss' index of selection (L) to evaluate selection for major food items:

$$L = Ri - Pi,$$

where

Ri = the proportion of prey item i in the diet, and
Pi = the proportion of prey item i in the environment (MacNeil et al. 2000).

Index values range from +1 (positive selection for a food item) to –1 (prey avoidance) (Bowen 1996).

We calculated values for Pi using data from lower Willamette River macroinvertebrate surveys (Friesen et al. 2004b). Ten Hester-Dendy multi-plate samplers were deployed in the study area for five weeks during May-June 2003, corresponding closely to peak of juvenile salmonid migrations (Friesen et al 2004a).

Chinook Salmon Diets among Nearshore Habitat Types

Considering ESA listings and associated restrictions intended to protect salmonids, differences in diets among nearshore habitats may have implications for future development in the lower Willamette River. We evaluated differences among general habitat types by season using the fish species with the largest sample size (Chinook salmon; N=346) and their dominant prey taxa (daphnia). Seasonal analyses were restricted to winter, spring, and autumn because we collected very few samples during summer.

Habitat types were defined qualitatively (based on appearance) but were adjusted seasonally for variations in river level. In addition, we classified a habitat as a particular type only if it extended into the water enough to realistically have an effect on fish use (1 m). Habitat types included beach, rock outcrop, riprap, mixed (usually beach and riprap), alcove (protected habitats removed from the main river channel), and seawall (vertical retaining walls). Habitat definitions are detailed in North et al. (2002).

We calculated the median proportion of daphnia in Chinook salmon diet samples to characterize differences in abundance of the major food item, and the body weight index to evaluate feeding intensity. We used the Kruskal-Wallis one-way ANOVA on ranks to compare values among bank habitats, and Dunn's test to identify where significant differences occurred. The Dunn's test was unable to identify differences among pairs in several cases due to small sample sizes and zero values. In these instances, we substituted the Mann-Whitney rank sum test.

RESULTS

Diet Composition

Juvenile Salmonids

We identified 42,606 specimens in the stomach contents of 346 juvenile Chinook salmon, which had the highest feeding rate (123 organisms/fish) of any species collected (Table 1). Although

Table 1. Diet summary for juvenile salmonids and introduced fish species (where N>10) in the lower Willamette River, 2002-2003. H' = Shannon diversity; E = diet evenness. For H', values increase with increasing diet diversity. For E, values approaching 1.00 indicate a uniform diet; values near 0.00 indicate an uneven diet.

Species	N	No. organisms	Total weight (g)	Taxa richness	H'	E
Chinook salmon	346	42,603	18.0	41	0.51	0.12
Coho salmon	49	3,171	1.6	22	0.84	0.25
Yellow perch	172	6,664	5.8	37	2.03	0.52
Smallmouth bass	48	277	10.0	17	1.94	0.64
Largemouth bass	14	32	1.0	10	1.95	0.85
Black crappie	11	898	0.5	14	1.16	0.42
Pumpkinseed	16	951	1.8	15	1.19	0.44
Bluegill	14	390	0.3	13	1.47	0.53

we identified 41 different taxa in Chinook salmon stomach contents, most were proportionally low in abundance, resulting in a relatively low diversity (H' = 0.51; E = 0.12). Daphnia were the most dominant group by both abundance (91%) and wet weight (43%)(Appendix Table 1). The amphipod corophium (*Corophium* spp.) was the only prey item other than daphnia that composed >1% of the total abundance (4%), though they were present in 51% of the samples examined. Calanoid copepods and unidentified aquatic insects occurred relatively often (18%) but each represented ≤1% of the diet by abundance and wet weight.

Daphnia occurred in over 65% of the Chinook salmon stomach samples collected (Appendix Table 1) and were an abundant food organism throughout most of the year (Figure 2). A slight dietary shift occurred in November, as corophium became an abundant food item and the proportional amount of daphnia consumed declined. We observed little change in overall diet with changes in fork length of juvenile Chinook salmon; percent daphnia by weight was lowest in the 141-160 and 161-180 mm size classes, whereas corophium were slightly more abundant in the stomach contents of fish over 141 mm FL.

Daphnia also dominated coho salmon diets, by both percent abundance (82%) and wet weight (48%) (Appendix Table 1). Daphnia also occurred more frequently (65% of samples) than any other food item. Coho salmon consumed fewer taxa (22) than Chinook salmon, but had a slightly higher dietary diversity (Table 1).

We collected diet samples from three juvenile steelhead; chironomids (43% of all prey items) and terrestrial insects (33%) were the most abundant food items (Appendix Table 2). Terrestrial insects (53%) and coleopterans (29%) dominated the diet by weight.

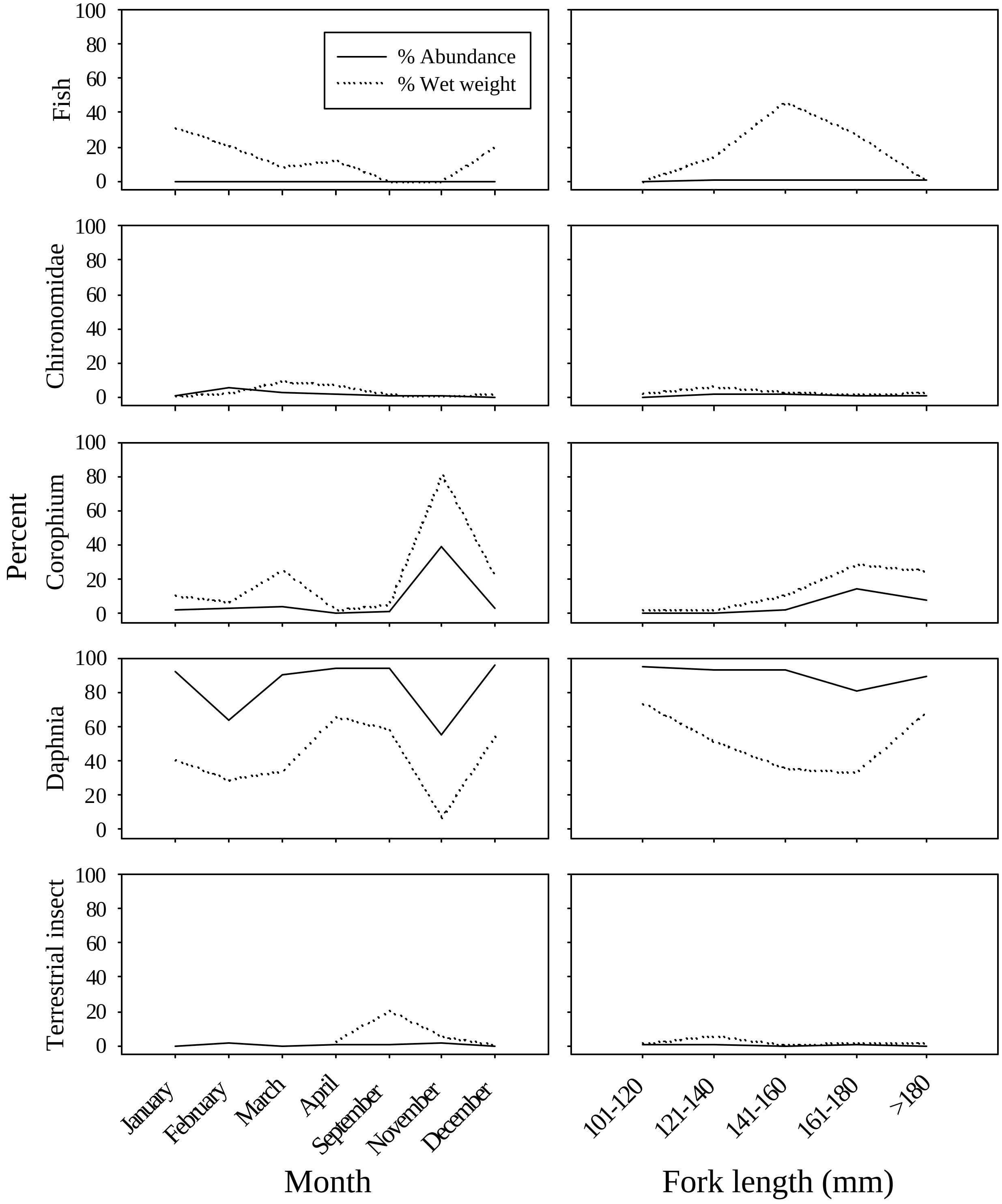


Figure 2. Percent abundance and percent wet weight of juvenile Chinook salmon prey items during select months and among 20-mm size classes, lower Willamette River (2002-2003).

Introduced Species

We identified 37 taxa in the stomach contents of 172 yellow perch, which had the most diverse diet of any fish species (Table 1). Yellow perch diets consisted mainly of zooplankton (60%) and chironomids (25%); cyclopoid copepods composed most of the plankton diet (Figure 3; Appendix Table 3). Crayfish and chironomids were proportionally more abundant by weight, as cyclopoid copepods represented just 1% of the overall wet weight. Corophium and chironomid larvae or pupae were all common in the diets of yellow perch; these three food items were present in 41-51% of the samples. We also collected two walleye *Sander vitreus*; one had an empty stomach and the other contained only prey fish (Appendix Table 3).

Smallmouth bass were the most common centrarchid we collected (n = 48). We identified 17 taxa in smallmouth bass diets, and they consumed relatively few organisms (5.7 organisms/fish) (Table 1). The Shannon index and evenness values for smallmouth bass (H' = 1.94; E = 0.64) were among the highest of any species, indicating a diverse diet. Daphnia was the most abundant organism (46%) in smallmouth bass stomach contents, but crayfish (62%) and fish (36%) constituted nearly all of the stomach content weight (Figure 3; Appendix Table 4). Chironomid pupae were the most common food item for smallmouth bass, occurring in 35% of the samples.

Fish were an important component of the largemouth bass *M. salmoides* diet (83% of the diet by wet weight; Appendix Table 4). The number of food items consumed by largemouth bass was among the lowest of any fish species (2.2 organisms/fish), but diet diversity was relatively high (Table 1).

Black crappie *P. nigromaculatus* preyed heavily on zooplankton and chironomids (Appendix Table 5). Daphnia were the most abundant food item (67%), but fish dominated the diet by weight (63%), and Chironomid pupae were the most common food item (82% of samples). Diet diversity was lower than for other introduced species (Table 1). A single white crappie *P. annularis* consumed primarily copepods and daphnia (Appendix Table 5).

Pumpkinseeds *Lepomis gibbosus* preyed mostly on chironomid larvae and corophium; bluegills *L. macrochirus* consumed primarily hydrachnids (water mites) and chironomid larvae (Appendix Table 6). Although corophium were not abundant in bluegill stomach contents, they were present in over half (57%) of the samples. Bluegill diets were slightly more diverse than pumpkinseed diets (Table 1).

Dietary Overlap

Juvenile Salmonids vs. Introduced Species

Schoener index values indicated there was no significant diet overlap between juvenile Chinook salmon and introduced fishes (Table 2). Dietary evaluation of Chinook salmon and yellow perch, the most abundant introduced species in the study, indicated dissimilar diets when compared by dietary abundance and wet weight. Although zooplankton were an important

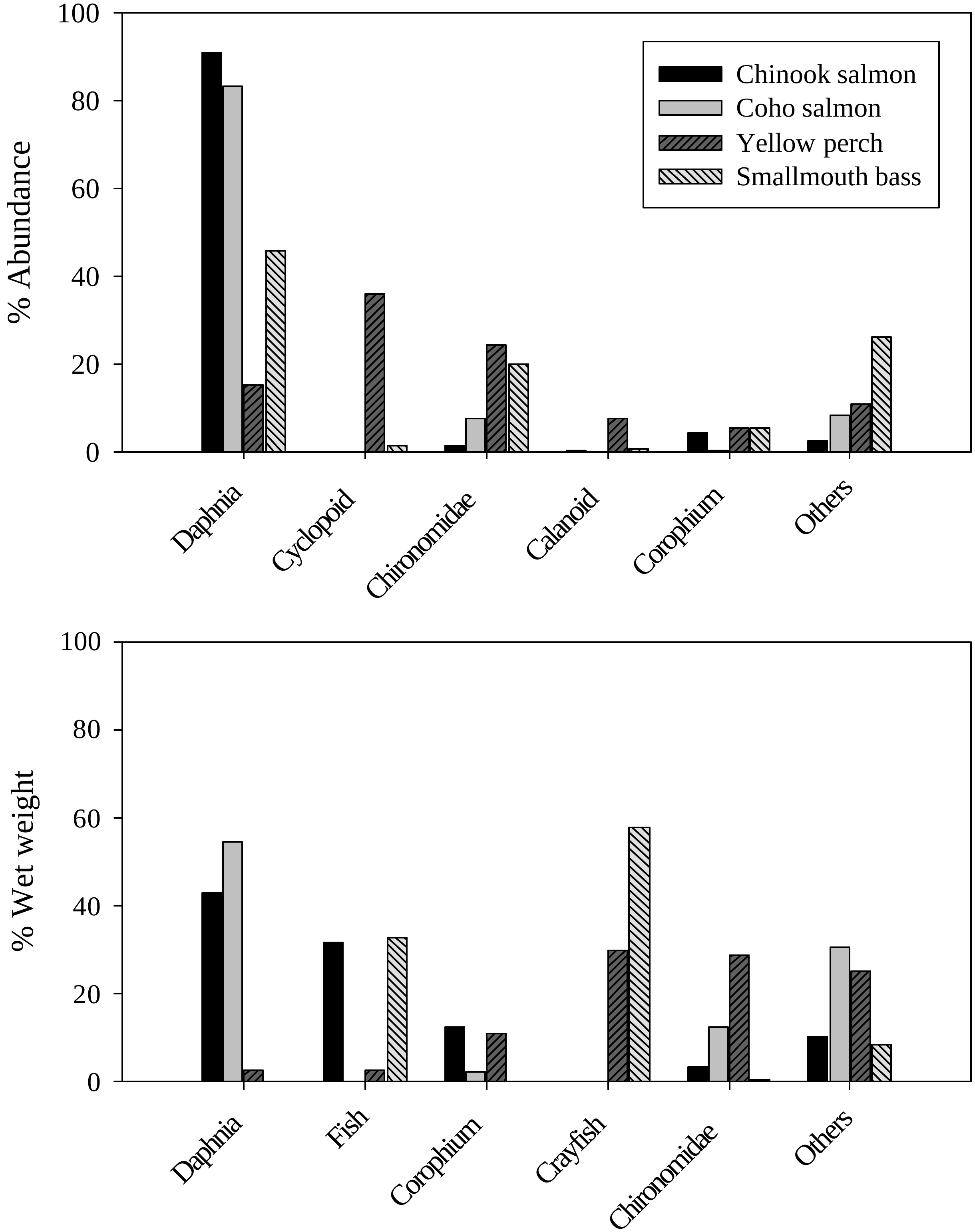


Figure 3. Percent abundance and percent wet weight of prey items consumed by juvenile Chinook and coho salmon, yellow perch, and smallmouth bass in the lower Willamette River, 2002-2003.

Table 2. Sample size, mean fork length, and Schoener index scores (diet similarity) calculated by abundance and wet weight for juvenile Chinook and coho salmon in the lower Willamette River, 2002-2003. Scores > 0.6 indicate significant dietary overlap.

	N	Mean fork length (mm)	Diet similarity	
			Abundance	Wet weight
Chinook salmon	346	153 ± 23	--	--
Yellow perch	172	115 ± 15	0.23	0.34
Smallmouth bass	48	162 ± 50	0.54	0.23
Other centrarchids	57	134 ± 32	0.35	0.48
Hatchery vs. unmarked	--	--	0.93	0.67
Coho salmon	50	139 ± 13	--	--
Yellow perch	172	115 ± 15	0.27	0.04
Smallmouth bass	48	162 ± 50	0.59	0.21
Other centrarchids	57	134 ± 32	0.38	0.16

dietary component of each species, Chinook salmon preyed heavily on daphnia, whereas copepods (cyclopoids) were more abundant in the diet of yellow perch (Figure 3).

Diets of smallmouth bass and juvenile Chinook salmon were somewhat similar, but overlap based on prey abundance was not significant (Table 2; Figure 3), and Schoener index values based on wet weight were very low. Dietary overlap with other centrarchids was also not significant (Table 2).

Diets of coho salmon and introduced fish species were dissimilar (Table 2). Overlap between coho salmon and yellow perch was very low, especially for wet weight comparisons. As with juvenile Chinook salmon, diets of smallmouth bass was somewhat similar to those of juvenile coho salmon ($\alpha = 0.59$; Figure 3), but were below the level considered significant ($\alpha = 0.60$).

Hatchery vs. Unmarked Chinook Salmon

We collected 60 diet samples from hatchery fish and 286 from unmarked fish. Dietary overlap was significant when analyzed by organism abundance and wet weight (Table 2). Daphnia were more abundant by overall number and weight in the stomach contents of unmarked juvenile Chinook salmon throughout most of the year (Figure 4), but dominated the diet of both groups (Figure 5). Hatchery fish fed more on corophium than unmarked fish, despite a low overall percent abundance. The percent weight composition of daphnia was higher for hatchery fish; prey fish composed a larger proportion of the unmarked Chinook salmon diet (by weight).

The %BW (relative stomach fullness) was significantly greater for unmarked juvenile Chinook salmon than for hatchery fish ($P < 0.01$; Figure 6). The mean number of organisms consumed

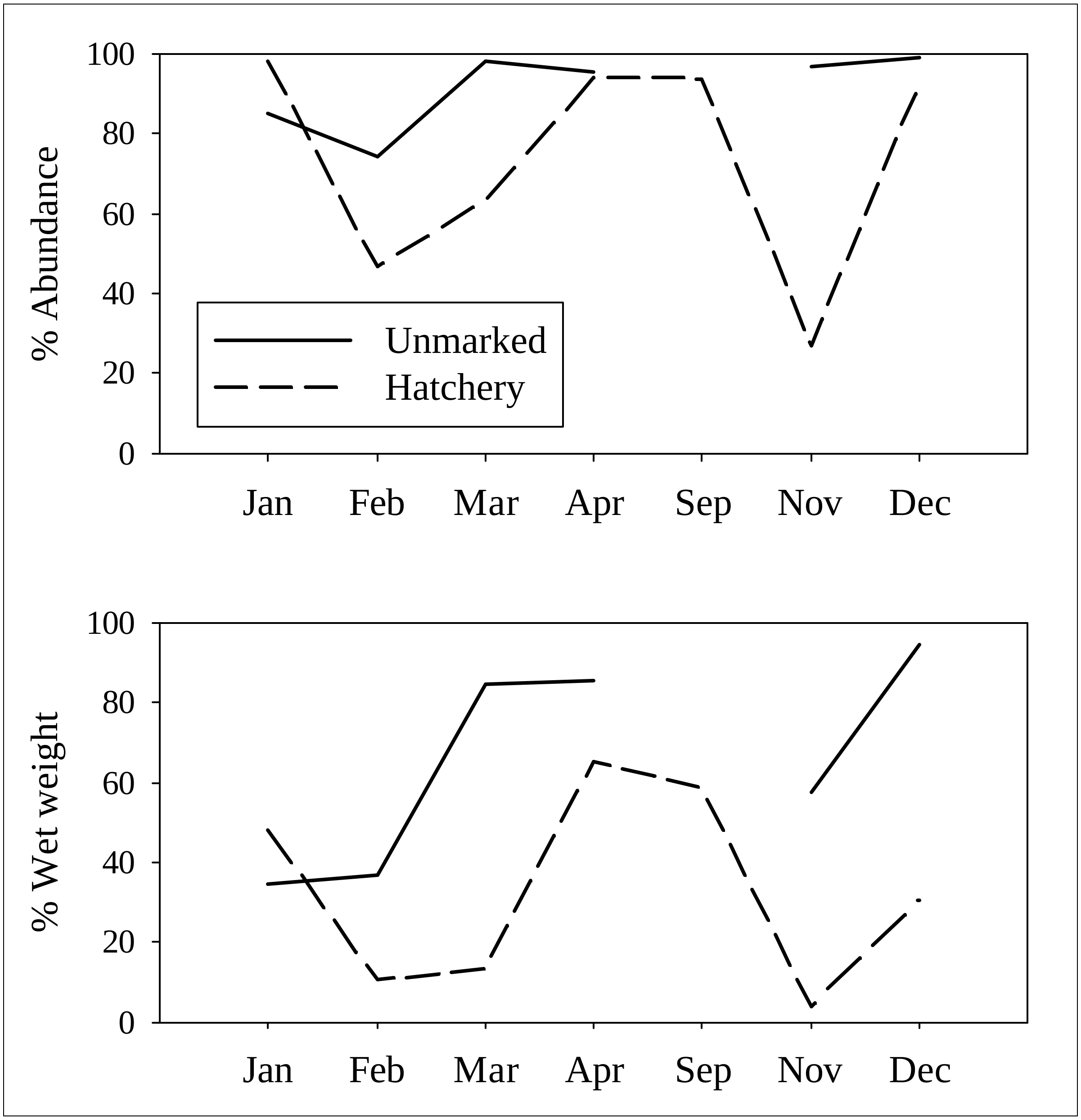


Figure 4. Percent abundance and percent wet weight of daphnia in unmarked and hatchery Chinook salmon diets during select months in the lower Willamette River, 2002-2003.

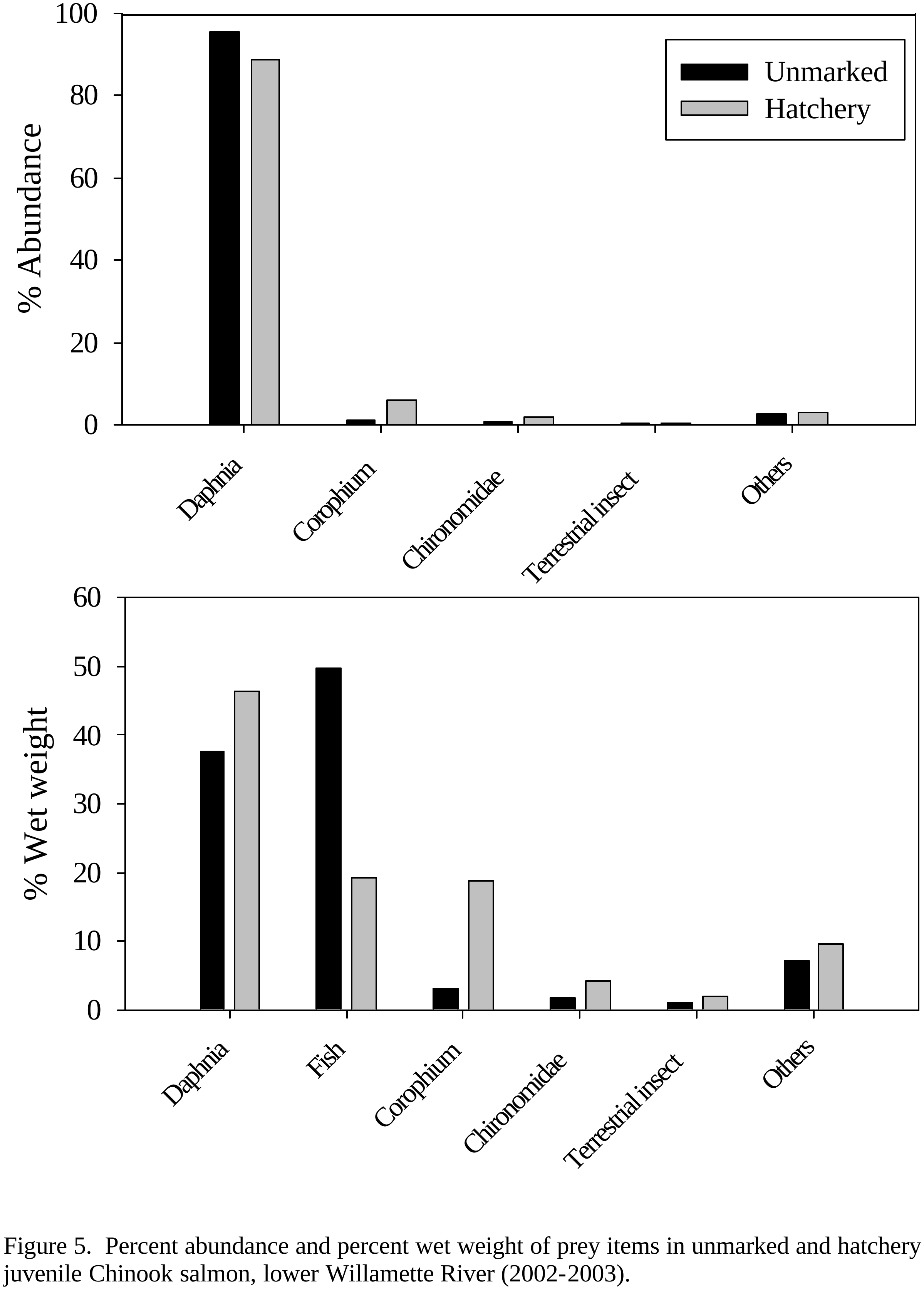


Figure 5. Percent abundance and percent wet weight of prey items in unmarked and hatchery juvenile Chinook salmon, lower Willamette River (2002-2003).

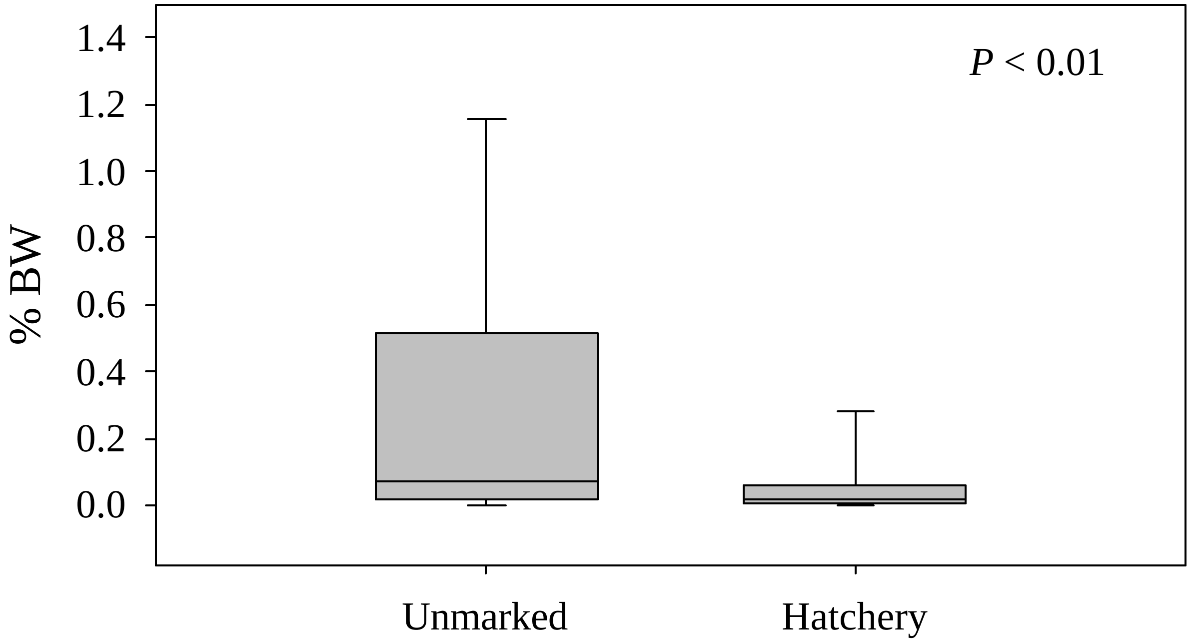


Figure 6. Percent body weight (% BW; an index of relative stomach fullness) for unmarked and hatchery juvenile Chinook salmon collected in the lower Willamette River, 2002-2003. The horizontal line inside the bar is the median, the ends of the bar are the 25th and 75th percentiles, and the whiskers are the 5th and 95th percentiles.

was higher for unmarked Chinook salmon (230/fish) than for hatchery fish (101/fish); in addition, the mean wet weight of stomach contents was higher for unmarked fish (0.12 g/fish) than for hatchery fish (0.04 g/fish). Diet diversity of unmarked Chinook salmon was lower than that of hatchery fish throughout most of the year (Figure 7), indicating unmarked fish were more selective in their feeding behavior.

The contents of a single unmarked juvenile Chinook salmon contained several fish, creating a skewed stomach weight distribution; however, when we removed this outlier the mean stomach content weight for unmarked fish (0.07 g) remained higher than for hatchery fish (0.04 g). Despite consuming more prey by abundance and weight, unmarked juvenile Chinook salmon were more likely to have an empty stomach (6.7% vs. 3.5%).

Feeding Strategies

The feeding strategy plot for juvenile Chinook salmon indicated specialized feeding towards daphnia, with small proportions of other food items in the diet of a few fish (Figure 8). The feeding strategy plot for coho salmon was similar, with a specialized feeding strategy toward daphnia, although rare prey were more abundant and common in the coho salmon diet. The within-phenotype component indicated most coho salmon were feeding on chironomids, but the contribution of chironomids to the overall diet was low.

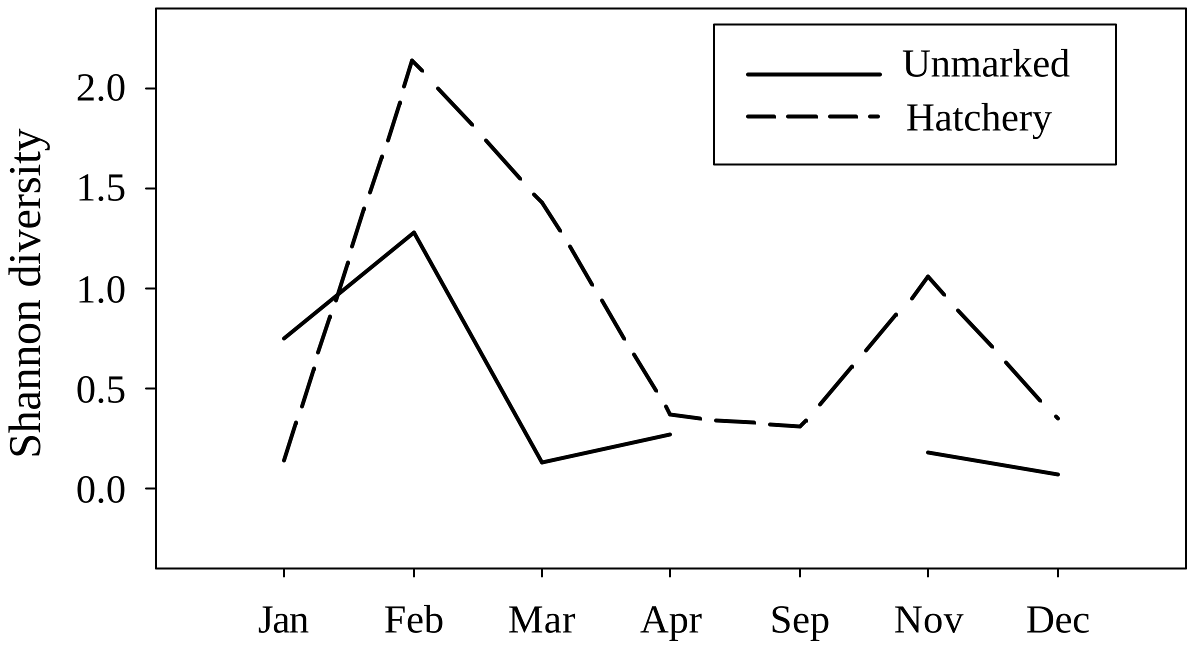


Figure 7. Shannon diversity scores for diets of unmarked and hatchery juvenile Chinook salmon during select months, lower Willamette River (2002-2003).

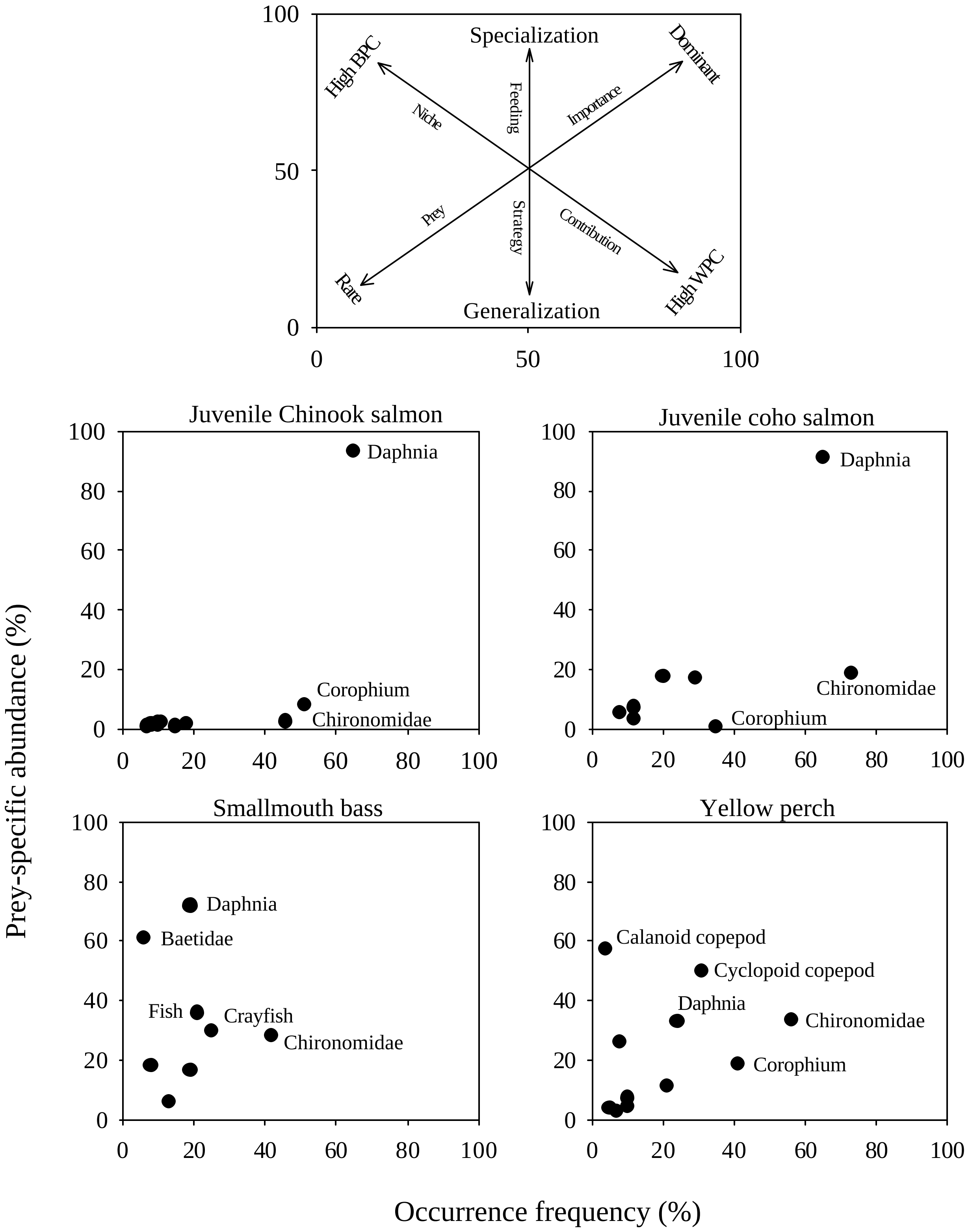


Figure 8. Feeding strategy plots (adapted from Amundson et al. 1996) for juvenile Chinook and coho salmon, smallmouth bass, and yellow perch in the lower Willamette River, 2002-2003. BPC = between-phenotype contribution; WPC = within-phenotype contribution.

Yellow perch had a generalized feeding strategy with relatively little between or within-phenotype contribution (Figure 8). Calanoid copepods were the most abundant organism, but were consumed by a few individual fish. Chironomids were consumed by most fish, but in low numbers.

Smallmouth bass exhibited a mixture of generalized and specialized feeding, with a low frequency of occurrence among prey items (Figure 8). A few individual smallmouth bass specialized on daphnia and baetid mayflies, which contributed to the between-phenotype niche contribution.

Prey Selection

Comparisons of diet composition to the proportional abundance of invertebrates in the environment indicated juvenile Chinook salmon selected daphnia and avoided chironomids (Table 3). Corophium were consumed in proportions similar to their abundance in the environment. Prey selection/avoidance was slightly more evident for unmarked Chinook salmon than for hatchery fish. Juvenile coho salmon exhibited similar positive selection for daphnia and avoidance of chironomids.

In contrast to salmonids, yellow perch and centrarchids (excluding smallmouth bass) strongly avoided daphnia. Copepods, the major yellow perch food item, were not sampled in the environment. Centrarchids displayed the strongest positive selection for corophium. Smallmouth bass avoided daphnia and chironomids to some degree, but proportions of organisms present in the diet samples were similar to those in the environment.

Chinook Salmon Diets among Nearshore Habitat Types

The mean number of daphnia consumed by juvenile Chinook salmon varied greatly and was highest at sites 006EN (beach), 012WN (riprap), 067EA (alcove), 107WA (alcove), 203WN (mixed), and 239EA (alcove) (Figure 9).

The percent of daphnia in juvenile Chinook salmon diets was most evenly distributed among bank treatments in spring; none of the comparisons were statistically significant (Figure 10). In general, percent daphnia composition was highest at mixed-habitat sites in winter and spring. The percent of daphnia present in stomach samples during winter was significantly higher at mixed and riprap habitats than at rock outcrop sites ($P = 0.03$). Juvenile Chinook salmon feeding at riprap sites during fall had significantly ($P = 0.03$) lower proportions of daphnia in their diets compared to alcove and beach habitats.

The percent body weight index for juvenile Chinook salmon among physical bank treatments was statistically significant during both spring and autumn (Figure 11). Median %BW during spring was significantly higher at mixed sites than at alcoves and higher at riprap sites than at beaches and alcoves ($P = 0.03$). Autumn index values were significantly higher for Chinook salmon stomach samples collected at alcove sites than at beach sites ($P = 0.02$). Body weight values were consistent among bank habitats during winter; no pairs differed significantly.

Table 3. Proportion of prey items in the diet (*Ri*), proportion of prey items in the environment (*Pi*), and the Strauss index of prey selection (*L*; *Ri*-*Pi*) for fish species collected in the lower Willamette River, 2002-2003. Values of *L* range from +1 (positive selection for a food item) to -1 (prey avoidance). Environmental data are from Friesen et al. (2004b).

	Daphnia			Corophium			Chironomidae		
Species	*Ri*	*Pi*	*L*	*Ri*	*Pi*	*L*	*Ri*	*Pi*	*L*
Chinook salmon (all)	0.91	0.63	0.28	0.05	0.02	0.03	0.02	0.32	-0.30
Unmarked	0.95	0.63	0.32	0.02	0.02	0.00	0.01	0.32	-0.31
Hatchery	0.88	0.63	0.25	0.04	0.02	0.04	0.02	0.32	-0.30
Coho salmon	0.82	0.63	0.19	0.01	0.02	-0.01	0.08	0.32	-0.24
Yellow perch	0.15	0.63	-0.48	0.06	0.02	0.04	0.25	0.32	-0.07
Smallmouth bass	0.46	0.63	-0.17	0.06	0.02	0.04	0.21	0.32	-0.11
Other Centrarchidae	0.27	0.63	-0.36	0.25	0.02	0.23	0.26	0.32	-0.06

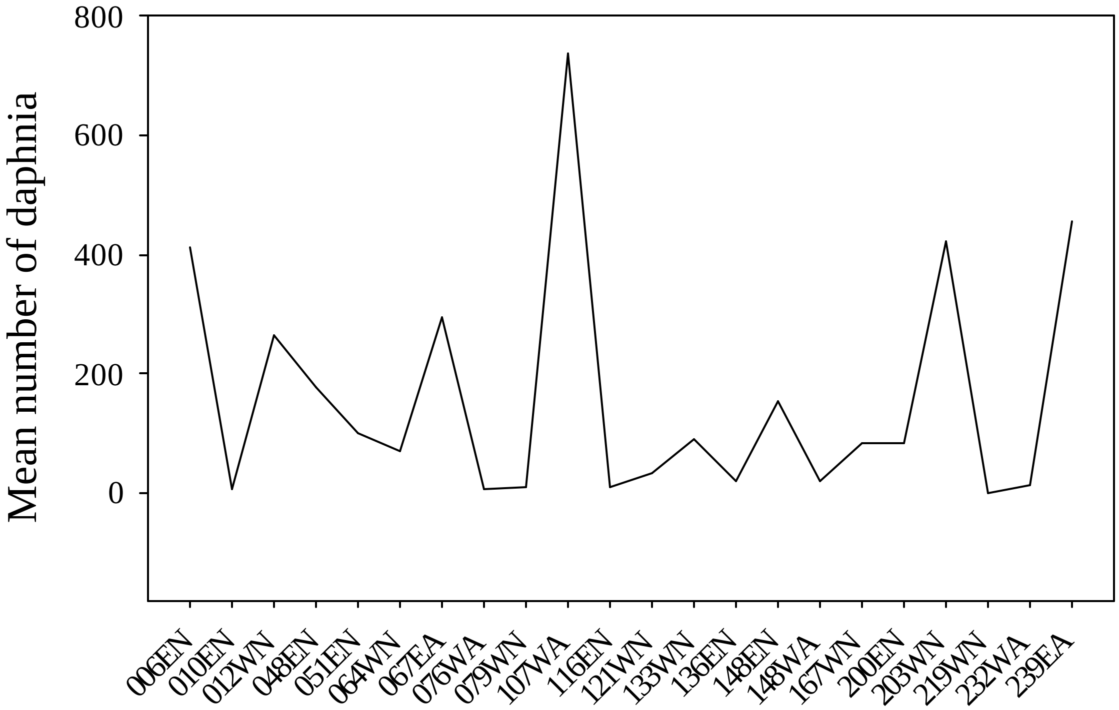
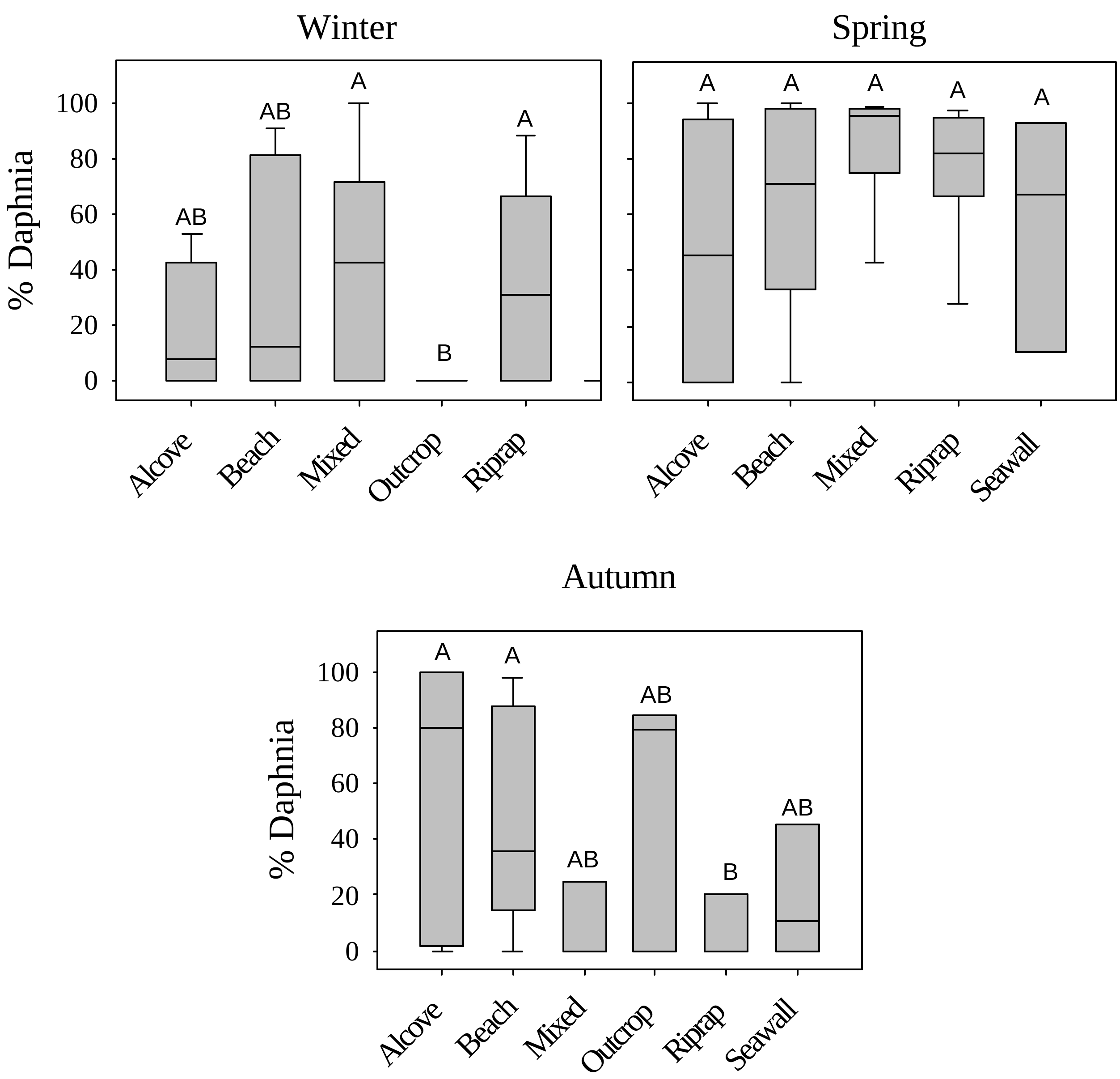


Figure 9. Mean number of daphnia in juvenile Chinook salmon diets by sampling site in the lower Willamette River, 2002-2003. Sampling site labels denote river mile (rm; xx.x) and east (E) or west (W) shore. N = standard nearshore site; A = alcove / off-channel site.



Winter

Spring

Autumn

Figure 10. Percent of juvenile Chinook salmon diets composed of daphnia during winter, spring, and autumn among nearshore habitat types in the lower Willamette River, 2002-2003. Bars not sharing a letter are significantly different ($P < 0.05$). The horizontal line inside the bar is the median, the ends of the bar are the 25th and 75th percentiles, and the whiskers are the 5th and 95th percentiles.

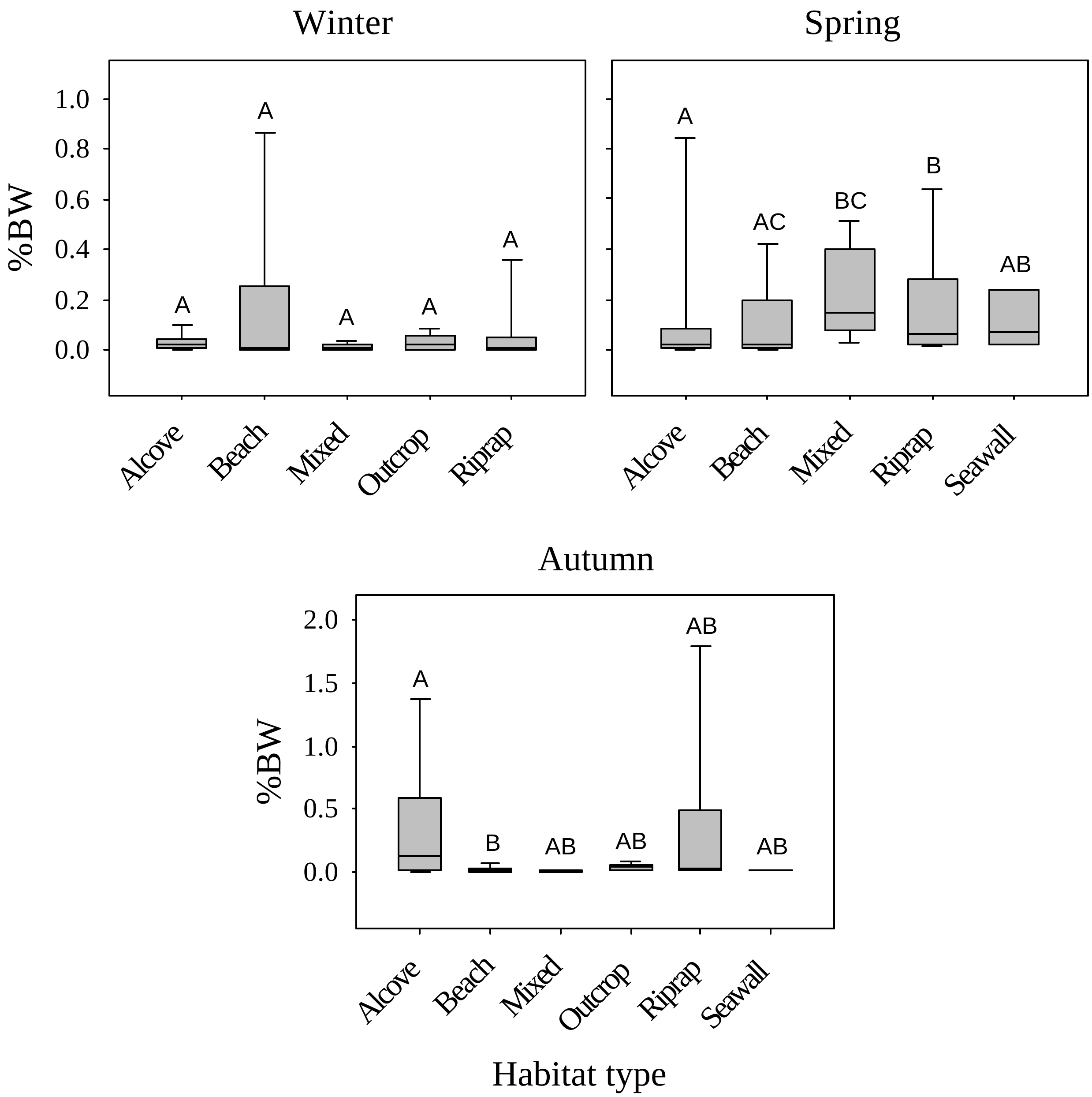


Figure 11. Percent body weight (%BW; an index of relative stomach fullness) for juvenile Chinook salmon among seasons and nearshore habitat types in the lower Willamette River, 2002-2003. Bars not sharing a letter are significantly different ($P < 0.05$). The horizontal line inside the bar is the median, the ends of the bar are the 25th and 75th percentiles, and the whiskers are the 5th and 95th percentiles.

DISCUSSION

Though actively migrating yearling Chinook salmon spend a short time in the lower Willamette River as they move towards the Columbia River (Friesen et al. 2004a), they extensively utilize available food resources. Juvenile Chinook and coho salmon fed largely on daphnia throughout winter, spring, and autumn. Our observations contrast a previous study; Durkin (1982) observed terrestrial insects and dipterans were the major food items for juvenile coho salmon in the Portland Harbor region of the lower Willamette River.

Our results are comparable to those from the impounded sections of the lower Columbia River, where subyearling Chinook salmon fed extensively on daphnia in reservoir habitats (Rondorf et al. 1990). These fish exhibited a dietary shift from larger caddisflies and chironomids in the free-flowing Hanford Reach to smaller cladocerans in the impounded sections. Although daphnia were abundant in the stomach contents of larger Chinook salmon, they were uncommon in plankton samples (Dauble et al. 1980). Our diet analyses and the environmental sampling of Friesen et al. (2004b) indicated daphnia are an abundant food source in the Willamette River throughout the year. The extensive feeding we observed is certainly related to the high daphnia density, which facilitates capture (Rondorf et al. 1990; Tabor et al. 1996).

Prey size is an important factor in determining zooplankton predation; in our study, many of the daphnia present in stomach samples were larger than 2.0 mm (carapace length) and some approached 3.0 mm, making them easy prey. Facultative and obligate zooplankton foraging by fish is prey-size dependent; planktivorous fish visually select the largest zooplankton available and can develop a search pattern based on zooplankton size when larger individuals are abundant (Wetzel 1983; Diana 1995).

Hester-Dendy multi-plate samplers (atypical zooplankton sampling devices) deployed in the lower Willamette River during spring 2003 (Friesen et al. 2004b) were colonized extensively by daphnia, attesting to their high abundance. The high numbers and large size of daphnia in this area may help explain the feeding behaviors of juvenile Chinook salmon we observed. Other zooplankton species are generally more abundant at the surface than daphnia, but their smaller size and ability to escape may prevent capture (Craddock et al. 1976; Wright and O'Brien 1984). Cladocerans such as daphnia tend to exhibit slow steady movements compared to the irregular darting typical of most copepods (Wetzel 1983).

Juvenile salmonid diets in systems lacking significant zooplankton populations can often resemble diets of introduced species; Chinook salmon and steelhead diets from Lower Granite Reservoir (Snake River) consisted mainly of mayflies, dipterans, and terrestrial insects that led to relatively high diet overlap values (a = 0.45 – 0.69) with introduced fish species (Karchesky and Bennett 1999). We found no significant overlap with any introduced species, and rejected our null hypothesis (*diet composition of juvenile salmonids does not differ from diet composition of introduced fishes)*. We did note a similarity in diets (based on the abundance of prey taxa) between juvenile salmonids and smallmouth bass (a = 0.54 - 0.59); however, their diets were quite dissimilar when assessed by weight (a = 0.21 - 0.23). Daphnia composed 43% of the weight of Chinook salmon diets, but <1% of the weight of smallmouth bass diets. In addition, the seasonal abundance of juvenile salmonids and smallmouth bass appear to differ, reducing the likelihood that they compete for the same food items. We collected the majority of our smallmouth bass during the summer, when juvenile salmonid abundance is lowest (Friesen et al. 2004a).

Diet composition dissimilarities among juvenile salmonids and introduced fish species are likely a result of divergent feeding strategies. Shannon diversity values, evenness, and prey-specific abundances suggested specialized feeding behavior by Chinook and coho salmon on daphnia. The diets of yellow perch, smallmouth bass, and other centrarchids were more diverse and indicative of generalized feeding.

Comparisons between hatchery and unmarked juvenile Chinook salmon indicated a similarity in diets by abundance and weight; we failed to reject our null hypothesis (*diet composition of hatchery juvenile salmonids does not differ from diet composition of unmarked juvenile salmonids)*. Although diets overlapped significantly, unmarked fish preyed more on daphnia throughout most of the year and exhibited a more selective feeding strategy than hatchery-produced fish. They also consumed larger amounts of prey items, by both number and wet weight. These differences suggest hatchery fish, raised on commercial feed during their first year of life, are less efficient at foraging in the wild than unmarked fish. Behavioral or morphological differences may contribute to feeding efficiency. Friesen et al. (2004a), for example, concluded larger hatchery Chinook salmon moved through the study area at a faster rate than smaller, unmarked fish. Because their diets are very similar, hatchery fish would undoubtedly compete with unmarked fish for food in a resource-limited environment.

Neither Chinook nor coho salmon consumed major food items at the same proportion that they were present in the environment. This was especially true for Chinook salmon, as daphnia composition in their diet was disproportionately high and chironomid composition was disproportionately low (compared to the environment). Previous studies corroborate our results. Juvenile Chinook salmon in the lower Columbia River fed extensively on daphnia, though *Bosmina* spp. and cyclopoid copepods were more abundant at various times of the year; selection indices indicated Chinook salmon positively selected daphnia and avoided *Bosmina* spp. and cyclopoids (Craddock et al. 1976). Our data provided definitive evidence to reject the null hypothesis (*diet composition of juvenile salmonids does not differ from the composition of food items available)*.

Differences in Chinook salmon diet indices among bank habitat types were rare. Considering the short residence time and mobility of juvenile salmonids in the lower Willamette River (Friesen et al. 2004a), and the likelihood of high macroinvertebrate drift rates, differences in diet among broad habitat categories may be difficult to detect. Fish captured at one location may have consumed prey items at another. Diet metrics from seawall habitats seem to support this point. These sites are typically homogenous and appear to be sub-optimal habitats for juvenile salmonids. However, stomach fullness and the percent of daphnia in diet samples from Chinook salmon collected at seawalls were not significantly different from fish collected at other habitats.

We did note several differences that may be related to seasonal flow patterns. For example, stomach fullness was similar among all habitat types during winter, but the proportion of daphnia in diet samples was significantly lower at rock outcrop sites than at other habitats. Rock outcrop sites tended to be associated with high nearshore flows in winter; velocities may act to wash prey items out of these areas or change the foraging strategy of salmonids.

In terms of food resources, introduced resident fishes do not appear to adversely affect the survival of juvenile salmonids. Even if diet overlap occurred, competition would likely be minimal or nonexistent due to the current high abundance of prey items, especially daphnia. Among the fish we studied, hatchery salmonids and smallmouth bass would be most likely to compete with naturally produced salmonids in a resource-limited environment.

RECOMMENDATIONS

The recommendations presented here were developed by the principal investigators, and will not necessarily be adopted as policies or guidelines by the Oregon Department of Fish and Wildlife. Recommendations are limited to those for additional studies.

1. **Continue monitoring fish diets and macroinvertebrate communities in the lower Willamette River.** Daphnia and other invertebrates are clearly important food sources for fish in the lower Willamette River, and are likely a critical component for the survival and success of ESA-listed salmonids. The effects of historic river development on these communities are largely unknown, and the effects of future development may go undetected without some level of monitoring.

2. **Future studies in the lower Willamette River should assess the impacts of other introduced species in relation to resource use, especially Asian shrimp *Exopalaemon modestus* and American shad *Alosa sapidissima*.** Although we found no significant dietary overlap among juvenile salmonids and introduced fishes, we did not evaluate the diets of some important species. Juvenile American shad, which feed heavily on zooplankton (Wydoski and Whitney 2003), were the most abundant species observed during the study (Friesen et al. 2003). Although studies of Delaware River American shad indicated their diets consist mainly of chironomid larvae/pupae and terrestrial insects, zooplankton were rarely collected in drift samples, indicating plankton density was relatively low (Ross et al. 1997). Cladocerans were important food items of juvenile shad in the Connecticut and Susquehanna Rivers (Levesque and Reed 1972; Johnson and Dropkin 1997). Juvenile American shad in the lower Willamette River exhibit overlaps in seasonal abundance and size with juvenile Chinook salmon (Friesen et al. 2003), and could utilize the same food resources. Juvenile American shad require dissection and removal of the digestive tract for diet analyses; this method would not have been comparable to our non-lethal sampling of juvenile salmonids.

   In addition, we noted freshwater Asian shrimp are abundant at various times of the year in the lower Willamette River. Little information exists about these exotic decapods and potential impacts they pose to native species. Emmett (2003) raised concerns regarding Asian shrimp predation on corophium in the Columbia River and the potential for dietary overlap with juvenile salmonids.

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Appendix

Diet Summaries for Juvenile Salmonids and Introduced Fish Species

Appendix Table 1. Number (No.), percent abundance (Abund.), percent weight (Wt.), and percent occurrence frequency (Occur.) of prey items from juvenile Chinook and coho salmon diet samples, lower Willamette River (2002-2003). L = larvae; P = pupae.

	Chinook salmon (N = 346)				Coho salmon (N = 49)			
		Percent				Percent		
Prey taxa	No.	Abund.	Wt.	Occur.	No.	Abund.	Wt.	Occur.
Bryozoa	3	<1	<1	1	0	--	--	--
Pelecypoda	2	<1	<1	1	1	<1	<1	2
Hydrachnidia	9	<1	<1	1	3	<1	<1	4
Cladocera	2	<1	<1	<1	0	--	--	--
Bosminidae	5	<1	<1	1	5	<1	<1	4
Daphnia spp.	38,644	91	43	65	2,603	82	49	65
Calanoida	180	<1	<1	18	3	<1	<1	6
Cyclopoida	98	<1	<1	8	1	<1	<1	2
Isopoda	1	<1	<1	<1	0	--	--	--
Amphipoda	2	<1	<1	<1	0	--	--	--
Corophium spp.	1,891	4	12	51	19	1	2	35
Gammaridae	43	<1	1	10	8	<1	1	12
Eogammarus spp.	1	<1	<1	<1	0	--	--	--
Decapoda								
Exopalaemon spp.	10	<1	2	1	0	--	--	--
Collembola	1	<1	<1	<1	0	--	--	--
Aquatic insect	285	1	1	18	75	2	4	29
Ephemeroptera	17	<1	<1	4	2	<1	<1	4
Heptageniidae	1	<1	<1	<1	6	<1	<1	10
Cinygmula spp.	60	<1	1	7	4	<1	<1	6
Rhithrogena spp.	1	<1	<1	<1	0	--	--	--
Epeorus spp.	3	<1	<1	1	4	<1	<1	6
Baetidae	18	<1	<1	3	7	<1	<1	8
Baetis spp.	62	<1	1	8	6	<1	1	8
Ephemeridae	1	<1	<1	<1	0	--	--	--
Ephemerella spp.	25	<1	<1	5	0	--	--	--
Caudatella spp.	1	<1	<1	<1	1	<1	<1	2
Tricorythodes spp.	1	<1	<1	<1	0	--	--	--
Caenis spp.	1	<1	<1	<1	0	--	--	--
Odonata								
Zygoptera	1	<1	<1	<1	0	--	--	--
Coenagrionidae	4	<1	<1	1	1	<1	<1	2

Appendix Table 1 (continued).

	Chinook salmon (N = 346)				Coho salmon (N = 49)			
		Percent				Percent		
Prey taxa	No.	Abund.	Wt.	Occur.	No.	Abund.	Wt.	Occur.
Plecoptera	6	<1	<1	2	1	<1	<1	2
Capniidae	1	<1	<1	<1	0	--	--	--
Capnia spp.[a]	109	<1	1	10	0	--	--	--
Isoperla spp.	7	<1	<1	1	1	<1	1	2
Hemiptera								
Corixidae	1	<1	<1	<1	0	--	--	--
Coleoptera	3	<1	<1	1	0	--	--	--
Carabidae	0	--	--	--	2	<1	<1	2
Trichoptera	5	<1	<1	1	0	--	--	--
Hydropsychidae	10	<1	<1	2	1	<1	<1	2
Hydropsyche spp.	8	<1	<1	1	8	<1	1	12
Ceratopsyche spp.	1	<1	<1	<1	0	--	--	--
Hydroptilidae	0	--	--	--	1	<1	<1	2
Amiocentrus spp.	4	<1	<1	1	0	--	--	--
Lepidoptera	1	<1	<1	<1	0	--	--	--
Petrophila spp.	2	<1	<1	1	0	--	--	--
Diptera L	3	<1	<1	1	0	--	--	--
Diptera P	71	<1	<1	4	6	<1	<1	2
Dixa spp.	2	<1	<1	1	0	--	--	--
Dixella spp.	1	<1	<1	<1	0	--	--	--
Chaoboridae L	3	<1	<1	<1	0	--	--	--
Chaoboridae P	1	<1	<1	1	0	--	--	--
Simuliidae	118	<1	1	15	2	<1	<1	4
Ceratopogonidae P	0	--	--	--	1	<1	<1	2
Chironomidae L	323	1	2	35	66	2	3	55
Chironomidae P	287	1	2	24	191	6	8	57
Tabanidae	1	<1	<1	<1	0	--	--	--
Insect	2	<1	<1	1	0	--	--	--
Terrestrial insect	198	<1	2	11	127	4	27	20
Spider	26	<1	<1	6	15	<1	2	8
Fish	14	<1	32	3	0	--	--	--
Unknown	25	<1	<1	4	0	--	--	--

[a] Merritt and Cummins (1996) do not distinguish among *Capnia*, *Capnura*, *Mesocapnia*, and *Utacapnia*.

Appendix Table 2. Number (No.), percent abundance (Abund.), percent weight (Wt.), and percent occurrence frequency (Occur.) of prey items from steelhead diet samples, lower Willamette River (2002-2003). L = larvae; P = pupae.

		Steelhead (N = 3)		
		Percent		
Prey taxa	No.	Abund.	Wt.	Occur.
Cladocera				
Daphnia spp.	2	10	<1	33
Coleoptera				
Carabidae	2	10	29	33
Diptera				
Chironomidae L	4	19	6	67
Chironomidae P	5	24	12	33
Terrestrial insect	7	33	53	33
Unknown	1	5	<1	33

Appendix Table 3. Number (No.), percent abundance (Abund.), percent weight (Wt.), and percent occurrence frequency (Occur.) of prey items from yellow perch and walleye diet samples, lower Willamette River (2002-2003). L = larvae; P = pupae.

	Yellow perch (N = 172)				Walleye (N = 2)			
		Percent				Percent		
Prey taxa	No.	Abund.	Wt.	Occur.	No.	Abund.	Wt.	Occur.
Oligochaete	1	<1	<1	1	0	--	--	--
Gastropoda	6	<1	1	3	0	--	--	--
Planorbidae	8	<1	<1	1	0	--	--	--
Pelecypoda	20	<1	1	5	0	--	--	--
Hydrachnidia	193	3	1	21	0	--	--	--
Cladocera	2	<1	<1	1	0	--	--	--
Bosminidae	71	1	<1	10	0	--	--	--
Daphnia spp.	1,032	15	3	24	0	--	--	--
Ostracoda	25	<1	<1	7	0	--	--	--
Copepoda	10	<1	<1	1	0	--	--	--
Calanoida	520	8	<1	4	0	--	--	--
Cyclopoida	2,392	36	1	31	0	--	--	--
Arguloida								
Argulus spp.	1	<1	<1	1	0	--	--	--
Mysidacea	60	1	6	10	0	--	--	--
Isopoda	32	<1	1	4	0	--	--	--
Amphipoda	2	<1	<1	1	0	--	--	--
Corophium spp.	362	5	11	41	0	--	--	--
Gammaridae	102	2	7	8	0	--	--	--
Eogammarus spp.	15	<1	1	4	0	--	--	--
Hyallela spp.	4	<1	<1	1	0	--	--	--
Decapoda								
Crayfish	4	<1	30	2	0	--	--	--
Exopalaemon spp.	3	<1	1	1	0	--	--	--
Aquatic insect	53	1	1	4	0	--	--	--
Ephemeroptera								
Cinygmula spp.	2	<1	<1	1	0	--	--	--
Baetidae	3	<1	<1	2	0	--	--	--
Baetis spp.	2	<1	<1	1	0	--	--	--
Ephemerella spp.	19	<1	1	1	0	--	--	--
Caenis spp.	1	<1	<1	1	0	--	--	--
Odonata								
Coenagrionidae	1	<1	<1	1	0	--	--	--

Appendix Table 3 (continued).

	Yellow perch (N = 172)				Walleye (N = 2)			
		Percent				Percent		
Prey taxa	No.	Abund.	Wt.	Occur.	No.	Abund.	Wt.	Occur.
Plecoptera	1	<1	<1	1	0	--	--	--
Capniidae	1	<1	<1	1	0	--	--	--
Capnia spp.[a]	1	<1	<1	1	0	--	--	--
Isoperla spp.	1	<1	<1	1	0	--	--	--
Coleoptera								
Cleptelmis spp.	1	<1	<1	1	0	--	--	--
Neuroptera								
Climacia spp.	13	<1	<1	2	0	--	--	--
Trichoptera								
Hydropsychidae	2	<1	<1	1	0	--	--	--
Hydroptilidae	2	<1	<1	1	0	--	--	--
Hydroptila spp.	21	<1	<1	2	0	--	--	--
Brachycentrus spp.	1	<1	<1	1	0	--	--	--
Diptera L	1	<1	<1	1	0	--	--	--
Diptera P	18	<1	<1	3	0	--	--	--
Tipulidae	1	<1	<1	1	0	--	--	--
Chaoboridae P	2	<1	<1	1	0	--	--	--
Simuliidae	1	<1	<1	1	0	--	--	--
Ceratopogonidae L	9	<1	<1	2	0	--	--	--
Probezzia spp.	1	<1	<1	1	0	--	--	--
Chironomidae L	1,210	18	16	51	0	--	--	--
Chironomidae P	423	6	13	41	0	--	--	--
Terrestrial insect	3	<1	<1	1	0	--	--	--
Fish	5	<1	3	2	1	100	100	50
Unknown	2	<1	1	1	0	--	--	--

[a] Merritt and Cummins (1996) do not distinguish among *Capnia*, *Capnura*, *Mesocapnia*, and *Utacapnia*.

Appendix Table 4. Number (No.), percent abundance (Abund.), percent weight (Wt.), and percent occurrence frequency (Occur.) of prey items from smallmouth bass and largemouth bass diet samples, lower Willamette River (2002-2003). L = larvae; P = pupae.

	Smallmouth bass (N = 48)				Largemouth bass (N = 14)			
		Percent				Percent		
Prey taxa	No.	Abund.	Wt.	Occur.	No.	Abund.	Wt.	Occur.
Nematoda	0	--	--	--	1	3	12	7
Pelecypoda	1	<1	<1	2	0	--	--	--
Hydrachnidia	2	<1	<1	2	3	10	<1	7
Cladocera								
Bosminidae	2	<1	<1	4	1	3	<1	7
Daphnia spp.	128	46	<1	19	0	--	--	--
Copepoda								
Calanoida	2	<1	<1	2	0	--	--	--
Cyclopoida	4	1	<1	2	1	3	<1	7
Mysidacea	1			0	0	--	--	--
Isopoda	2	<1	<1	4	0	--	--	--
Amphipoda								
Corophium spp.	16	6	<1	19	3	10	<1	14
Gammaridae	7	3	<1	13	0	--	--	--
Eogammarus spp.	1	<1	<1	2	1	3	<1	7
Decapoda								
Crayfish	15	5	62	25	0	--	--	--
Aquatic insect	1	<1	<1	2	0	--	--	--
Ephemeroptera								
Cinygmula spp.	1	<1	<1	<1	0	--	--	--
Baetidae	14	5	<1	6	0	--	--	--
Baetis spp.	5	2	<1	4	0	--	--	--
Diptera P	1	<1	<1	2	0	--	--	--
Chironomidae L	8	3	<1	10	4	13	<1	7
Chironomidae P	48	17	<1	35	9	29	<1	7
Terrestrial insect	4	1	<1	8	1	3	2	7
Fish	14	5	35	21	8	25	84	29

Appendix Table 5. Number (No.), percent abundance (Abund.), percent weight (Wt.), and percent occurrence frequency (Occur.) of prey items from black crappie and white crappie diet samples, lower Willamette River (2002-2003). L = larvae; P = pupae.

	Black crappie (N = 11)				White crappie (N = 1)			
		Percent				Percent		
Prey taxa	No.	Abund.	Wt.	Occur.	No.	Abund.	Wt.	Occur.
Oligochaete	0	--	--	--	2	1	3	100
Hydrachnidia	10	1	<1	27	11	4	8	100
Cladocera								
Bosminidae	5	1	<1	18	4	2	<1	100
Daphnia spp.	602	67	4	73	72	28	5	100
Ostracoda	1	<1	<1	9	0	--	--	--
Copepoda								
Calanoida	19	2	<1	27	14	5	<1	100
Cyclopoida	147	16	<1	64	110	43	5	100
Mysidacea	2	<1	3	18	0	--	--	--
Amphipoda								
Corophium spp.	13	1	6	36	0	--	--	--
Gammaridae	1	<1	<1	9	0	--	--	--
Eogammarus spp.	1	<1	1	9	0	--	--	--
Aquatic insect	1	<1	1	9	0	--	--	--
Diptera								
Chaoboridae P	10	1	3	18	0	--	--	--
Chironomidae L	5	1	<1	27	26	10	8	100
Chironomidae P	72	8	19	82	18	7	71	100
Terrestrial insect	1	<1	<1	9	0	--	--	--
Fish	8	1	63	18	0	--	--	--

Appendix Table 6. Number (No.), percent abundance (Abund.), percent weight (Wt.), and percent occurrence frequency (Occur.) of prey items from bluegill and pumpkinseed diet samples, lower Willamette River (2002-2003). L = larvae; P = pupae.

	Bluegill (N = 14)				Pumpkinseed (N = 16)			
		Percent				Percent		
Prey taxa	No.	Abund.	Wt.	Occur.	No.	Abund.	Wt.	Occur.
Oligochaete	0	--	--	--	3	<1	<1	13
Gastropoda	0	--	--	--	1	<1	<1	6
Pelecypoda	1	<1	1	7	9	1	1	31
Hydrachnidia	117	30	11	50	13	1	<1	38
Cladocera								
Bosminidae	2	1	<1	14	4	<1	<1	25
Daphnia spp.	7	2	<1	21	17	2	<1	25
Ostracoda	0	--	--	--	3	<1	<1	13
Copepoda								
Cyclopoida	7	2	<1	21	16	2	<1	31
Mysidacea	0	--	--	--	1	<1	1	6
Isopoda	7	2	2	7	0	--	--	--
Amphipoda								
Corophium spp.	34	9	13	57	576	61	80	75
Gammaridae	1	<1	<1	7	0	--	--	--
Eogammarus spp.	2	1	7	7	0	--	--	--
Aquatic insect	2	1	<1	7	0	--	--	--
Ephemeroptera								
Baetidae	1	<1	<1	7	0	--	--	--
Trichoptera					0	--	--	--
Agraylea spp.	5	1	<1	7	0	--	--	--
Hydroptila spp.	0	--	--	--	1	<1	<1	6
Limnephilidae	0	--	--	--	1	<1	<1	6
Brachycentrus spp.	1	<1	1	7	0	--	--	--
Diptera P	1	<1	<1	7	0	--	--	--
Chironomidae L	189	48	59	50	230	24	13	81
Chironomidae P	13	3	5	29	75	8	6	63
Terrestrial insect	0	--	--	--	1	<1	<1	6

A Brief Survey of Aquatic Invertebrates in the Lower Willamette River

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INTRODUCTION

In large river systems, invertebrates are the principal processors of organic matter, constitute a large portion of the biomass, and serve as the primary food resource for other organisms (Merritt et al. 1984). They are also used to determine water quality and biotic health, as they are easy to collect and responsive to human disturbances. The relative tolerance of many aquatic invertebrates to organic pollution is well known, and their communities tend to be relatively diverse (Plafkin et al. 1989; Barbour et al. 1999). In the Willamette River basin, agencies and consulting firms have conducted a multitude of aquatic invertebrate surveys, but these efforts have been inconsistent, and are often not comparable because of their varied methodologies. Data from the lower Willamette River (below Willamette Falls; Figure 1) is scarce. Altman et al. (1997) systematically reviewed all of the available literature pertaining to macroinvertebrates in the Willamette River basin through 1995, and identified only one study, (an unpublished annual report, Ward et al. 1988) specific to the lower Willamette River.

Five stocks of Pacific salmon *Oncorhynchus* spp. are listed as threatened or endangered in the Willamette River basin, including lower Columbia River (LCR) and upper Willamette River (UWR) Chinook salmon *O. tshawytscha*, LCR and UWR winter steelhead *O. mykiss*, and LCR coho salmon *O. kisutch* (NOAA 1998; NOAA 1999a; NOAA 1999b; Chilcote 1999). Lower Columbia River stocks include those found in the Willamette River up to Willamette Falls at river kilometer (rkm) 42.8. Juvenile Chinook and coho salmon feed extensively on daphnia (*Daphnia* spp.) and other invertebrates in the lower Willamette River (Vile et al. 2004), and Friesen et al. (2004) observed significant increases in fork length and body weight of juvenile Chinook salmon during their outmigration through this area. Previous studies have documented the importance of aquatic invertebrates in the diets of juvenile salmonids in the nearby Columbia River (Craddock et al. 1976; Rondorf et al. 1990; Muir and Coley 1996).

This report is one component of a four-year study commissioned by the City of Portland, Oregon to assess the biology, behavior, and resources of anadromous and resident fish in the lower Willamette River. Because aquatic invertebrate surveys in this area are rare, our primary objective was to describe and characterize their communities and provide baseline data relating to distribution, density, diversity, and biotic integrity. As future habitat modifications are likely, we also analyzed aquatic invertebrate distributions among generalized nearshore habitat types. Habitat conservation and restoration could enhance invertebrate communities, providing benefits to threatened and endangered salmonids.

METHODS

We sampled aquatic invertebrates at sites that were used in concurrent studies of resident and anadromous fish (Friesen et al. 2004 and Pribyl et al. 2004; Figure 1). We segregated the sites into groups based on subjective classifications of their nearshore habitat. Habitat types were adjusted seasonally to account for variations in river flow, and we classified sites as a particular type only if the dominant structure or substrate extended into the water far enough to realistically have an effect on invertebrate use (1 m). Habitat types included beaches, floating structures, rock outcrops, rock revetments (riprap), vertical walls and bulkheads (seawalls), and mixed

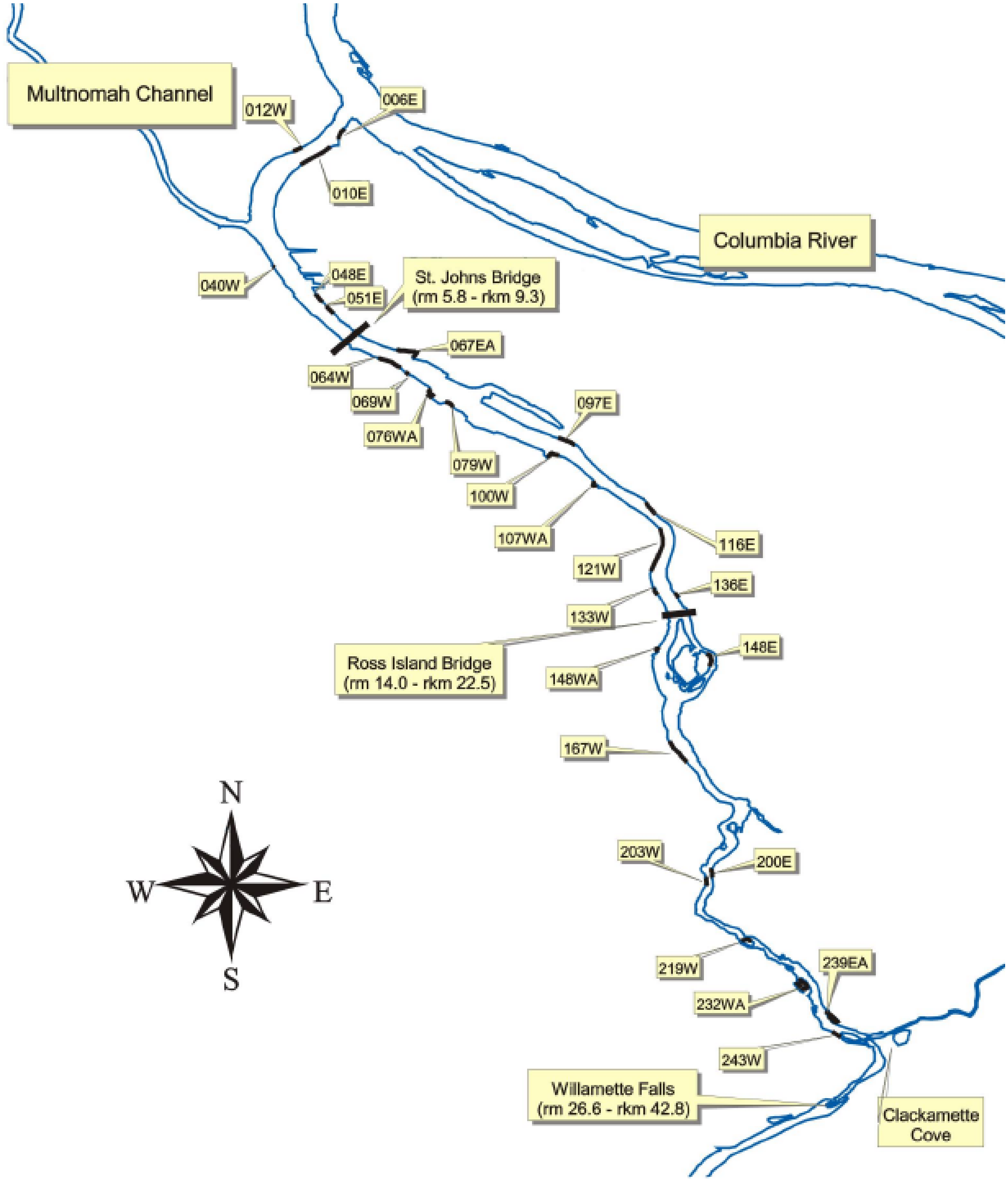

Figure 1. The lower Willamette River and associated features. Sampling site labels denote river mile (rm; xx.x) and east (E) or west (W) shore. A = alcove site, rkm = river kilometer.

habitats. Mixed habitats were not dominated by a single habitat type, but often included beach, riprap, and unclassified fill (e.g. concrete). Detailed descriptions of habitat types and sampling sites are provided in North et al. (2002) and Vile and Friesen (2004).

Field Sampling

We chose a combination of three sampling methods to provide the most complete picture of the aquatic invertebrate community. We used a ponar grab sampler to collect organisms living in the substrate, a plankton net to assess surface invertebrate drift, and artificial substrates to obtain information from sites where hard, rocky substrates rendered the ponar grabs ineffective. All sampling was conducted during May and June of 2003.

Ponar Samples

We used a standard ponar dredge (525 cm^2) to collect benthic invertebrates from nearshore areas at 23 sampling sites (Table 1). Using a geographic information system (ArcView, version 3.2), we created a polygon grid that randomly selected sample locations within the nearshore habitat area of each sampling site. We used a global positioning system (Garmin III Plus) to navigate to the coordinates, and if the water depth was > 1 m, we collected a single grab sample. We emptied the contents from the ponar into a sieve bucket (# 30 mesh) and rinsed the sample to remove silt and fine sediment. We transferred the remaining material into labeled 1-L sample jars and added 70% ethanol as a preservative. Rose bengal, an organic stain, was added to visually separate invertebrates from detritus and other matter.

Multiple-Plate Samples

Hester-Dendy multiple-plate samplers (Hester and Dendy 1962) consisted of a series of eight round, 7.6-cm masonite plates attached to an eyebolt (Figure 2). A series of spacers were used to separate the plates to varying degrees, providing differently sized spaces for colonization. Each sampler had a total surface area of 0.068 m^2. We attached the samplers to a length of PVC pipe and used a series of floats to keep the array within 1.3 m of the surface. An array consisted of six samplers with four floats. Two floats kept the samplers near the surface; the remaining two aided in retrieval. We set the arrays perpendicular to the river flow, using two pyramid anchors to secure each side of the unit. Ten arrays were deployed in May 2003 and left undisturbed for five weeks. We placed arrays at four beaches (006E, 010E, 097E, and 243W), three riprapped sites (012W, 079W, and 136E), two rock outcrops (200E and 219W), and one mixed habitat site (133W) (Table 1).

We retrieved the arrays in June 2003 and randomly selected five of the six samplers from each array for analysis. These were removed from the array and placed in labeled 1-L sample jars. We preserved the samples in 70% ethanol and added rose bengal to stain the invertebrate specimens.

Table 1. Sampling locations, nearshore habitat type, and gears employed (D = drift net, H = Hester-Dendy multiple-plate, and P = ponar) for surveys of aquatic invertebrates in the lower Willamette River, May-June 2003.

River mile	Shore	Habitat type	Gear type
0.6	East	Beach	D H P
1.0	West	Beach	D H P
1.2	East	Riprap	D H P
4.0	West	Beach	D P
4.8	East	Seawall	P
5.1	East	Mixed	D P
6.4	West	Mixed	D P
6.7	East	Mixed	P
6.9	West	Beach	D P
7.6	West	Mixed	P
7.9	West	Riprap	D H P
9.7	East	Beach	D H P
10.0	West	Riprap	D P
10.7	West	Mixed	P
11.6	East	Riprap	D
12.1	West	Seawall	D P
13.3	West	Mixed	D H P
13.6	East	Riprap	D H P
14.8	East	Beach	D P
14.8	West	Mixed	P
16.7	West	Beach	D P
20.0	East	Rock outcrop	D H
20.3	West	Floating	D P
21.9	West	Rock outcrop	D H
23.9	East	Mixed	P
24.3	West	Beach	D H P

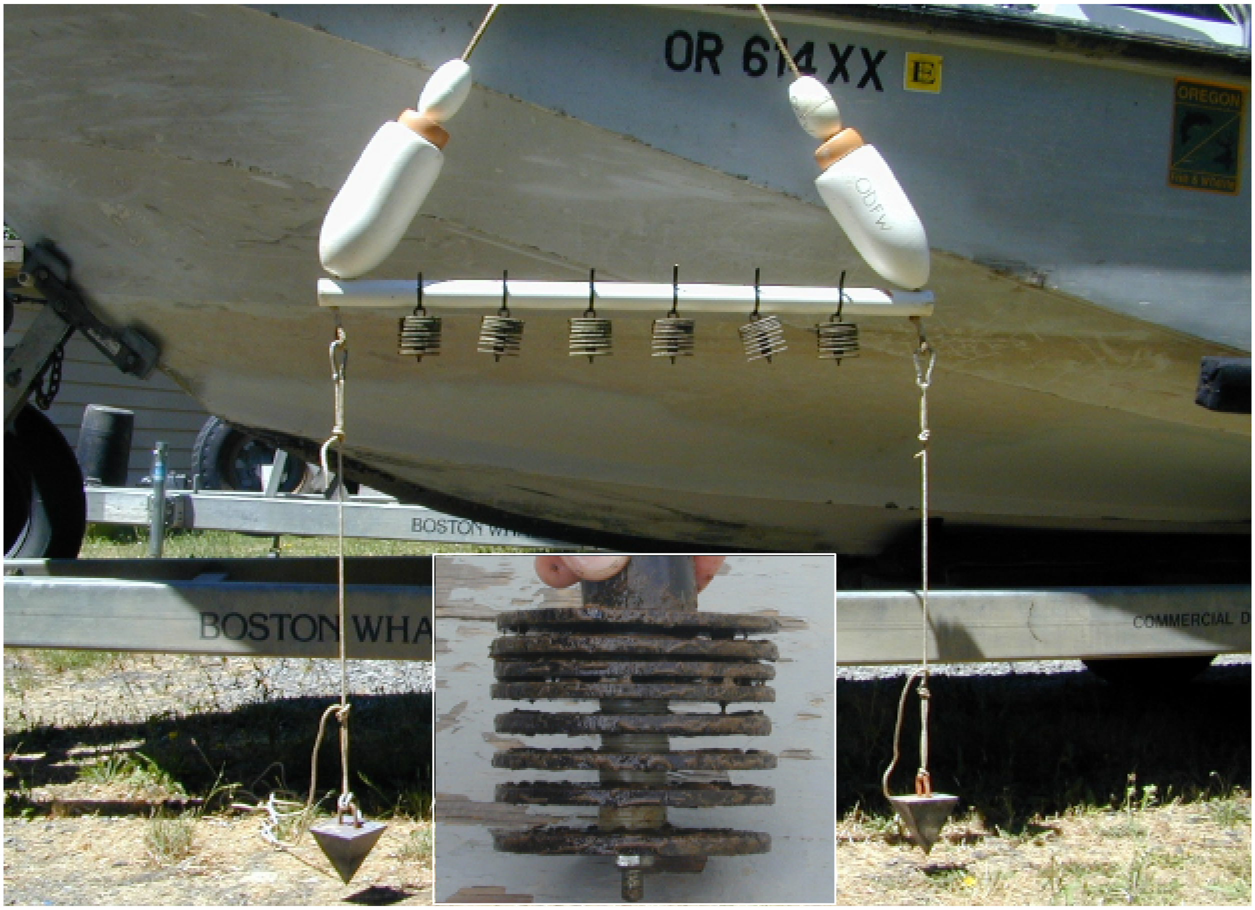

Figure 2. Hester-Dendy multiple-plate sampler (inset) and array used for epibenthic invertebrate surveys of the lower Willamette River, May-June 2003.

Drift Samples

We sampled the aquatic invertebrate drift using a 363-µm plankton net deployed from a boat and held upright in the current. We attached a General Oceanics model 2030R standard flowmeter to the mouth of the net to determine the volume of water sampled. When the river flow was inadequate to keep the net upright, we drove the boat slowly upstream. We maneuvered as close to shore as possible, and maintained a constant depth of 1-3 m. Nets were deployed at 21 sites, including eight beaches, three mixed-habitat sites, two rock outcrops, five riprapped sites, and one seawall (Table 1). After 10 minutes of deployment, we pulled the mouth of the net into the boat and rinsed the mesh to collect all debris and organisms in the cod end. We emptied the contents into a 1-L sample jar, preserved the sample in 70% ethanol, and added rose bengal.

Sample Processing

For all gear types, we placed samples into a 500-µm sieve and rinsed them to remove excess ethanol and rose bengal. We placed a small amount of the sample in a white pan with water and swirled to evenly distribute the material. Using a 2x-magnifying lamp, we sorted organisms into four groups (oligochaetes, chironomids, gastropods and bivalves, and others), and placed them in glass vials containing 70% ethanol. We sorted samples in their entirety to accurately characterize aquatic invertebrate assemblages and eliminate subsampling biases.

We identified all organisms except oligochaetes, chironomids, gastropods, and bivalves to the lowest practical taxon, usually genus, using dichotomous keys by Merritt and Cummins (1996) and Smith (2001). We did not include items such as fish eggs, insect exuviae, oligochaete fragments, or bryozoans (“moss animals”) in taxa identifications or subsequent analyses.

Data Analysis

For each gear and habitat type, we provided the total number and density of organisms collected. Density was calculated as the number of organisms / m^3 in drift samples, and as the number of organisms / m^2 in multiple-plate and ponar samples.

Taxa richness (TR; the number of distinct taxa) represents diversity in a sample and is an important metric for rapid bioassessment protocols (e.g. Plafkin et al. 1989) and biotic health indices (e.g. Kerans et al. 1992, Kerans and Karr 1994). Taxa richness decreases with increasing environmental perturbation. Similarly, Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) taxa, collectively known as EPT, are generally sensitive to diminished water quality and are good indicators of aquatic community health (Barbour et al. 1999). We calculated TR and EPT taxa richness for each habitat and gear type.

We used the Shannon diversity index (H') to describe taxa diversity:

$$H' = -\mathop{S}_{i=1}^{S} (p_i) \ln(p_i)$$

where p_i is the proportion of each taxa in the sample (Ludwig and Reynolds 1988). Diversity increases with increasing H' scores.

We further assessed biotic health using the Hilsenhoff biotic index (HBI; Hilsenhoff 1987):

$$HBI = S\ (Pi)(t),$$

where

Pi = proportion of each taxa, and

t = regional tolerance value.

We used tolerance values developed for the western United States by the U. S. Environmental Protection Agency (USEPA) to assess aquatic community health (Barbour et al. 1999). Values for each taxa range from 0 (poor) to 10 (excellent) and indicate the ability of an organism to tolerate organic pollution; we included all organisms (macroinvertebrates and zooplankton) with established tolerance values. We then compared mean index scores for each habitat type to ranges provided by Hilsenhoff (1987) to provide a general assessment of water quality and organic pollution. Stream ratings ranged from 0.00 (excellent water quality, no organic pollution) to 10.00 (very poor water quality, severe organic pollution; Table 2).

Table 2. A general guide to the water quality of streams based on the Hilsenhoff biotic index for aquatic invertebrates. Adapted from Hilsenhoff (1987).

Biotic index score	Water quality	Degree of organic pollution
0.00 – 3.50	Excellent	No apparent organic pollution
3.51 – 4.50	Very good	Possible slight organic pollution
4.51 – 5.50	Good	Some organic pollution
5.51 – 6.50	Fair	Fairly significant organic pollution
6.51 – 7.50	Fairly poor	Significant organic pollution
7.51 – 8.50	Poor	Very significant organic pollution
8.51 – 10.00	Very poor	Severe organic pollution

RESULTS

We identified 37,897 organisms from 44 taxa in drift net, multiple-plate, and ponar samples (combined). Examples of common fauna collected are illustrated in Figure 3.

Drift Samples

We collected 12,649 organisms in 20 drift net samples, and density averaged 16.6 organisms / m^3 (Table 3). Although taxa richness was relatively high (29), we observed only two EPT taxa. The overall biotic index score for drift samples was 5.45, indicating good water quality. Cladocerans (primarily unidentified bosminids and daphnia) were the most common organisms by number, abundance, and density (Table 4). Copepods and unidentified aquatic insects were also abundant, comprising 26.0% and 17.7% of all organisms observed. Together, cladocerans, copepods, and aquatic insects constituted the majority (89.6%) of organisms identified in drift net samples.

Aquatic invertebrate metrics for drift net samples often varied considerably among habitat types (Table 3). Mean density, for example, was low at rock outcrop (4.6 organisms / m^3) and seawall (4.4) sites, but high at riprapped sites (33.2) and a floating structure (32.5). Similarly, HBI scores varied from 1.08 (excellent water quality) at the floating structure to 7.22 (fairly poor water quality) at a seawall. Shannon diversity scores were similar (range 1.5 – 1.9) among all habitat types except the floating structure (0.7). Taxa richness was higher at beach, riprap, and mixed habitat sites than at floating, rock outcrop, and seawall sites, and the number of EPT taxa was ≤ 1 for all six habitat categories.

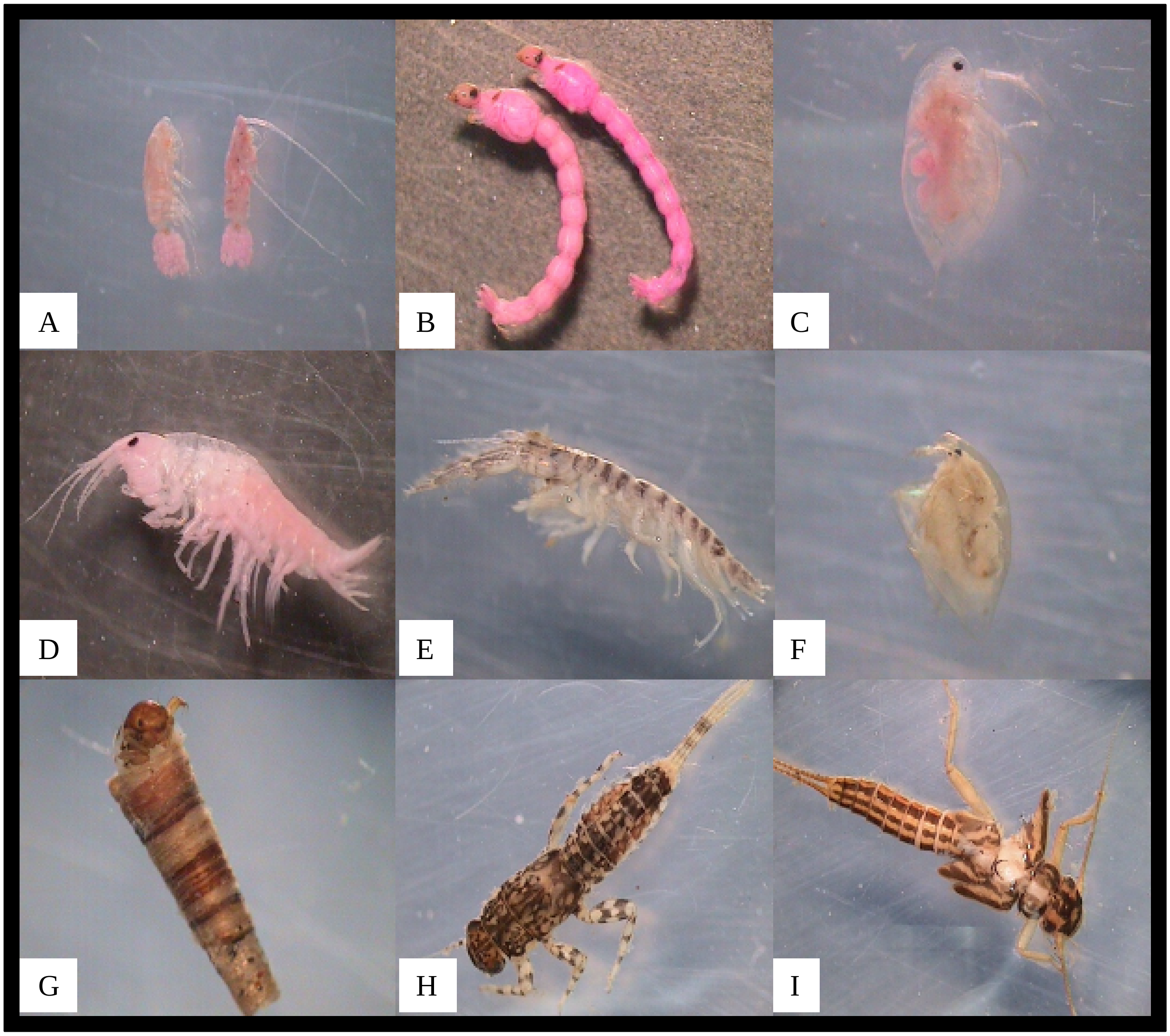

Figure 3. Representative taxa collected during aquatic invertebrate surveys of the lower Willamette River, May-June 2003: (A) copepods (Calanoida), (B) chironomids (Diptera), (C) *Daphnia* spp. (Cladocera), (D) *Eogammarus* spp. (Amphipoda), (E) *Corophium* spp. (Amphipoda), (F) *Bosmina* spp. (Cladocera), (G) caddisfly (Trichoptera), (H) mayfly (Ephemoptera), and (I) stonefly (Plecoptera).

Table 3. Number of organisms (count), Hilsenhoff biotic index (HBI), mean density, Shannon diversity (H'), taxa richness (TR), and Ephemeroptera, Plecoptera, and Trichoptera taxa richness (EPT) among gear and habitat types for aquatic invertebrate surveys in the lower Willamette River, May-June 2003.

Gear type	Habitat type (N)	Count	HBI	Density[1]	H'	TR	EPT
Drift net	Beach (8)	3,504	5.91	11.5	1.9	17	1
	Floating (1)	1,363	1.08	32.5	0.7	8	1
	Rock outcrop (2)	392	2.39	4.6	1.3	9	1
	Riprap (5)	5,788	5.98	33.2	1.5	19	1
	Seawall (1)	149	7.22	4.4	1.7	6	1
	Mixed (3)	1,453	6.25	9.8	1.6	14	0
	Total[2]	12,649	5.45	16.6	1.7	29	2
Multiple plate	Beach (3)	7,418	6.66	7,273	1.0	14	5
	Riprap (2)	9,244	7.69	13,594	0.4	10	3
	Rock outcrop (2)	2,617	6.50	3,849	1.2	14	6
	Mixed (1)	2,241	6.78	6,591	1.0	13	4
	Total[2]	21,520	6.89	7,912	0.9	22	9
Ponar	Beach (8)	1,436	5.37	3,432	1.3	9	2
	Floating (1)	233	5.43	4,455	1.1	7	1
	Riprap (5)	665	5.55	2,543	1.3	13	1
	Seawall (2)	92	5.56	880	0.8	5	0
	Mixed (7)	1,302	5.62	3,556	1.2	12	0
	Total[2]	3,728	5.50	3,099	1.3	21	3

[1] Ponar and multiple plate = number of organisms / m^2, drift net = number of organisms / m^3

[2] Values for HBI, density, and H' are means

Table 4. Number, abundance, and mean density (number of organisms / m^3/ site) of invertebrates collected with drift nets in the lower Willamette River, June 2003.

Taxa	Number	Abundance (%)	Density
Nematoda	1	<0.1	<0.1
Oligochaeta	46	0.4	0.1
Gastropoda	1	<0.1	<0.1
Hydrachnidia	8	0.1	<0.1
Cladocera			
Bosminidae	3,231	25.5	5.4
Daphnidae			
Daphnia spp.	2,586	20.4	3.2
Leptodora spp.	37	0.3	0.1
Ostracoda	2	<0.1	<0.1
Copepoda			
Calanoida	2,163	17.1	2.6
Cyclopoida	1,129	8.9	1.4
Amphipoda	1	<0.1	<0.1
Corophiidae			
Corophium spp.	1	<0.1	<0.1
Gammaridae	4	<0.1	<0.1
Eogammarus spp.	2	<0.1	<0.1
Collembola	11	0.1	<0.1
Aquatic Insect	2,244	17.7	2.6
Ephemeroptera	1	<0.1	<0.1
Baetidae			
Baetis spp.	9	0.1	<0.1
Leptophlebiidae			
Leptophlebia spp.	1	<0.1	<0.1
Odonata			
Coenagrionidae	1	<0.1	<0.1
Hemiptera			
Saldidae	1	<0.1	<0.1
Coleptera	3	<0.1	<0.1
Carabidae	3	<0.1	<0.1
Hydraenidae			
Ochthebius spp.	15	0.1	<0.1
Hydrophilidae	3	<0.1	<0.1
Staphylinidae	3	<0.1	<0.1

Table 4.--Continued.

Taxa	Number	Abundance (%)	Density
Scirtidae	1	<0.1	<0.1
Elmidae			
Dubiraphia spp.	1	<0.1	<0.1
Curculionidae	7	0.1	<0.1
Lepidoptera			
Noctuidae	1	<0.1	<0.1
Diptera	192	1.5	0.2
Chaoboridae	1	<0.1	<0.1
Ceratopogonidae	27	0.2	<0.1
Probezzia spp.	1	<0.1	<0.1
Chironomidae	505	4.0	0.5
Terrestrial insect	362	2.9	0.4
Spider	30	0.2	<0.1
Fish	3	<0.1	<0.1
Unknown	10	0.1	<0.1

Mean densities of the major taxa collected in drift nets also varied among habitats (Figure 4). Aquatic insects dominated the floating structure and rock outcrop sites; bosminids, calanoid copepods, and daphnia were absent or present at very low densities. Conversely, bosminids and copepods were the dominant organisms at riprapped sites. Relative densities of the major taxa were similar among beach, seawall, and mixed habitat sites.

Multiple-Plate Samples

We were unable to locate two of the multiple-plate samplers during recovery (sites 010E and 012W). From the remaining eight, we collected 21,520 specimens representing 22 taxa (Table 3); the mean density was 7,912 organisms / m^2. Though taxa richness was lower than for drift net samples, we identified more EPT taxa (nine), including five ephemeropterans, one plecopteran, and three trichopterans. The HBI score was relatively high (6.89; indicating fairly poor water quality), and diversity was generally lower (0.9) than for drift net samples. Daphnia and chironomids were the most abundant taxa, representing 94.9% of all organisms collected (Table 5). Daphnia were present at a mean density of 4,997 individuals / m^2. We also observed relatively large numbers (>100) of the amphipods *Corophium* spp. and *Eogammarus* spp., and the caddisfly *Agraylea* spp.

Among habitat types, the mean density of aquatic invertebrates was considerably higher at riprapped sites (13,594 organisms / m^2) than at any other habitat type (Table 3). Biotic integrity scores did not vary considerably, ranging from 6.50 (fair water quality) at rock outcrops to 7.69

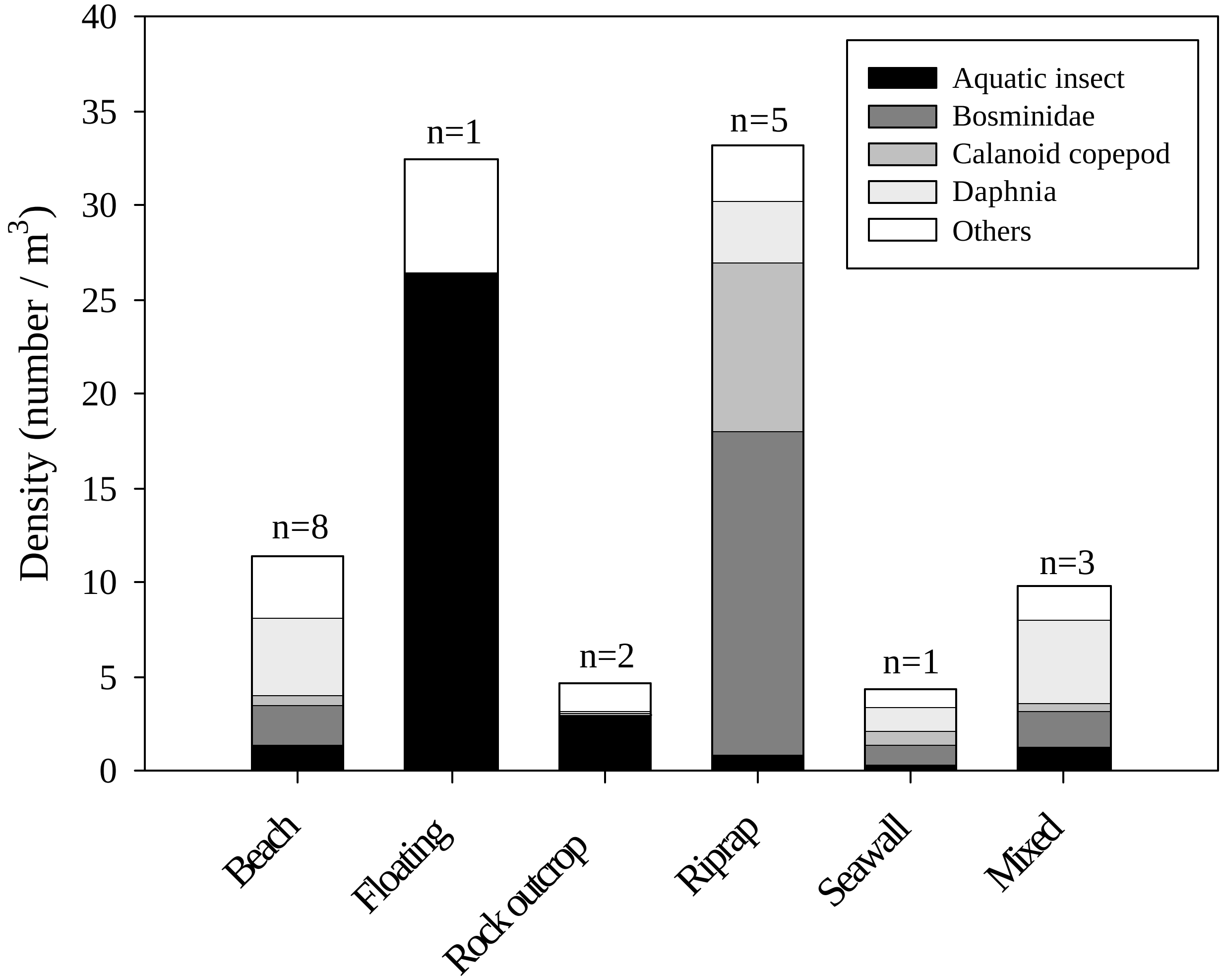

Figure 4. Mean densities of major aquatic invertebrate taxa from drift net samples among generalized nearshore habitat types in the lower Willamette River, spring 2003.

Table 5. Number, abundance, and mean density (number of organisms / m^2 / site) of invertebrates collected with Hester-Dendy multiple-plate samplers in the lower Willamette River, May-June 2003.

Taxa	Number	Abundance (%)	Density
Nematoda	12	0.1	4.4
Oligochaeta	55	0.3	20.2
Gastropoda	1	<0.1	0.4
Pelecypoda	10	<0.1	3.7
Hydrachnidia	2	<0.1	0.7
Cladocera			
Bosminidae	4	<0.1	1.5
Daphnidae			
Daphnia spp.	13,593	63.2	4,997.4
Amphipoda			
Corophiidae			
Corophium spp.	336	1.6	123.5
Gammaridae	74	0.3	27.2
Eogammarus spp.	108	0.5	39.7
Ephemeroptera	1	<0.1	0.4
Heptageniidae	1	<0.1	0.4
Cinygmula spp.	6	<0.1	2.2
Baetidae	1	<0.1	0.4
Baetis spp.	1	<0.1	0.4
Callibaetis spp.	1	<0.1	0.4
Ephemerellidae			
Ephemerella spp.	3	<0.1	1.1
Tricorythidae			
Tricorythodes spp.	6	<0.1	2.2
Plecoptera			
Perlodidae			
Isoperla spp.	2	<0.1	0.7
Coleptera	1	<0.1	0.4
Trichoptera	4	<0.1	1.5
Hydroptilidae	12	0.1	4.4
Agraylea spp.	358	1.7	131.6
Hydroptila spp.	69	0.3	25.4
Brachycentridae			
Brachycentrus spp.	7	<0.1	2.6

Table 5.--Continued.

Taxa	Number	Abundance (%)	Density
Diptera	1	<0.1	0.4
Chaoboridae	2	<0.1	0.7
Ceratopogonidae			
Probezzia spp.	1	<0.1	0.4
Chironomidae	6,824	31.7	2,508.8
Aquatic insect	19	0.1	7.0
Spider	1	<0.1	0.4

(poor water quality) at riprapped sites. Diversity indices (H', TR, and EPT) were also lower at riprapped sites than at beaches, rock outcrops, and mixed habitats.

The mean density of daphnia was much greater at riprapped sites (11,690 organisms / m^2) than at beaches, rock outcrops, or mixed habitats (mean 2,534 organisms / m^2; Figure 5), and riprapped sites had relatively low densities of *Agraylea* spp. and other organisms. Mean densities of chironomids were similar among habitat types.

Ponar Samples

We collected 3,728 specimens from 21 taxa in ponar samples (Table 3). The mean density for all taxa combined was 3,099 invertebrates / m^2; oligochaetes and chironomids composed the highest overall densities (1,482 and 1,076 organisms / m^2) and the majority (47.8 and 34.7%) of the organisms collected (Table 6). Pelycopods (bivalves) and *Corophium* spp. were also relatively abundant, representing 5.9 and 5.5% of the total. We collected several larval fish, including three lamprey *Lampetra* spp. ammocoetes. Overall diversity (H' = 1.3) and EPT richness (3) of ponar samples were low, and the HBI score was 5.50, indicating fair to good water quality.

The mean density of aquatic invertebrates varied from 880 organisms / m^2 at seawalls to 4,455 organisms / m^2 at the floating structure (Table 3). Diversity was lowest (H' = 0.8) at seawalls, which had only five taxa and no EPT taxa. Riprapped sites had the highest taxa richness (13), and no habitat type had more than two EPT taxa. Biotic integrity scores varied only slightly among habitats, ranging from 5.37 (good water quality) at beaches to 5.62 (fair water quality) at mixed habitats.

Mean densities of the major taxa collected in ponar samples were similar among habitat types (Figure 6), except beaches had considerably higher densities of *Corophium* spp. than other habitats. The single seawall sample contained no pelycopods or *Corophium* spp., and had relatively low densities of chironomids and oligochaetes.

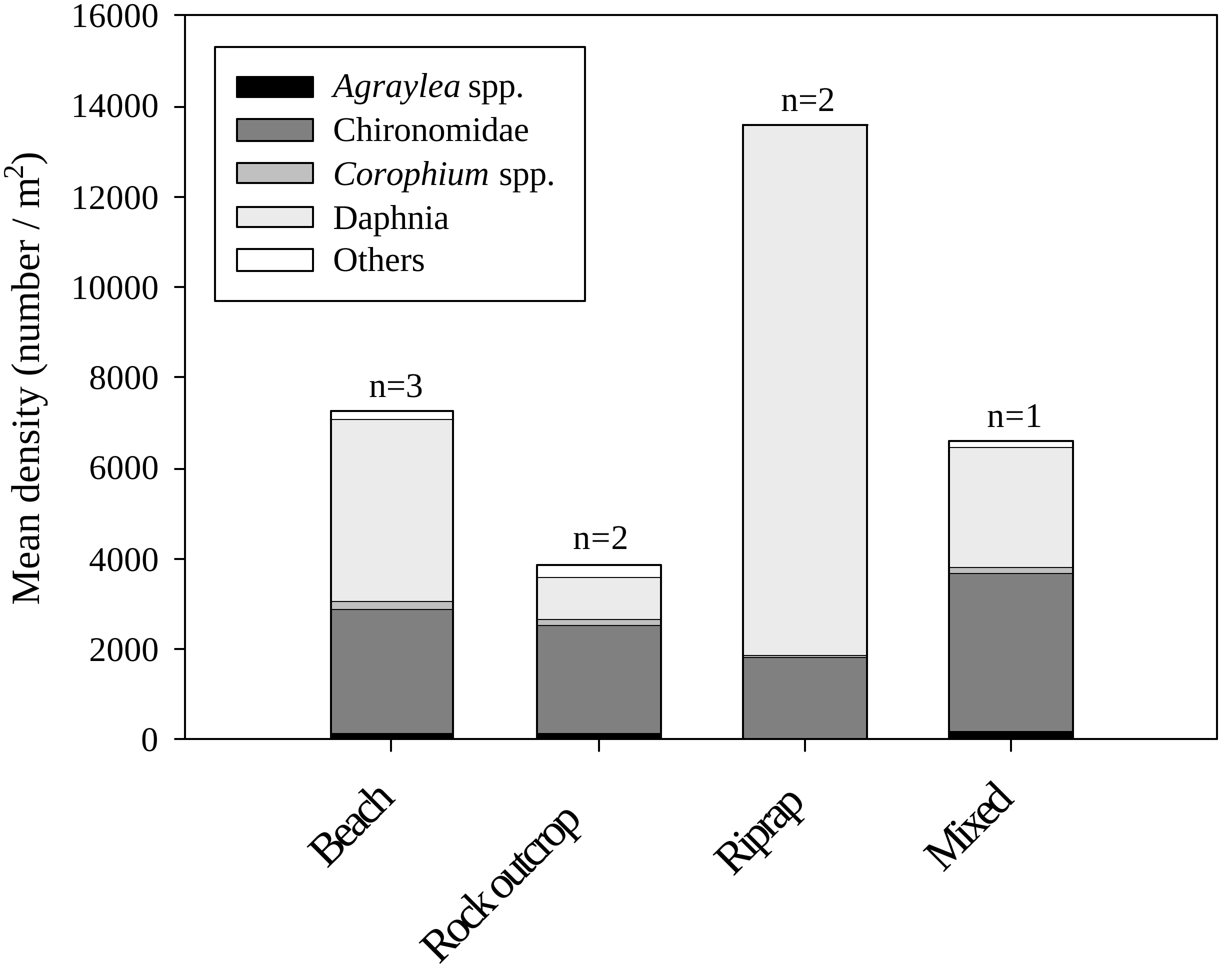

Figure 5. Mean densities of major aquatic invertebrate taxa collected in Hester-Dendy multiple-plate samplers among generalized nearshore habitat types in the lower Willamette River, spring 2003.

Table 6. Number, relative abundance, and mean density (number of organisms / m^2 / site) of invertebrates collected with ponar dredges in the lower Willamette River, June 2003.

Taxa	Number	Abundance (%)	Density
Nematoda	47	1.3	39.1
Nematomorpha	3	0.1	2.5
Oligochaeta	1,783	47.8	1,482.3
Tubificidae			
Branchiura sowerbyi spp.	2	0.1	1.7
Gastropoda	1	<0.1	0.8
Pelecypoda	221	5.9	183.7
Hydrachnidia	2	0.1	1.7
Ostracoda	2	0.1	1.7
Calanoida	3	0.1	2.5
Cyclopoida	38	1.0	31.6
Isopoda	15	0.4	12.5
Amphipoda			
Corophiidae			
Corophium spp.	205	5.5	170.4
Gammaridae	1	<0.1	0.8
Eogammarus spp.	1	<0.1	0.8
Ephemeroptera	1	<0.1	0.8
Baetidae			
Baetis spp.	1	<0.1	0.8
Ephemeridae			
Hexagenia spp.	1	<0.1	0.8
Odonata			
Gomphidae			
Gomphus spp.	1	<0.1	0.8
Trichoptera			
Leptoceridae			
Oecetis spp.	2	0.1	1.7
Diptera	6	0.2	5.0
Chaoboridae	1	<0.1	0.8
Culicidae			
Culicoides spp.	1	<0.1	0.8
Ceratopogonidae			
Probezzia spp.	83	2.2	69.0
Bezzia spp.	1	<0.1	0.83
Chironomidae	1,294	34.7	1,075.7
Aquatic insect	3	0.1	2.5

Table 6.--Continued.

Taxa	Number	Abundance (%)	Density
Fish (*Lampetra* spp.)	3	0.1	2.5
Fish (unknown)	1	<0.1	0.8
Unknown	5	0.1	4.2

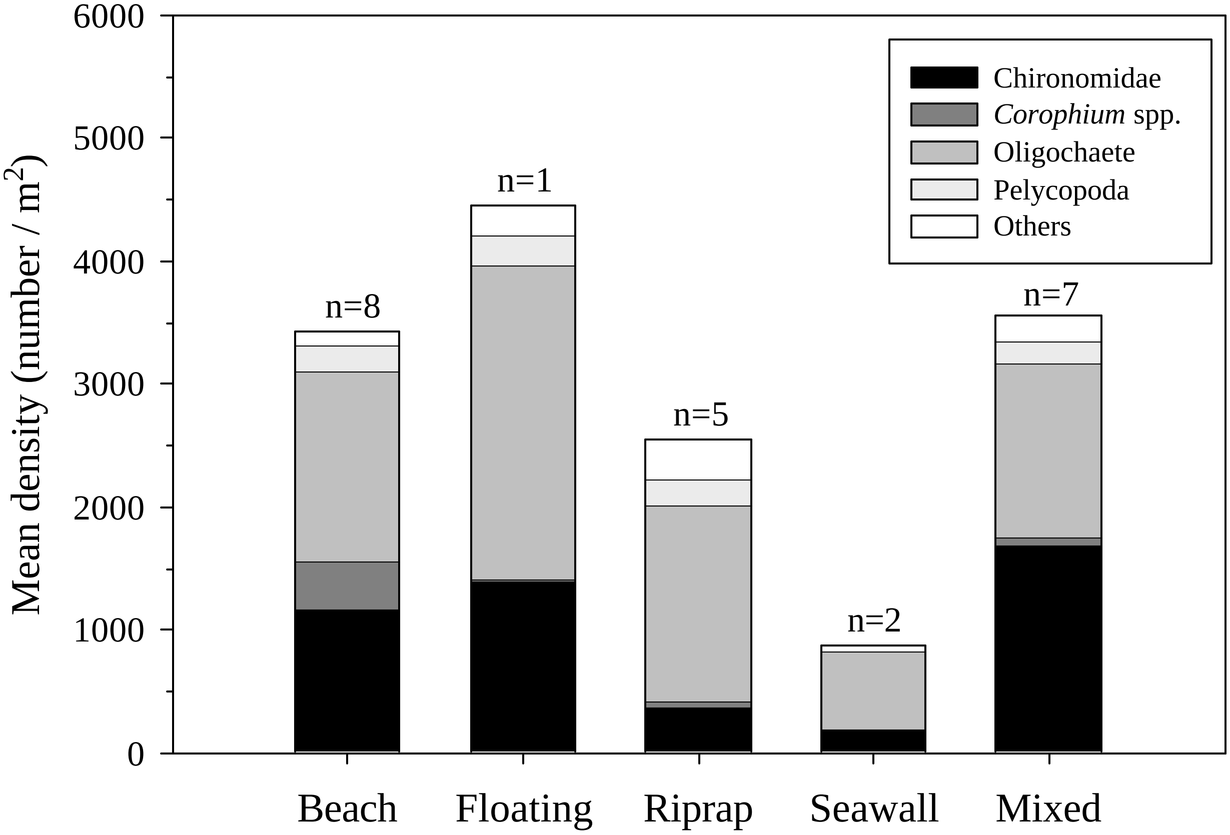

Figure 6. Mean densities of major aquatic invertebrate taxa collected in ponar samples among generalized nearshore habitat types in the lower Willamette River, spring 2003.

DISCUSSION

Many aquatic invertebrate surveys have been conducted in the Willamette River basin, but differences in sampling efforts, methodologies, and taxonomic identification make meaningful comparisons among studies difficult (Altman et al. 1997). The results of many studies appear only in gray literature, and relatively few surveys have occurred in the mainstem Willamette River below Willamette Falls. With these caveats, our surveys may be broadly compared to other examples from the lower Columbia and Willamette rivers. Ward et al. (1988), for example, conducted surveys of benthos in the Willamette River at six sites from rkm 2 to 27. As in our benthic surveys, oligochaetes were numerically dominant; amphipods and chironomids were also common. In contrast to our results, unidentified cladocerans were also quite abundant, second only to oligochaetes by number.

Windward Environmental (2004) surveyed a number of sites in the Portland Harbor area of the lower Willamette River (rkm 5 to 22) using both van Veen grabs to collect benthic samples, and Hester-Dendy multiple-plate arrays to sample the epibenthic community. Though their methods for epibenthic sampling were similar to ours, Windward Environmental (2004) did not count or identify zooplankton species. Consequently, the results were somewhat divergent from our study. Oligochaetes, chironomids, and *Corophium* spp. dominated (95% of all organisms) the Windward Environmental (2004) samples. Our multiple-plate arrays were colonized almost exclusively (95%) by cladocerans (primarily daphnia) and chironomids, and we collected relatively few *Corophium* spp. Sample timing may be another factor contributing to these differences; Windward Environmental (2004) conducted their epibenthic sampling from mid-July to the end of August. Results from the benthic surveys were similar between the studies. Oligochaetes were generally the most abundant taxa, followed by chironomids and bivalves.

Hjort et al. (1984) sampled benthic organisms in the Willamette River above Willamette Falls (rkm 93 to 106) to assess the effects of rock revetments on invertebrate fauna. Though assemblages varied considerably among sites, oligochaetes and chironomids were by far the most common organisms collected, similar to our results. Gastropods and pelycopods were often abundant in side channels, and sensitive taxa (especially ephemopterans and trichopterans) were more abundant than in our surveys of the lower river.

McCabe et al. (1997) assessed benthic invertebrate communities in the lower Columbia River, with several sample transects within 24 rkm of the mouth of the Willamette River. McCabe et al. (1997) found lower densities of oligochaetes and chironomids than in our surveys, often <100 organisms / m^2. Bivalves (primarily the Asian clam *Corbicula fluminea*) and Ceratopogonidae (midge) larvae dominated many samples. *Corophium* spp. were also abundant, but at lower densities than we observed in the lower Willamette River.

Investigations pertaining to the effects of nearshore habitat type on aquatic invertebrate communities are rare. Sample sizes in our survey were too small to provide a rigorous assessment of differences among habitat types, but we noted several trends. Beaches, for example, tended to have relatively high species diversity, taxa richness, and EPT taxa richness. The floating structure and rock outcrops (to a lesser extent) appeared to be preferred habitats of aquatic insects. Aquatic insects dominated the drift at these sites, and their low tolerance values resulted in low HBI scores (indicating higher water quality) relative to other habitats. Seawalls appeared to be poor habitats for aquatic invertebrates; density and taxa richness were lower than at other habitat types (for both drift and ponar samples), and Shannon diversity and EPT scores were also low relative to other habitats (ponar samples). The lack of interstitial spaces or other complex microhabitats at these homogenous structures likely contributed to the lack of diversity.

The value of riprapped sites appeared to be mixed. These sites had very high densities of organisms, with the exception of ponar samples, and high taxa richness (drift and ponar samples). A large number of organisms colonized the multiple-plate samplers at riprapped sites, but Shannon diversity, taxa richness, and EPT taxa richness were comparatively low. Hjort et al. (1984) noted similar results for other areas of the mainstem Willamette River; densities of aquatic organisms were higher at riprapped sites than at other habitats, but species richness and diversity varied. Hjort et al. (1984) speculated that interstitial spaces and associated pockets of calm water provided good rearing habitat for invertebrates, but long-term effects of riprap may be detrimental due to habitat losses caused by channel constriction. In the lower Willamette River, interstitial spaces may fill with sediment, allowing opportunistic species to flourish.

Though some habitats had higher aquatic invertebrate densities and greater taxa diversity than others, we noted only a few differences in the proportional distribution of major taxa groups, suggesting a generally homogenous community structure. As noted above, aquatic insects dominated the invertebrate drift at the floating structure and rock outcrop sites; daphnia, copepods, and bosminids were largely absent. The drift at riprapped sites consisted primarily of bosminids and calanoid copepods. Colonization of multiple-plate samplers was similar among habitats, except for riprapped sites, which had much higher densities of daphnia and no *Agraylea* spp. The distribution of major taxa was also similar among habitats sampled with ponar, though densities of *Corophium* spp. varied slightly.

The HBI was originally developed for small midwestern streams (Hilsenhoff 1987), and lacking a northwest equivalent, we applied it primarily to compare relative biotic health among habitat types. Few large rivers have “excellent” water quality, and the oligochaetes and chironomids we observed typically dominate the taxa in these systems. Identification of these organisms to species (time- and cost prohibitive in our study) would improve the resolution of the HBI and better identify sites with relatively poor water quality. Interpreted broadly, HBI scores from our study and Hilsenhoff’s (1987) guide suggest the lower Willamette River has moderate to “fairly significant” levels of organic pollution based on the aquatic invertebrate community. “Excellent” HBI scores at the floating structure and rock outcrops reflected only the drift, which was composed largely of aquatic insects that presumably preferred these habitats. Index scores for ponar and multiple-plate samples at these sites suggested higher levels of organic pollution. The infaunal community scores (ponar samples) were very consistent and indicated better water quality (“good” to “fair”) than the epibenthic community (multiple-plate samples; “fair” to “fairly poor”). These moderate levels of impairment suggest biotic communities may respond well to habitat and water quality improvements.

RECOMMENDATIONS

The recommendations presented here were developed by the principal investigators, and will not necessarily be adopted as policies or guidelines by the Oregon Department of Fish and Wildlife. Recommendations are limited to those for additional studies.

1. **Continue to monitor invertebrate populations in the lower Willamette River using standardized protocols.** Our survey of aquatic invertebrates in the lower Willamette River, while similar to previous studies, was largely cursory and emphasizes the need for a coordinated effort. Standardized procedures (sampling gears, locations, timing, level of taxonomic identification, and biotic indices) would be particularly useful for identifying changes in aquatic invertebrate communities as anthropogenic development of the lower Willamette River continues. Biomonitoring could also aid in prioritizing habitat restoration projects and documenting the success of these efforts.

2. **Assess factors affecting aquatic invertebrate communities in the lower Willamette River.** Water depth, sediment composition (percent silt and clay), sediment grain size, and percent volatile solids were significantly ($P \leq 0.05$) related to benthic invertebrate density in the lower Columbia River (McCabe et al. 1997). Identifying similar factors in the lower Willamette River may help direct habitat restoration efforts and provide benefits for fish populations.

3. **Include zooplankton in future studies, especially daphnia.** Past studies often focused exclusively on macroinvertebrates, ignoring zooplankton entirely. Daphnia were very common in our study, dominating the taxa collected in both multiple-plate samplers (which are generally not considered to be effective zooplankton sampling devices) and drift nets. Daphnia are a primary food source for juvenile salmon and other fish in the lower Willamette River (Vile et al. 2004), but little is known about their populations and factors affecting them.

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