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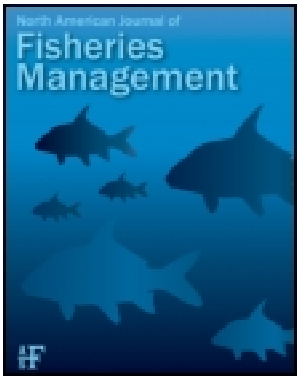

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Abstract.—Subyearling fall chinook salmon's *Oncorhynchus tshawytscha* use of unaltered and riprap habitats in Lake Wallula of the Columbia River was determined with point abundance data collected by electrofishing in May 1994 and 1995. We documented the presence or absence of subyearlings at 277 sample sites and collected physical habitat information at each site. Based on logistic regression, we found that the probability of fish presence was greater in unaltered shoreline habitats than in riprap habitats. Substrate size was the most important factor in determining fish presence, with dominant substrates larger than 256 mm having the lowest probability of fish presence. Water velocity, also included in our model due to its biological importance, was not a significant factor affecting presence or absence (P = 0.1102). The correct prediction rate of fish presence or absence in our sample sites using cross validation was 67%. Our model showed that substrate was the most important factor determining subyearling habitat use, but the model did not include other habitat variables known to be important to subyearlings in more diverse systems. We suggest that resource managers consider alternative methods of bank stabilization that are compatible with the habitat requirements of the fish that use them.

Hydropower development has transformed the Columbia and Snake rivers from natural fluvial systems into two series of reservoirs. Large portions of the shorelines of impoundments have been modified by the addition of riprap revetments to prevent bank erosion and to protect roads, railways, and bridges. The four lowest reservoirs on the Snake River currently have about 156 km (34%) of shoreline armored with riprap (U.S. Army Corps of Engineers 1999). Shoreline areas provide critical habitat for subyearling fall chinook salmon *Oncorhynchus tshawytscha* rearing in the main-stem Snake and Columbia rivers (Dauble et al. 1989; Connor et al. 2001).

Substrate may be an important component of subyearling fall chinook salmon (hereafter referred to as subyearlings) rearing habitat in main-stem reservoirs. Subyearlings rearing in Lower Granite Reservoir on the Snake River preferred habitats that contained primarily sand substrates, but strongly avoided habitats where riprap was the dominant substrate (Curet 1993). However, Key et al. (1994) found no relation between the percentage of fine substrates and subyearling abundance in the Columbia River. In a recent review of existing literature, Schmetterling et al. (2001) stated that the effects of riprap on salmonid populations have not been well studied. Although riprap has been shown to reduce the densities of juvenile salmon and trout in smaller streams (Elser 1968; Knudsen and Dilley 1987), we found few studies on riprap in large, regulated rivers such as the Columbia River. The objective of our study was to determine subyearling use of riprap and unaltered habitats and to identify the factors that contributed to habitat use.

Study Area

Lake Wallula is a 98-km impoundment created by McNary Dam, which is located 470 river kilometers (rkm) above the mouth of the Columbia River. Just upstream of Lake Wallula is the Hanford Reach, the only unimpounded reach of the main-stem Columbia River between Bonneville Dam and the Canadian border. The Hanford Reach provides spawning and rearing habitat for the interiormost healthy population of fall chinook salmon in the Pacific Northwest and California (Huntington et al. 1996). The Hanford Reach produces an estimated 20–30 million subyearlings annually (Washington Department of Fish and Wildlife, unpublished data), many of which rear in Lake Wallula (Key et al. 1994). We conducted our study in the upper end of Lake Wallula between rkm 506 and 538, where the river has an average width of 1.8 km (range = 0.7–3.6 km) and a variety of shoreline habitats, including riprap.

Methods

We determined subyearling use of shoreline habitats in Lake Wallula by point electrofishing

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(Persat and Copp 1990) between dawn and dusk during three intervals: 23–27 May 1994, 1–4 May 1995, and 30 May to 1 June 1995. Sampling was restricted to May, coincident with the period of greatest nearshore abundance of subyearlings in Lake Wallula (Key et al. 1994). We divided shoreline habitats into two categories: (1) shorelines modified with riprap revetments (riprap) and (2) unmodified shorelines. Riprap areas generally consisted of large broken rock substrates greater than 256 mm in diameter, with minimal fine silt or sand filling the interstitial spaces.

We designed our sampling to include a wide range of habitats within the study area. Our interest in evaluating fish presence in various combinations of water velocity, depth, and substrate guided our sampling efforts. Habitat combinations, or blocks, included velocity × depth, velocity × substrate, and depth × substrate. The habitat variables in each block were divided into strata, so as to include a range of conditions for each variable. Velocity was divided into eight 0.05-m/s strata ranging from 0 to 0.4 m/s, with an additional stratum for velocities greater than 0.04 m/s. Depth was divided into five 0.6-m strata ranging from 0 to 3.3 m, with an additional stratum for depths greater than 3.3 m. Velocity and depth strata were based on categories devised by Key et al. (1994). Substrate was divided into five strata based on mean size: less than 1 mm, 1–4 mm, 4–16 mm, 16–256 mm, and greater than 256 mm (McMahon et al. 1996).

Because the habitat variables in each sampling block were stratified, each block contained a number of habitat combinations equal to the product of the number of strata for each variable. For example, the nine velocity strata times the six depth strata produced 54 individual combinations, or cells, in the velocity × depth block. We tried to collect at least three samples for each cell, although some habitat cells were unlikely or impossible (e.g., high velocity, shallow, sandy areas). We allocated our sampling effort disproportionately by sampling relatively rare habitats with the same frequency as more abundant habitats. We did this because juvenile salmon might select rare habitats disproportionately.

Daily fluctuations in river level caused by hydroelectric operations above and below the study area resulted in high variability in water depths and velocities at any given sampling location; therefore, we were unable to make random a priori selections of sampling sites. Random a priori site selections were also prevented by the size of the study area and the costs associated with daily pre-sampling assessments. Therefore, sample sites were selected after preliminary assessments to obtain data for the cells in each block. Preliminary assessments were made from a boat at distances far enough from the sites to prevent forewarning fish, but close enough to determine the habitat combinations. Sampling proceeded in an upstream or downstream direction each day, and each site was sampled only once. New sampling blocks were used for each sampling trip, to allow coverage of the widest possible range of habitats.

Data were collected from a 5.5-m electrofishing boat with two 1.0-m umbrella anode arrays and an electrical output of 2 A at 60 pulses/s DC. We collected a sample by piloting the boat directly towards the shoreline, stopping abruptly, and electroshocking an area perpendicular to the shoreline for a mean duration of 13 s (range = 3–23 s, SD = 3.8) in 1994 or 8 s (range = 6–10 s, SD = 0.3) in 1995. Shorter durations were used in 1995 to reduce the risk of injury to subyearlings. Our electrofishing method allowed us to shock a localized area with minimal forewarning to fish. The resulting data were comparable between electroshock points (Persat and Copp 1990). A similar technique has been used successfully in a number of habitat studies (Copp 1991, 1992; Jurajda 1999).

After the point electroshock was completed, a buoy was set to mark the area where fish were observed or at the center of the shocked area, if fish were absent. Stunned fish were visually identified and enumerated, and as many stunned fish as possible were collected with dip nets. We hereafter refer to the number of fish caught or observed as ''catch.'' Captured fish were sorted by species, counted, anesthetized with a 26-mg/L solution of tricaine methanesulfonate, and measured to the nearest 1 mm (fork length). All fish were allowed to recover for approximately 15 min before they were returned to the river.

Physical habitat characteristics were measured at each site. Mean water velocity at the electroshock point was measured to the nearest 0.01 m/s with a current meter. Water depth and flow direction were collected concurrently with water velocity measurements. The distance between the electroshock point and the shoreline was measured to the nearest 1 cm with a measuring tape. Dominant substrate size at the electroshock point was visually assessed (Platts et al. 1983) based on a Wentworth classification modified from McMahon et al. (1996). Water turbidity (nephelometric turbidity units [NTU]) was measured every 2 h during a sampling day.

We constructed a logistic regression model to predict the probability P_i of subyearling presence in a cell, given the measured habitat characteristics. P_i can be expressed as

$$P_i = \frac{e^{g(x)}}{1 + e^{g(x)}}$$

where $g(x)$ is the linear combination of parameter estimates of the predictor variables. We considered water velocity, depth at the electroshock point, distance to shore, substrate, lateral slope, velocity and lateral slope interaction, sample location (rkm), and sampling trip as potential predictor variables. Lateral slope was calculated by dividing the depth at the electroshock point by the distance from shore and multiplying the quotient by 100. Substrate categories were converted to four design variables: sand/silt (<1 mm), gravel (4–16 mm), cobble (16–256 mm), and boulder (>256 mm), with boulder serving as the reference category. We were unable to locate any areas dominated by 1–4-mm substrates. All sampling data from 1994 and 1995 were pooled to increase sample size for model development. Fish were considered present in a habitat cell if they were captured or observed there.

The first step in model development was the regression of fish presence against each variable separately, to determine whether each one-variable model was significantly different from the constant-only model. The G-statistic ($-2\log L$) in the likelihood ratio test was used to compare the two models. The G-statistic was then compared to the chi-square distribution with 1 degree of freedom, at an α value of 0.05 (Hosmer and Lemeshow 2000). Habitat variables with P values less than 0.25 were considered as possible candidates for multivariate analyses (Hosmer and Lemeshow 2000).

One of the assumptions of logistic regression is the linear relation between the predictor and the logit. The linearity assumption was examined (following the methods of Demaris [1992]) for velocity and lateral slope, which were identified as significant continuous variables in the univariate analyses. We modeled lateral slope as a design variable (Hardy 1993; Hosmer and Lemeshow 2000), because the linearity assumption was not met.

We proceeded with the next step in multivariate logistic regression by estimating a model that included all significant variables from the univariate analyses. Variables were then removed one at a time based on their Wald chi-square statistic. The importance of each variable was determined by a likelihood ratio test, which compared the models with and without the variable. A nonsignificant result indicated that the variable did not contribute to the model. Significance of a given variable was assumed at P values less than 0.05, but we retained nonsignificant variables that we believed were biologically important (Hosmer and Lemeshow 2000).

The fit of our final model was evaluated with the Hosmer–Lemeshow statistic (Hosmer and Lemeshow 2000), for which a high P value, or nonsignificant result, indicated a good fit. We evaluated the performance of our logistic regression model with cross validation, which involved removing one observation from the data set and estimating the logistic model from the remaining observations. The probability of fish presence in the excluded observation was then estimated according to the logistic model. This process was repeated for each observation in the data set, and classifications of fish presence and absence were then tabulated.

Probabilities were assigned to each sample and examined to describe the differences in subyearling presence between riprap and unaltered habitats. The range, mean, and standard error of the probability of fish presence were calculated for the samples, and differences between the mean probability of subyearling presence in riprap and unaltered habitats were compared by a two-sample t-test for unequal sample sizes. All statistical analyses were performed with SAS software (SAS Institute 2000).

Results

We collected 277 point-electrofishing samples in 1994 and 1995; of these, 218 were collected in unaltered habitats and 59 were collected in riprap habitats. In unaltered habitats, subyearlings were present in 101 samples and absent from the remaining 117. In riprap habitats, fish were present in 8 samples and absent from 51. Mean subyearling fork length was 57 mm ($N = 73$, SD = 10) in 1994, 44 mm ($N = 294$, SD = 8) in the first sampling trip in 1995, and 53 mm ($N = 44$, SD = 8) in the second sampling trip in 1995. Few fish were associated with water faster than 0.4 m/s or lateral slopes steeper than 25%. However, we were only able to collect five samples in velocities greater than 0.4 m/s. The mean turbidity during our study was 13.8 NTU (range = 2.2–21.2 NTU).

TABLE 1.—Summary of the final logistic regression model used to predict the probability of subyearling fall chinook salmon presence in shoreline rearing habitats in Lake Wallula, Washington. The categories of substrate design variables are shown, with the substrate greater than 256 mm serving as the reference category. The likelihood ratio of the model was 42.8, with 4 df ($P < 0.0001$). The 95% Wald confidence limits are shown for the regression coefficients.

Variable	Variable category	Regression coefficient	95% Wald confidence limits	SE	Odds ratio
Intercept		−1.66	−2.32 to −1.01	0.333	
Velocity		−2.57	−5.73 to 0.58	1.612	0.08
Substrate	<1 mm	2.15	1.24 to 3.05	0.460	8.55
	4–16 mm	2.33	1.46 to 3.19	0.442	10.23
	16–256 mm	1.40	0.65 to 2.15	0.382	4.04

Univariate analyses of subyearling habitat variables showed that each variable was significantly different from the constant-only model, with the exception of distance to shore. Our final multivariate model included substrate and velocity (Table 1) and is expressed as:

$$g(x) = -1.66 - 2.57V + 2.15S_1 + 2.33S_2 + 1.40S_3,$$

where V represents water velocity (m/s) and S_{1-3} represent different categories of dominant substrates (Table 1). The Hosmer–Lemeshow statistic for our final model (3.7248, $P = 0.8811$, df = 8) indicated a good fit to the data. The rate of correct classifications of fish presence and absence in rearing habitats, based on cross validation, was 67%.

Substrate was the most important habitat variable determining subyearling presence in rearing habitats ($P \leq 0.0003$ for all design variables). As substrate sizes decreased, the probability of fish presence increased, except for a slight decrease in the probability of fish presence over fine (sand) substrate (Table 1). For example, fish were 10 times more likely to be found over gravel substrate than boulder substrate. We also included water velocity in our final model although it was not significant ($P = 0.11$), because numerous studies have demonstrated its biological importance to subyearling chinook salmon (Everest and Chapman 1972; Hillman et al. 1987; Murphy et al. 1989). Slower water velocities were also associated with an increased probability of fish presence. Each 0.01-m/s decrease in velocity increased the probability of fish presence by 0.08 (Table 1).

The probability of subyearling presence in riprap habitats was lower than in unaltered habitats. The mean probability of fish presence in riprap habitats was 0.14 (SD = 0.04, range = 0.04–0.36), which was significantly different from that of unaltered habitats ($t = 28.363$; $P < 0.0001$; 95% confidence interval = 0.28−0.36). Unaltered habitats had a mean probability of fish presence of 0.46 (range = 0.11–0.66, SD = 0.15).

Discussion

Point electrofishing was effective for sampling subyearling fall chinook salmon during our study. This sampling method is effective in a wide variety of habitats (e.g., riprap) that often cannot be sampled with other gear, such as beach seines. Beach seines have been used extensively to sample subyearlings in the main-stem Columbia and Snake rivers (Curet 1993; Key et al. 1994; Connor et al. 2001). Another advantage of point sampling was that it allowed us to collect microhabitat information at the sites of fish capture. Precise microhabitat sampling is often not possible with beach seines, because captured fish may come from anywhere in the sampled area, which can be quite large (Key et al. 1994).

The effectiveness of point electrofishing can be limited by physical and biological factors. As with any type of electrofishing, high turbidity limits visibility and fish identification, and may allow fish to avoid capture (Reynolds 1996). The low turbidity in our study enabled us to see the river bottom at all sampled depths (range = 0.1–1.5 m). Shallow depths may also reduce capture efficiency due to fish detection of the boat and reduced boat maneuverability. When electroshocking areas with low water velocities and lateral slopes, we observed that subyearlings more readily detected and avoided the boat, resulting in a lower catch in these habitats. Another limitation of point electrofishing is that small fish are not as easily shocked as large fish and are less visible to dipnetters (Reynolds 1996).

Subyearling fall chinook salmon were the dominant fish in shoreline areas in Lake Wallula during the spring rearing period. In 1993, 98% (N = 14,105) of all fish caught via beach seining in Lake Wallula from mid-April to mid-August were identified as subyearlings (Key et al. 1994). Of the 2%

of fish that were not classified as subyearlings, larger yearling spring chinook salmon and other salmonids accounted for 0.5% ($N = 73$) of the total catch. Similarly, Dauble et al. (1989) found that about 90% of salmonids collected in the Hanford Reach were subyearling chinook salmon. Given the dominance of subyearlings in beach-seine catches and our general ability to clearly view shocked fish, we were confident that most of the salmonids we electroshocked were subyearling fall chinook salmon.

The probability of subyearling presence in sampled areas of Lake Wallula was greater in unaltered shoreline habitats than in riprap habitats. Substrate size was the most important factor determining fish presence in our logistic regression analysis. Habitats with dominant substrates larger than 256 mm had the lowest probability of subyearling presence. The dense distributions of large rocks used in riprap revetments to stabilize banks and prevent erosion did not occur naturally in our study area. Naturally occurring rocks larger than 256 mm were widely spaced, rounded, and heavily embedded in silt.

Although we attempted to assess the importance of riprap substrate to rearing subyearlings, we recognized that many other factors influenced subyearling habitat selection. The impounded nature of Lake Wallula may have obscured the role of habitat variables known to be important to subyearlings in more complex and diverse systems (e.g., the Hanford Reach). For example, water velocity was of limited significance in our analysis, although its importance in site selection by subyearling chinook salmon has been demonstrated (Murphy et al. 1989; Key et al. 1994; Tiffan et al. 2002). Water velocities in our study area were generally low and exhibited low variability. Similarly, lateral slopes were also low and did not significantly contribute to the presence of subyearlings. In contrast to our results, lateral slope was the most important determinant of subyearling presence in the Hanford Reach (Tiffan et al. 2002), but our study area lacked the range of lateral slopes found in that study. We also did not consider factors such as temperature or the presence of potential predators such as smallmouth bass *Micropterus dolomieu* and northern pikeminnow *Ptychocheilus oregonensis*, which prey upon subyearlings in the upper reach of Lake Wallula (Tabor et al. 1993).

The reason for the low occurrence of subyearling in riprap habitat could not be determined from this study. Studies of riprap revetment habitats have shown decreased rearing densities of subyearling salmonids in riprap banks compared to unaltered banks (Knudsen and Dilley 1987). Simplification of available sediments after the introduction of riprap, which may have consequences for available food, cover, and spawning sites, has been cited as potentially affecting salmonids in small streams and rivers (Schmetterling et al. 2001). For example, Janecek and Moog (1994) found riprap in impounded rivers supported few insects suitable as food for salmonids. Li et al. (1984) determined that juvenile chinook salmon in the Willamette River were absent from continuous riprap revetments, but present at sites with spur dikes. The authors suggested that the difference was due to high water velocities, steep slopes, and greater depths along riprapped shorelines. Shoreline alterations may also provide habitat for invasive, nonnative fishes (Moyle and Light 1996). For example, riprap provides the type of boulder structure that smallmouth bass reportedly use (Munther 1970; Todd and Rabeni 1989; Sammons and Bettoli 1999), and predator presence may discourage subyearling use of riprap.

Schmetterling et al. (2001) recognized that resource managers face a continual struggle to maintain fluvial processes while protecting public infrastructure and private property. Unfortunately, the protection and stabilization of riverbanks and modified channels are often achieved by constructing riprap revetments. Such technological fixes, where used, should mimic natural conditions rather than countering them (ISG 2000). Our study showed that substrate was the most important factor determining shoreline areas of use and nonuse by subyearling fall chinook salmon. Given the importance of shoreline habitats to subyearlings, we suggest that resource managers consider other methods of bank stabilization as alternatives to riprap. The selected method should maintain the integrity of local ecosystems, natural fluvial processes, and structures, and should be compatible with the habitat requirements of the local fish species that use shoreline areas.

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