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Outmigration of Juvenile Chinook Salmon in the Lower Willamette River, Oregon

Abstract

We used direct sampling and radio telemetry to describe the outmigration of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the lower Willamette River downstream of Willamette Falls from 2000 to 2003. Juvenile Chinook salmon were present all year, with peak densities occurring in winter and spring. Small, naturally-produced (and therefore ESA-listed) fish were present in December and January, a period when in-water work (e.g. dredging) is authorized. Small fish were likely spring-run stocks that outmigrated as subyearlings. Juvenile Chinook salmon were significantly larger at downstream sampling sites, suggesting growth occurs, or larger fish entering from the Columbia River use this area as rearing habitat. Radio-tagged fish (>100 mm fork length) migrated at a median rate of 11.3 km/d, and hatchery fish migrated significantly faster than naturally-produced fish (12.4 vs. 8.4 km/d). Fork length and river flow were significant predictors of migration rate. Radio-tagged fish were distributed evenly across the river channel regardless of year, time of day, or origin (hatchery or naturally produced). Except for a possible affinity for pilings, the distribution of radio-tagged fish appeared to closely follow the proportional availability of nearshore habitat types, suggesting they do not select for specific habitats during their outmigration. We recommend that additional work focus on subyearling fish, which may have more specific habitat requirements and are more vulnerable to predation and other limiting factors. Considering the large number of subyearling juvenile Chinook salmon present during winter, restricting in-water work to July–October may help protect and recover these stocks.

Introduction

The lower Willamette River near Portland, Oregon, is unique in providing a major fishery for Pacific salmon (*Oncorhynchus* spp.) near a large metropolitan area. In 2004, anglers harvested approximately 30,000 salmon from the Willamette River and its tributaries. An additional 13,500 Willamette stock spring Chinook salmon *O. tshawytscha* were harvested in lower Columbia River commercial and sport fisheries (Oregon Department of Fish and Wildlife, unpublished data). Salmonids produced in the Willamette basin are also caught by fishers in the Pacific Ocean, provide ceremonial and consumptive fisheries to Northwest Indian tribes, and contribute to the identity of the region.

The Willamette River below Willamette Falls (Figure 1) 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 this reach, from river kilometer (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

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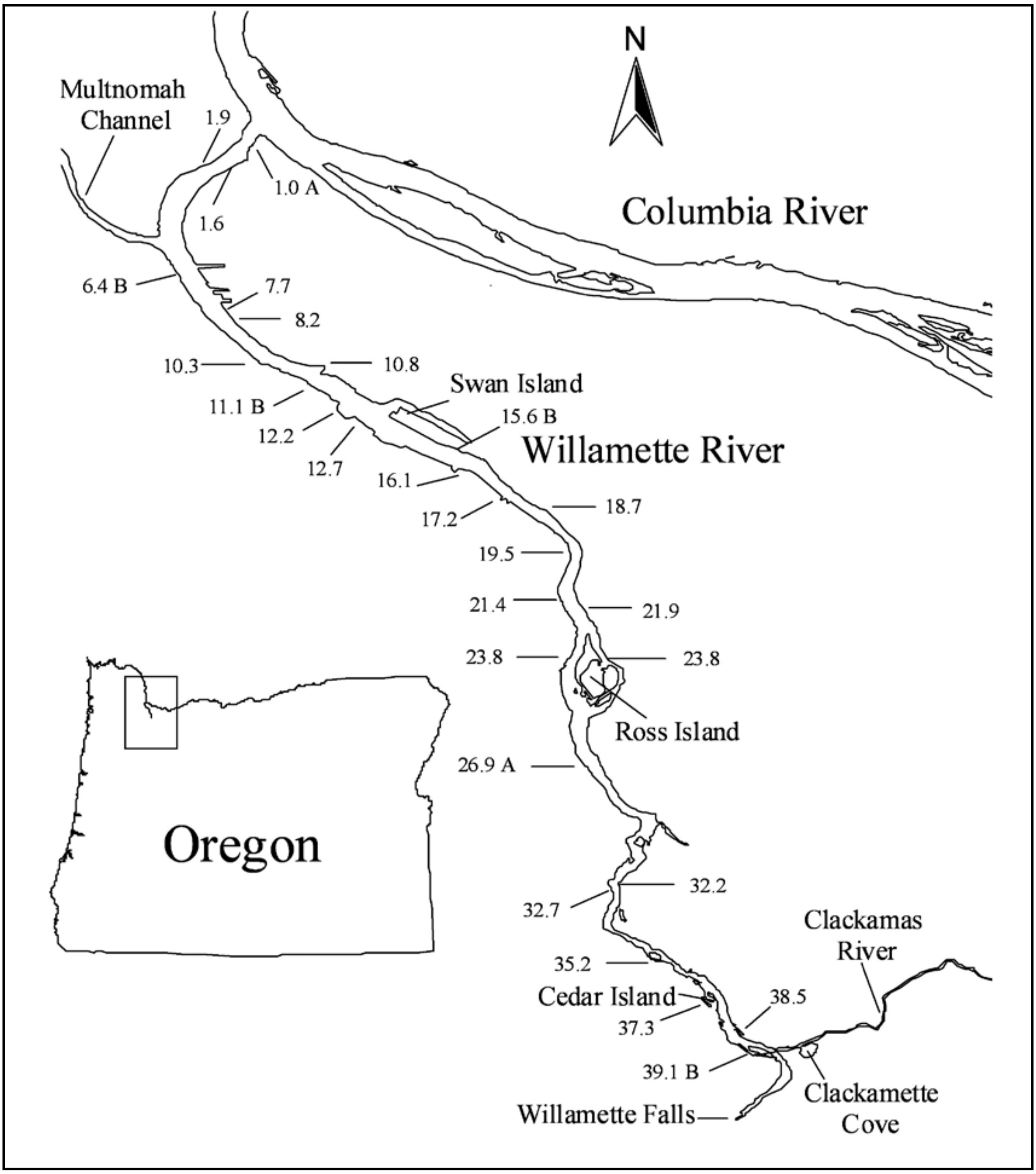

Figure 1. The lower Willamette River study area and associated features. Numbers indicate the location (river kilometer) of sites sampled by boat electrofishing and beach seining. All sites were electrofished, except B=beach seine only and A=both gears.

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.

Four evolutionarily significant units (ESUs) of naturally-propagated anadromous salmonids were listed as threatened under the federal Endangered Species Act (ESA) in the late 1990s, including lower Columbia River and upper Willamette River Chinook salmon (NOAA 1999). The lower

Columbia River ESU includes the Willamette River from the mouth to Willamette Falls at rkm 42.6 (Figure 1).

Following the ESA listings and consultations with regional fisheries managers, the City of Portland sponsored a new study directed at describing the relationships of nearshore development and bank treatments on both resident and anadromous fish species. This work was intended specifically to help the City of Portland protect and recover listed species. As part of this research, we examined the migratory characteristics of juvenile Chinook salmon in the lower Willamette River. Where possible, we assessed both hatchery and naturally-produced fish, and focused largely on elements that would have important management implications and increase our understanding of juvenile Chinook salmon behavior: outmigration timing, size structure, growth, migration rate, and nearshore habitat use.

Methods

Field Sampling

Electrofishing and Beach Seining

We used electrofishing and beach seining to collect juvenile Chinook salmon and assess their origin (hatchery or naturally produced), size, run timing, and growth. Repeated sampling was conducted at 27 sampling stations (Figure 1). Of these, 21 were sampled with electrofishing, four were sampled with beach seines, and two were sampled using both gears. Prior to winter 2001, sampling was conducted during a 4-6 week period seasonally (spring, summer, autumn, and winter), resulting in some temporal gaps (sampling did not occur in some months). We corrected this by redesigning the sampling so all months were sampled equally. Beginning in December 2001, electrofishing was conducted four days per month. We sampled all sites once over two consecutive days, then repeated the sampling in a subsequent week. We conducted beach seining once per week (each seining site sampled once).

Boat electrofishing was conducted after sunset. Because one goal of the study was to characterize the effects of nearshore development on juvenile Chinook salmon, we sampled as close to shore as possible. Navigation was difficult in water <1 m deep, and sampling effectiveness was probably reduced at depths >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 sec (continuous energized direct current) at each sample site, and used 30 pulses/sec at 50–100% of the low range, which maximized taxis and minimized tetany. These settings resulted in an electrofisher output of <1.0–2.0 amperes, depending on conductivity. The conservative settings (selected to minimize harming ESA-listed and sensitive species) sometimes prevented us from collecting all fish observed when densities were high.

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 × 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 easily and were recorded as unidentified salmonids. Nearly all (98.3%) of the 18.5 million hatchery Chinook salmon released into the Willamette River from 2001 to 2003 were finmarked (PSMFC 2007), so we assumed fish without missing fins were naturally propagated and are hereafter referred to as "unmarked." We measured (fork length in mm) a maximum of 30 juvenile Chinook salmon from each group (hatchery or unmarked) after each electrofishing run or beach seine set.

Radio Telemetry

Radio telemetry was intended to provide information on actively migrating juvenile Chinook salmon. We used telemetry data to calculate migration rates, describe the distribution of fish across the river channel, and explore possible habitat associations. We collected juvenile Chinook salmon each spring (2001–2003) for radio tagging. Fish 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.

We held fish for 16-48 hours following collection to allow for the evacuation of stomach contents, minimizing the risk of infection during tag placement. 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 regional office in Clackamas in large spring-fed tanks with continuous water circulation.

Radio tags were coded microprocessor transmitters (NTC-2-1 NanoTags®) manufactured by Lotek Engineering, Inc. We programmed all tags with a continuous 4 sec burst rate, and the minimum estimated battery life was 11 d. Tag size was 4.5 × 6.3 × 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 × 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; we attempted to collect and tag fish ≥16 g for NTC-2-1 tags, and ≥28 g for MCFT-3KM tags.

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

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 by boat, 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. We defined nearshore recoveries as those occurring within 10% of the measured channel width of either shore. 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 midpoint 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 8-10 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 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 recorded the general habitat types for all nearshore recoveries; categories included beach, riprap, rock outcrop, other natural rock, seawall, fill, and pilings (Table 1; modified from Greenworks P.C. et al. 2001). A ground survey was conducted in January 2001 to determine the proportional availability (by length) of each habitat type. We also recorded whether fish were recovered in areas outside of the main river channel (e.g. alcoves, lagoons, backwaters, and secondary channels). Nearshore habitat type and other data were recorded in the same manner as main-channel recoveries.

We also employed a variable number of fixed telemetry sites, consisting of a six-element yagi-style antenna attached to a fixed object (buildings or river channel markers), a receiver, and a power supply. The receiver was programmed to continuously monitor the tag frequencies and to record the

TABLE 1. Habitat type definitions used during radio telemetry of juvenile Chinook salmon in the lower Willamette River, 2001–2003. Habitat types were modified from Greenworks P.C. et al. (2001).

Habitat type	Description
Offshore	Open water offshore, arbitrarily defined as 11–89% of the river width.
Nearshore	The portion of the river within ≤10% of the measured river width of either bank.
Beach	A shallow, shelving shoreline consisting of sand, silt, or fine gravel up to 64-mm diameter. May also include native bank materials in their natural position (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 in diameter.
Seawall	Impervious vertical retaining walls, generally composed of concrete, timber, or sheet pile, that extend below the ordinary low water level. These habitats are uniformly deep and homogenous (e.g. building foundations, bulkheads).
Riprap	Continuous stone revetments placed to curtail erosion and prevent alterations to the main channel. Vegetative cover varies but may include canopy, understory, and ground cover that occupy a minimum of 20% of the bank below flood stage.
Fill	Areas that have been filled with miscellaneous unconsolidated materials (e.g. cement slabs). The surfaces of banks composed of fill have not been covered with engineered riprap or structures. Such banks generally contain debris of various types and may be unstable due to erosion.
Pilings	Stationary support structures consisting of concrete, metal, or timber used to elevate docks, buildings, or other structures above the water.

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 reduced the number of fixed telemetry sites used each year due to interference from automobile traffic and logistical concerns (e.g., increased security at channel markers maintained by the U.S. Coast Guard). We used eight fixed telemetry sites in 2001, located at rkm 1.1 (2 receivers), 4.8, 9.5 (2 receivers), 18.7 (two receivers), and 26.7. In 2002 we employed one receiver at rkm 9.5 and two at rkm 18.7. A new station was added during 2002 in Multnomah Channel (Figure 1), 2.4 rkm downstream from the head of the channel. This was the only site used in 2003.

Data Analysis

Density and Timing

To assess run timing, we calculated the relative density of juvenile Chinook salmon 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. We calculated monthly index values for fish captured by electrofishing and beach seining to provide information on relative density and temporal distribution. Separate indices were calculated for hatchery and unmarked fish.

Growth

Growth of juvenile salmonids implies active feeding and the existence of suitable rearing habitat. We used the Mann-Whitney test (a nonparametric equivalent of the T-test; Zar 1999) to compare fork length (FL) and weight of juvenile salmonids among sampling sites in the upstream and downstream portions of the study area. 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 at rkm 1.0 and 6.4 to upstream sites at rkm 26.9 and 39.1 (Figure 1). Electrofishing sites were at rkm 1.0, 1.6, and 1.9 (downstream) and at rkm 26.9, 32.2, and 35.2 (upstream). We conducted separate analyses of length and weight for fish captured during spring and winter, and for both seasons combined.

Radio Telemetry

Migration rates. We calculated migration rates (km/d) based on travel time from the initial release point to subsequent downstream relocation points. We established conservative assumptions to ensure we tracked only live, actively migrating fish: 1) fish that were pinpointed multiple times in the same location for >24 hours were presumed dead and not included in subsequent analyses; 2) fish that moved upstream with no subsequent downstream movement were not actively migrating, or may have been consumed by predators; 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 pinpoint), the data was not included in calculations of migration rate. We verified river kilometer estimates for relocations by plotting the GPS waypoints onto an Oregon Lambert-projected ortho-photo (0.6-m resolution) using ArcView 3.2a (Environmental Systems Research Institute, Inc. 2002).

Factors influencing migration. Because the release timing of radio-tagged fish varied annually, there was some potential for environmental conditions, primarily river flow, to affect telemetry results. To explore this factor, we calculated median, minimum, and maximum flow values (kcfs) using U.S. Geological Survey (USGS) river flow data collected at the Morrison Bridge gauging station (USGS 2004) for each period we tracked 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 similarly compared migration rates between upstream (rkm 22.6–42.6) and downstream (rkm 0.0–22.5) sections of the study area. Factors that could influence migration rates, including river flow, water temperature (°C), release day, and fish size (fork length) were assessed using simple linear regressions.

Habitat use. We used distributions of radio telemetry relocations across the river channel to determine if juvenile Chinook salmon were closely associated with nearshore areas, and 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, which could indicate selection or avoidance of specific habitats. Nearshore habitat was defined as the area within 10% of the measured channel width of either shoreline.

Prior to conducting any field work, we set our decision level for statistical analyses at P=0.05. We tested all data for assumptions of normality and constant variance to determine whether to use parametric or non-parametric procedures.

Results

From May 2000 to July 2003, we performed 982 electrofishing runs and 568 beach seine sets. Sampling occurred in all months except October 2000 and July, August, and October 2001. We collected 5,030 juvenile salmonids identifiable to species; 4,383 (87%) were Chinook salmon. Hatchery fish comprised about 54% of the total Chinook salmon catch, but there was a pronounced difference in the proportion of hatchery fish between gear types. The electrofishing catch consisted primarily (81%) of hatchery fish, while unmarked fish dominated (92%) the beach seine catch. We captured juvenile Chinook salmon in every month we sampled except May 2001, when we conducted limited beach seining and no 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 2). Few hatchery Chinook salmon were captured with beach seines, and were similar in size to those captured with electrofishing gear. Unmarked fish in beach seine catches were generally much smaller than those captured by electrofishing, and exhibited a

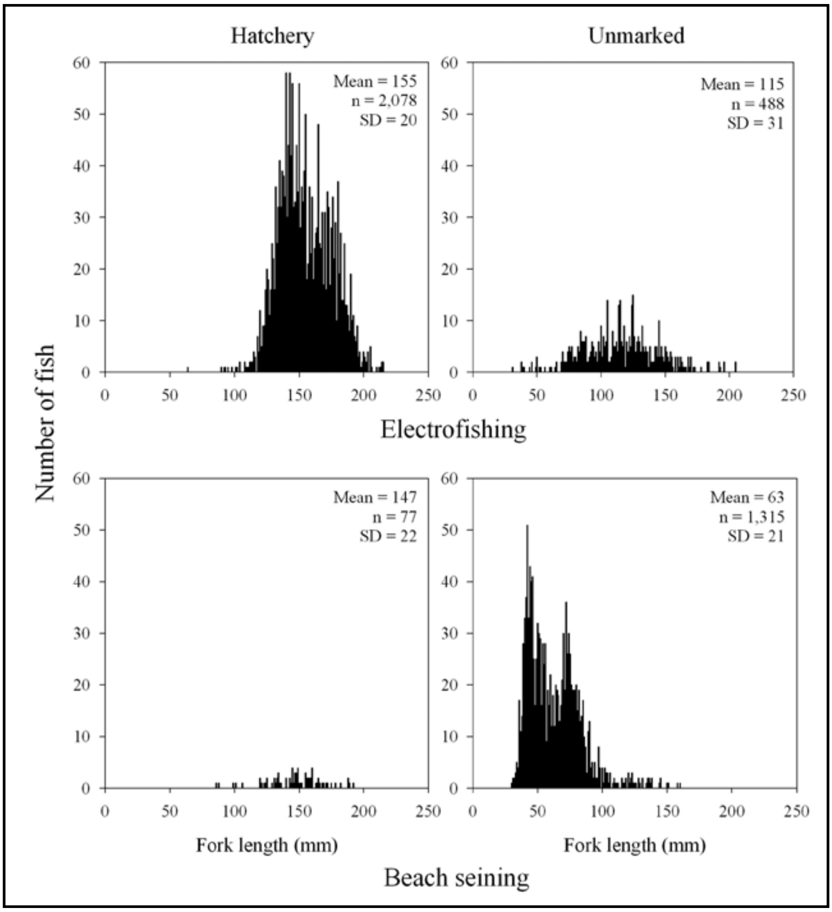

Figure 2. Fork length distributions for hatchery and unmarked juvenile Chinook salmon captured by electrofishing (top panels) and beach seining (lower panels) in the lower Willamette River, 2000-2003. SD=standard deviation.

bimodal length distribution, with peak numbers of fish occurring at about 45 and 75 mm FL.

Density and Timing

From May 2000 to July 2003, density index 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 3). 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.

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 3). Densities of unmarked fish increased sharply in February and declined to near zero in July. Densities of unmarked fish were also 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.

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 (Mann-Whitney test; all $P<0.01$; Figure 4). Differences were more

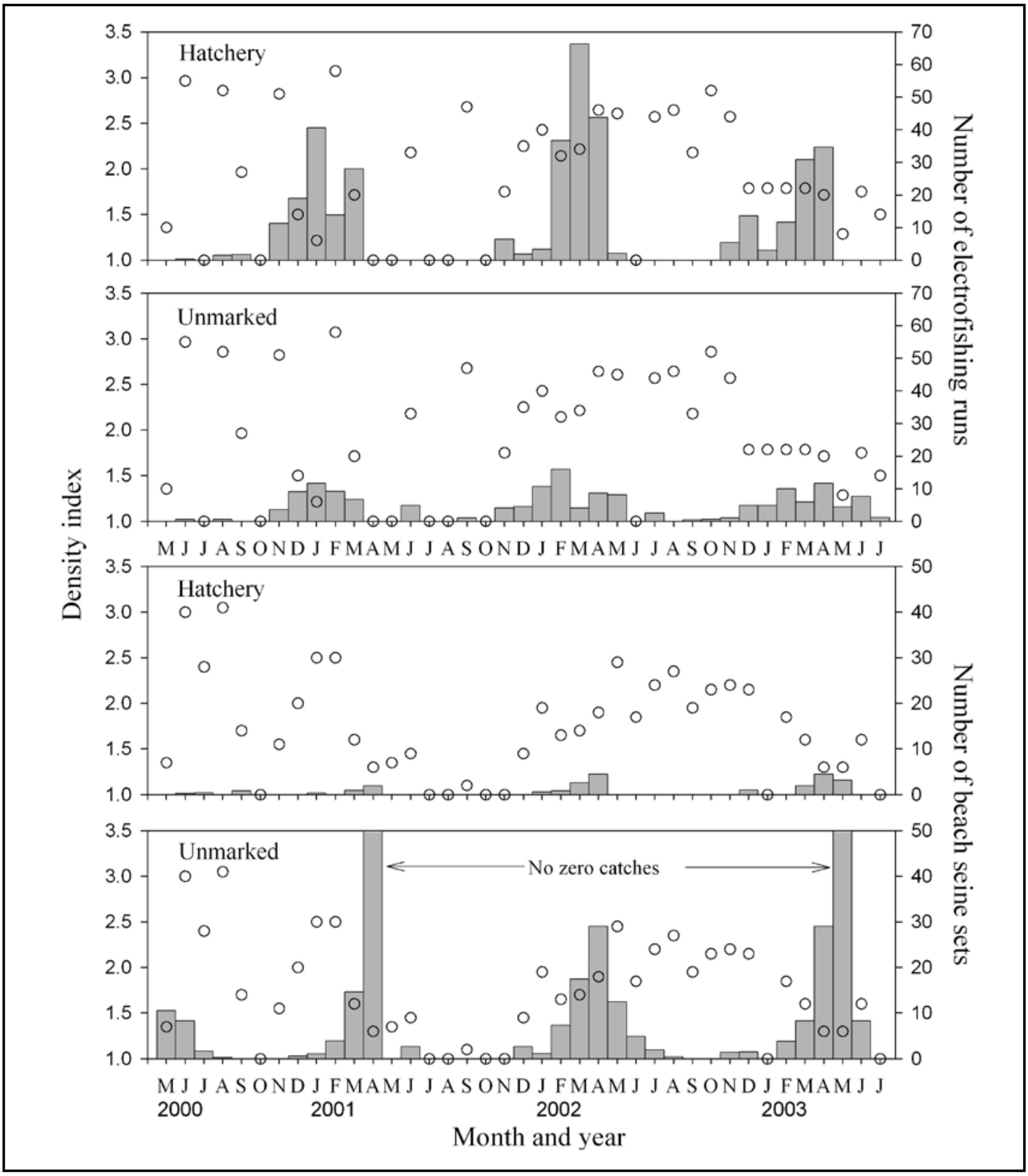

Figure 3. Monthly relative density for juvenile Chinook salmon (hatchery and unmarked) captured by electrofishing (top panels) and beach seining (lower panels) in the lower Willamette River, 2000–2003. Open circles indicate sampling effort (right axis).

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 than those captured at upstream sites (Mann-Whitney test; all $P<0.001$; Figure 4).

Length and weight differences for unmarked subyearling Chinook salmon among upper and lower sampling sites were less distinct (Figure 5). Median fork lengths were always greater

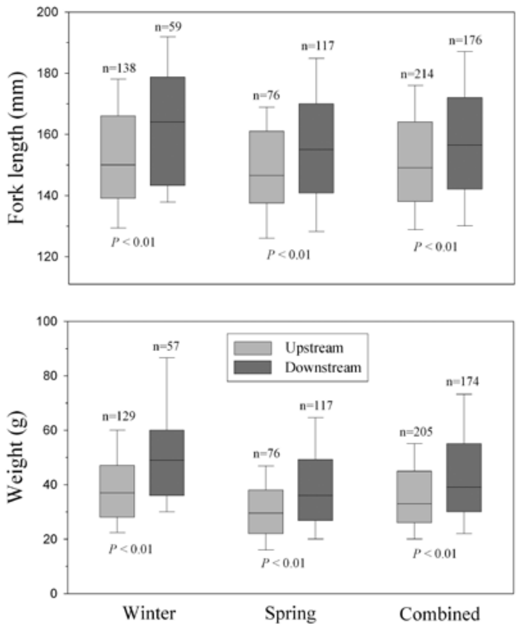

Figure 4. Seasonal fork length and weight of juvenile hatchery Chinook salmon captured by electrofishing at upstream (river kilometer 26.9, 32.2, and 35.2) and downstream (river kilometer 1.0, 1.6, and 1.9) sites in the lower Willamette River, 2000–2003. The horizontal line within each bar is the median, the ends of the bar are the 25th and 75th percentiles, and the error bars indicate 10th and 90th percentiles.

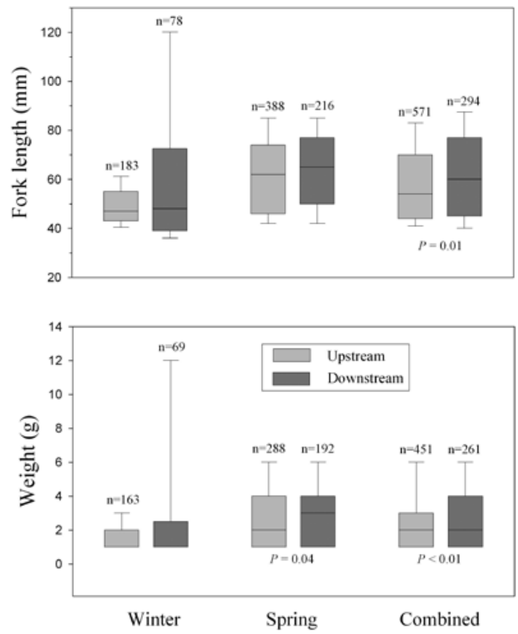

Figure 5. Seasonal fork length and weight of unmarked juvenile Chinook salmon captured by beach seining at upstream (river kilometer 26.9 and 39.1) and downstream (river kilometer 1.0 and 6.4) sites in the lower Willamette River, 2000–2003. The horizontal line within each bar is the median, the ends of the bar are the 25th and 75th percentiles, and the error bars indicate 10th and 90th percentiles.

TABLE 2. Summary of radio-tagged juvenile Chinook salmon released in the lower Willamette River, 2001–2003. H = hatchery; U = unmarked. Relocations include only those from fish assumed to be alive and actively migrating.

Year	Origin	Number released	Number recovered	Number of relocations	Fork length (mm)		Weight (g)	
					Range	Mean	Range	Mean
2001	U	14	13	61	108-125	115	13-19	15
	H	18	18	67	118-150	140	17-32	25
2002	U	14	12	36	112-166	125	15-51	22
	H	4	3	0	160-186	178	52-77	63
2003	U	13	13	38	123-156	141	16-33	27
	H	32	30	77	131-180	154	21-55	35
Total		95	89	279	108-186	141	13-77	28

(1–6 mm) at downstream sites but significantly different from upstream sites only where winter and spring data were combined (Mann-Whitney test; T=136313, P=0.01). Median weights were significantly greater at downstream sites during spring and for both seasons combined (Mann-Whitney test; all P<0.05), but were not significantly different during winter.

Radio Telemetry

From 2001 to 2003, we released 95 radio-tagged Chinook salmon, including 54 hatchery fish and 41 unmarked fish (Table 2). Hatchery fish were significantly larger than unmarked fish (Kruskal-Wallis ANOVA; H=33.76, df=1, P<0.001). Due to difficulties in obtaining fish that were heavy

TABLE 3. Boat tracking effort (hours) for radio-tagged juvenile Chinook salmon 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 included alcoves, backwaters, side channels, and other areas displaced from the primary river channel.

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

enough to radio tag, our tags occasionally composed up to 6.5% of the weight of the fish during 2001 and 2002. Tracking effort totaled 401 hours (Table 3). Nearshore (53%) and offshore (47%) efforts were similar, and 66% of tracking occurred during daylight hours. We logged 279 recoveries, and relocated 94% of the fish at least once (Table 2). Twelve fish were excluded from subsequent analyses because they were detected in the same location several times over a 24-hour period immediately after their release (we assumed death, predation, or tag loss). An additional 17 fish moved downstream for a period of time before being located in the same position multiple times over 24 hours; in these instances we used the data up to the point the fish stopped moving.

About 89% of the telemetry recoveries occurred in the main river channel. Among the 77 fish we assumed were alive and actively migrating at some point, 25 (32%) were detected at an off-channel site at least once. Individual fish using off-channel areas were relocated in Multnomah Channel (n=15), the east channel and lagoon at Ross Island (n=6), the Swan Island lagoon (n=3), and the alcove at Cedar Island (n=1) (Figure 1).

Multnomah Channel (rkm 5.0) terminates in the Columbia River, providing an alternative passage route for fish leaving the Willamette River. We relocated 21 radio-tagged fish in the mainstem Willamette River below rkm 5.0, and 15 in Multnomah Channel, suggesting that a relatively large proportion of downstream migrants continue to the Columbia River via this shortcut. The passage route of the 41 fish detected only above rkm 5.0 was not determined.

Migration Rates. Juvenile Chinook salmon migrated at a median rate of 11.3 km/d (Figure 6), and hatchery fish migrated significantly faster (12.4 km/d) than unmarked fish (8.4 km/d) (Mann-Whitney test; T=925, $P<0.001$). Migration rates also varied among years (Figure 7). The median migration rate was significantly faster in 2003 (15.7 km/d) than in 2002 (7.3 km/d) or 2001 (8.6 km/d) (Kruskal-Wallis ANOVA; H=27.04, df=2, $P<0.001$). The median migration rate for fish tracked in the upstream portion of the study area (11.7 km/d) was significantly faster than in the downstream portion (8.1 km/d; Kruskal-Wallis ANOVA; H=5.86, df=1, $P<0.05$).

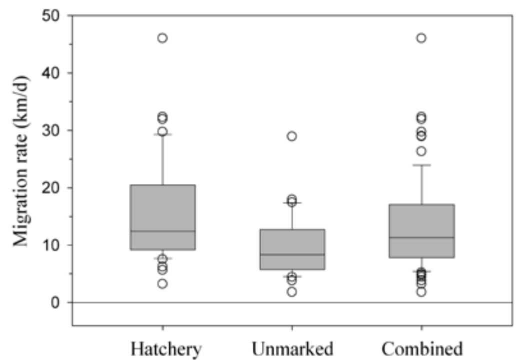

Figure 6. Migration rates for juvenile Chinook salmon >100 mm fork length in the lower Willamette River. The horizontal line within each bar is the median, the ends of the bar are the 25th and 75th percentiles, the error bars indicate 10th and 90th percentiles, and open circles denote outliers.

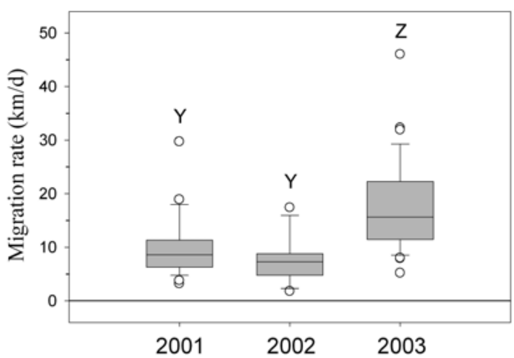

Figure 7. Migration rate by year for radio-tagged juvenile Chinook salmon in the lower Willamette River. The horizontal line within each bar is the median, the ends of the bar are the 25th and 75th percentiles, the error bars indicate 10th and 90th percentiles, and open circles denote outliers. Bars without a letter in common are significantly different ($P<0.05$).

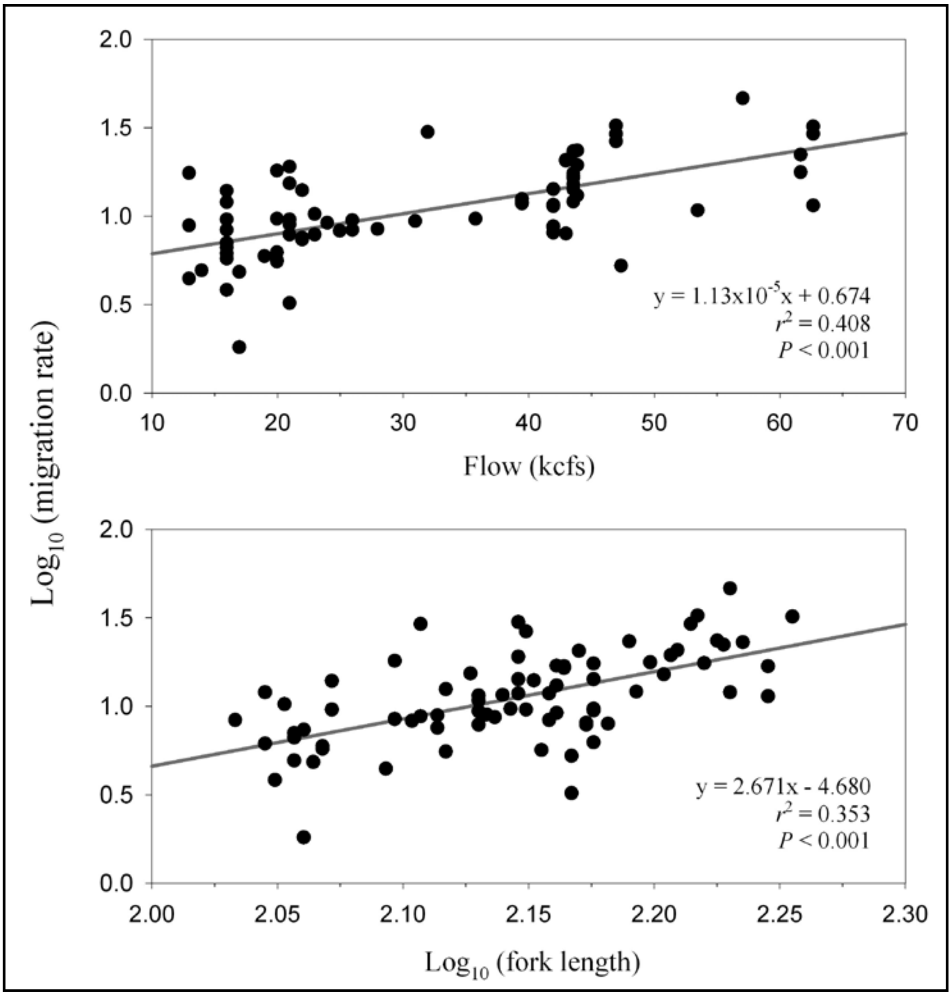

Figure 8. Linear regressions of migration rate (km/d) on river flow (on last recovery date) and fork length (mm) for radio-tagged juvenile Chinook salmon in the lower Willamette River.

Factors Influencing Migration Rate. River flow and the timing of radio telemetry efforts varied among years. 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. In 2001, median flow during the tracking period (25 April–13 June) was 20 kcfs (range 13-34). Median flow during the 2002 tracking period (1 June–27 June) was 17 kcfs (range 12–25) kcfs, and was 33 kcfs (range 18-63) during 2003 (14 April–23 May). All pairwise comparisons differed significantly (Kruskal-Wallis ANOVA; H=51.72, df=2, P<0.001).

Simple linear regressions identified several variables that helped explain variation in the migration rates of juvenile Chinook salmon. Assumptions of normality and constant variance in the regressions were met when we log-transformed migration rate and fork length; river flow was not transformed. Migration rate increased linearly with both flow (r^2=0.408) and fork length (r^2=0.353) (Figure 8). Independently, release date and water temperature were linearly related to migration rate, but were strong covariates of flow (Spearman r = -0.893 and -0.697; all P=0.00).

Habitat Use. The majority (76.3%) of Chinook salmon radio telemetry relocations occurred

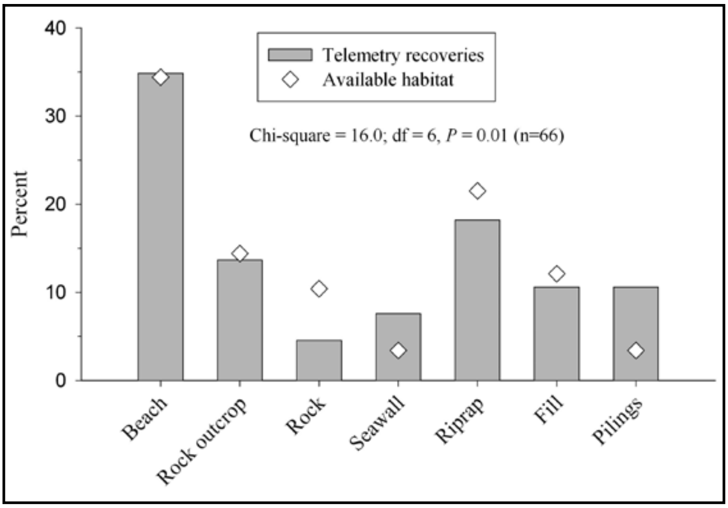

Figure 9. Proportional distribution of radio telemetry recoveries for juvenile Chinook salmon among nearshore habitat types in the lower Willamette River.

offshore (>10% of the measured channel width), and nearshore relocations varied significantly with the relative availability of habitat types (chi-square=16.0, df=6, *P*=0.01; Figure 9). Radio-tagged fish were recovered at lower-than-expected rates (based on the proportional distribution of habitat types) at rock and riprap habitats and at a higher-than-expected rate near pilings.

Relocation frequencies of radio-tagged juvenile Chinook salmon across the river channel indicated they were distributed relatively evenly from the west bank to the east bank (Figure 10), except in 2003, when relocations tended to occur more frequently towards the east bank (chi-square=30.7, df=9, *P*<0.005). Day and night channel distributions were similar (Figure 11). We detected no significant differences in channel distribution patterns between hatchery and unmarked fish (Figure 11); relocations of both groups were evenly distributed across the river channel.

Discussion

We concluded the juvenile Chinook salmon we collected were largely spring-run stocks, as fall Chinook salmon are not indigenous to the upper Willamette River basin and wild fall Chinook salmon 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 2005, 964 adult fall Chinook salmon were counted, compared to 35,453 adult spring-run fish (ODFW 2005). Some production of fall Chinook salmon occurs in the upper watershed; Schroeder et al. (2003) estimated 6% of sub-yearling 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

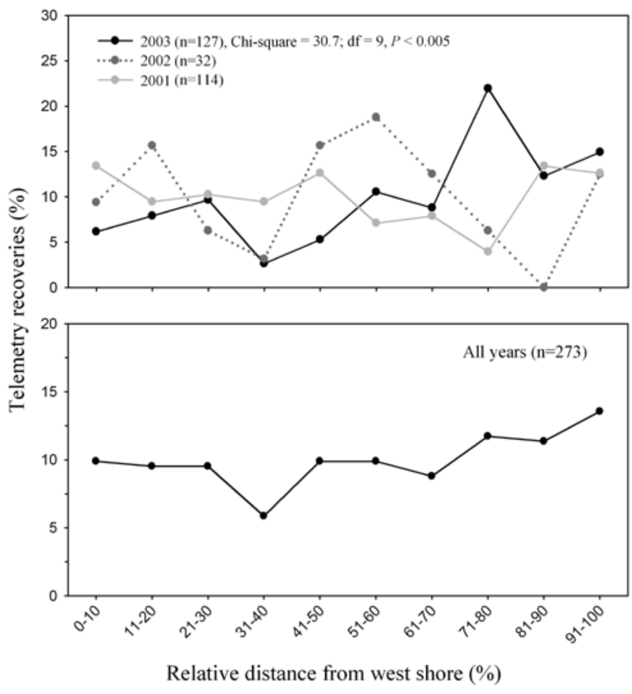

Figure 10. River channel distribution of radio-tagged Chinook salmon in the lower Willamette River, 2001–2003. West bank of river = 0%; east bank of river = 100% (X axis). Chi-square statistics are included where expected n ≥ 5 for each category.

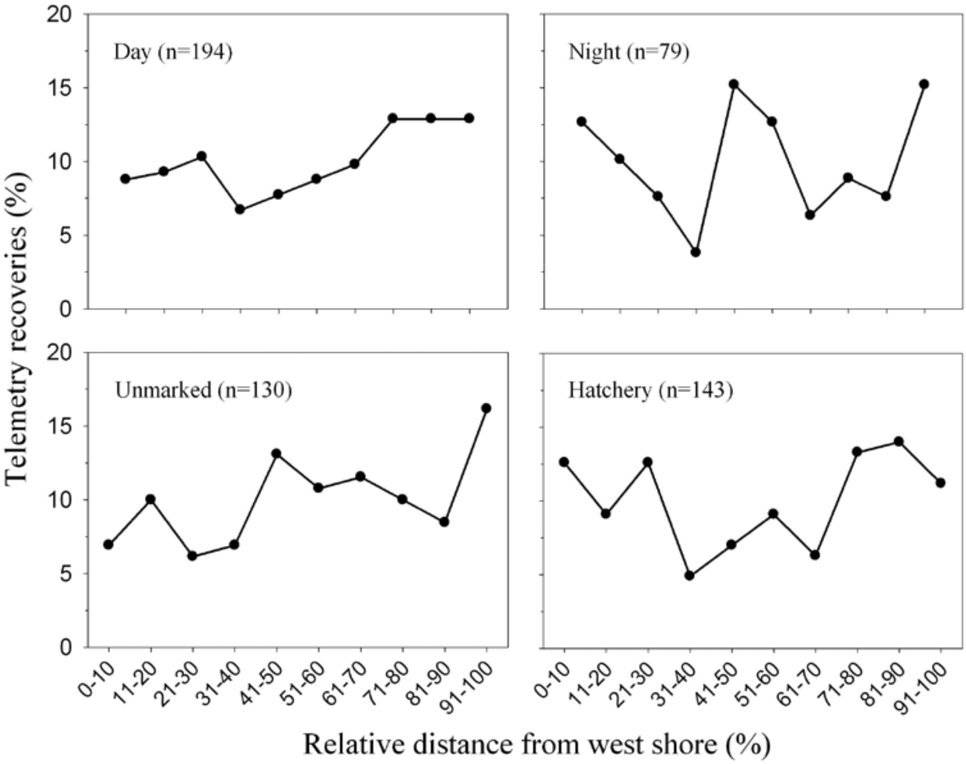

Figure 11. River channel distributions for radio-tagged Chinook salmon recovered during night and day (upper panels) and for unmarked and hatchery fish (lower panels) in the lower Willamette River, 2001–2003. West bank of river = 0%; east bank of river = 100% (X axis).

prevalent in beach seine catches. We acknowledge that gear selectivity and our sampling scheme likely contributed to this pattern. Electrofishing typically selects for larger individuals of a species (Reynolds and Simpson 1978; Reynolds 1996), and we frequently could not conduct boat electrofishing in the shallowest water, where seine catches indicated smaller fish were abundant. Large juvenile Chinook salmon were likely able to avoid our beach seines more effectively than smaller fish. Finally, diurnal patterns may have biased some of the catch data; seining occurred during daytime hours, where electrofishing was performed primarily at night (though radio telemetry results showed no difference in the distribution of juvenile Chinook salmon >100 mm FL between day and night).

We were concerned about handling stress and incidental mortality, so we did not attempt to collect scales or other structures for aging. 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 analyze length-at-age and address the origin and race of these fish.

Timing

The outmigration period for Chinook salmon, both hatchery and unmarked, was surprisingly long. The presence of fish often increased in late autumn and persisted into the next summer. Juvenile Chinook salmon were present during every season and 34 of 35 months we sampled. 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.

The nearly constant presence of juvenile Chinook salmon may have implications for activities such as dredging, bank stabilization, and construction in the lower Willamette River. 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. Adverse impacts of in-water work can include any modification (physical, chemical, or biological) that reduces the quality or quantity of essential fish habitat (NOAA 2004). The existing work period for the lower Willamette River and Multnomah Channel is 1 July–31 October and 1 December–31 January (ODFW 2000). Our findings indicated juvenile Chinook salmon (including a large number of unmarked fish) were present during December and January, often at high densities. Restricting in-water work in the lower Willamette River to July through October will help minimize risks to listed stocks of Chinook salmon.

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 11.3 km/d, so their travel time between the upper and lower sites was about 2.6 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 travel time would result in observed growth of 2.0-2.7 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 slow as 1.8 km/d, and the median migration rate was significantly slower below rkm 22.6. 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 greater at downstream sites, again suggesting growth occurs. We observed increases in fork length from one to six mm. 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 radio tag 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 comparison. Future studies in the lower Willamette River addressing migration rates of age-0 fish would be helpful to assess risks associated with their exposure to predation, toxins, and degraded habitat.

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 Willamette River appears to be minimal (Buchanan 1981; FES 2001; Pribyl et al. 2004), and we observed no other 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) 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 migrate 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 conclude that juvenile salmonids 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 Rate

The migration rates we calculated 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, where we estimated a median rate of 11.3 km/d from 2001–2003.

In general, spring migration rates for juvenile Chinook salmon were faster (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 slower (4.1 km/d) in the Columbia River below rkm 75.0 (Fisher and Pearcy 1995). Dawley et al. (1986) observed that tagged coho salmon (*O. kisutch*) in the Columbia River traveled faster when they were released farther upstream. We observed a similar pattern in the lower Willamette River; radio-tagged Chinook salmon traveled faster in the upstream portion of the study area. 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.

The implications of migration rates are uncertain. Delayed migration due to hydropower development, 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 fish spend less time exposed to degraded or suboptimal habitat, predation by introduced species, 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 currently 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 (Buchanan et al. 1981; FES 2001; Pribyl et al. 2004) suggest the lower Willamette River has value as rearing habitat. If this is the case, the importance of rapid migration rates may be negligible. The 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

Our study corroborates other evidence indicating river flow and outmigration 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 (*O. nerka*), hatchery steelhead (*O. mykiss*), and wild steelhead.

We also observed a relatively strong positive linear relationship between fork length and migration rate. 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 juvenile Chinook salmon (r^2=0.59). Hatchery Chinook salmon in our study migrated significantly faster than unmarked fish. This was likely 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.

Habitat Use

Telemetry data indicated large, actively migrating Chinook salmon were not highly associated with nearshore areas; they were distributed evenly across the river channel regardless of year (except in 2003), time of day (day or night), or origin (hatchery or unmarked). 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, and smaller fish (age-0 Chinook salmon) were most abundant near shore.

Radio-tagged Chinook salmon located near shore were distributed unevenly with respect to the availability of different habitat types. However, these fish did not show clear selection for, or avoidance of, particular habitat types. Except for a possible affinity for pilings, associations with specific habitats were weak, and the distribution of telemetry recoveries appeared to closely follow the proportional availability of habitat types. In addition, because a relatively small proportion (about 24%) of the radio-tagged Chinook salmon were relocated near shore, we concluded the influence of shoreline habitat on large (>100 mm FL), actively migrating fish was minimal.

Much of the original off-channel habitat (alcoves, lagoons, backwaters, and secondary channels) has been eliminated from the Willamette River (Schreck et al. 1994). In our study, the remaining off-channel areas were used by migrating yearling salmonids, and a considerable proportion of our radio-tagged fish entered the Multnomah Channel. These areas should be considered when planning future development or habitat improvement activities near Portland.

An 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 subyearling Chinook salmon. This is supported by numerous studies which are 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, Johnsen 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. Very little is known about the origin and race, habitat use, migration rate, diet, and survival of age-0 Chinook salmon in the lower Willamette River, and we strongly recommend additional studies focus on these topics. Our observations indicated subyearling Chinook salmon were abundant and used beach habitats extensively, but we focused largely on yearling fish 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, appear to be associated with a specific habitat type.

We found little evidence to suggest that nearshore habitat as it currently exists is a critical factor affecting larger (>100 mm FL), actively migrating juvenile Chinook salmon. However, the effects of development are incompletely explored, especially with respect to subyearling fish. Anecdotally, the lower Willamette River has been described as a simple "migration corridor," implying that it has little value as rearing habitat. While large juvenile Chinook salmon do appear to pass relatively quickly through this area, they feed (Vile et al. 2004), exhibit changes in size, and utilize a variety of habitats. Unaltered nearshore habitats (beaches) appear to be important to smaller fish. Additional habitat modifications are highly likely, as Oregon's population is expected to increase by about 1.8 million people in the next 35 years (Oregon Department of Administrative Services 2004). Considering the historic reductions in natural habitat and the threatened status of wild Chinook salmon stocks in the lower Willamette River, future development should be planned carefully to avoid further detrimental impacts and encourage recovery.

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