Behavior of Juvenile Salmonids Migrating Through the Willamette River Near Portland, Oregon

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INTRODUCTION

The Willamette River supports several species of anadromous salmonids, including spring and fall races of chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, and summer and winter races of steelhead *O. mykiss*. Willamette River spring chinook salmon make a significant contribution to recreational and commercial fisheries. In 1989, Willamette River adult spring chinook salmon contributed 10,900 fish to the lower Columbia River commercial catch, and 29,100 fish to sport catch in the Columbia and Willamette rivers (Bennett 1989). A total of 69,200 Willamette River spring chinook salmon returned over Willamette Falls (river mile 26) in 1989. Hatchery releases of spring (yearling) chinook salmon into the Willamette River system have steadily increased since 1977, with 5.1 million released in 1989. Hatchery releases of other anadromous salmonids into the Willamette River system during 1988 included 5.1 million fall (subyearling) chinook salmon, 1.1 million coho salmon, 700,000 summer steelhead, and 400,000 winter steelhead.

Limited information exists on migratory behavior of juvenile salmonids in the Willamette River. Bradford and Shreck (1990) reported on migratory characteristics of yearling chinook salmon in the Willamette River between river mile (RM) 26 and RM 200, but information on migration through the lower river downstream from Willamette Falls has yet to be reported. Some factors thought to affect migratory behavior of anadromous juvenile salmonids include flow, time-of-day, turbidity, water velocity, and fish size. Increased river flow has been correlated with peaks in juvenile salmon migration (French and Wahle 1959; Mains and Smith 1964; Becker 1970); however, it is not certain whether increased flows flush juveniles downstream or cause them to actively migrate (Diamond and Pribble 1978). Becker (1973) showed streamflow to be important to the survival of juvenile salmon, especially with respect to food availability. Although fish have been reported moving primarily at night (French and Wahle 1959; McDonald 1960; Mains and Smith 1964; Krcma and Raleigh 1970), the need to migrate at night may be reduced in rivers exhibiting high turbidity (Meehand and Siniff 1962). Lister and Genoe (1970) found that with increased size, juvenile salmon moved into habitat of progressively higher water velocity. Bradford and Shreck (1990) found that migration rate of radiotagged yearling chinook salmon released in the upper Willamette River decreased significantly as fish moved downstream. They also noted that fish that originally traveled in discrete groups began to exhibit greater variability in movement patterns as they approached the lower river.

The purpose of this report is to describe the behavior of juvenile salmonids, primarily chinook salmon and steelhead, migrating through the Portland Harbor section of the Willamette River. We emphasize identifying factors that affect migration rate and distribution, and on determining the importance of an alternate migration route, Multnomah Channel, for juvenile salmonids. We used data collected during a 4-year cooperative effort between the Oregon Department of Fish and Wildlife and the Port of Portland to evaluate the effects of waterway development in Portland Harbor on anadromous and resident fish (Ward et al. 1988; Ward and Farr 1989). Knowledge of spatial and temporal distribution of migrating juvenile salmonids will assist in determining if waterway development has an impact on juvenile salmon and steelhead migrating through Portland Harbor.

STUDY AREA

Portland Harbor includes the Willamette River from river mile (RM) 0 to RM 12. Our study area included the harbor and extended upstream to RM 16.8 (Figure 1). We also sampled in Multnomah Channel, which flows from the Willamette River at RM 3 to the Columbia River at RM 87. Physical characteristics of shoreline and nearshore habitat throughout the Willamette River downstream of RM 16.8 do not vary much except when altered by structures. Shorelines associated with structures are often steeply placed riprap, or in some cases a vertical wall. In the harbor the river has mostly a clay, silt, or sand bottom that is steeply sloped because of dredging. The Willamette River in Portland Harbor is approximately 1,000 to 2,000 ft wide. River flow from 1987 to 1989 averaged between 24,190 and 29,080 cfs with a high over 170,000 cfs during January 1988 and a low of 6,980 cfs during August 1988.

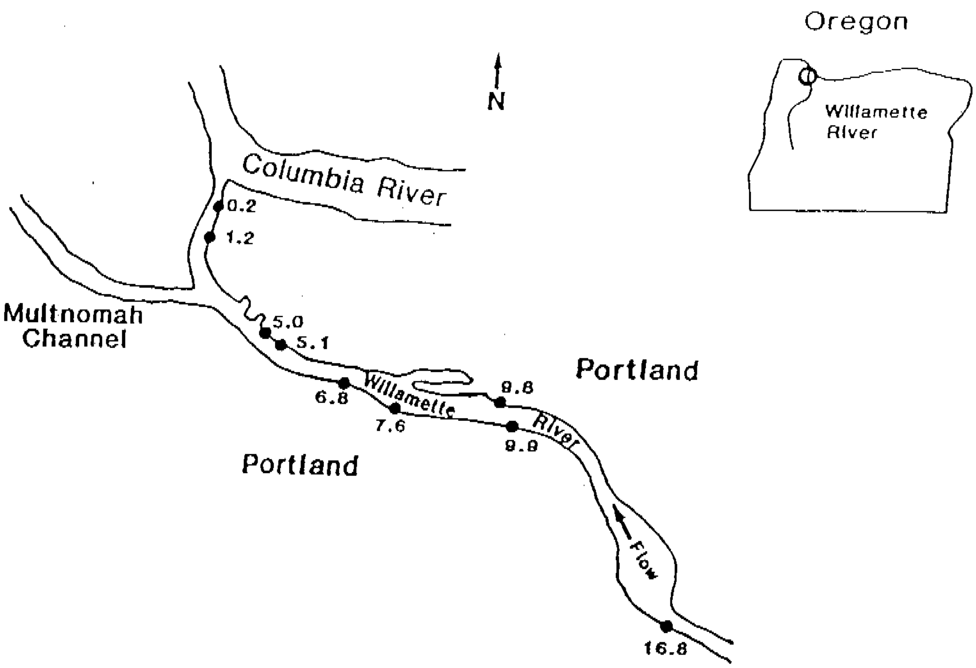

Figure 1. Locations of sampling areas (designated by river mile) in the lower Willamette River.

METHODS

Field Sampling

From 1987 through 1990 we used beach seines, purse seines, vertical gillnets, and an electrofishing boat to collect juvenile salmonids at sampling sites in the lower Willamette River (Figure 1; Table 1). We also used radiotelemetry to monitor the migratory behavior of yearling chinook salmon and juvenile steelhead. Sampling methods and gear specifications were described by Ward et al. (1988), Ward and Farr (1989), and Ward and Knutsen (1991). We concentrated sampling during times of expected peak migration of juvenile salmonids (March-June and November).

Table 1. Description of sampling sites in the lower Willamette River.

Sampling area (river mile)	Structure, support	Shoreline
0.2	None	Sandy beach
1.2	Offshore wharf, pilings	Sandy beach
5.0	Wharf, landfill	Vertical wall
5.1	Floating platform	Riprap, sandy beach
6.8	None	Riprap, sandy beach
7.6	Pier, Pilings	Clay beach
9.8	None	Riprap, sandy beach
9.9	Wharf, Pilings	Riprap
16.8	None	Sandy beach

During 1987 and 1988 we collected fish with a purse-seine and electrofishing boat to determine time of occurrence and relative abundance of juvenile salmonids in Portland Harbor. During 1987 we purse-seined from mid-March to mid-June, and electrofished during January, February, April, and July. During 1988 we purse-seined during March, May, and June and electrofished from March through June. We identified catches to species, counted them, and measured fork length (nearest millimeter).

During 1988, 1989, and 1990 we used radio telemetry to monitor migratory behavior of juvenile salmonids in our study area. In 1988 we monitored movements of 13 yearling chinook salmon during March and April, and 6 yearling chinook salmon during October and November. In 1989 we monitored movements of 14 yearling chinook salmon and 4 juvenile steelhead from March through May, and 5 yearling chinook salmon in November. In 1990 we monitored movements of 19 yearling chinook salmon during March, and 11 juvenile steelhead during May. We released all radiotagged fish at RM 14, except the March and April 1988 group that we released at RM 20. We usually released 2-7 fish at a time; however, in 1990 we released all 11 juvenile steelhead at once. We tracked radiotagged fish from a boat.

We used vertical gillnets from March through June of 1989 and 1990 to examine vertical distribution of juvenile salmonids. We identified catches to species and counted them. We measured fork length (nearest millimeter) of all juvenile salmonids and recorded the 10-ft depth interval in which they were captured (capture depth). Immediately after pulling a vertical gillnet and recording catch information we measured current velocity (feet per second) in each 10-ft depth interval, depth of water (feet), and the distance to shore (feet) from the nearshore edge of the net.

We conducted a mark-and-recapture study in November of 1987 and of 1988 to estimate survival rate and describe behavior of yearling chinook salmon migrating through Portland Harbor. In 1987 we used cold-brands to mark 12 groups of juvenile chinook salmon that contained approximately 10,000 fish each. In 1988 we cold-branded nine distinguishable groups of juvenile chinook salmon that contained approximately 9,500 fish each. We released marked fish into the Willamette River upstream from and within Portland Harbor, and used gillnets, beach seines, purse seines, and the electrofishing boat to recover them at predetermined sites in the harbor. We identified catches to species, examined fish for marks, counted them, and measured fork length (nearest millimeter).

Data Analysis

Occurrence and Abundance

We summarized purse-seine and electrofishing catches to determine time of occurrence and relative abundance of juvenile salmon and steelhead in Portland Harbor. To evaluate differences in time of occurrence between yearling and subyearling chinook salmon we prepared length-frequency histograms for catches of juvenile chinook salmon during March, April, May, and June of 1987 and March, May, and June of 1988.

Migration Rate

We used radio telemetry data to calculate the migration rate (river miles traveled per 24 hours) of radiotagged yearling chinook salmon and juvenile steelhead in Portland Harbor. For each radiotagged fish we calculated the migration rate for each day the fish was located. We pooled daily migration rates of individual fish to determine mean migration rate in the harbor for each species. We used least-squares linear regression analysis (SAS Institute, Inc. 1987) to determine the relationship between daily migration rate and river flow for yearling chinook salmon. We were unable to determine the relationship between daily migration rate and flow for steelhead in 1989 and 1990 because we released all fish at the same time and they all migrated through the study area within a few days.

We used analysis of covariance (SAS Institute, Inc. 1987) to test for significant differences ($P \le 0.05$) between night and day in migration rate of yearling chinook salmon. We pooled data from all three years and used river flow as the covariate to adjust differences in migration rate between night and day for differences in river flow (Sokal and Rohlf 1981). We calculated migration rate (river miles traveled per 24 hours) for each fish whenever more than one observation was made during a day or night period. If a fish did not move downstream or if it moved upstream, we estimated migration rate for that period to be zero.

Distribution

We used radio telemetry data to plot locations of radiotagged yearling chinook salmon and juvenile steelhead on a grid system overlaid on a map of the lower Willamette River. Each side of a grid square represented approximately 600 ft. We designated grid squares as nearshore if any part of the square contacted the shore; otherwise, we designated them as offshore. We totaled the number of nearshore and offshore locations of both species in Portland Harbor with the limitation that each length of stay by a fish in one grid square counted as only one location. We then used a test of significance of binomial proportions (Snedecor and Cochran 1967) to determine if the proportion of nearshore locations for each species differed significantly ($P \leq 0.05$) from the proportion of nearshore river surface area.

We used stepwise discriminant analysis (SAS Institute, Inc. 1987) to compare values of variables (distance from shore, water depth, capture depth, and current velocity) associated with catches (including no catch) of yearling and subyearling chinook salmon, coho salmon, and steelhead in our vertical gillnets. We identified variables that differed significantly ($P \leq 0.05$).

To determine if the habitat used by migrating juvenile salmonids before they encounter Portland Harbor is used by or is available to them within the harbor, we subjectively compared values of variables (distance from shore, water depth, capture depth, and current velocity) associated with catches at RM 16.8 to those associated with catches at developed sites within Portland Harbor (see Table 1, page 3). Because catch of yearling chinook salmon was low during 1990, we used data from 1989 for comparisons; because catch of subyearling chinook salmon was low during 1989, we used data from 1990 for comparisons.

We used chi-square analysis (SAS Institute, Inc. 1987) to determine if yearling and subyearling chinook salmon caught in vertical gillnets occupied similar depth ranges. We separated catch from each year into three depth intervals (<10 ft, 10-19.9 ft, and ≥20 ft).

We used two-way analysis of variance (SAS Institute, Inc. 1987) to test for significant differences ($P \leq 0.05$) in mean catch of yearling and subyearling chinook salmon among depth intervals and current velocities. Catch (X) was transformed to $\log_{10}(X + 1)$ before analysis. We pooled data from 1989 and 1990, and categorized current velocity as slow (<0.40 ft per second), medium (0.40-0.79 ft per second), or fast (≥0.80 ft per second). We separated depth intervals similar to those above. We then used Tukey's studentized range test (SAS Institute, Inc. 1987) to perform pairwise comparisons of mean catch among depth intervals and current velocities.

Migration Routes

We used radio telemetry data from 1988 through 1990 and mark-and-recapture data from 1987 and 1988 to subjectively compare the percentage of juvenile chinook salmon and steelhead that migrated through Multnomah Channel to the percentage that migrated out the mouth of the Willamette River. We adjusted mark-and-recapture data to account for differences in effort among sampling locations.

RESULTS

Occurrence and Abundance

Time of occurrence and abundance in the lower Willamette River varied among species and races of juvenile salmonids. Purse-seine catches from 1987 and 1988 indicated that abundance of yearling chinook salmon peaked in mid to late March, soon after releases from upstream hatcheries (Figure 2).

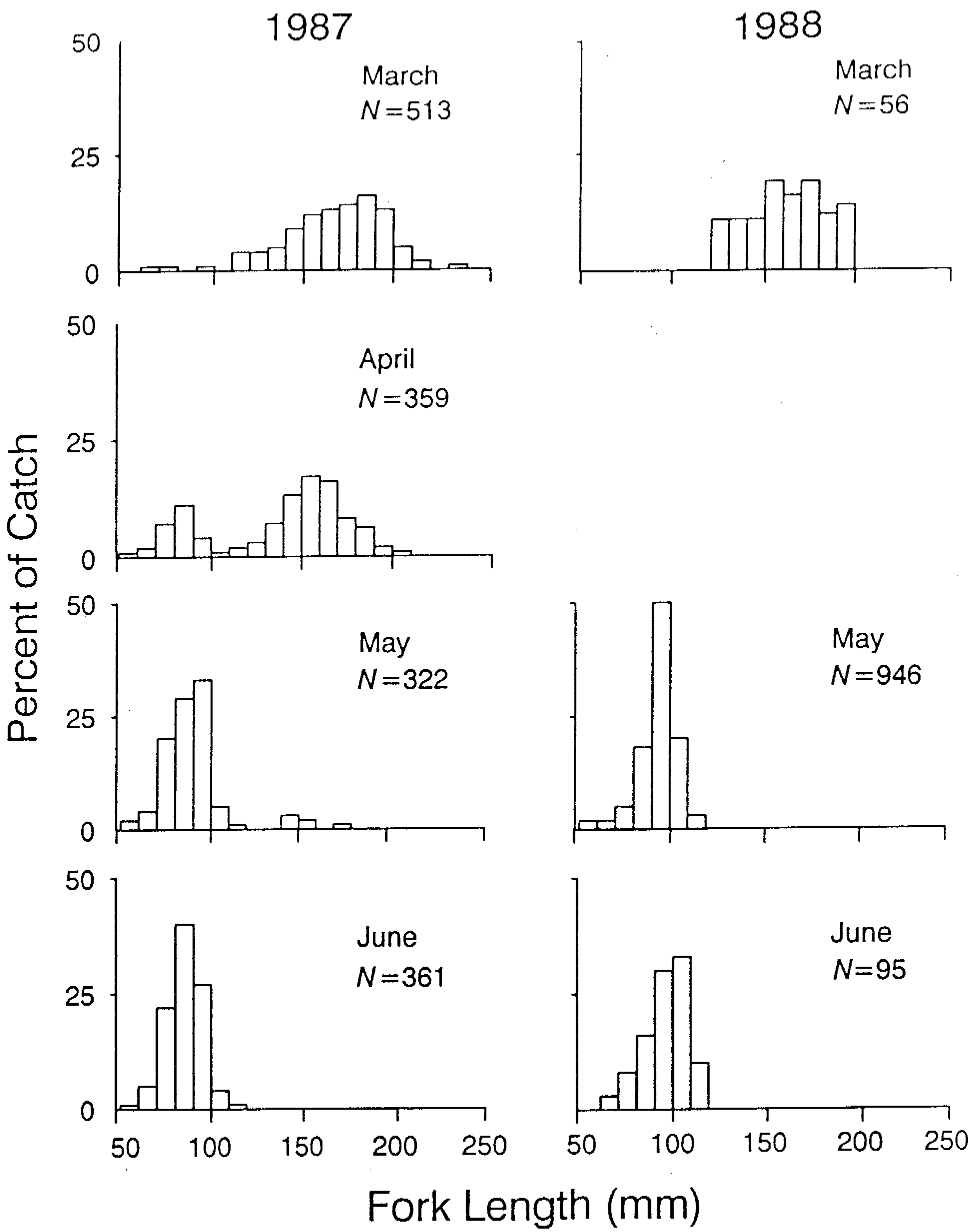

Figure 2. Grouped length-frequency distributions of juvenile chinook salmon caught by purse-seining (1987) and electrofishing (1988) each month in the lower Willamette River. No electrofishing was conducted during April 1988.

Subyearling chinook salmon appeared in the catch by late April, peaked by mid-May, and remained in decreasing numbers through June (Figure 2). Juvenile coho salmon and steelhead also began to appear in the catch during late April; coho salmon remained in the catch through May and steelhead remained through June. We collected few juvenile salmonids from July through October. However, hatchery release schedules in recent years have varied, and have included releases of yearling chinook salmon into the Willamette River during August and September. Yearling chinook salmon are also released into the Willamette River in early November each year. We collected moderate numbers of fish in the harbor throughout November.

We caught yearling chinook salmon as large as 239 mm and subyearling chinook salmon as small as 42 mm. Juvenile coho salmon ranged in size from 106 to 193 mm and averaged 140 mm. Juvenile steelhead ranged in size from 136 to 273 mm and averaged 200 mm.

Electrofishing catches from 1987 indicated that some juvenile salmonids may over-winter in the lower Willamette River. We collected a small number of yearling and subyearling chinook salmon during January and February, approximately three months after the most recent hatchery release.

Migration Rate

Migration rates of radiotagged yearling chinook salmon and juvenile steelhead in Portland Harbor varied among individual fish (Table 2). Juvenile steelhead appeared to migrate faster than yearling chinook salmon. Migration rate of yearling chinook salmon was not related to river flow in 1988 ($r^2 = 0.16$, $P = 0.22$), 1989 ($r^2 = 0.03$, $P = 0.48$), or 1990 ($r^2 = 0.11$, $P = 0.12$).

Yearling chinook salmon migrating through Portland Harbor appeared to move as often during the day as at night, and we did not find a significant difference ($P = 0.83$) between day and night migration rates. The average day-time migration rate was 6.10 river miles per 24 hours, and the average migration rate at night was 5.29 river miles per 24 hours. River flow did not vary significantly ($P = 0.68$) between day and night periods.

Distribution

We could not detect any pattern to the downstream migration of radiotagged yearling chinook salmon or juvenile steelhead. We located yearling chinook salmon in numerous grid squares, and we found five or more fish in only 10 grid squares (Figure 3). We found no significant difference between the proportion of nearshore locations of radiotagged yearling chinook salmon and the proportion of nearshore river surface area in Portland Harbor (Table 3). Although we found a lower proportion of radiotagged juvenile steelhead nearshore, the difference between proportions was not significant (Table 3). We found three or more juvenile steelhead in only six grid squares, of which two were nearshore and four offshore (Figure 4).

Variables that characterized habitat occupied by juvenile salmonids appeared to vary temporally and among species. Capture depth and current

Table 2. Migration rate (river miles per 24 hours) of radiotagged yearling chinook salmon and juvenile steelhead in Portland Harbor.

Year, Species	Number of fish	Days sampled	Migration Rate		
			Mean	Median	Range
1988:					
Chinook salmon:					
Spring	8	8	7.0	6.7	2.1-12.6
Autumn	4	6	1.5	0.0	0.0-8.5
1989:					
Chinook salmon:					
Spring	9	20	7.0	5.4	0.0-26.0
Autumn	3	6	7.3	7.0	5.8-8.9
Steelhead	4	5	7.9	11.1	1.6-12.0
1990:					
Chinook salmon	13	23	5.9	6.1	0.3-13.2
Steelhead	8	12	9.9	10.3	0.5-19.6

Table 3. Proportions of nearshore locations of radiotagged yearling chinook salmon (1988-90) and juvenile steelhead (1989-90) compared with proportion of nearshore river surface area in Portland Harbor. *P* = significance level of difference between proportions.

Species	*N* (fish locations)	Proportion nearshore		*P*
		Surface area	Fish locations	
Chinook salmon	364	0.46	0.46	0.88
Steelhead	136	0.46	0.34	0.21

velocity were the only variables significant in characterizing habitat occupied by yearling chinook salmon during March and April of 1989 (Tables 4 and 5). We usually collected yearling chinook salmon near the surface and in areas with relatively low current velocity. We collected no other juvenile salmonids during March and April of 1989. During May and June 1989, velocity throughout the lower Willamette River was low enough to have little effect on behavior of juvenile salmonids. Water depth was the only variable that differed ($P \leq 0.05$) among habitats occupied by juvenile salmonids (Table 4).

During April 1990, distance from shore, water depth, and capture depth were variables significant ($P \leq 0.05$) in characterizing habitat occupied by migrating juvenile salmonids and habitat in which no fish were collected (Tables 4 and 5). We found juvenile steelhead further from shore yet in shallower water than yearling chinook salmon. Both species were usually found near the surface. During May 1990, water depth, capture depth, and current velocity differed ($P \leq 0.05$) among habitats occupied by migrating juvenile

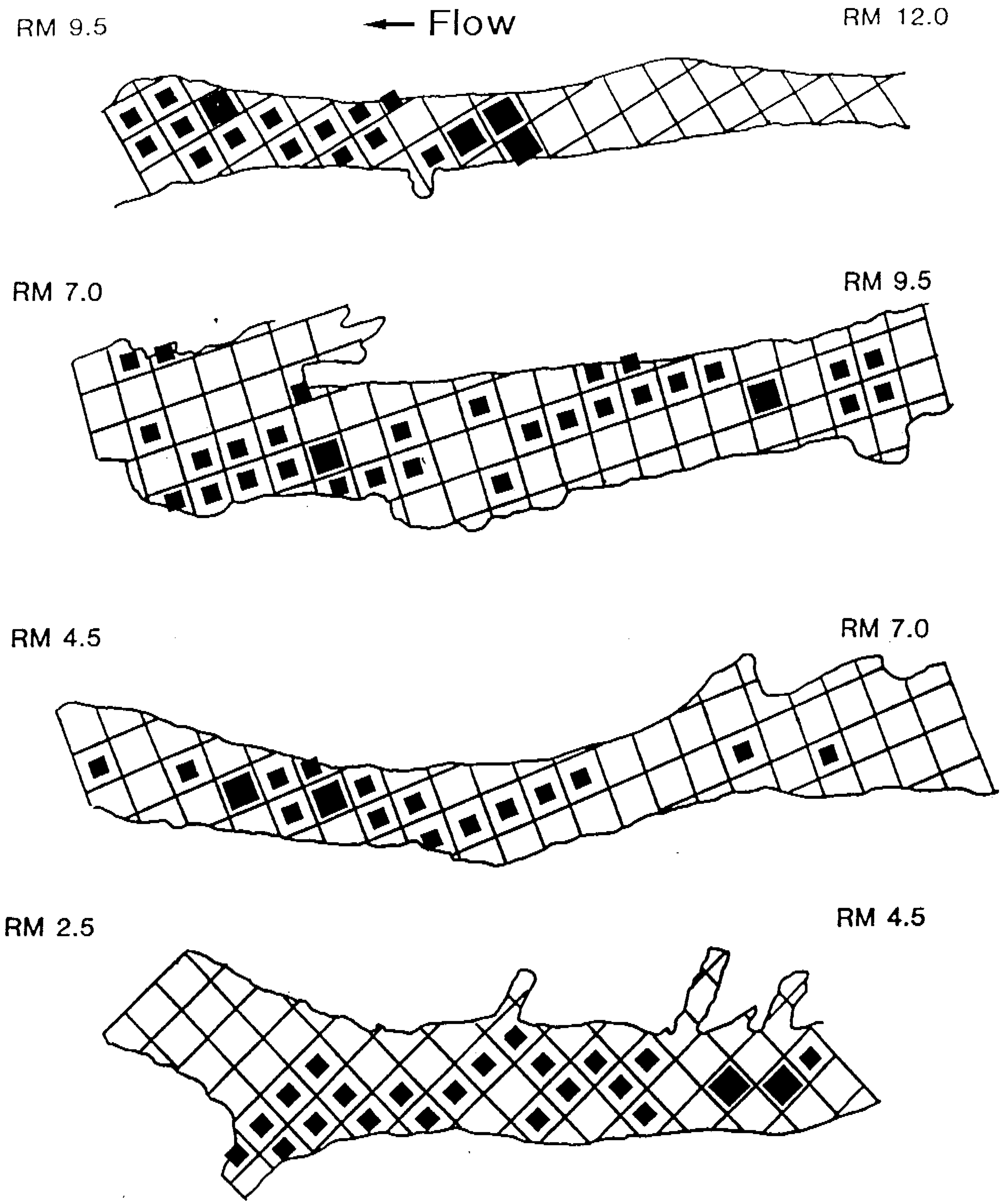

Figure 3. Distribution of radiotagged yearling chinook salmon in the lower Willamette River, 1988-90 combined (■ indicates grid squares in which 2-4 radiotagged fish were located; ■ indicates grid squares in which 5 or more radiotagged fish were located). River flow is from southeast to northwest.

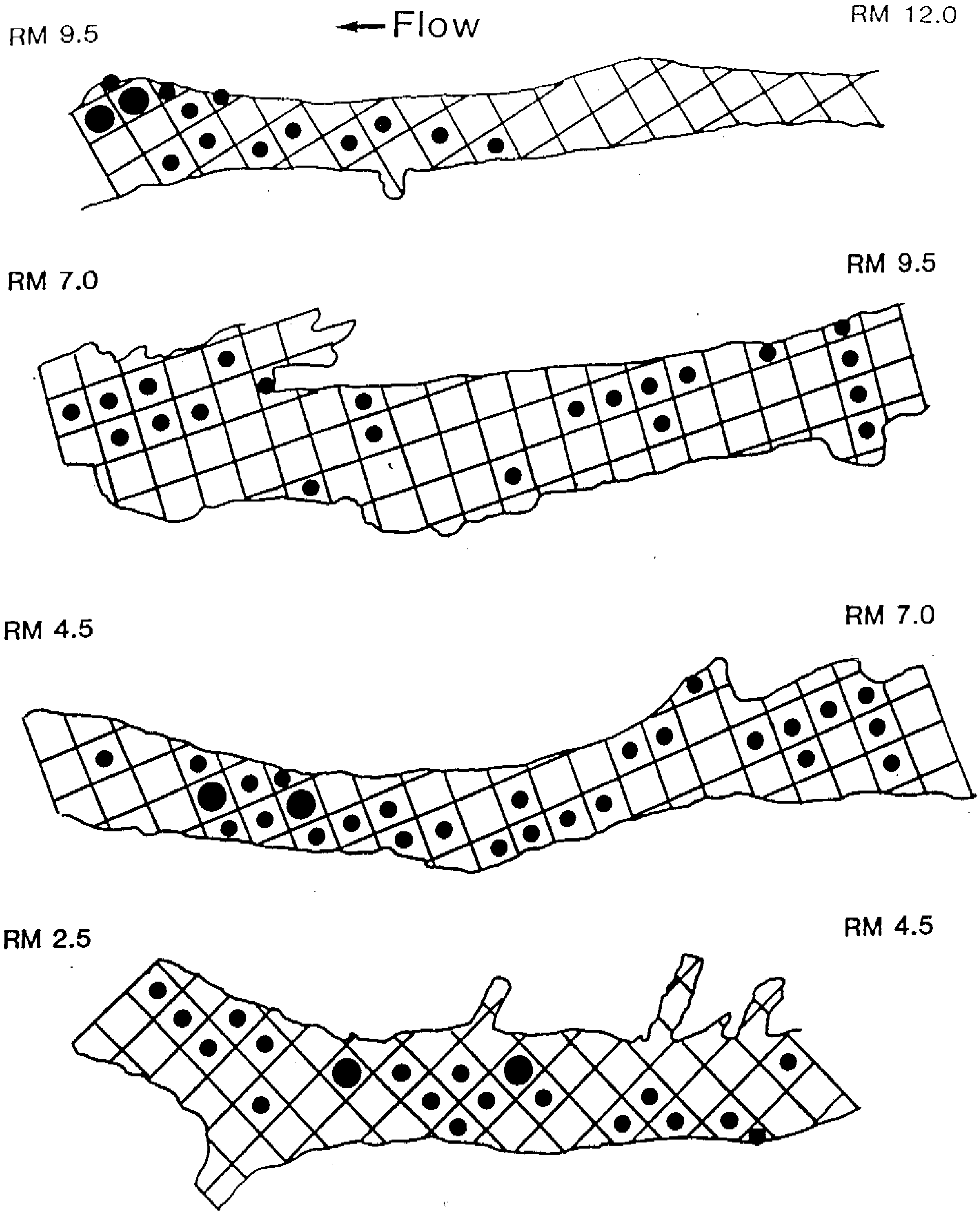

Figure 4. Distribution of radiotagged juvenile steelhead in the lower Willamette River, 1988-90 combined (● indicates grid squares in which 1-2 radiotagged fish were located; ⬤ indicates grid squares in which 3 or more radiotagged fish were located). River flow is from southeast to northwest.

Table 4. Mean values for variables associated with sampling with vertical gillnets for juvenile salmonids in the lower Willamette River, 1989 and 1990.

Year, sampling period, variable	Chinook salmon		Coho salmon	Steelhead	No fish
	Subyearling	Yearling			
1989:					
March-April:[a]					
Number of sets	0	51	0	0	88
Distance to shore (ft)	--	75	--	--	95
Water depth (ft)	--	19	--	--	22
Velocity (ft/sec)	--	0.17	--	--	0.31
May-June:[b]					
Number of sets	29	0	7	7	156
Distance to shore (ft)	75	--	55	65	85
Water depth (ft)	18	--	10	15	22
Velocity (ft/sec)	0.19	--	0.18	0.14	0.16
1990:					
April:[c]					
Number of sets	0	14	0	8	90
Distance to shore (ft)	--	48	--	83	72
Water depth (ft)	--	43	--	23	37
Velocity (ft/sec)	--	0.22	--	0.16	0.12
May:[d]					
Number of sets	50	11	0	8	41
Distance to shore (ft)	121	88	--	101	122
Water depth (ft)	37	24	--	33	39
Velocity (ft/sec)	0.22	0.23	--	0.28	0.15

[a] *Catch included 214 yearling chinook salmon*
[b] *Catch included 44 subyearling chinook salmon, 7 coho salmon, and 7 steelhead.*
[c] *Catch included 28 yearling chinook salmon and 9 juvenile steelhead.*
[d] *Catch included 13 yearling chinook salmon, 116 subyearling chinook salmon, and 9 juvenile steelhead.*

salmonids and habitat in which we collected no fish. We found yearling chinook salmon in shallower water than other juvenile salmonids. Velocity throughout the lower Willamette River was as low as that preferred by juvenile salmonids.

Habitat occupied by migrating juvenile salmonids at the undeveloped site at RM 16.8 appeared to be different than that available at developed sites within Portland Harbor. At RM 16.8 we typically found yearling chinook salmon relatively close to shore (47 ft), and in shallow water (7 ft) of moderate

Table 5. Percent distribution of catch by depth for juvenile salmonids captured in vertical gillnets in the lower Willamette River 1989-90. Values are corrected for differences in effort among depth intervals.

Year, sampling period, depth interval (ft)	Chinook salmon		
	Subyearling	Yearling	Steelhead
1989:			
March-April:			
0-9.9	--	48	--
10-19.9	--	41	--
20-29.9	--	11	--
May-June:			
0-9.9	33	--	42
10-19.9	13	--	58
20-29.9	4	--	0
30-39.9	0	--	0
40-49.9	50	--	0
1990:			
April:			
0-9.9	--	40	88
10-19.9	--	8	12
20-29.9	--	12	--
30-39.9	--	12	--
40-49.9	--	0	--
50-59.9	--	28	--
May:			
0-9.9	47	92	60
10-19.9	28	8	20
20-29.9	10	--	20
30-39.9	12	--	0
40-49.9	3	--	0

velocity (0.43 ft per second). We found subyearling chinook salmon further from shore (140 ft), in deeper water (29 ft) of low velocity (0.28 ft per second). We generally caught yearling and subyearling chinook salmon relatively close to the surface. Juvenile steelhead appeared to occupy habitat similar to that of yearling chinook salmon except they were captured during periods of slower water velocity. Although catch of coho salmon at RM 16.8 was low, we found them occupying habitat very similar to that of subyearling chinook salmon.

At developed sites within Portland Harbor, water velocity associated with catches of juvenile salmonids was always less than that observed at RM 16.8. Mean water depth in which we caught yearling chinook salmon was 24 ft, and mean distance from shore was 91 ft. However, we caught yearling chinook salmon relatively close to shore at two adjoining developed sites at RM 5.0

and RM 5.1. The site at RM 5.0 is characterized by having water up to 45 ft deep immediately off a long (about 1,000 ft) vertical wall shoreline, whereas the site at RM 5.1 has a more gradual sloping shoreline with the water reaching a depth of 47 ft off a dock which floats approximately 50 ft offshore.

Compared with catches at RM 16.8, we found subyearling chinook salmon in deeper water (40 ft), but closer to shore (96 ft) at developed sites within the harbor. We caught subyearling chinook salmon at the developed site at RM 9.9 in shallower water (24 ft) and closer to shore (65 ft) than at other developed locations. This site contained a wharf supported by closely spaced (<10 ft) pilings and a completely riprapped shoreline. A relatively large (about 3 acres) and shallow backwater with a soft bottom was present at the downstream end of the wharf. At developed locations we generally caught yearling chinook salmon closer to the surface than subyearling chinook salmon.

Mean catch of yearling and subyearling chinook salmon in Portland Harbor sometimes differed among depth intervals. During 1989 we did not find a significant difference ($P = 0.31$) in vertical distribution between yearling and subyearling chinook salmon (Table 5). However, during 1990 we found significantly more ($P = 0.04$) yearling chinook salmon than subyearling chinook salmon occupying the 0-10 ft depth interval (Table 5).

We found no significant difference ($P = 0.43$) in mean catch of yearling chinook salmon among water velocities. However, we did find a significant difference ($P = 0.01$) in the mean catch of yearling chinook salmon among depths. We found significantly more yearling chinook salmon occupying the 0-10 ft depth interval than the other depth intervals. Although we found more yearling chinook salmon in the 10-20 ft depth interval than in deeper water, the difference was not significant. We found no evidence to suggest that the catch of yearling chinook salmon among different velocities was affected by depth.

We did not capture any subyearling chinook salmon in water with velocity ≥0.80 ft per second. Mean catch of subyearling chinook salmon was highest ($P \leq 0.01$) in the 0.40-0.79 ft per second velocity interval. We did not find a significant difference in mean catch among depth intervals, and we found no evidence to suggest that the catch of subyearling chinook salmon among different velocities was affected by depth.

Migration Routes

Yearling chinook salmon and juvenile steelhead appeared to migrate through Multnomah Channel more often than out the mouth of the Willamette River; however, the same does not appear to be true for subyearling chinook salmon. We recaptured 157 yearling chinook salmon during our mark-and-recapture studies; 119 of these were recovered in Multnomah Channel. We also found that 12 of 17 radiotagged yearling chinook salmon and 3 of 5 radiotagged juvenile steelhead monitored downstream of RM 3.0 used Multnomah Channel instead of migrating out the mouth of the Willamette River. Our purse-seine catch rate of subyearling chinook salmon was almost six times greater in the Willamette River below the mouth of Multnomah Channel than in Multnomah Channel.

DISCUSSION

Peaks in migration of juvenile salmonids in the lower Willamette River varied temporally within species and races as well as among species and races. Peak catches of yearling chinook salmon during early spring and subyearling chinook salmon during late spring appeared to correspond to dates of hatchery releases. Dawley et al. (1984) reported similar peaks in migration for juvenile salmonids in the Columbia River near Jones Beach. Although hatchery juvenile salmonids composed a majority of our catches, we caught a few wild subyearling chinook salmon during May. However, since catches of wild subyearling chinook salmon were low, we are not sure at what other times of the year they were present in Portland Harbor.

We found that larger yearling chinook salmon were present in Portland Harbor earlier than smaller yearling chinook salmon; larger fish may be more efficient swimmers (Dawley et al. 1982). We found no relationship between size of subyearling chinook salmon and when they arrived in the harbor. Subyearling chinook salmon were present in the harbor over a more protracted periodthan yearling chinook salmon, probably because they actively fed during migration, and a small percentage was actively migrating (Miller and Sims 1984). Hatchery release dates and anticipated times of arrival of juvenile salmonids in Portland Harbor should be considered before in-river activities with potential negative effects (i.e., dredging and construction) are scheduled.

The effects of waterway development on behavior of juvenile salmonids migrating through Portland Harbor may have been related to the amount of time they spent in the harbor. Juvenile steelhead migrated through Portland Harbor faster than yearling chinook salmon and therefore encountered waterway developments or activities occurring within the harbor over shorter time periods. Although yearling chinook salmon moved through the harbor more slowly than juvenile steelhead, most appeared to be actively migrating, and even during periods of low river flow they did not spend more than a few days in the harbor area. Migration rates of yearling chinook salmon through the harbor appeared to be consistent with those reported by Bradford and Shreck (1990) for the upper river, to the extent that migration rate slowed as fish approached the lower river.

Information on migratory behavior of subyearling chinook salmon in Portland Harbor remains limited. We found subyearling chinook salmon in the harbor over a longer period than other species or races of juvenile salmonids. However, we are not certain to what extent they were actively migrating. Since at least a few juvenile salmonids appeared to over-winter in Portland Harbor, they were present there at most times of year. Therefore, we believe that regardless of time of year, in-river activities will still effect at least a portion of the juvenile salmonid population.

Migration of yearling chinook salmon during day and night may have been related to turbidity, which was often highest during times of peak migration. Meehand and Siniff (1962) reported increased turbidity provided protection from predators during daylight migration.

We did not observe any significant pattern to the horizontal distribution of yearling chinook salmon or juvenile steelhead in Portland Harbor. We found evidence to suggest that factors such as water depth may have influenced horizontal distribution; however, this influence varied among species. Alteration of water depth is commonly associated with waterway developments in Portland Harbor. Subyearling chinook salmon were found closer to shore at developed sites than at undeveloped sites; however, we cannot be certain if this was related to increased water depth or to the presence of developments themselves. Waterway development may have less influence on juvenile steelhead in terms of encounters with shoreline structures because juvenile steelhead appeared to migrate farther from shore.

Habitat used by juvenile salmonids at the undeveloped site at RM 16.8 did not appear to be available at most sites within or downstream from Portland Harbor. Undeveloped sites within or downstream from the harbor were deeper and had greater bottom slopes than RM 16.8 because of dredging. Some developed sites had water depth and bottom slope similar to that at RM 16.8, but this habitat was found in associated backwater areas with little or no water velocity. Habitat was much different at RM 16.8 than at developed sites similar to RM 5.0 where the shoreline consisted of a vertical wall. No shallow water habitat was available at these locations. Although we did not find any evidence to indicate that waterway developments directly attract juvenile salmonids or slow migration, developments such as that at RM 5.0 may have subtle indirect effects because of loss of preferred habitat.

We believe that a majority of yearling chinook salmon left the lower Willamette River via Multnomah Channel, whereas subyearling chinook salmon migrated out the mouth of the Willamette River. We are not certain why this occured, but we do believe that caution should be used when considering further development in Multnomah Channel because of its importance as a migration route.

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