Spatial Distribution of Juvenile Salmonids in the Hanford Reach, Columbia River

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ABSTRACT: The cross-sectional distribution of juvenile chinook salmon, sockeye salmon, and steelhead was determined in the Hanford Reach of the Columbia River from July to September 1983 and from April to July 1984. Fish were sampled with fyke nets from anchored barges, movable shoreline fyke nets, seines, and with electroshocking equipment. Fall chinook salmon from naturally spawning populations and from hatchery releases were the principal species collected in the spring. Zero-age fall chinook salmon occurred primarily in shoreline areas of reduced current velocity but were present throughout the river cross section during their early rearing and outmigration period. Hatchery-released fall chinook smolts were less abundant in nearshore areas than were wild fish. Yearling spring chinook salmon, sockeye salmon, and steelhead smolts from upriver areas were collected mainly from the bottom, midchannel zone of the river. Principal downstream movement of all species occurred from 2200 to 0400 [PDT]. Fish collections followed an activity pattern that included migration, feeding, and resting periods.

Knowledge of the distribution of migrating fish is important both to fisheries managers and to scientists interested in migratory behavior. From a practical standpoint, knowledge of where fish migrate may allow technology to be developed with minimal impact on that resource. Information on the location of fish during different phases of their life cycle may also provide clues to specific environmental factors that influence their behavior and ultimately affect their survival (Coutant 1986). Migrational characteristics are adapted toward particular life history strategies (Smith 1985); therefore, comparisons of distribution among species or size classes can further our understanding of anadromous fish biology.

Information on the spatial distribution of juvenile salmonid outmigrants in nonimpounded waters of the mainstem Columbia River is limited to studies of 0–age fall chinook salmon, *Oncorhynchus tshawytscha*, by Mains and Smith (1964). Investigations of the distribution of migrating salmonids in other river systems have been directed at determining the behavior of juveniles during movement from spawning or nursery areas. For example, in the Skeena River drainage in Canada, the lateral distribution of outmigrant pink salmon, *O. gorbuscha*, and sockeye salmon, *O. nerka*, was positively correlated with current velocity. In contrast, coho, *O. kisutch*, and chum, *O. keta*, salmon fry were more uniformly distributed across the river (McDonald 1960). Studies with juvenile sockeye salmon in the Newhalen River, AK showed that most fry and smolts were present in the faster midchannel areas and near the surface (Dames and Moore 1982). To our knowledge, no studies have been conducted to quantify and compare the cross-sectional distribution of juvenile salmonids in lotic environments.

Descriptions of habitat selection have been conducted for many salmonid species in small stream systems. Most indicate a general relationship between increased fish size and greater water depth and/or current velocity (Hartman et al. 1967; Lister and Genoe 1970; Everest and Chapman 1972; Wankowski and Thorpe 1979). Whether this relationship applies to the spatial distribution of migrating fish in a large river has not been established.

We report results from field studies conducted in the Hanford Reach of the mid-Columbia River in 1983 and 1984. The Hanford Reach is now the only unimpounded section of the mainstem Columbia River above Bonneville Dam and below the international border (Fig. 1). Our objective was to obtain estimates of the relative cross-sectional distribution of juvenile chinook salmon, sockeye salmon, and steelhead, *O. mykiss*, during their spring and summer outmigration from upriver spawning and nursery areas. These estimates of distribution were needed to assess the potential for fish to pass through a midriver thermal discharge, located downstream from the study site. Capture locations of fish were also

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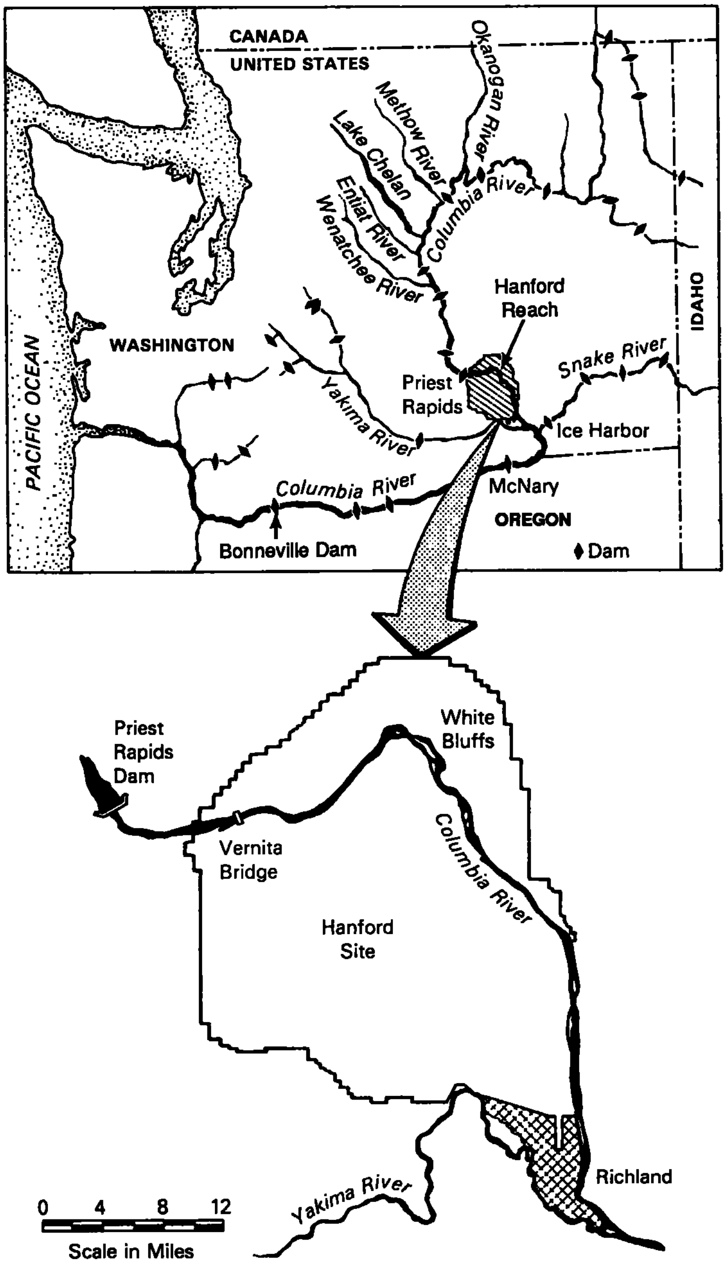

FIGURE 1.—Location of the study area in southeastern Washington.

described in relation to bathymetric and hydrologic characteristics of the river.

STUDY AREA

The Columbia River is about 330 m wide at the study site (river km 613) with average flows of 3,400 m^3/s. The channel is straight, and there are no islands or other major changes in the channel configuration within 6 km of the site. The river bottom slopes gradually from the Benton County side of the river to a distinct channel and rises steeply to the opposite shoreline (Fig. 2). Bottom substrate consists primarily of packed cobble, >10 cm in diameter, and boulders.

River flows in the Hanford Reach are controlled by releases at upriver dams in response to hydroelectric power demand and fish passage requirements. Seasonal flows at the site ranged from 1,220 to 5,270 m^3/s in the summer of 1983 and from 2,600 to 6,330 m^3/s in the spring of 1984. River depths varied by about 4 m as a

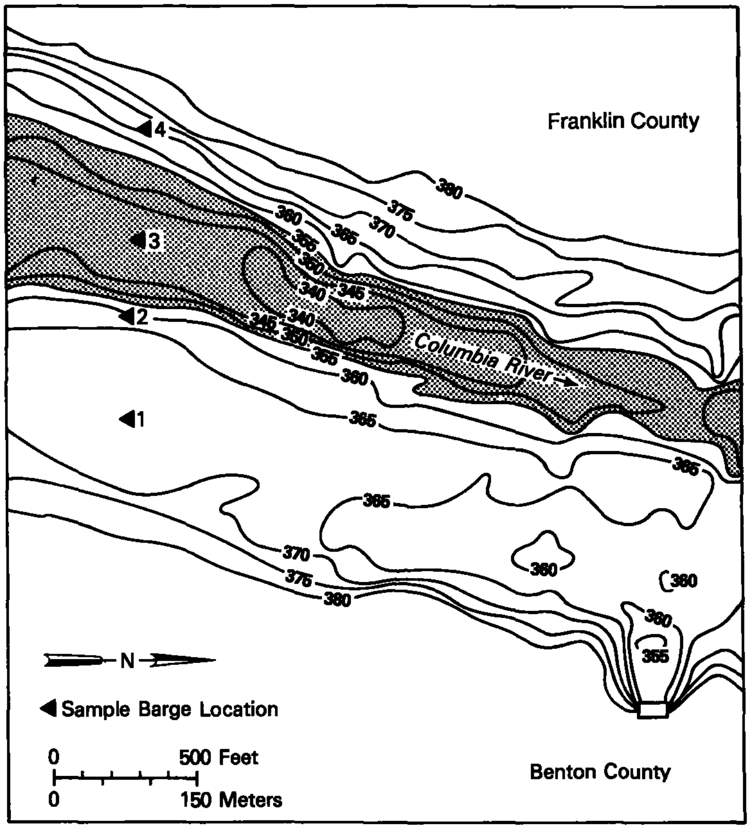

FIGURE 2.—Bathymetry of the Columbia River near the study site, and relative position of barge sampling stations. Contour intervals are river level elevations in feet. The stippled portion shows the midchannel region.

result of this flow pattern. Velocities across the river depended on location, station depth, and river stage (Table 1). Maximum velocities occurred near the river surface. Velocities at midchannel ranged from 0.6 to 2.6 m/s and velocities near the shoreline ranged from 0.1 to 0.5 m/s.

Water temperatures ranged from 18.0°C in August 1983 to 5.2°C in April 1984. Temperatures were uniform across the river until late May; however, from late May through September, daytime water temperatures differed by 2° to 3°C between nearshore and midstream areas because of solar radiation. Visibility (Secchi disc depth) ranged from 142 to 440 cm. Visibility was at a minimum during the late spring freshet and at a maximum in September.

METHODS

Several types of gear were used to provide estimates of fish distribution. Offshore fyke nets mounted on stationary barges were the principal

TABLE 1.—Mean river depth and current velocities at the fyke net sample positions during spring 1984 studies.

Station	Mean depth (m)	Net position	Mean water velocity (m/s)
Barge 1	5.5	Surface	0.79
		Middepth	0.67
		Bottom	0.37
Barge 2	6.5	Surface	1.25
		Middepth	1.16
		Bottom	0.98
Barge 3	12.1	Surface	1.59
		Middepth	1.43
		Bottom	1.28
Barge 4	5.9	Surface	0.98
		Middepth	0.79
		Bottom	0.24
Shoreline 1[1]	1.5	Surface	0.18
Shoreline 2[2]	1.6	Surface	0.37

[1] Benton County shoreline.
[2] Grant County shoreline.

collection method because the nets could be simultaneously used at different depths and locations. In 1984, fyke nets were also used near the shoreline to provide comparisons of nearshore abundance. These nets could be moved to accommodate daily fluctuations in river flow. Boat electroshocking and beach seining were also used to monitor nearshore abundance of juvenile salmonids.

Fyke Net Systems

Four steel barges were used as fishing platforms for the offshore fyke nets (barges 1, 2, 3, and 4; see Figure 2). Two barges were permanently anchored at opposite shorelines, one in midstream, and the other in midchannel. The dimensions of the two barges were 4.3 by 8.1 m and two were 4.9 by 9.1 m. The platforms and rigging setup were modified after Mains and Smith (1964). A 13 mm (½-in.) steel cable was used to attach each barge to a 4,500 kg steel anchor (Fig. 3). A drum winch, with a 6 or 8 mm windlass cable, was used to raise and lower the net from the back of the barge. Battery-powered windlass winches (Superwinch, Model EW 600[1]) and hydraulic-powered gypsy hoists (Kolstrand Model 5-24) were used to operate the drum winch on the two shoreline and two midstream stations, respectively. Hand hoists (come-alongs) were used to maintain tension on the windlass cables because the river levels fluctuated daily.

Each barge fyke net had a 1.5 × 1.5 m opening and was 7 m long. The main body tapered uniformly to a 20 cm diameter opening at the cod end. All netting was made of 6 mm (¼ in.), heavy-duty, knotless nylon mesh. The net frame was built from streamlined aircraft tubing, measuring 86 × 36 × 1 mm. A General Oceanics Model 2030 flowmeter was attached to the mouth of the net. In 1984, a detachable net constructed of 5 mm (3/16 in.) heavy-duty, knotless nylon mesh was attached to the nylon sleeve on the cod end to retain smaller fish. This net was 1 m long, 20 cm across, and had a zippered opening for reaching fish and removing debris.

Shoreline fyke nets had a 1 m^2 opening and were 4.5 m long. No wings were used, but an internal fyke was added that decreased the effective mouth size to 0.3 m^2. All netting was made of 5 mm (3/16 in.), heavy-duty, knotless nylon mesh. The mouth or upstream end of the net was rigged with a weight/float line to keep it vertical. A weight/float retrieval line was also attached to the downstream end of the net.

Fyke Net Sampling Design and Procedure

The offshore nets were fished from each of the four barges for five 24 h periods each week from 26 July through 24 September 1983 and from 23 April to 29 June 1984. We also sampled for four days in late July 1984. The spring sampling coincided with the expected maximum abundance of

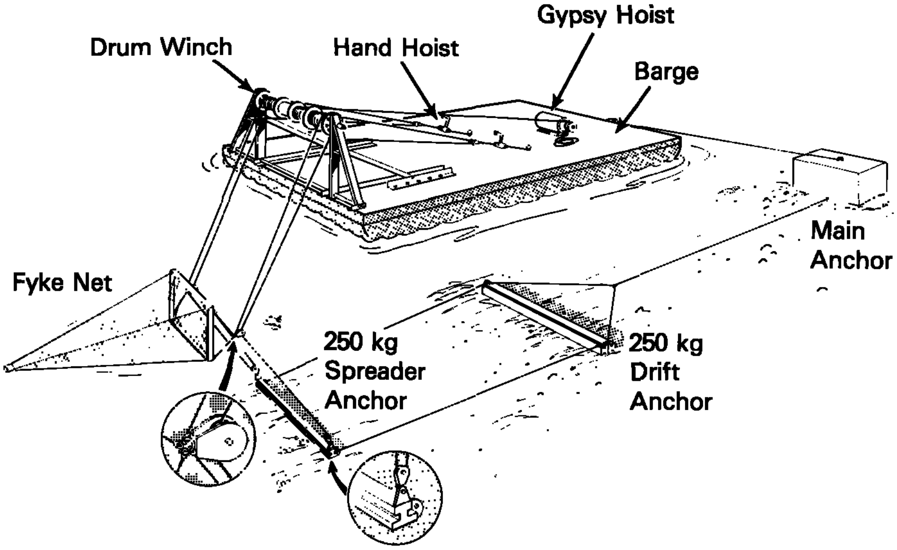

FIGURE 3.—Design of the fyke net rigging and anchoring system.

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

juvenile fall chinook salmon emerging from the Vernita Bar area (Page et al. 1976) and with the period of greatest catches of juvenile coho, chinook, and sockeye salmon, and steelhead at Priest Rapids Dam (Becker 1985). The late summer sampling corresponded to the period of greatest catches of 0–age fall chinook salmon at Priest Rapids Dam (Raymond 1967; Sims and Miller 1977; Hovland et al. 1982).

Sampling periods within each week were selected by a stratified random process to give equal weight to weekday and weekend intervals. To differentiate between diel variations in migration pattern, each day was divided into four equal time blocks starting at 0400 PDT (i.e., 0400–1000, 1000–1600, 1600–2200, and 2200–0400). The scheme provided one all-dark, one all-light, and two transition (dawn and dusk) periods. All barge stations were fished simultaneously at a predetermined depth. One net set of approximately 2 h duration was taken at each of the surface, mid-, and bottom depths according to a random schedule during each 6 h time block. Water temperature, sample and station depths, duration of set, and flowmeter readings were recorded for each sample. Secchi disc depth was recorded daily at noon. Current velocity measurements were taken at 1 m below the surface, at middepth, at 1 m from the bottom at each of the four stations, and over a range of flows using a Bendix Model Q-15 current meter.

Three people worked each shift. Generally, a net could be raised, checked for catches, cleaned of debris, and lowered to the next sampling depth within 5 minutes. Nets at all four stations would usually be tended and repositioned within 15 to 30 minutes. Some samples were lost because of water levels and high flows. Once, a submerged log hit the midchannel net and broke the spreader anchor cable.

The shoreline fyke nets were used for five 24 h periods each week from 30 April to 29 July 1984. To differentiate between diel variations in catch, each 24 h day was divided into four equal time blocks of 6 hours each. Collection intervals coincided with the four barge fyke net sampling periods. Nets were set parallel to the shoreline and opposite the barges at depths of 1 to 2 m.

Supplemental Sampling Gear

A boat-mounted electroshocker (Smith-Root Type VI Electrofisher), powered by a 240 volt generator, was used to sample nearshore fish populations near the barge stations during 1983 and 1984. Each shoreline station was sampled once per week during each of the four 6 h time blocks when fyke nets were sampled. A single pass with the electroshocker was conducted through each 400 m transect at depths of 1 to 2 m. Stunned fish were collected with dip nets, and all juvenile salmonids were measured and released. Catch per unit effort was based on duration of shock.

Duplicate seine hauls were made at each of four permanent stations near the barges with a 9.1 by 1.2 m net constructed of 3 mm (⅛ in.), heavy-duty, knotless nylon mesh. The stations were sampled once per week during daylight hours from April through June 1984. About 50 m^2 of shoreline were sampled with each set. All salmonids were enumerated and subsamples (usually five fish per station) were retained for measurements.

Data Analysis

Estimates of the proportional distribution of fish groups caught at various stations and depths by fyke net were based on a multinomial distribution of the fish caught among the various combinations of station and depth (Cochran 1977). Relative catch per unit effort (CPUE) was calculated on the basis of unit time/cross-sectional area sampled and on volume sampled. A log-linear model was developed to evaluate proportional distribution estimates of 0-age fall chinook, spring chinook, and sockeye salmon smolts using the CATMOD procedure in SAS (SAS 1985). The model was then used to test for two-way interactions among fish groups, barge location, and sample depths. A binomial test for differences (Mainland et al. 1956) was also used to evaluate patterns of distribution for some species.

RESULTS

Estimates of cross-sectional distribution were different for each of the six groups of juvenile salmonids collected. The differences are described in terms of species, life stage, and migration timing.

Distribution of 0-Age Chinook Salmon

Three groups of 0–age chinook salmon were collected: 1) naturally produced (wild) fish originating from adults spawning in the Hanford Reach above the study site, 2) hatchery fish from the Priest Rapids Dam rearing facility, and 3) late summer migrant fish from wild stocks that spawn above Priest Rapids Dam or from hatchery releases at Wells Dam. Peak abundance of these three groups occurred at different times (Fig. 4). Juvenile fall chinook salmon originating from the Hanford Reach were collected in higher numbers than any other salmonid group. These fish were already present in the river when sampling began in late April 1984. Populations peaked in late May, and small numbers were still present in late June when sampling ended. About 60% of the 0–age fall chinook salmon collected in 1984 were wild fish that originated from the Hanford Reach. Hatchery-reared fish appeared in nets within 24 hours of their release from the Priest Rapids rearing facility. These fish differed from wild salmon because of their larger size and deeper body. Most salmonids collected during June were hatchery-released fish. Small numbers of 0-age summer or fall chinook salmon were also collected from July to September 1983 and in July 1984. These fish probably originated in the Wenatchee River, with lesser contributions from the Entiat, Methow, and Okanogan Rivers. Only limited spawning of fall and/or summer chinook salmon occurs in the mainstem Columbia River above Priest Rapids Dam (Horner and Bjornn 1981).

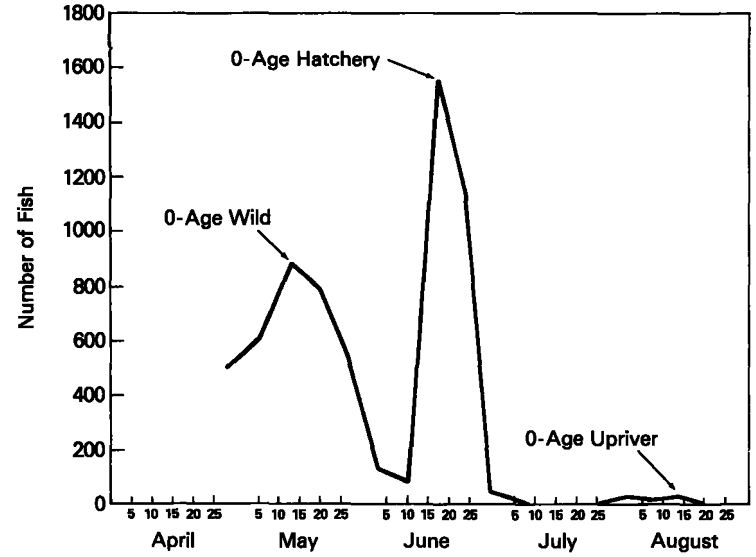

FIGURE 4.—Seasonal patterns of abundance for 0-age chinook salmon populations captured by fyke net near the study site. Sampling effort was uniform throughout the collection period.

Spring Outmigration

Wild and hatchery 0–age chinook salmon occurred throughout the river cross section at Hanford, but the highest concentrations occurred at nearshore barge stations (Fig. 5). About 45% of the fish (n = 6,281) were collected at barge 4. In contrast, only 7% of the 0–age chinook salmon were collected in the shoreline nets.

TABLE 2.—Summary of average catch per unit effort for 0-age chinook salmon caught by fyke nets in spring 1984.

Station	Depth	Number/h	Number/m^3 × 10^6
Shoreline 1[1]	Surface	0.3	669.0
Barge 1	Surface	0.4	50.7
	Middepth	0.9	120.8
	Bottom	1.3	199.9
Barge 2	Surface	0.6	50.7
	Middepth	0.4	36.4
	Bottom	0.9	88.6
Barge 3	Surface	1.4	90.4
	Middepth	0.5	33.6
	Bottom	2.2	164.6
Barge 4	Surface	1.7	230.5
	Middepth	2.0	285.7
	Bottom	3.5	829.6
Shoreline 2[2]	Surface	0.2	975.0

[1] Benton County shoreline.
[2] Grant County shoreline.

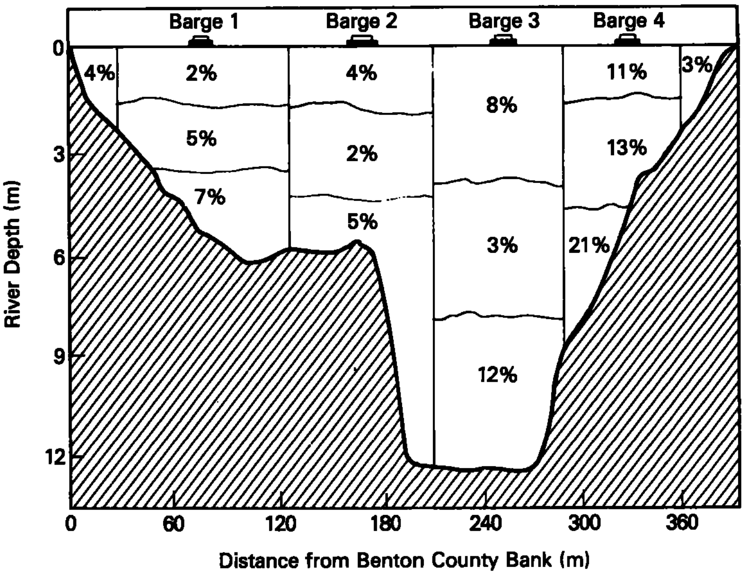

FIGURE 5.—Cross-sectional distribution of 0-age fall chinook salmon (n = 6,281) caught in shoreline and barge fyke nets during spring 1984. Note: horizontal scale is reduced.

Overall, fyke net catches of 0–age chinook salmon ranged from an average of 0.3 fish/h at the Benton County shoreline (shoreline 1), to 3.5 fish/h at barge 4 (Table 2). A peak catch of 152.8 fish/h occurred on June 14 from the bottom depth at barge 4. This quantity corresponded to 5.6 fish/100 m^3 of water filtered through the net. Based on water volume, catch per unit effort was greatest at the Grant County shoreline (shoreline 2).

Little change in fish size was noted for 0–age chinook salmon collected with fyke nets in April and May; 80 to 90% of the fish collected were ≤45 mm fork length (FL) (Fig. 6). However, in June the 0–age chinook salmon collected in the shoreline nets were smaller than those collected in the barge nets. In June, the barge nets collected mainly hatchery fish >80 mm FL, while 60% of the shoreline net totals were wild fish <70 mm FL.

The relative proportion of 0–age chinook salmon caught at the various fyke net stations

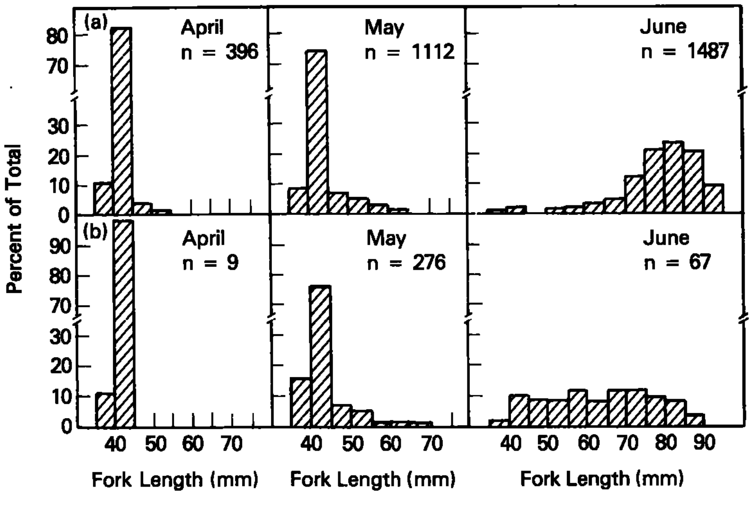

FIGURE 6.—Length-frequency of 0-age fall chinook salmon collected with fyke nets: a) barge sets and b) shoreline sets.

varied seasonally. In general, fish caught in April and May (all wild fish) occurred to a greater extent in shoreline areas where currents were reduced than fish caught in June (~90% hatchery fish). Nearly three times as many 0-age salmon were collected from the two midstream stations (barges 2 and 3) in June than in April and May (Table 3). Analysis of the number of fish caught showed a highly significant interaction ($P \leq 0.0001$) between the April/May and June groups and capture location (barge or depth).

Late-Summer Outmigrants

Low numbers of juvenile fall and summer chinook salmon occurred at Hanford during late summer (July to September). We captured most of these fish (21 of 26) in the midchannel station (barge 3), and 68% of them were collected from the bottom sets. CPUE at barge 3 was 2.2 fish/100 h of sampling (all depths combined). This corresponded to only 1.6 fish/m^3 × 10^6 of water filtered through the nets. CPUE at barge 3 during the peak sampling interval (early August 1983) was 7.1 fish/100 h, or 4.7 fish/m^3 × 10^6 of water filtered through the net.

Distribution of Spring Chinook Salmon Smolts

Yearling-sized chinook salmon occurred throughout the spring in 1984. Most fish originated from the estimated 4 million spring chinook salmon released from upper Columbia River hatcheries in late April.

Catches of yearling chinook salmon were greatest at the midchannel station (73%, n =

TABLE 3.—Estimates of proportional distribution (%) for wild versus hatchery populations of 0-Age fall chinook salmon. Shoreline stations were fished only at ~1 m depth.

		Sample station					
			Barge nets				
Month of capture	Net position	Shoreline 1	1	2	3	4	Shoreline 2
April/May	Surface	6.7	3.2	2.1	4.8	14.3	4.5
(n = 3,451)	Middepth	—	7.1	2.0	2.8	9.1	—
	Bottom	—	6.9	2.2	3.2	20.9	—
June	Surface	1.4	1.3	5.7	11.3	6.6	0.8
(n = 2,824)	Middepth	—	2.9	2.9	2.8	5.1	—
	Bottom	—	6.9	8.8	21.9	21.6	—

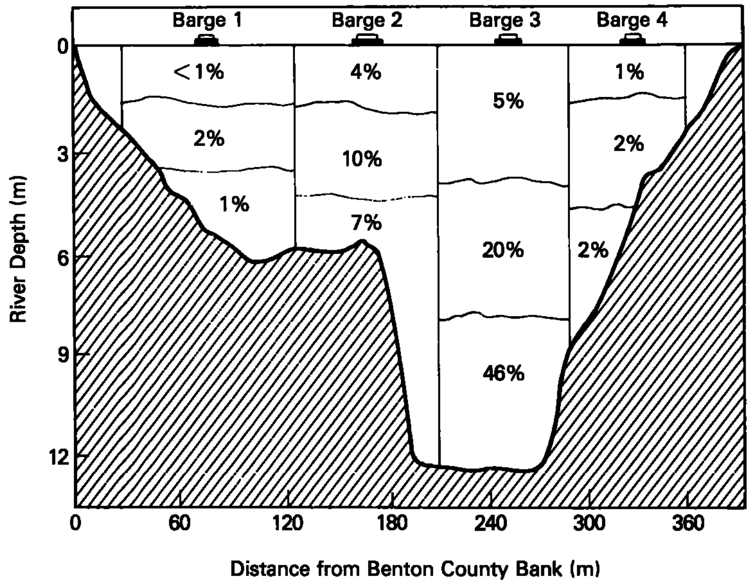

FIGURE 7.—Cross-sectional distribution of yearling chinook salmon (n = 459) caught in shoreline and barge fyke nets during spring 1984. Note: horizontal scale is reduced.

459) (Fig. 7). Catches were low at barges 1 and 4, and no yearling chinook salmon smolts were captured in the shoreline fyke nets. Overall catches were significantly higher ($P \leq 0.01$) from the bottom and middepths at barge 3 than for any other station/depth combination.

The number of spring chinook salmon smolts collected per 100 hours of sampling averaged from 0.3 fish at surface depth (barge 1) to 57.8 fish at bottom depth (barge 3) (Table 4). Although station differences were not as pronounced when CPUE was expressed by volume, the greatest numbers of fish appeared to pass barge 3 in the main river channel.

Spring chinook salmon smolts ranged from 101 to 224 mm FL. Mean size varied little, possibly because most of the fish originated from hatcheries. Scale analysis confirmed that most of the fish (171 of 173) were yearlings.

TABLE 4.—Summary of average catch per unit effort for chinook salmon smolts caught by fyke nets in spring 1984. No smolts No smolts were caught in the shoreline fyke nets.

Station	Depth	Number/h × 10^2	Number/m^3 × 10^6
Barge 1	Surface	0.3	0.4
	Middepth	2.8	3.7
	Bottom	1.8	2.8
Barge 2	Surface	4.2	3.5
	Middepth	10.4	9.5
	Bottom	7.5	7.8
Barge 3	Surface	6.7	4.5
	Middepth	27.3	18.0
	Bottom	57.8	42.6
Barge 4	Surface	1.3	1.7
	Middepth	2.5	3.6
	Bottom	2.1	5.0

Distribution of Sockeye Salmon Smolts

Juvenile sockeye salmon were the third most abundant salmonid group collected at the site. These fish originated from wild stocks in upper Columbia River tributaries, primarily the Okanogan and Wenatchee River systems (Allen 1977). Peak catches of juvenile sockeye salmon occurred in mid-May 1984.

A total of 173 sockeye salmon smolts was collected at the barge stations, but none were captured by shoreline fyke nets. Most of the sockeye salmon smolts (90%) were caught in midstream areas (barges 2 and 3) from the middepth and bottom sets (Fig. 8). Catch profiles indicated that sockeye salmon smolts migrated at greater depths than other salmonids in 1984. Catches from the bottom depth at barge 3 were significantly greater ($P \leq 0.01$) than catches from any other station/depth combination.

Catch per unit effort for juvenile sockeye salmon averaged from 0.3 to 29.2 fish/100 h of sampling, depending on station and depth (Table

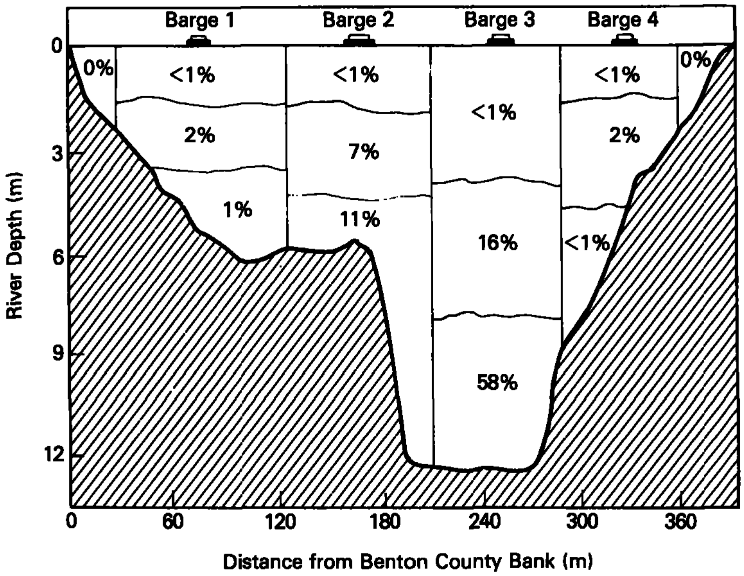

FIGURE 8.—Cross-sectional distribution of sockeye salmon smolts (n = 173) caught in shoreline and barge fyke nets during spring 1984. Note: horizontal scale is reduced.

5). Estimated densities ranged from about 0.2 to 21.6 fish/m^3 × 10^6 of water sampled. Lowest catches were noted for surface sets.

Sockeye salmon were intermediate in size between 0–age fall chinook salmon and spring chinook salmon smolts. Outmigrant sockeye salmon ranged from 74 to 101 mm FL. About 80% of the sockeye salmon were >95 mm FL and, of 96 fish examined, almost all their scales had not yet formed an annulus. Circuli counts for all fish ranged from 8 to 17 and were positively correlated (R^2 = 0.71) with fish length.

TABLE 5.—Summary of average catch per unit effort for sockeye salmon smolts caught by fyke nets in spring 1984. No smolts were caught in the shoreline fyke nets.

Station	Depth	Number/h × 10^2	Number/m^3 × 10^6
Barge 1	Surface	0.28	0.35
	Middepth	0.84	1.11
	Bottom	0.59	0.92
Barge 2	Surface	0.26	0.22
	Middepth	2.93	2.67
	Bottom	5.25	5.20
Barge 3	Surface	0.28	0.19
	Middepth	7.25	4.77
	Bottom	29.20	21.64
Barge 4	Surface	0.50	0.67
	Middepth	1.00	1.42
	Bottom	0.26	0.62

Distribution of Steelhead Smolts

Small numbers of juvenile steelhead were collected from late April through early June 1984. Most fish had eroded fins characteristic of hatchery stocks. Various agencies released approximately 1.1 million steelhead smolts into the Columbia River above Priest Rapids Dam in 1984. Almost all juvenile steelhead (34 of 39) were collected in the main river channel (barge 3) and from either the middepth or bottom positions. No steelhead were collected in shoreline fyke nets and only one was collected at a nearshore barge station (barge 4).

An average of 0.3 to 5.4 steelhead were collected/100 h of sampling, depending on the net location (Table 6). Catches were highest from the bottom depth at the midchannel station, where about four fish were collected per m^3 × 10^6 of water sampled.

Size of the juvenile steelhead ranged from 165 to 241 mm FL. Scales of 14 fish were examined: 10 fish were yearlings and 4 were age 2.

Other Salmonids

No juvenile coho salmon were captured, even though about 500,000 juveniles were released about 192 km upriver in May 1984 and some were collected by gatewell dipping at Priest Rapids Dam. One juvenile mountain whitefish, *Prosopium williamsoni*, 77 mm FL, was collected in late May 1984.

Distribution Based on Supplementary Sampling

Chinook salmon were the primary salmonid species collected by electroshocking (Table 7). Numbers of chinook salmon smolts peaked in nearshore areas in early May 1984. Wild 0–age chinook salmon dominated catches in late May, and hatchery-released 0–age chinook salmon dominated in late June. Late-summer migrant chinook salmon smolts were also electroshocked in small numbers from late July to early September 1983. Steelhead comprised 7% of the total (*n*

TABLE 6.—Summary of average catch per unit effort for steelhead smolts collected by barge fyke nets in spring 1984. No smolts were caught in the shoreline fyke nets.

Station	Depth	Number/h × 10^2	Number/m^3 × 10^6
Barge 1	Surface	0	0
	Middepth	0	0
	Bottom	0	0
Barge 2	Surface	0.26	0.21
	Middepth	0.26	0.24
	Bottom	0.55	0.55
Barge 3	Surface	0	0
	Middepth	2.61	1.72
	Bottom	5.37	3.98
Barge 4	Surface	0	0
	Middepth	0	0
	Bottom	0.26	0.62

TABLE 7.—Seasonal totals for juvenile salmonids caught by boat electroshocker in shoreline transects. Each of two 400 m shoreline transects was sampled four times daily.

		Species		
Date	Total sample days	Chinook salmon	Sockeye salmon	Steelhead
August 1983	4	2	0	0
September 1983	3	4	0	0
April 1984	1	3	0	0
May 1984	5	168	0	3
June 1984	4	191	1	1

= 375) yearling-sized salmonids collected by electroshocking during the spring 1984 studies. Only one juvenile sockeye salmon was collected by boat electroshocking.

Overall, 3,982 0–age chinook salmon and 1 juvenile sockeye salmon were collected by beach seining. Almost all of the chinook salmon captured with seines originated from upstream spawning areas near Vernita Bar. Catches peaked on 17 May with 178 fish/seine haul. Numbers declined in June despite the large numbers of hatchery fish present. The size of 0–age chinook salmon collected with seines (Fig. 9) was similar to those collected with fyke nets in April and May. However, fish collected with barge fyke nets in June (see Figure 5) were generally larger than those collected with seines. No juvenile spring chinook salmon or steelhead were collected with beach seines.

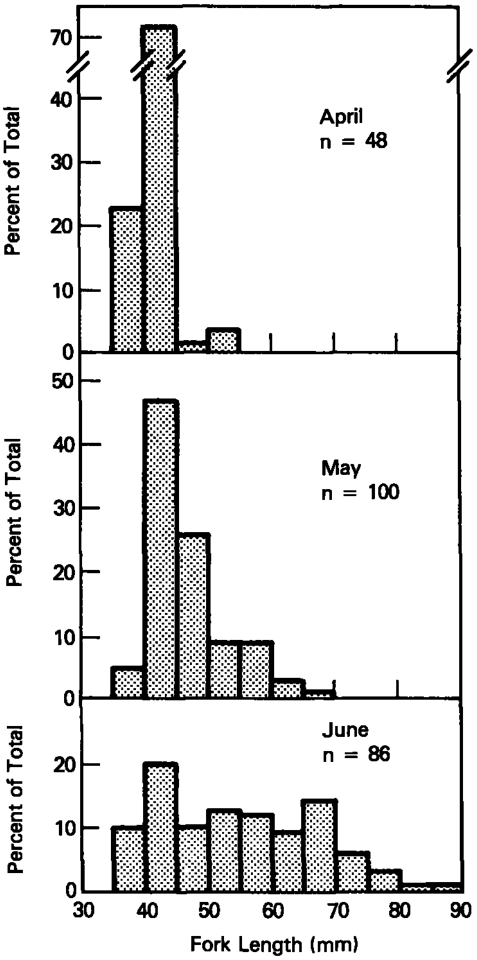

FIGURE 9.—Length-frequency of 0-age fall chinook salmon captured by beach seine in spring 1984.

Diel Patterns In Salmonid Migration

Principal movement of all salmonids occurred between the hours of 2200 and 0400, based on barge fyke net collections; however, differences in peak movement among species were evident from the barge catches (Fig. 10). For example, only 0–age fall chinook salmon (wild and hatchery populations) were collected during daylight hours. For these populations, peak catches occurred just after darkness (2200 to 2400). In contrast, fyke net catches of sockeye salmon, spring chinook salmon, and steelhead smolts peaked between 2400 and 0400. Although nocturnal movement was also evident based on shoreline fyke net catches, a higher proportion (~22%) of the 0–age chinook salmon were collected in shoreline nets during daylight hours (Fig. 11).

Diel patterns of distribution based on electroshock catch totals contrasted among the different groups of chinook salmon (Fig. 12). Peak numbers (55%) of the 0–age fall chinook salmon in April and May were collected from the hours of 1600 to 2200; 44% of the 0–age hatchery fall chinook salmon (June fish) were collected from 0400 to 1000; and 80% of the hatchery spring chinook salmon and late summer migrant chinook salmon were collected during the night from 2200 to 0400.

DISCUSSION

Our studies showed that distributional patterns were different for each of the three most abundant groups of juvenile salmon (i.e., fall chinook, spring chinook, and sockeye salmon). Our hypothesis that fish distribution was independent of barge station and depth was rejected, suggesting that different groups acted differently at different barges and at different depths. Salmonid outmigrants in the Hanford Reach exhibited patterns of proportional distribution that were mainly size related (Table 8). Larger outmigrants (i.e., chinook salmon, sockeye salmon, and steelhead) occurred near the bottom, midchannel zone of the river, while the smaller wild and hatchery 0–age fall chinook salmon preferred the shallower shoreline areas.

The relatively high contribution of fall chinook salmon to the total catch during the spring resulted primarily from the large numbers of wild fish emerging in the Hanford Reach and the hatchery fish released there. About 90% of the salmonids collected were 0–age chinook salmon. Collectively, this group comprised about 70% of

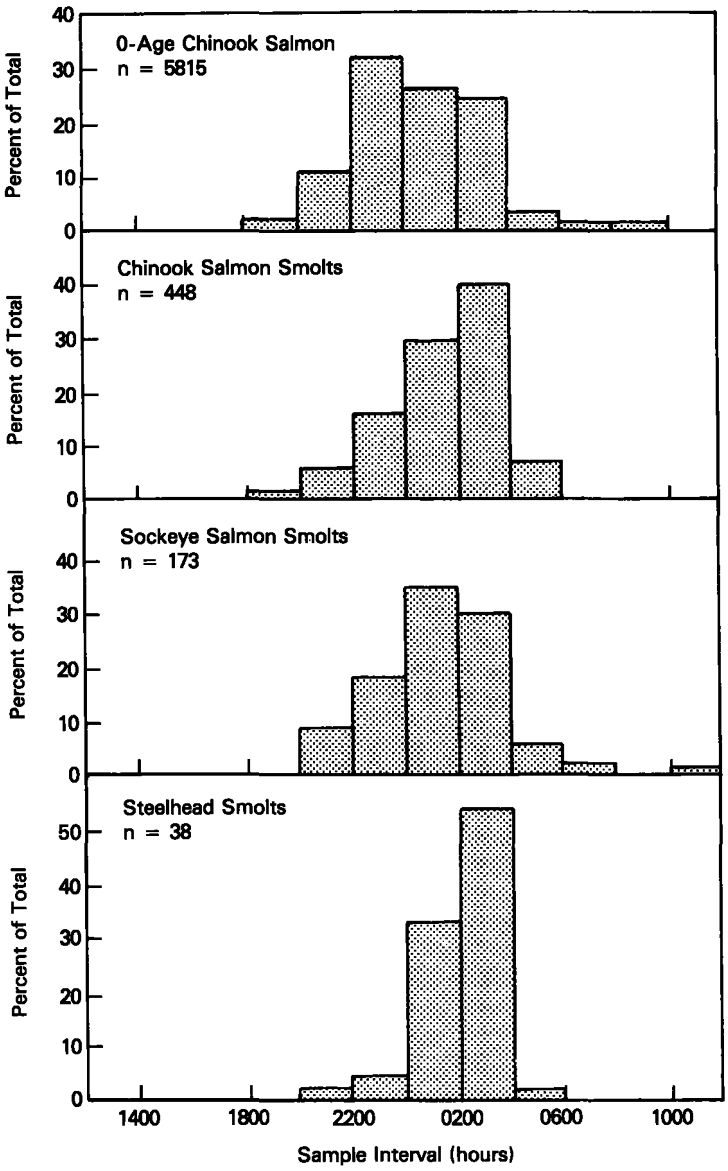

FIGURE 10.—Diel catch patterns of juvenile salmonids collected by barge fyke nets during spring 1984.

the juvenile salmonids estimated to pass the study site in 1984. Wild populations of 0–age fall chinook salmon were more vulnerable to active and passive netting techniques because they were smaller relative to juvenile salmonids produced or released upriver. Because the smaller 0–age fall chinook salmon that emerge from redds at Vernita Bar use the Hanford Reach primarily for temporary feeding and rearing (Becker 1973), their distribution may differ from the distribution of smolts migrating from upstream sites.

The cross-sectional distribution of chinook salmon fry (36 to 70 mm FL) in our collections was similar to that observed by Mains and Smith (1964) for 0–age fall chinook salmon in the Columbia River at river km 550. Although Mains and Smith also reported data from "yearling" outmigrants in June and July, the length (85 to 90 mm FL) of these fish approximated that of later-migrating stocks of 0–age fish from upriver. The spatial distribution described by Mains and Smith for yearlings (based on volume sampled) was nearly identical to the distributions that we obtained for naturally produced stocks of 0–age fall chinook salmon. In both

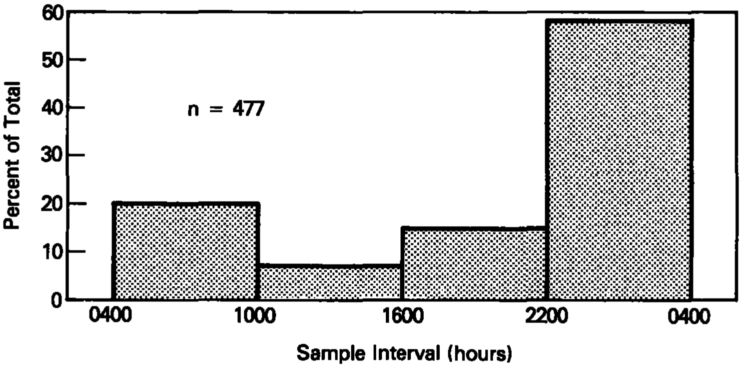

FIGURE 11.—Diel catch patterns of 0-age fall chinook salmon collected by shoreline fyke nets during spring 1984.

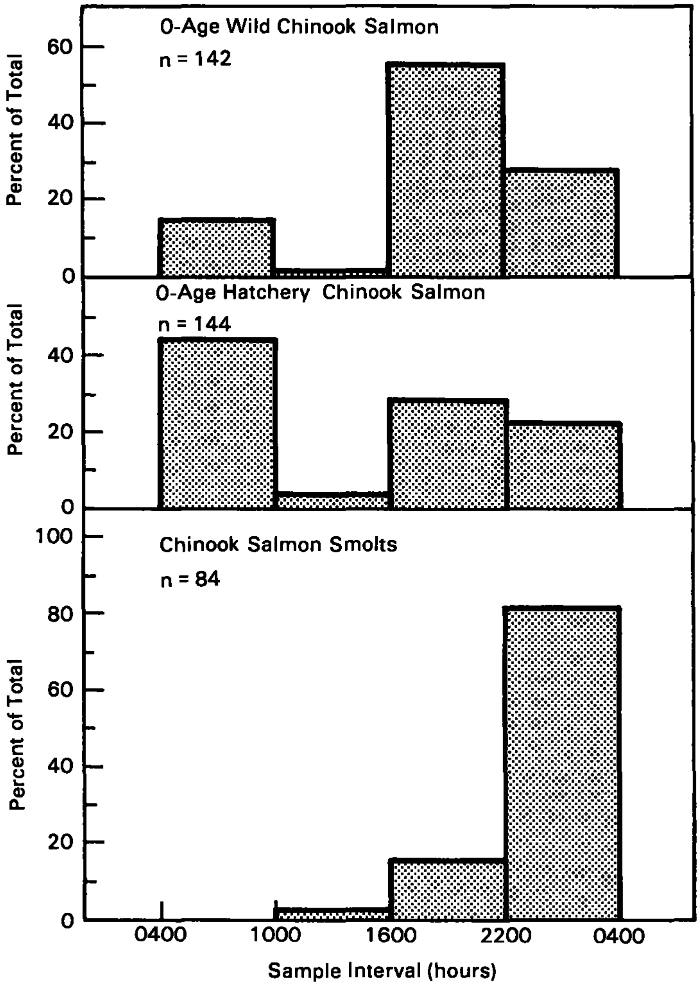

FIGURE 12.—Diel catch patterns of juvenile chinook salmon collected by shoreline electroshocking during spring 1984.

TABLE 8.—Relationship of juvenile salmonid size to fyke net capture location. Key: S1,S2= shoreline stations, B1-B4 = barge stations, s = surface, m = middepth, b = bottom, ns = not sampled.

			Proportional distribution (%)					
Population	Mean size (mm)	Depth zone	S1	B1	B2	B3	B4	S2
Chinook salmon								
0-age fall (wild)	45	s	7	3	2	5	14	3
(*n* = 3,451)		m	ns	7	2	3	19	ns
		b	ns	7	2	2	21	ns
0-age fall (hatchery)	85	s	1	1	6	4	7	1
(*n* = 2,824)		m	ns	3	3	3	5	ns
		b	ns	7	9	22	22	ns
0-age summer migrant	114	s	ns	0	0	9	0	ns
(*n* = 26)		m	ns	0	0	14	5	ns
		b	ns	0	0	73	0	ns
1-age spring	140	s	0	1	4	5	1	0
(*n* = 459)		m	ns	2	10	20	2	ns
		b	ns	1	7	40	2	ns
Sockeye salmon	90	s	0	1	4	5	1	0
(*n* = 173)		m	ns	2	6	16	2	ns
		b	ns	1	11	58	1	ns
Steelhead	200	s	0	0	3	0	0	0
(*n* = 39)		m	ns	0	3	23	0	ns
		b	ns	0	8	62	3	ns

studies, most fish were collected in shoreline areas, but catches from one shoreline were about three times greater than catches from the opposite shoreline. Thus, the physical features of some shorelines appear to influence the distribution of juvenile fall chinook salmon.

Low catches of chinook salmon smolts during the late summer may reflect the small population size in upriver areas. The number of summer and fall chinook salmon spawning above Priest Rapids Dam in 1982 was lower than the 1972–82 10 yr average.[2] The total outmigration of up-river 0–age chinook salmon in 1983 was about 1 million fish (estimate based on escapement of adult summer and fall chinook salmon over Priest Rapids Dam in 1982 and historical production factors), or only 40% of the numbers estimated by Sims and Miller (1977) for the 1976 outmigration. Because the mouth openings of the four barge fyke nets collectively only sample 0.1–0.2% of the river cross section, small sample numbers would be predicted for fish present at low densities.

Species-specific differences in behavior also affected spatial distribution. For example, almost all sockeye salmon smolts were collected from midstream portions of the river. This phenomenon was not entirely consistent with the size-related model of fish distribution noted for the different groups of juvenile chinook salmon. Other studies of lateral distribution have shown that yearling sockeye salmon migrate primarily in midriver, utilizing areas of highest current velocity (Dames and Moore 1982). The apparent preference of juvenile sockeye salmon for the river bottom near our study site also contrasts to that observed for lentic populations, which reportedly migrate primarily near the surface (Johnson and Groot 1963).

Electroshocking and beach seining showed that the shoreline fyke nets could not be used to effectively collect larger juvenile salmonids. Although differences in gear effectiveness make direct comparison of methods impossible (Hulbert 1983), it appears that nearshore estimates of distribution based on shoreline fyke net catches were low. For example, spring salmon and steelhead smolts were sometimes electroshocked at night in nearshore areas ~1 m deep, but none were collected in shoreline fyke nets that were fished at similar depths. Daytime catches in shoreline fyke nets were also low when compared with the observed densities of

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[2] Rod Woodin, Washington Department of Fisheries, Olympia, WA 98504, pers. commun. November 1983.

0–age chinook salmon during seining. For some species, active sampling techniques helped support distribution trends observed from fyke net data. For example, the preference of migrating sockeye smolts for offshore areas was also indicated by the absence of sockeye salmon in nearshore collections using electroshocking and seines.

In our study, hatchery-reared 0–age chinook salmon (range 75 to 90 mm FL) were less abundant in shallow nearshore areas than wild stocks. This spatial segregation was evident for both seining and fyke net collections. Thus, differences in distribution patterns that may be attributed to size, season, or physiological condition were also evident.

Diel movement patterns were consistent with those observed in previous studies of migrating juvenile salmonids in the Columbia River. Principal movement of outmigrating juvenile chinook salmon occurred during the night at Priest Rapids Dam (Sims and Miller 1977) and at Byers Landing (Mains and Smith 1964). Smith (1974) collected 91% of primarily 1-age juvenile chinook salmon at night in impounded waters on the Snake River. Sockeye salmon have also shown a preference for nocturnal movement in other river systems (Kerns 1961; Dames and Moore 1982). In general, natural light intensity appears to be the major environmental factor controlling diel migration patterns of salmonid fry (Godin 1982).

The observed patterns of diel behavior may have affected the cross-sectional distribution of the juvenile salmonids. For example, we observed that spring chinook salmon smolts were often abundant just after sunset in shallow nearshore areas (≤30 cm deep) of low current velocity. This inshore appearance may have preceded active or passive downstream movement. Nighttime movement into the current may result from a loss of visual contact with the surroundings (McDonald 1960) or a reduction of rheotactic response (Hoar 1953). Both of these mechanisms could result in passive downstream displacement; however, there were distinct differences in diel timing among the four species collected. These differences suggest that migration is not controlled solely by passive mechanisms.

Documented migration rates of juvenile salmonids in the Columbia River are consistent with activity rhythms that include feeding, quiescent behavior, and active migration. At midstream velocities averaging 1 m/s, a passively drifting fish would travel about 29 km in an 8 h night. Migration rates would be faster with higher current velocities, as occurs during the spring freshet (2–3 m/s), or for actively migrating fish. Most salmonid smolts apparently migrate actively in midchannel for only a few hours daily since reported mean migration rates of juvenile salmon through the Hanford Reach are about 56 km/d (Weitkamp and McEntee 1982). The patterns of distribution that we observed probably provide only a partial description of the interacting behavioral characteristics that increase species survival and efficient use of energy reserves.

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