Abstract. – Beach and purse seine catches at Jones Beach, River kilometer 75, were used to examine diel movement patterns of juvenile chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, and steelhead *O. mykiss* as they migrated downstream in the Columbia River estuary. The patterns were monitored during five 24-hour periods in 1978, 1979, and 1980, and compared with patterns obtained from extensive morning-hour sampling conducted during 1979–83. Diel catch patterns were generally consistent among the sampling periods and there was reasonable agreement with morning-hour sampling. However, diel movement was different than that reported for salmonids in other river systems and in other locations in the Columbia River. The times and lateral position of greatest downstream movement which provided the largest catches of salmonid juveniles were as follows: sunrise to early afternoon nearshore for subyearling chinook salmon, sunrise to early afternoon midriver for yearling chinook salmon, midmorning to early evening nearshore and sunrise to early afternoon midriver for coho salmon, and noon to early evening midriver for steelhead. Decreased movement during darkness was apparent for all salmonids. No relationship between tidal cycle and catch was evident from either beach or purse seine sampling.

Manuscript accepted 24 July 1990.
Fishery Bulletin, U.S. 89:69–78 (1991).

Diel Sampling of Migratory Juvenile Salmonids in the Columbia River Estuary

Richard D. Ledgerwood
Coastal Zone and Estuarine Studies Division
Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA
2725 Montlake Boulevard East, Seattle, Washington 98112-2097

Frank P. Thrower
Auke Bay Laboratory, Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
P.O. Box 210155, Auke Bay, Alaska 99821

Earl M. Dawley
Coastal Zone and Estuarine Studies Division
Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA
2725 Montlake Boulevard East, Seattle, Washington 98112-2097

Successful and cost-effective timing and survival studies for juvenile salmon and steelhead are dependent on understanding migratory behavior as well as sampling effectiveness. Literature regarding the migratory behavior of juvenile Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* indicates a wide variation in diel movement patterns, from greatest movement during daylight hours (Sims et al. 1976) to greatest movement at night (Smith et al. 1968) (see also Table 1). Catches used for the reported observations were obtained using an assortment of sampling equipment in large and small rivers and reservoirs during a range of turbidity conditions. Juveniles captured varied in life stage from emergent fry to migrating smolt. It was difficult to determine from some of the literature whether the greatest catches represented increased fish movement or times of greatest susceptibility to sampling equipment.

Personnel of the National Marine Fisheries Service conducted a sampling program at Jones Beach, Columbia River, kilometer (Rkm) 75, to examine diel movement patterns of juvenile chinook salmon *O. tshawytscha*, coho salmon *O. kisutch*, and steelhead in the upper Columbia River estuary. The objective was to establish the optimum time of day and lateral location for the most effective sampling of these fish during the peak of the spring migration. Also, this program was to provide data to compare with previous sampling results at Jones Beach which indicated midriver orientation of yearling fish, shore orientation of subyearling fish, and substantially decreased movement of shore-oriented migrants at night (Dawley et al. 1986).

Methods

Diel migration patterns were monitored using beach and/or purse seines during five 24-hour periods: 18–19 May 1978, 14–15 June 1978, and 14–15 May 1980 for beach seine; and 10–11 May 1979, 23–24 May 1979, and 14–15 May 1980 for purse seine. Sampling dates were based on peaks of juvenile salmonid migrations recorded in other years (1966–83) at Jones Beach (Dawley et al. 1986).

Purse seining was conducted midriver from the north edge of the ship channel toward Puget Island; beach

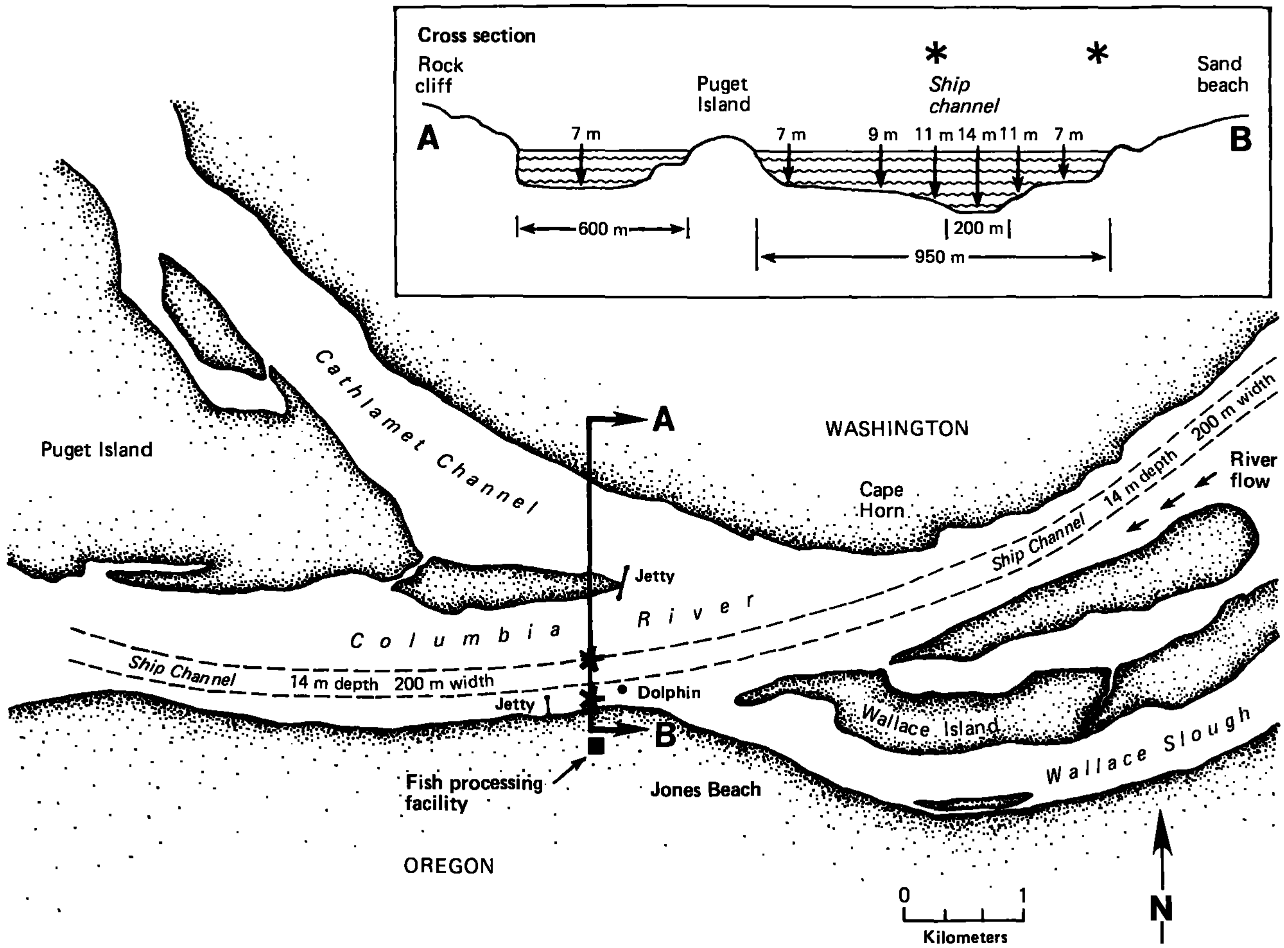

Figure 1
Jones Beach sampling site. Beach and purse seining areas are denoted by the two asterisks on the cross section.

seining was on the south shoreline, lateral to the purse seine site (Fig. 1).

Conditions of the Columbia River were different during each sampling period. River flows ranged from 6800 to 7600 m^3/second (U.S. Army Corps of Engineers 1978–80). Turbidity and water temperatures ranged from 5 to 11 Jackson Turbidity Units and 12° to 17°C, respectively. Tides at Jones Beach are semidiurnal (~7 hours of ebb and 4.5 hours of flood current); flow reversal occurs during flood tides throughout most of the year. River flows in the range of 5000–12,000 m^3/second generally occur during the period May through mid-July, and flood tide effects are diminished at these high flows.

Captured salmonids were anesthetized, identified to species, and enumerated (Dawley et al. 1985). Subyearling and yearling chinook salmon were separated on the basis of fork length; separation points were determined from the bimodal curves of length frequency. Verification of age from marked fish of known age (4.8–6.5% of catch) showed about 4% error in separation. All captured fish were either held in tanks onshore until sampling was complete and then released or transported downstream from the sampling area and released.

Beach seining

The beach seine was 95 m long by 5 m deep with 1–2 cm (stretch) webbing (Sims and Johnsen 1974). The net was fished downstream regardless of tidal influence. An anchor was used to secure one end of the net onshore and the opposite end, containing the bunt, was towed upstream at the 1-m depth contour, then arched downstream and back to shore. The effective fishing depth of the net was 2–3 m in water up to 6 m deep. The net was pulled onto the beach which crowded the fish into the bunt for capture. Completion of each set required about 25 minutes; sets were made at 45-minute intervals.

Catch data from the first two or three seine sets on the first morning of each sampling period were not used for analysis of diel movement because some salmonids probably resided in the sampling area overnight, and the initial sets were used to clear the sampling site of those residents. Of the beach seine sets in each 24-hour period, 34% (11 of 32) were made during darkness and 66% (21 of 32) during daylight.

Purse seining

The purse seine was 206 m long by 11 m deep with 1–2 cm (stretch) webbing (Durkin and Park 1967). A depressor weight was used during the pursing operation to increase the effective fishing depth to about 6 m. The vessels used were a 10-m pontoon barge powered by outboard engines and an outboard- motored seine skiff; lights were mounted on the barge for night operation. A depth finder, a compass, and channel markers were used to locate the sampling site.

The seine was set near midriver in water 9–14 m deep, and towed upstream at constant power in a "U" configuration (Dawley et al. 1985). After 5 minutes, the ends of the net were brought together and the net bottom was closed (pursed) and hauled aboard the barge with a boom and hydraulic capstan. Then the cork line and webbing were retrieved and the catch was placed in 75-L containers supplied with circulating river water. Completion of each set required about 40 minutes; sets were made at 90-minute intervals. About 31% (5 of 16) of the purse seine sets were made during darkness and 69% (11 of 16) during daylight.

Data analysis

Each set represented one time interval within the 24-hour sampling period. Twice as many beach seine sets were made in each 24-hour period as purse seine sets; consequently, time intervals are one-half those for the purse seine. The catch per set (CPS) interval was calculated in terms of the percentage of the total 24-hour catch by species and stock. An overall percent CPS was calculated for each seine type by averaging interval values from the three appropriate sampling dates.

Diel catch data for each species were compared graphically and with linear regression to corresponding tidal heights at Jones Beach.

Results

During 14–15 May 1980, the only period we sampled with both beach and purse seines, the beach seine accounted for 79% of the total catch of subyearling chinook salmon (predominately fall race) (Van Hyning 1973), while the purse seine produced the largest catches of yearling fish: 92% of the yearling chinook salmon (predominately spring race); 82% of the coho salmon; 100% of the sockeye salmon *O. nerka*; and 97% of the steelhead. Daylight sampling in previous years produced similar beach seine to purse seine catch ratios (Dawley et al. 1986).

Examination of catch data indicated there was no apparent relationship to tidal variations for any species during any sampling period; correlation coefficients ranged from −0.51 to 0.14. Catch/tidal data are available upon request. Dawley et al. (1986) also observed a lack of correlation between tidal cycles and beach seine catches of subyearling chinook salmon from the Columbia River estuary.

Subyearling chinook salmon

Beach seine catches of subyearling chinook salmon (13,513 fish) peaked during the interval about 1.5 hours after sunrise (6.9% CPS) followed by steady catches during the daylight intervals, each near 4.0% CPS. About 1.5 hours before sunset, a second, smaller peak was observed in two intervals (CPS of 5.2% each), followed by a sharp and continued decrease with darkness through the night intervals (average CPS = 0.9%). The night catch was 10.2% (3.8 SD) of the total catch for a 24-hour period. Catches increased again about 45 minutes before sunrise (Fig. 2A).

Purse seine catches of subyearling chinook salmon (1461 fish) increased just before sunrise and decreased throughout the day (Fig. 2B). Again, only 10% (1.7 SD) of the total purse seine catch was at night.

Coho salmon

About 21% of the yearling coho salmon captured were from beach seining (1092 by beach seine and 3990 by purse seine). The June 1978 sampling period produced only 17 fish and was not included in the assessment of movement behavior. Beach seine catches in daylight were low until about 1000 hours then generally increased, with large fluctuations between intervals, to a peak at about 1430 hours (10.7% CPS) (Fig. 2C). In the late afternoon and evening, catches generally decreased with large fluctuations between intervals. The CPS dropped at dusk to 2.5% followed by lower catches during darkness. The night catch averaged

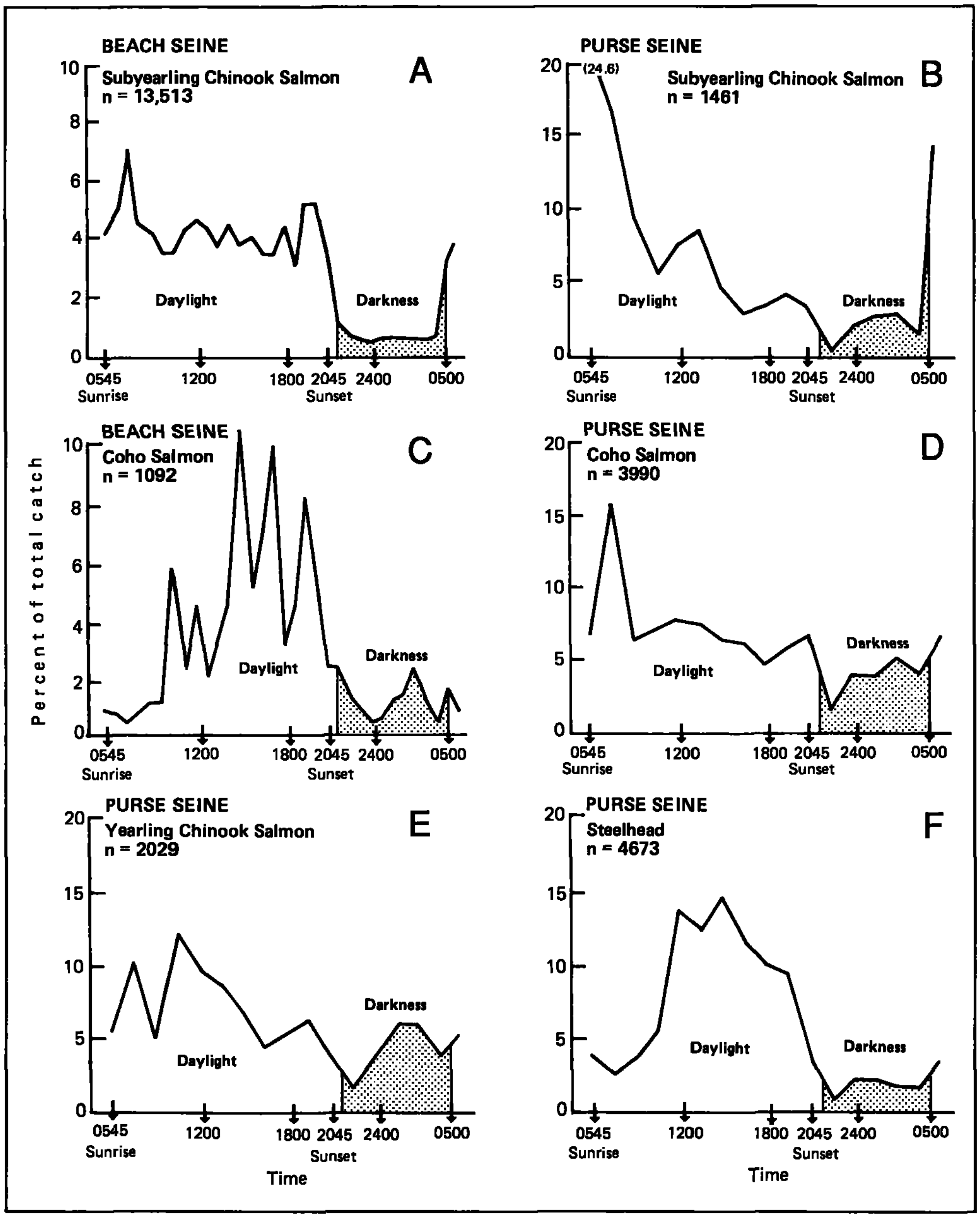

Figure 2
Diel catch patterns for chinook salmon, coho salmon, and steelhead from beach and purse seine sampling at Jones Beach, 1978–80 (samples combined and averaged).

13.7% of the total catch for the two 24-hour sampling periods.

Purse seine catches peaked during the interval about 1.5 hours after daylight (15.8% CPS) and remained near 6.5% CPS throughout the daylight intervals the (Fig. 2D). Catches decreased in the night intervals to an average 3.7% CPS; 18.5% (4.6 SD) of the CPS was obtained during darkness.

Yearling chinook salmon

The majority of yearling chinook salmon migrated midriver; purse seine catches totaled 2029 fish compared with 113 from the beach seine. The peak catch with the purse seine was during the interval 0946 to 1115 hours (12.3% CPS). Overall, 46% of the total catch was taken in 31% of the sets (1.5 hours after sunrise to about 1330 hours) (Fig. 2E). Purse seine catches were smallest from dusk to midnight (average 3.2% CPS), with larger catches occurring during the remainder of the night intervals (average 5.4% CPS). The night catch was 21.1% (7.0 SD) of the total purse seine catch for a 24-hour period.

Sockeye salmon

Sockeye salmon juveniles were caught only in the purse seine (222 fish), with 15% (6.3 SD) captured at night. An insufficient number of fish were captured to allow a more detailed analysis of the diel migration pattern.

Steelhead

Over 98% of the juvenile steelhead were caught by purse seine (4673 by purse seine and 74 by beach seine). Purse seine catches were moderate in the four intervals after sunrise (average 4% CPS), peaked at the interval from 1416 to 1545 hours (14.6% CPS), decreased at dusk, and remained low throughout the night intervals (average 1.7% CPS) (Fig. 2F). The night catch was 8.7% (1.0 SD) of the total catch for a 24-hour period.

Discussion

Catch data from our beach and purse seines appear to represent movement and position of juvenile salmonids during their migration through the upper Columbia River estuary. Catches of subyearling chinook salmon at both purse and beach seining sites indicate a substantially decreased migration during darkness. Beach (nearshore) and purse (midriver) seine catches of coho salmon indicate a fairly uniform migration throughout the daylight period. Data obtained for yearling chinook salmon, sockeye salmon, and steelhead indicate a midriver orientation with decreased migration during darkness. Other researchers have reported different diel movement patterns, but conditions, equipment, and life stages of the fish sampled are so variable that direct comparison between experiments is difficult (Table 1).

Table 1

Summary of diel observations of juvenile chinook and coho salmon and steelhead in various Pacific Northwest and Alaska river systems.

Environment	Life stage	Location	Method	Pertinent observations of movement behavior	Source
Yearling chinook salmon					
River	Smolt	Central Ferry Bridge (Snake R.)	Fyke net	Largest catches between 0300 and 0600h, smallest catches between 0600 and 1200h. Largest catches from shoreline areas during low and medium river flow, and midriver areas during high flow. Catches uniform in number from surface to bottom.	Mains and Smith 1964
River	Smolt	Byer's Landing (mid-Columbia R.)	Fyke net	Largest catches (70%) between 1800 and 0600h. Largest catches in shoreline areas. Largest catches in surface water (0.8m).	Mains and Smith 1964
Reservoir	Smolt	John Day (Columbia R.)	Purse seine	Largest catches during daylight (0700–2100h).	Sims et al. 1976
Reservoir	Smolt	Lower Monumental (Snake R.)	Monofilament gillnet	Largest catches at night; 92% of total catch. Catches in the upper 7.3m were 5 during the day and 109 at night, and catches below 7.3m increased from 6 during the day to 19 at night. Largest catches in central portion of reservoir, day and night.	Smith 1974
Reservoir	Smolt and fry	Mayfield (Cowlitz R.)	Floating fish trap	Largest catches (82% of total obtained between 2000 and 0800h.	Allen 1965
Reservoir	Fingerling and fry	Upper Mayfield (Cowlitz R.)	Trawl and gillnet	Largest catches during darkness or periods of high turbidity (trawl). Largest catches (87%) in upper 7.3m. Movement of fish not strongly downstream.	Smith et al. 1968
Reservoir	Smolt and fingerling	North Fork (Clackamas R.)	Gillnet	Largest catches during darkness near surface (0–5m) over deep water (15m).	Korn et al. 1967
Reservoir	Smolt	Rocky Reach (Columbia R.)	Sonar	Highest movement between dusk and dawn.	Leman 1978

Table 1 (continued)

Environment	Life stage	Location	Method	Pertinent observations of movement behavior	Source
Yearling chinook salmon (continued)					
Dam	Smolt	John Day (Columbia R.)	Dip net and airlift pump	Largest catches (92% of total) between dusk and dawn (8.5-h period). Turbine intake, 20 m below surface.	Sims et al. 1976 Sims and Ossiander 1981
Dam	Smolt	The Dalles (Columbia R.)	Fyke net in turbine intake	Largest catches (94%) at night (1900–0700 h). Largest catches (75% of total) from upper third of intakes (top of turbine intake, 6 m below surface).	Long 1968
			Dip net in gatewell	Largest catches during daylight (0700–2100 h) with only 11% of total caught in darkness (8.5-h period).	Sims et al. 1976 Nichols 1979
Dam	Smolt	The Dalles (Columbia R.)	Fyke net in sluiceway	Largest catches in daylight (0800–1400 h) with few fish after dark; 3-ft deep surface flow over sluiceway gate. Largest catches near dusk (1700–2200 h) with few fish at other periods; 2-ft deep surface flow over sluiceway gate.	Nichols 1979
Subyearling chinook salmon					
Estuary	Smolt	Puget Island and Jones Beach (Columbia R. estuary)	Beach seine	90% of catch from daylight sets (0600–2100 h). Largest catches during early morning and at dusk.	Dawley et al. 1986
River	Fingerling and fry	Sixes R. (Oregon R.)	Traps	Both emergence of fry from the gravel and downstream migration of fry and fingerling primarily during darkness.	Reimers 1973
Reservoir	Smolt	John Day (Columbia R.)	Purse seine	Largest catches during daylight (0700–2100 h).	Sims et al. 1976
Dam	Smolt	John Day (Columbia R.)	Dip net and airlift pump in gatewell	Largest catches (88% of total) between dusk and dawn. Turbine intake, 20 m below surface.	Sims et al. 1976 Sims and Ossiander 1981
Dam	Smolt	The Dalles (Columbia R.)	Fyke net in turbine intake	Largest catches (67%) at night (1900–0700 h). Largest catches (49% of total) from upper third of water column (4.4 m) entering the intakes (top of turbine intake, 6 m below surface).	Long 1968
			Dip net in gatewell	Largest catches during daylight (0700–2100 h) with 10% of total caught in darkness (8.5-h period). Turbine intake, 6 m below surface.	Sims et al. 1976 Nichols and Ransom 1980
Dam	Smolt	The Dalles (Columbia R.)	Fyke net in sluiceway	Largest catches in daylight (0600–0700 and 1400–2100 h) with few fish after dark; 3-ft deep surface flow over sluiceway gate.	Nichols and Ransom 1980
Coho salmon					
Estuary	Smolt	Columbia R.	Purse seine	Largest catches at midday (1000–1400 h).	Durkin 1982
River	Smolt	Minter Creek (Puget Sound)	Trap	Largest catches at dawn and dusk.	Salo and Bayliff 1958
River	Smolt	Taku R. (S.E. Alaska)	Scoop trap	Largest catches at dawn and dusk.	Meehan and Siniff 1962
Reservoir	Smolt	Brownlee (Snake R.)	Fyke net	Largest catches at dawn and dusk.	Monan et al. 1969
Reservoir	Smolt	John Day (Columbia R.)	Purse seine	Largest catches during daylight (0700–2100 h).	Sims et al. 1976

Table 1 (continued)

Environment	Life stage	Location	Method	Pertinent observations of movement behavior	Source
Coho salmon (continued)					
Reservoir	Smolt and fingerling	North Fork (Clackamas R.)	Gillnet	Largest catches at dawn and dusk; near surface during darkness and deeper during daylight.	Korn et al. 1967
Reservoir	Smolt and fingerling	Round Butte (Deschutes R.)	Gillnet	Few fish captured during daylight during any season. During spring migration period, smolts captured principally near surface (0–3.7 m).	Korn et al. 1967
Reservoir	Fingerling and fry	Upper Mayfield (Cowlitz R.)	Trawl and gillnet	Largest catches during darkness or periods of high turbidity (trawl). Largest catches (87%) near surface (0–7.3 m). Movement of fish not strongly downstream.	Smith et al. 1968
Dam	Smolt	John Day (Columbia R.)	Dip net in gatewell of dam	Largest catches during darkness (2100–0700 h). Turbine intake, 20 m below surface.	Sims et al. 1976
Dam	Smolt	The Dalles (Columbia R.)	Dip net in gatewell of dam	Largest catches during daylight (0700–2100 h). Turbine intake, 6 m below surface	Sims et al. 1976
Dam	Smolt	The Dalles (Columbia R.)	Fyke net in sluiceway	Largest catches in daylight (0800–1400 h) with few fish after dark; 3-ft deep surface flow over sluiceway gate. Largest catches near dusk (1700–2200 h) with few fish at other periods; 2-ft deep surface flow over sluiceway gate.	Nichols 1979
Steelhead					
Reservoir	Smolt	John Day (Columbia R.)	Purse seine	Largest catches during daylight (0700–2100 h).	Sims et al. 1976
Reservoir	Smolt	Lower Monumental (Snake R.)	Monofilament gillnet	Largest catches at night; 76% of daily total. Catches in the upper 7.3 m increased from 146 during the day to 396 at night and catches below 7.3 m from 56 during the day to 420 at night. Uniform distribution across the reservoir day and night.	Smith 1974
Reservoir	Smolt and fry	Mayfield (Cowlitz R.)	Floating fish trap	Largest catches (82% of total) obtained between 2000 and 0800 h.	Allen 1965
Reservoir	Fingerling and fry	Upper Mayfield (Cowlitz R.)	Trawl and gillnet	Largest catches during darkness or periods of high turbidity (trawl). Largest catches (87%) in upper 7.3 m. Movement of fish not strongly downstream.	Smith et al. 1968
Reservoir	Smolt and fingerling	North Fork (Clackamas R.)	Gillnet	Largest catches (few fish) during darkness near surface over deep water.	Korn et al. 1967
Dam	Smolt	John Day (Columbia R.)	Dip net and airlift pump in gatewell of dam	Largest catches (77% of total) between dusk and dawn (8.5 h period). Turbine intake, 20 m below surface.	Sims et al. 1976
Dam	Smolt	The Dalles (Columbia R.)	Fyke net in turbine intake	Largest catches (85%) at night (1900–0700 h). Largest catches (72% of total) from the upper third of the water column (4.4 m) entering the intakes (top of turbine intake, 6 m below surface).	Long 1968

Table 1 (continued)

Environment	Life stage	Location	Method	Pertinent observations of movement behavior	Source
Steelhead (continued)					
Dam	Smolt	The Dalles (Columbia R.)	Fyke net in turbine intake	Largest catches during daylight with only 29% of total caught in darkness (8.5h period). Turbine intake, 6m below surface.	Sims et al. 1976
Dam	Smolt	The Dalles (Columbian R.)	Fyke net in sluiceway	Largest catches in daylight (0800–1400h) with few fish after dark; 3-ft deep surface flow over sluiceway gate. Largest catches near dusk (1700–2200h) with few fish at other periods; 2-ft deep surface flow over sluiceway gate.	Nichols 1979

Variability of catch between sets and sampling periods was higher for yearling chinook salmon than for other salmonids. The origin of marked fish varied substantially among the three purse-seine sampling periods (Table 2). The largest portions of the catch originated in the Willamette, mid-Columbia, and Snake Rivers for the first, second, and third sampling periods, respectively. Stock differences and changes in abundance among stocks during the diel sampling periods may have caused the higher variability in the catch.

We found reasonable agreement among the diel catch patterns reported here and those from extensive morning sampling (2615 sets) at Jones Beach in May and June 1979–83 (Dawley et al. 1986) (Fig. 3). A noteworthy exception was that beach seine catches near sunrise were lower during the diel study because sets were made before sunrise to remove fish which resided in the area overnight.

It is generally agreed that net avoidance is probably greatest in daylight; therefore, decreased net catches at night should represent decreased fish abundance in the water sampled. It seems unlikely that decreased catches at Jones Beach during darkness were caused by surface- or midwater-oriented juveniles maintaining their position against current velocities up to 5 km/hour. Data obtained at Jones Beach by Dawley et al. (1986) showed that marked subyearling chinook salmon released into the shoreline sampling area at night were recaptured at a much higher rate than marked fish released during daylight (30.6 vs. 8.0%). Because midriver-oriented yearling fish do not appear in shoreline areas at Jones Beach during darkness, they probably hold near the bottom,

Table 2

Origin of marked yearling chinook salmon captured by purse seine during diel sampling, 1979 and 1980.

Origin	Sampling dates: 10–11 May 1979	23–24 May 1979	14–15 May 1980
	% of marks		
Snake River	7	19	60
mid-Columbia River	13	47	40
Transported and released downstream from Bonneville Dam	33	28	0
Willamette River	40	0	0
Lower Columbia River	7	6	0

Table 3

Measured movement rates of juvenile salmonids and water velocities in a 155-km reach of the Columbia River between Bonneville Dam and Jones Beach at two volumes of river flow.

River flows (1000 m^3/s)	Water velocity (km/h)[b]	Movement rates (km/h)[a]: Chinook salmon, Subyearling	Chinook salmon, Yearling	Coho salmon	Steelhead
8.1 ± 0.5	4.8	0.9	0.8	1.4	3.2
11.3 ± 0.5	5.0	1.0	—	0.9	1.7

[a] Zero to nine marked groups were available for each calculation of average movement rate at these designated river flows (Dawley et al. 1986).
[b] From Blahm (1974).

particularly in deep areas of low current velocity. This premise is supported by studies on water velocity (Blahm 1974) and the movement rates of marked juvenile salmon released below Bonneville Dam and recovered at Jones Beach (Dawley et al. 1986) (Table 3). In all cases, fish migration speeds from release site to capture in the estuary were less than water velocity (Dawley et al. 1986).

In conclusion, the most appropriate times and locations for sampling to attain maximum CPSs are as follows: Subyearling chinook salmon, sunrise to early afternoon nearshore; yearling chinook salmon, sunrise to early afternoon midriver; yearling coho salmon, midmorning to early evening nearshore and sunrise to early afternoon midriver; juvenile steelhead, noon to early evening midriver.

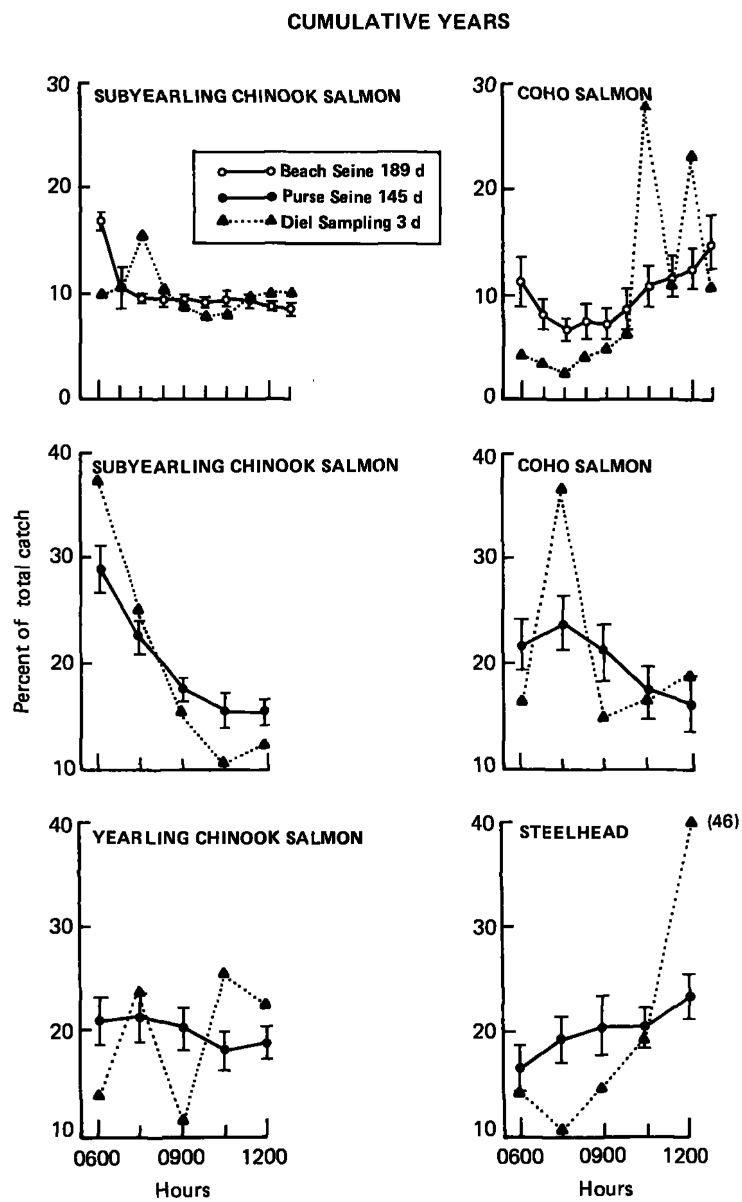

Figure 3
Percent total catch of juvenile salmonids during morning hour sampling at Jones Beach, Columbia River (1979–83) compared with diel sampling results (mean value per time interval and 95% confidence limits); d = total number of sampling days used for each estimate.

Acknowledgment

The authors acknowledge Dr. Theodore Blahm (deceased) for providing inspiration and encouragement while conducting this study.

Citations

Allen, R.
1965 Juvenile fish collector operation at Lake Mayfield July 1, 1964 to June 30, 1965. Report to Bureau of Commercial Fisheries, Contract 14-17-0001-1357. Wash. Dep. Fish., Olympia, 23 p.

Blahm, T.H.
1974 Gas supersaturation research, Prescott Facility–1974. Report to U.S. Army Corps of Engineers, Contract DACW57-74-F-0414. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98112, 34 p.

Dawley, E.M., R.D. Ledgerwood, and A.L. Jensen
1985 Beach and purse seine sampling of juvenile salmonids in the Columbia River estuary and ocean plume, 1977–1983; Vol. I. Procedures, sampling effort, and catch data. NOAA Tech. Memo. NMFS F/NWC-74, Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98112, 260 p.

Dawley, E.M., R.D. Ledgerwood, T.H. Blahm, C.W. Sims, J.T. Durkin, R.A. Kirn, A.E. Rankis, G.E. Monan, and F.J. Ossiander
1986 Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966–1983. Report to Bonneville Power Administration, Portland, Oregon. Contract DE-A179-848BP39652. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98112, 256 p.

Durkin, J.T.
1982 Migration characteristics of coho salmon (*Oncorhynchus kisutch*) smolts in the Columbia River and its estuary. *In* Kennedy, V. (ed.), Estuarine comparisons, p. 365–375. Academic Press, NY.

Durkin, J.T., and D. L. Park
1967 Purse seine for sampling juvenile salmon. Prog. Fish-Cult. 29:56–59.

Korn, L.M., L.H. Hreha, R.G. Montagne, W.G. Mullarkey, and E.J. Wagner
1967 The effects of small impoundments on the behavior of juvenile anadromous salmonids. Final Report to U.S. Bureau of Commercial Fisheries, Contract 14-17-0001-597,767,917, 1093, and 1238. Fish Comm. Oreg., Res. Div., Clackamas, 127 p.

Leman, B.D.
1978 Coordinated spilling at Columbia River dams during low river flows; response by Public Utility Districts. Unpubl. manuscr., Chelan County, Public Utility District #1, Wenatchee, WA, 15 p.

Long, C.
1968 Diel movement and vertical distribution of juvenile anadromous fish in turbine intakes. Fish. Bull., U.S. 66: 599–609.

Mains, E.M., and J. M. Smith
1964 The distribution, size, time and current preferences of seaward migrant chinook salmon in the Columbia and Snake Rivers. Wash. Dep. Fish., Fish. Res. Pap. 2(3):5–43.

Meehan, W.R., and D.B. Siniff
1962 A study of the downstream migrations of anadromous fish in the Taku River, Alaska. Trans. Am. Fish. Soc. 91: 399–407.

Monan, G.E., R.J. McConnell, J.R. Pugh, and J.R. Smith
1969 Distribution of debris and downstream-migrating salmon in the Snake River above Brownlee Reservoir. Trans. Am. Fish. Soc. 98:239–244.

Nichols, D.W.
1979 Passage efficiency and mortality studies of downstream migrant salmonids using The Dalles ice-trash sluiceway during 1978. Report to U.S. Army Corps of Engineers, Contract DACW 57-78-C-0058. Oreg. Dep. Fish Wildl., Portland, 28 p.

Nichols, D.W., and B.H. Ransom
1980 Development of The Dalles Dam ice and trash sluiceway as a downstream migrant bypass system, 1980. Final report to U.S. Army Corps of Engineers, Contract DACW 57-78-C-0058. Oreg. Dep. Fish Wildl., Portland, 37 p.

Reimers, P.E.
1973 The length of residence of juvenile fall chinook salmon in Sixes River, Oregon. Res. Rep. Fish Comm. Oreg. 4(2): 3–43.

Salo, E.O., and W.H. Bayliff
1958 Artificial and natural production of silver salmon, *Oncorhynchus kisutch*, at Minter Creek, Washington. Wash. Dep. Fish. Res. Bull. 4:1–76.

Sims, C.W., and R.C. Johnsen
1974 Variable mesh beach seine for sampling juvenile salmon in the Columbia River estuary. Mar. Fish. Rev. 36(2):23–26.

Sims, C.W., and F.J. Ossiander
1981 Migrations of juvenile chinook salmon and steelhead trout in the Snake River from 1973 to 1979, a research summary. Final report to U.S. Army Corps of Engineers, Contract DACW68-78-C-0038. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98112, 53 p.

Sims, C.W., R.C. Johnsen, and W.W. Bentley
1976 Effects of power peaking operations on juvenile salmon and steelhead trout migrations, 1975. Final report to U.S. Army Corps of Engineers, Contract DACW68-77-C-0025. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98112, 61 p.

Smith, J.R.
1974 Distribution of seaward migrating chinook salmon and steelhead trout in the Snake River above Lower Monumental Dam. Mar. Fish. Rev. 36(8):42–45.

Smith, J.R., J.J. Pugh, and G.E. Monan.
1968 Horizontal and vertical distribution of juvenile salmonids in upper Mayfield Reservoir, Washington. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 566, 11 p.

U.S. Army Corps of Engineers
1978–1980 Annual fish passage reports, Columbia and Snake Rivers, for salmon, steelhead, and shad. U.S. Army Corps of Engineers, North Pac. Div., Portland, OR, 41 p.

Van Hyning, J.M.
1973 Factors affecting the abundance of fall chinook salmon in the Columbia River. Res. Rep. Fish Comm. Oreg. 4(1):3–87.