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Survival of Subyearling and Yearling Fall Chinook Salmon Released at Lyons Ferry Hatchery or Barged Downstream

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Washington Department of
FISH AND WILDLIFE
Hatcheries Program
Assessment and Development Division

Report # H96-08

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Abstract

We compared the release-to-adult survivals of coded-wire tagged groups of fall chinook salmon (Oncorhynchus tshawytscha) in a 2x2 factorial experimental design: subyearlings and yearlings released directly from Lyons Ferry Hatchery versus those barged below two mainstem hydroelectric dams on the Snake River, Washington. Releases comprised six brood years over a six year period. In every release year, salmon released as yearlings performed better than subyearlings, both in escapement to the Snake River, and in contribution to Pacific Ocean and lower Columbia River fisheries. We found no consistent differences in rates of escapement and fishery contribution between transported and on-station releases for either age class. Survival rates of both subyearlings and yearlings varied significantly with year of release. Median travel speeds of branded salmon released on-station varied directly with Snake River flows. However, we saw no general relation between flow (and attendant spill) in the Snake and lower Columbia rivers and subsequent release-to-adult survivals, both for subyearlings and yearlings. Likewise, transportation did not improve survival of yearlings in low-flow conditions, and had limited but inconsistent benefits to subyearlings when Snake River flow and spill were low. The advantages of transportation past two mainstem dams were probably offset by: 1) additional handling stress of loading and unloading fish for transportation, coupled with 2) the short duration of transport relative to the time required to acclimate to barge hauling. Transported salmon strayed to freshwater areas outside the Snake River Basin at a higher rate than those released on-station. Conversely, salmon released on-station strayed to locations within the Snake River Basin at a higher rate than transported salmon. Overall, the stray rate for all treatment groups to freshwater locations outside the Snake River Basin was 1.8%.

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Introduction

Means to improve survival of chinook salmon (Oncorhynchus tshawytscha) smolts during downstream migration in the Columbia and Snake rivers is an acute concern to Pacific Northwest fishery managers (Netboy 1980; Raymond 1988). Two primary avenues to reduce losses are to improve fish passage capabilities through the mainstem dams (Raymond 1979; Giorgi et al. 1988), and to collect and transport smolts to a point downstream of some or all of the dams (Ceballos et al. 1991, 1992). Attempts to improve survival in the Snake River through smolt transportation have been underway for over three decades (Ellis 1956; Ebel 1980; Matthews 1992). Under certain conditions, survival benefits gained through transportation may be compromised by increased stray rates of the returning adults (Slatick et al. 1982; Park 1985), which presumably is because the smolt's ability to imprint during transport can be reduced (Slatick et al. 1988), particularly when transported directly from a hatchery. The alternate strategy, to bypass smolts around powerhouses at the hydroelectric dams (Brege at al. 1988; Giorgi et al. 1988), has met with variable success. Bypass efficiency may be a function of river flows and velocities during the juvenile outmigration (Raymond 1968; Bentley and Raymond 1976), powerhouse configuration of each dam (Bentley and Raymond 1968), bypass and spill capabilities at each dam (Anderson 1988; Peters 1992), and predation near the dams (Ruggerone 1986; Rieman et al. 1991).

The U.S. Congress authorized the Lower Snake River Fish and Wildlife Compensation Plan (LSRCP) in 1976 (Public Law 94-587). As part of the LSRCP, Lyons Ferry Fish Hatchery (FH) was constructed in 1985. This hatchery produces fall chinook salmon to compensate for those fish lost through inundation of their habitat and passage mortalities due to the Snake River dams (USACE 1975). Lyons Ferry fall chinook salmon were developed from salmon indigenous to the Snake River (Bugert et al. 1995). This stock is "ocean-type" in life history characteristics (Healey 1991), which among other tendencies, typically migrates to the ocean as subyearlings. The production capacity for fall chinook salmon at Lyons Ferry FH is 46,176 kg (9,162,000 subyearlings at 5 g). During this study, smolt production was 18-52% of capacity, because of poor escapement of this stock to the Snake River. Therefore, each year at least 400,000 eggs were designated for yearling production, which has been shown to increase overall survival at other Pacific salmon hatcheries (Seidel and Mathews 1977; Sholes and Hallock 1979; Martin and Wertheimer 1989). This strategy could be even more beneficial on the Snake River, where migration conditions are poorer in summer than spring (Raymond 1968; Buettner and Nelson 1990). Subyearling smolts typically emigrate to the sea in July and August, when river flows and dam spills are lower and water temperatures are higher (Connor et al. 1992). Consequently, subyearling smolts are presumed to suffer greater mortality than yearling smolts, which typically emigrate in April and May (Raymond 1988).

The first objective of this study was to compare release-to-adult survival rates of subyearling and yearling fall chinook salmon reared at Lyons Ferry FH and released either on-station or transported by barge downstream of Lower Monumental and Ice Harbor dams on the Snake River. At the time of this study, these two hydroelectric dams had no juvenile fish bypass facilities. Juvenile passage through these dams was via the powerhouse or spillway. A second objective of this study therefore, was to determine whether barging fish downstream of two dams would increase survival of these hatchery salmon.

Study Area and Methods

Lyons Ferry FH is located at the confluence of the Palouse and Snake rivers at river km 95 (Figure 1), 617 km from the Columbia River estuary. The hatchery is 28 km upstream of Lower Monumental Dam and 78 km upstream of Ice Harbor Dam, the hydroelectric dams furthest downstream on the Snake River. Migrating smolts encounter four more dams on the lower Columbia River before reaching the estuary. Lyons Ferry FH is the only hatchery in the Snake River Basin capable of direct loading of smolts from the raceways to a barge, which can be moored adjacent to the facility. At McNary Dam, smolts are bypassed downstream, or collected for transport around the four lower Columbia River dams (Giorgi and Sims 1987; Brege et al. 1988; Stuehrenberg and Johnson 1990). Some migrants from all four release groups would therefore have been intercepted at McNary Dam for transport--we assumed the interception rates for on-station and transported release groups were the same.

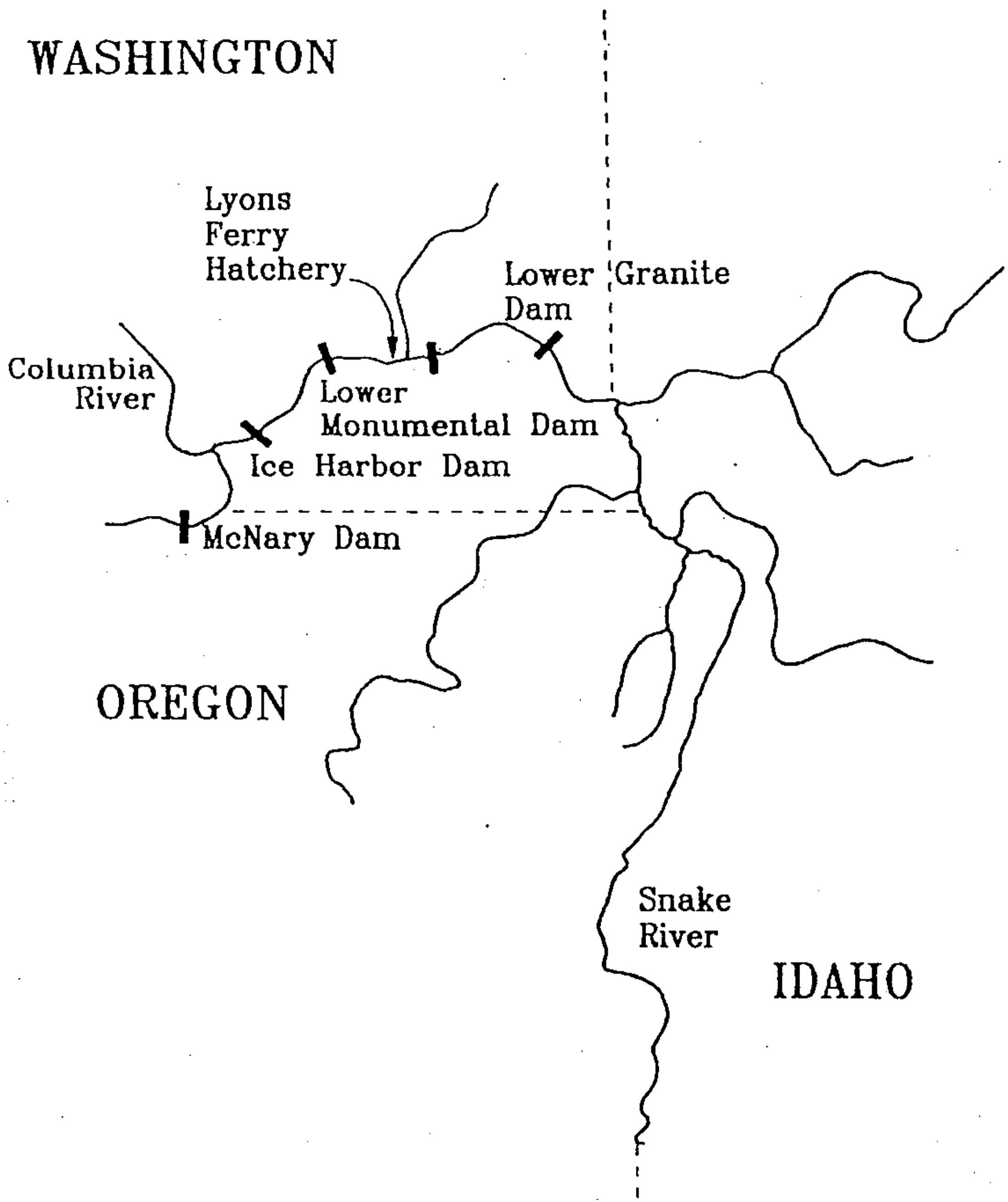

Figure 1. Lower Snake and mid Columbia rivers, showing locations of Lyons Ferry Fish Hatchery, Lower Granite, Lower Monumental, Ice Harbor, and McNary dams.

We compared the survival of subyearling and yearling fish using two different release methods in a 2x2 randomized-block factorial comparison (Kirk 1982). The fish were released either on-station (directly from the hatchery) or transported off-station. Transported smolts were released immediately downstream of Ice Harbor Dam, allowing them 17 km of uninterupted migration downstream to the mouth of the Snake River and 51 km in the Columbia River to McNary Dam. The salmon released on-station had to migrate through the two lower Snake River dams and four Columbia River dams if they were not collected for transport at McNary Dam.

The experimental unit was the aggregate of those salmon handled together and randomized. These aggregates were marked with coded-wire tags (CWT; Bergman et al. 1968; Vreeland 1990), with one to five codes per experimental unit, depending upon the year and treatment. The treatment groups were released each year over a six-year period (1985 to 1990), which we blocked in our analyses to isolate the variation attributed to the year of release. Lyons Ferry FH produced enough salmon in 1987 through 1990 to do all four treatments in the experiment. We did not have sufficient production in 1985 and 1986 to complete all treatments of the experimental design (Figure 2). Average numbers of salmon tagged for each treatment cell were 243,164 (SD=8,715) subyearlings and 161,488 (SD=77,992) yearlings (Table 1).

Hatchery Rearing

The average sizes at release and rearing density indices for those salmon within each age group were held the same (Table 2). Rearing densities for all treatment groups were well below the recommended levels for chinook salmon (Martin and Wertheimer 1989; Banks 1994, Ewing and Ewing 1995). No significant epizootics or other fish health problems occurred to any treatment group during this study. Water source and temperature (12° C during incubation and rearing) were the same for all treatment groups. All water was single use. The raceways at Lyons Ferry FH were not designed to allow direct release into the Snake River. The salmon were therefore crowded and pumped, or gravity-released, into the river for the on-station release. Salmon were crowded and pumped via a pipe into the barge for the transported release. Distance from the raceways to the barge mooring was between 80 and 120 m. On-station fish were released near the barge mooring, so transported and on-station release groups were handled the same.

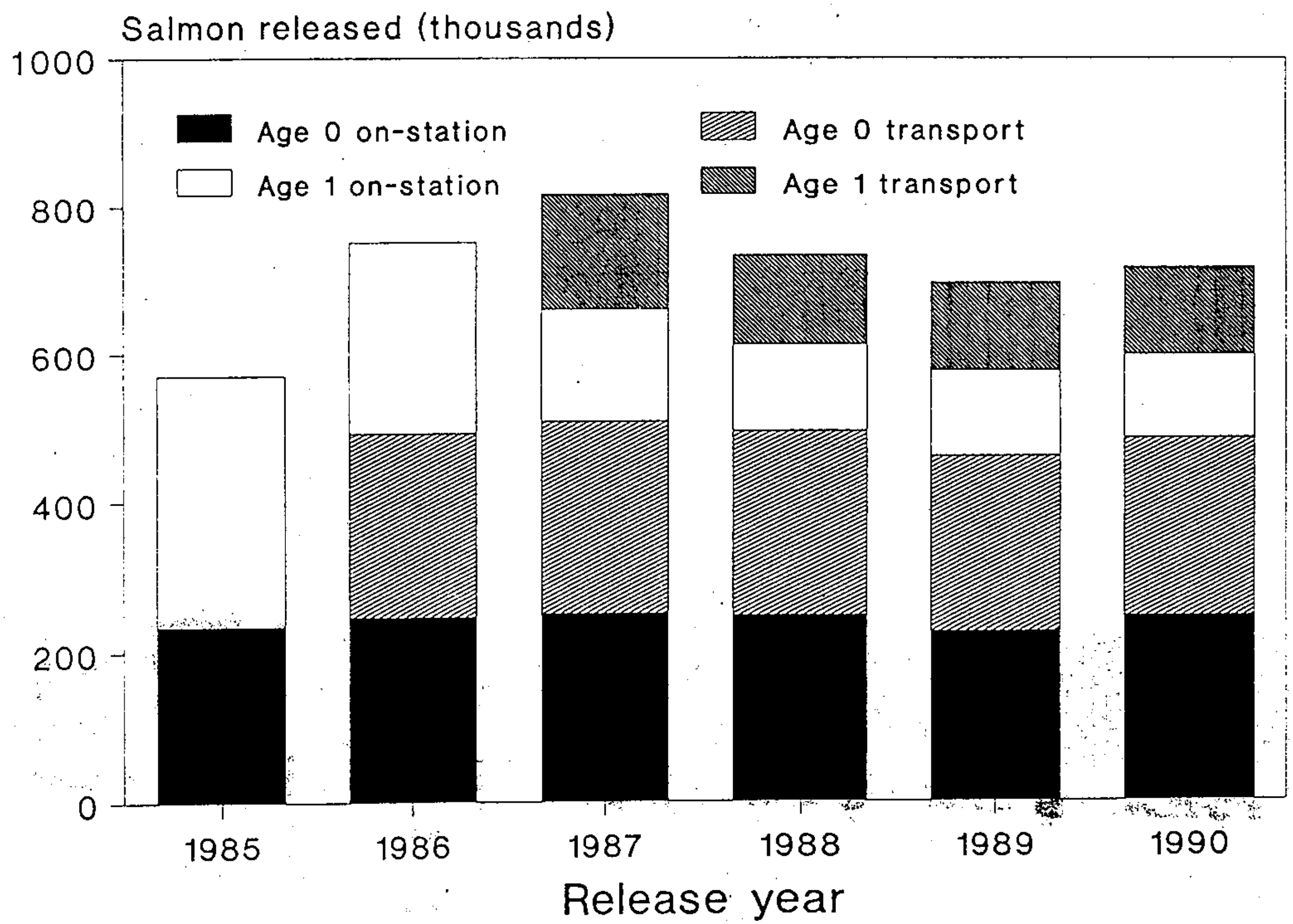

Figure 2. Number of coded-wire tagged fall chinook salmon released by treatment type from Lyons Ferry FH from 1985-1990.

Table 1. Numbers of coded-wire tagged fall chinook salmon released within each treatment from Lyons Ferry Fish Hatchery from 1985 to 1990.

Release year	Subyearling on-station	Subyearling transport	Yearling on-station	Yearling transport
1985	234,985	--	334,442	--
1986	246,625	245,560	258,355	--
1987	251,646	255,998	152,479	156,036
1988	248,739	245,749	117,705	120,804
1989	226,478	234,103	115,350	119,217
1990	246,873	238,045	112,519	117,977

On-Station Releases

The dates of release for both yearlings and subyearlings were coordinated annually with the Corps of Engineers for controlled spills at Lower Monumental and Ice Harbor dams from 1800 to 0600 hours beginning the following day. However, only limited spill was provided at both dams in 1987, and there was no spill at Ice Harbor Dam in 1988. All releases were made in conjunction with the yearly Water Budget Coordinated Plan of Operation (CPO), authorized by the Northwest Power Planning Council (NPPC 1987). In general, subyearling chinook salmon were released in the first week of June (seven to nine months after fertilization) at a mean fork length of 88 mm. Yearlings were released at a mean fork length of 168 mm in mid-April (17 to 19 months after fertilization; Table 2). From 1986 to 1990, representative groups of salmon released on-station were marked with freeze brands (Mighell 1969), to estimate travel times from the hatchery to downstream sampling stations (Lower Monumental Dam on Snake River and McNary Dam on Columbia River). Typically, 80,000 subyearlings and 40,000 yearlings were branded each year. Additionally, in 1987 and 1988, 240 branded salmon from each age group were sampled to determine gill Na^+K^+ ATPase levels (Ewing and Birks 1982; Virtanen and Soivio 1985) before release, and during their passage through McNary Dam.

Table 2. Mean release sizes (with SD) and final rearing conditions of coded-wire tagged fall chinook salmon released from Lyons Ferry Fish Hatchery from 1985 to 1990. Releases were comprised of four treatments: subyearlings and yearlings released on-station, and transported (barged) downstream of Ice Harbor Dam.

	Mean release size		Final rearing conditions	
Treatment	Fork length (mm)	Condition factor[1]	Pond loading[2]	Density index[3]
Subyearling on-station	88.2 (5.8)	1.03 (0.08)	11.3 (5.5)	0.129
Subyearling transport	87.6 (4.7)	1.09 (0.08)	12.1 (7.3)	0.138
Yearling on-station	168.9 (13.7)	1.12 (0.09)	10.7 (3.8)	0.063
Yearling transport	167.6 (14.0)	1.08 (0.07)	15.0 (2.1)	0.089

[1] Condition factor (K) is expressed as (weight/fork length^3)x100,000.

[2] Pond loading is expressed as kg biomass/cubic meter of rearing space.

[3] Density index is expressed as pond loading/fork length (adapted from Banks 1994).

Transported (barged) Releases

Salmon were loaded into a fish transportation barge the day after the on-station releases, and were released adjacent to the lower navigation wing wall at Ice Harbor Dam the following day. The actual dates of on-station and transported releases were based upon the CPO, and the schedule of the barge operators. Average confinement in the barge was 34 h, about 20 h of which were spent moored adjacent to the hatchery after the fish were loaded. Based on recoveries of branded fish at Lower Monumental and McNary dams, and the known time of release from the barge, we infer that salmon from transported and on-station releases arrived at the confluence of the Snake River on, or near, the same day. Water was continuously pumped through the barge during transport, to acclimate fish to changes in ambient water temperatures (Ceballos et al. 1991), and as an assumed means to aid fish in olfactory acclimation (McCabe et al. 1979) to the Snake River.

The unique location of Lyons Ferry FH and our experimental needs precluded the simultaneous transport of salmon from the hatchery with fish collected at upstream collection points. The salmon transported for this study were therefore never mixed with steelhead (O. mykiss) or other salmon. Loadings for salmon transported in the barges were often low, relative to mainstem collection and transport conditions. The range in loadings for yearlings during transport was 280 to 530 g/L/min. Subyearlings were typically transported at 200 g/L/min except the 1988 release, which was transported at 640 g/L/min. All groups except those subyearlings transported in 1988 were well below the FTOT[1] maximum loading criterion of 600 g/L/min water inflow (Ceballos et al. 1992).

Coded-Wire Tag Recoveries

We compared the release-to-adult survival of the treatment groups two ways: 1) escapement to the Snake River (all recovery locations in the Snake River), and 2) overall survival, which includes escapement to the Snake River plus all other recoveries listed in the Regional Mark Information System (RMIS) of the Pacific States Marine Fisheries Commission. Escapement to the Snake River was determined through CWT recoveries at Lyons Ferry FH, adult trapping operations at Ice Harbor and Lower Granite dams (Figure 1), limited sport harvest, and on the spawning

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[1] The Fish Transportation Oversight Team (FTOT), provides recommendations on the Columbia River transport program through annual biological monitoring.

grounds of the Snake River and tributaries. Recoveries were expanded by trap efficiency at Lower Granite Dam where 50-70% of tagged fall chinook salmon intercepted at the dam were collected for CWT recovery. Recovery rates on spawning grounds or sport harvest were expanded by the sampling rate. Expansions did not include the ratio between the marked and unmarked fish released, since we believe that the marked fish may not adequately represent the entire population.

We estimated contribution to ocean and freshwater fisheries, as well as escapement, through retrieval of CWT recovery data from the RMIS on 24 May 1995. We combined those data with recent CWT recoveries (through December 1994) in the Snake River Basin that were not yet in the RMIS (Appendix A). Some of the fishery recovery data were expanded, based upon several assumptions, increasing the probability for discrepancies in expansion rates by location or agency of CWT recovery (de Libero 1986). For this reason, we used only escapement to the Snake River for statistical comparisons between treatment groups in our analyses, except where noted. We assumed there was no difference in harvest rates among treatment groups. For all treatment groups and years, escapement to the Snake River was strongly correlated with overall survival (fishery contribution plus escapement; r^2=0.94). An average of 24.5% of the fish were recovered as Snake River escapement (Appendix B).

We compared the expanded recovery estimates for our treatment groups using the SAS General Linear Models procedures for unbalanced experimental designs (SAS Institute Inc. 1988). Expanded recovery estimates were arcsine transformed prior to statistical analyses (Zar 1984). Multiple contrasts were made with a protected least squares difference method for unbalanced data. Statistical power analyses were performed using the SYSTAT design module (Dallal 1988).

Homing Abilities

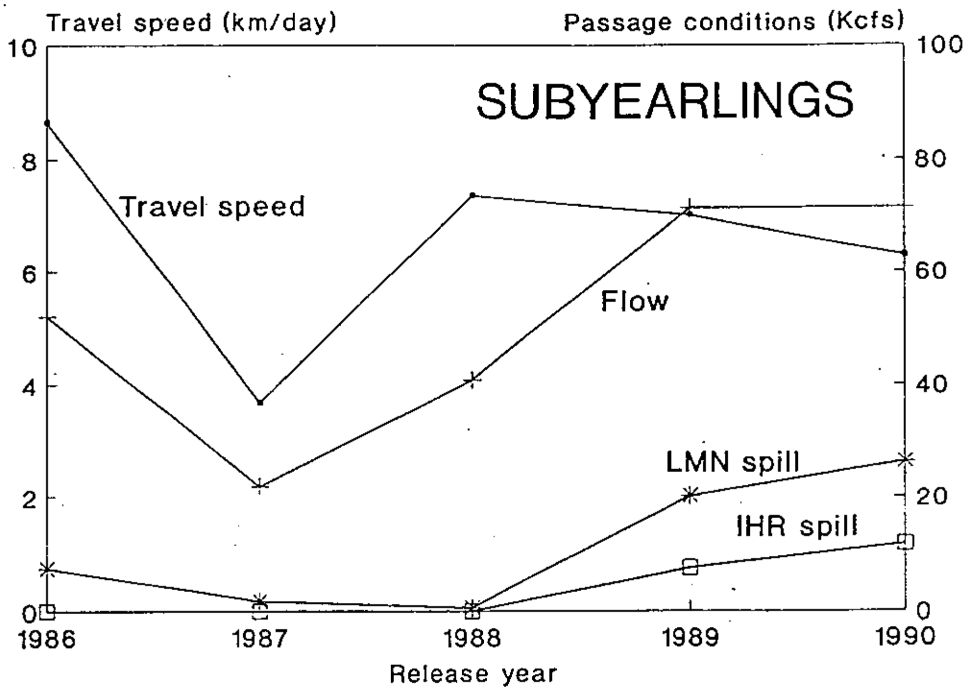
To compare homing rates of the on-station and transport treatment groups, we compiled data from all hatcheries, fish traps, and spawning grounds, within and outside the Snake River Basin, where Lyons Ferry CWT recoveries were reported. We also evaluated the extent to which salmon bypassed Lyons Ferry FH to spawn naturally in the Snake River Basin. From 1985 to 1994, returning salmon were killed or recovered dead at Lyons Ferry FH, Dworshak FH, Lower Granite Dam, and spawning grounds. We identified and recorded the recovery location for each fish with a CWT. This enabled us to assess homing abilities of the treatment groups within the Snake River Basin. Within basin homing rates were then expressed as a percentage of Snake River CWT recoveries. We compared the within and outside the Snake River Basin homing rates through two independent Chi square analyses (2x2 tests).

Results

Fish Passage

Branded subyearling and yearling salmon released on-station from Lyons Ferry FH typically began arriving at Lower Monumental Dam two days after liberation. For both release groups, spill at Lower Monumental and Ice Harbor dams varied within and between years, depending upon instantaneous discharge and spill levels negotiated through the CPO. Spill for both the yearling and subyearling groups terminated at the projected 90th percentile of the total Snake River spring and summer outmigrants, respectively. Based upon analysis of cumulative brand recoveries at downstream sampling locations, 90% of the salmon released each year from Lyons Ferry FH passed both Lower Monumental and Ice Harbor dams before spill termination (except when no spill was provided at Ice Harbor Dam in 1988; Figure 3).

Travel speeds of branded subyearling (1986 to 1990 release years) and yearling (1986 to 1989 release years) on-station releases from Lyons Ferry FH to McNary Dam (147 km downstream) appeared to vary directly with Snake River flow (measured at Lower Monumental Dam; Figure 3). Duration of the middle 80% subyearling passage at McNary Dam was typically 23 days (10% passage by 17 June, 90% passage by 9 July), with a range in median travel times (Berggren and Filardo 1993) of 20 to 40 days (Table 3). The middle 80% of branded yearling salmon generally passed McNary Dam between 26 April and 9 May (13 days; range, 18 to 26 days). Representative groups of subyearlings and yearlings released on-station from Lyons Ferry FH had mean gill ATPase levels of 24 and 27 μmol P_i/mg protein/h at release, respectively. At McNary Dam, the yearlings' enzyme activity was only slightly higher than release levels, but the subyearlings' enzyme activity increased until the late part of the outmigration.



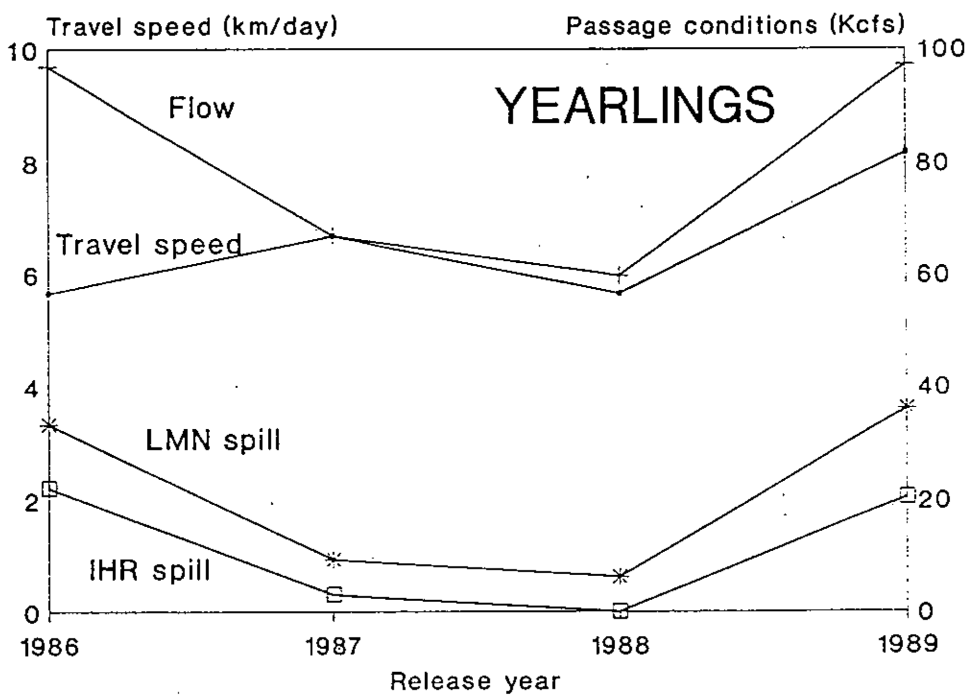


Figure 3. Travel speeds of branded subyearling (upper graph) and yearling (lower graph) fall chinook salmon from Lyons Ferry FH to McNary Dam. Travel speeds are compared to the average daily flow (measured at Lower Monumental Dam) and spills at both Lower Monumental and Ice Harbor dams during their middle 80th percentile of passage through each dam.

Table 3. Comparison of the middle 80% passage periods through Lower Monumental and McNary dams of branded subyearling and yearling fall chinook salmon released from Lyons Ferry Fish Hatchery in 1985 to 1990. Passage periods are compared with the number (and percent) of days spill was provided, and the average instantaneous daily rates of flow and spill at the dams during passage. Within each year, the upper and lower rows are the yearling and subyearling passage periods, respectively. The 1985 passage periods and the 1990 yearling passage period are interpolated from the known passage periods.

Project Year	Passage period	Days with spill	Days without spill	Percent with spill	Average flow (kcfs)	Average spill (kcfs)
Lower Monumental Dam						
1985	17 Apr to 6 May	20	0	100	88.92	18.46
	6 Jun to 30 Jun	7	18	28.0	71.57	7.37
1986	8 Apr to 29 Apr	22	0	100	96.94	33.30
	17 Jun to 16 Jul	20	10	66.7	51.98	7.37
1987	23 Apr to 2 May	10	0	100	66.86	9.25
	19 Jun to 24 Jul	16	20	44.4	21.80	1.74
1988	19 Apr to 9 May	18	3	85.7	59.76	6.14
	4 Jun to 10 Jul	5	22	18.5	40.80	0.54
1989	17 Apr to 30 Apr	14	0	100	97.18	36.04
	10 Jun to 28 Jun	18	1	94.7	71.31	20.04
1990	19 Apr to 5 May	17	0	100	65.84	21.59
	9 Jun to 30 Jun	22	0	100	71.42	26.20
McNary Dam						
1985	25 Apr to 10 May	6	10	37.5	220.17	12.75
	20 Jun to 13 Jul	0	23	0	138.51	0
1986	19 Apr to 9 May	16	5	76.2	248.68	26.32
	19 Jun to 16 Jul	2	26	7.1	158.92	0.39
1987	2 May to 11 May	10	0	100	240.55	37.67
	2 Jul to 6 Aug	0	36	0	106.90	0
1988	30 Apr to 15 May	0	17	0	175.01	0
	12 Jun to 10 Jul	0	30	0	129.80	0
1989	25 Apr to 10 May	14	2	87.5	246.78	21.61
	20 Jun to 12 Jul	0	23	0	127.18	0
1990	25 Apr to 10 May	7	9	43.8	230.77	9.42
	20 Jun to 15 Jul	17	8	68.0	248.99	31.54

Yearling Versus Subyearling Survival Rates

Salmon released as yearlings escaped at consistently higher rates to the Snake River than subyearlings released that same year (F=51.85; df=1, 12; P=0.0001), regardless of whether they were released on-station or transported (Figure 4, Table 4). The mean rates of escapement and overall survival for salmon released as yearlings were 0.453% (SD=0.370%) and 1.999% (SD=2.127%), respectively. The mean rates of escapement and overall survival for subyearlings released in the study were 0.052% (SD=0.048%) and 0.212% (SD=0.202%), respectively (Appendix A). Both age groups provided large contributions to catches in commercial and sport fisheries. Ocean harvest rates ranged from 16.5-70.3% for subyearling releases and 51.4-62.7% for yearling releases, depending upon the year. In general, subyearling releases were strongly represented in British Columbia high seas fisheries; yearling releases were recovered more in high seas fisheries off the Washington and Oregon coasts (Figure 5, Appendix B). On average, 42.0% of the subyearling harvest and 28.1% of the yearling harvest were in the Columbia River.

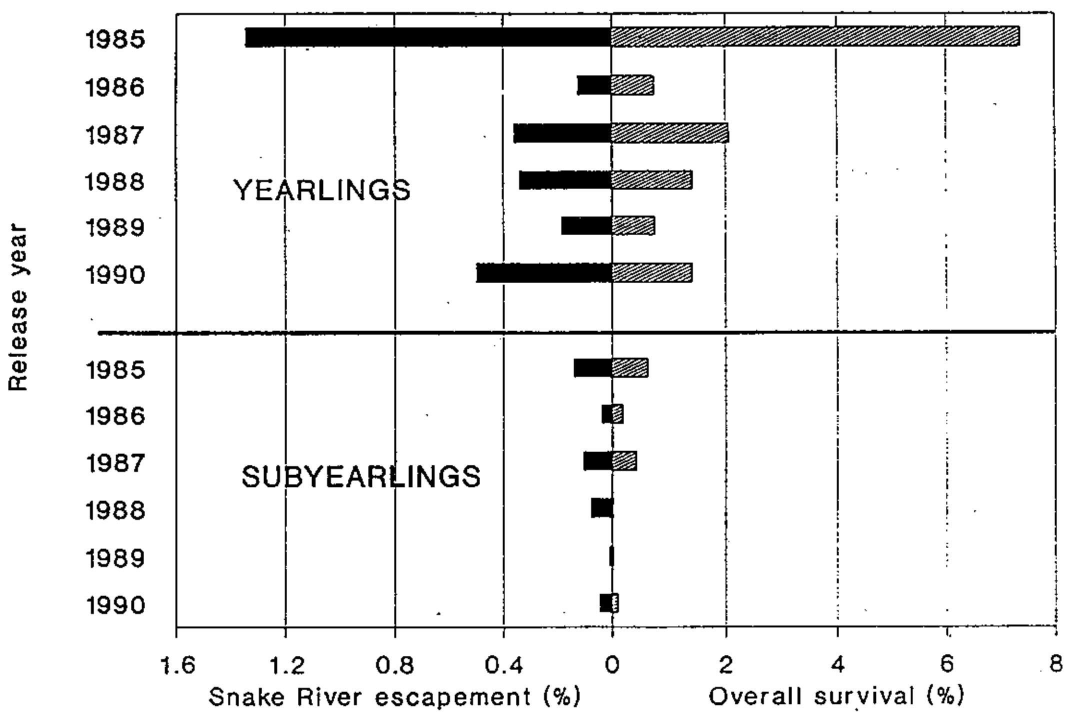


Figure 4. Escapement to the Snake River and overall survival (escapement plus expanded recoveries outside the Snake River) of Lyons Ferry fall chinook salmon released as yearlings and subyearlings from 1985 to 1990.

Table 4. Percent escapement to the Snake River and overall survival (escapement plus expanded recoveries outside the Snake River) of fall chinook salmon released as subyearlings and yearlings at Lyons Ferry FH (on-station), or transported and released downstream of Ice Harbor Dam. Means are weighted by the number of fish released per treatment group each year (Table 1).

Release year	Survival	Subyearling On-station	Subyearling Transport	Yearling On-station	Yearling Transport
1985	Snake River	0.143	- -	1.345	- -
	Overall	0.633	- -	7.370	- -
1986	Snake River	0.049	0.030	0.126	- -
	Overall	0.216	0.170	0.749	- -
1987	Snake River	0.058	0.155	0.406	0.319
	Overall	0.301	0.557	2.076	2.051
1988	Snake River	0.012	0.004	0.350	0.333
	Overall	0.025	0.015	1.376	1.464
1989	Snake River	0.014	0.008	0.092	0.279
	Overall	0.025	0.039	0.320	1.119
1990	Snake River	0.047	0.044	0.508	0.496
	Overall	0.097	0.100	1.339	1.432
Weighted mean					
	Snake River	0.054	0.050	0.599	0.354
	Overall	0.215	0.181	3.048	1.555
Weighted mean, excluding 1985 release					
	Snake River	0.036	0.050	0.269	0.354
	Overall	0.135	0.181	1.136	1.555

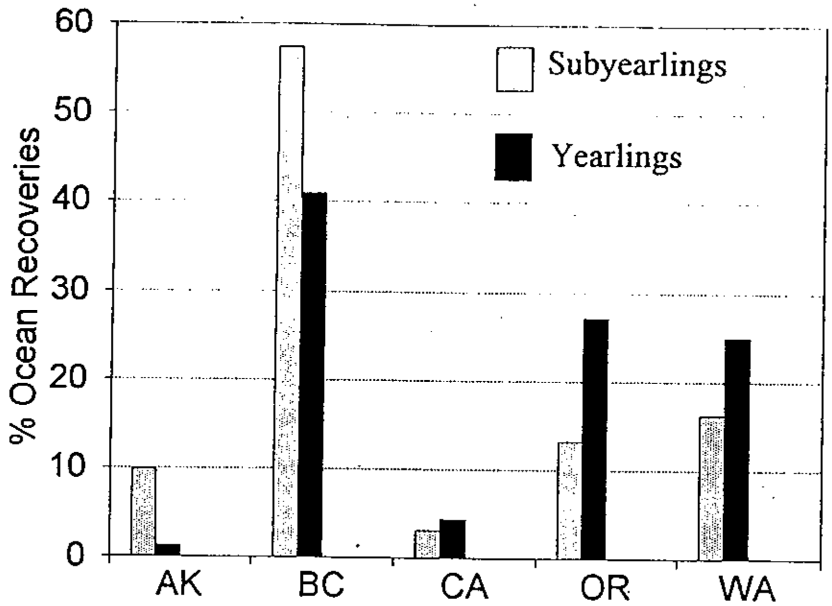
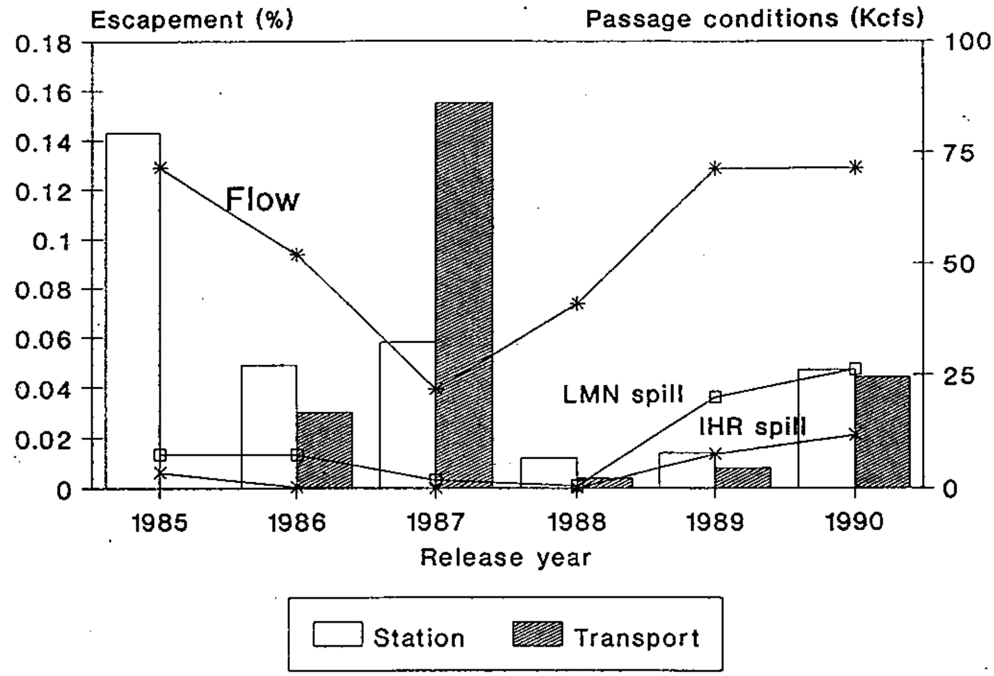


Figure 5. Ocean harvest distribution of Lyons Ferry fall chinook salmon (expanded from CWTs) reported in Alaska (AK), British Columbia (BC), California (CA), Oregon (OR), and Washington (WA). Small percentages reported by the National Marine Fisheries Service for various high sea fisheries are not graphed (see Appendix B).

On-Station Versus Transported Survival Rates

We detected no difference in escapement between the salmon released directly from the hatchery and those transported downstream of Ice Harbor Dam ($F=0.32$; $df=1, 12$; $P=0.58$), regardless of the age at release. The mean rates of escapement and overall survival for salmon released on-station were 0.235% (SD=0.367%) and 1.068% (SD=1.972%), respectively (Appendix A). The mean rates of escapement and overall survival for those salmon transported downstream of Ice Harbor Dam were 0.155% (SD=0.169%) and 0.618% (SD=0.660%), respectively. Based on a posteriori power analysis, we would have had to see a 0.13% difference in escapement rates to have an 80% chance of declaring transported and on-station escapements different with six years of data. The observed difference of 0.08% (0.235-0.155) is well below 0.13%. Escapement rates of subyearlings released in 1986, 1988, 1989 and 1990 were approximately the same between on-station and transported groups (Table 4, Figure 6). However, the transported subyearling salmon in 1987 returned at nearly three times the rate of fish released on-station. The escapement rates of yearlings that were released on-station or transported were essentially the same in 1987, 1988, and 1990 (Table 4, Figure 7).



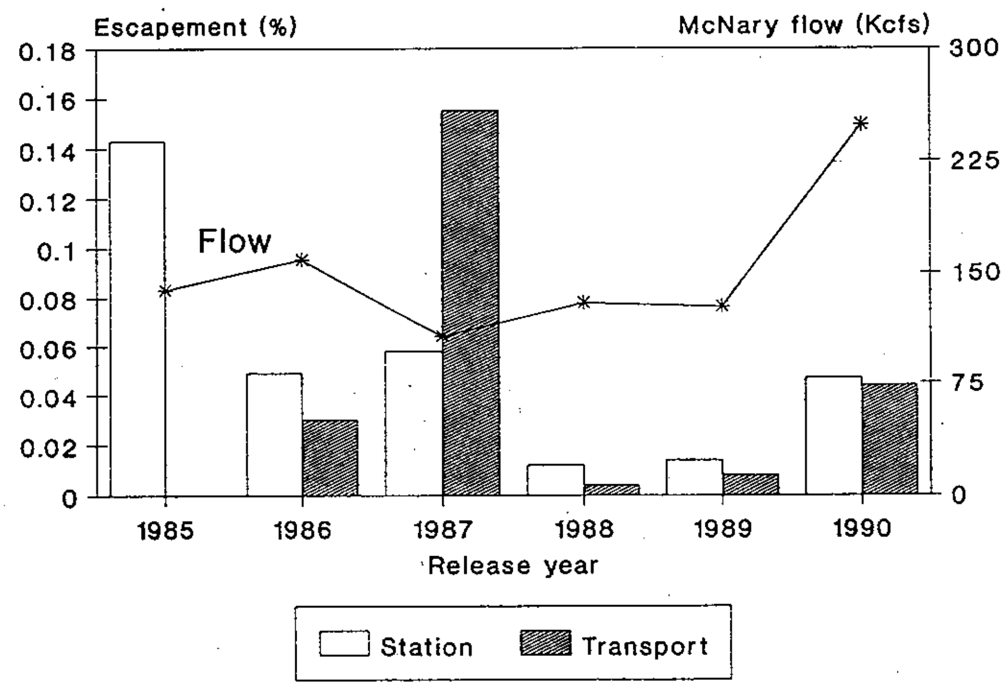


Figure 6. Subyearling fall chinook salmon escapement from on-station and barged releases compared with downstream passage conditions for the year they were released from Lyons Ferry FH. The upper graph shows the average Snake River flow (measured at Lower Monumental Dam) and spills at both Lower Monumental and Ice Harbor dams during their middle 80th percentile of passage through each dam. The lower graph shows the average daily flow at McNary Dam during the middle 80th percentile of passage.

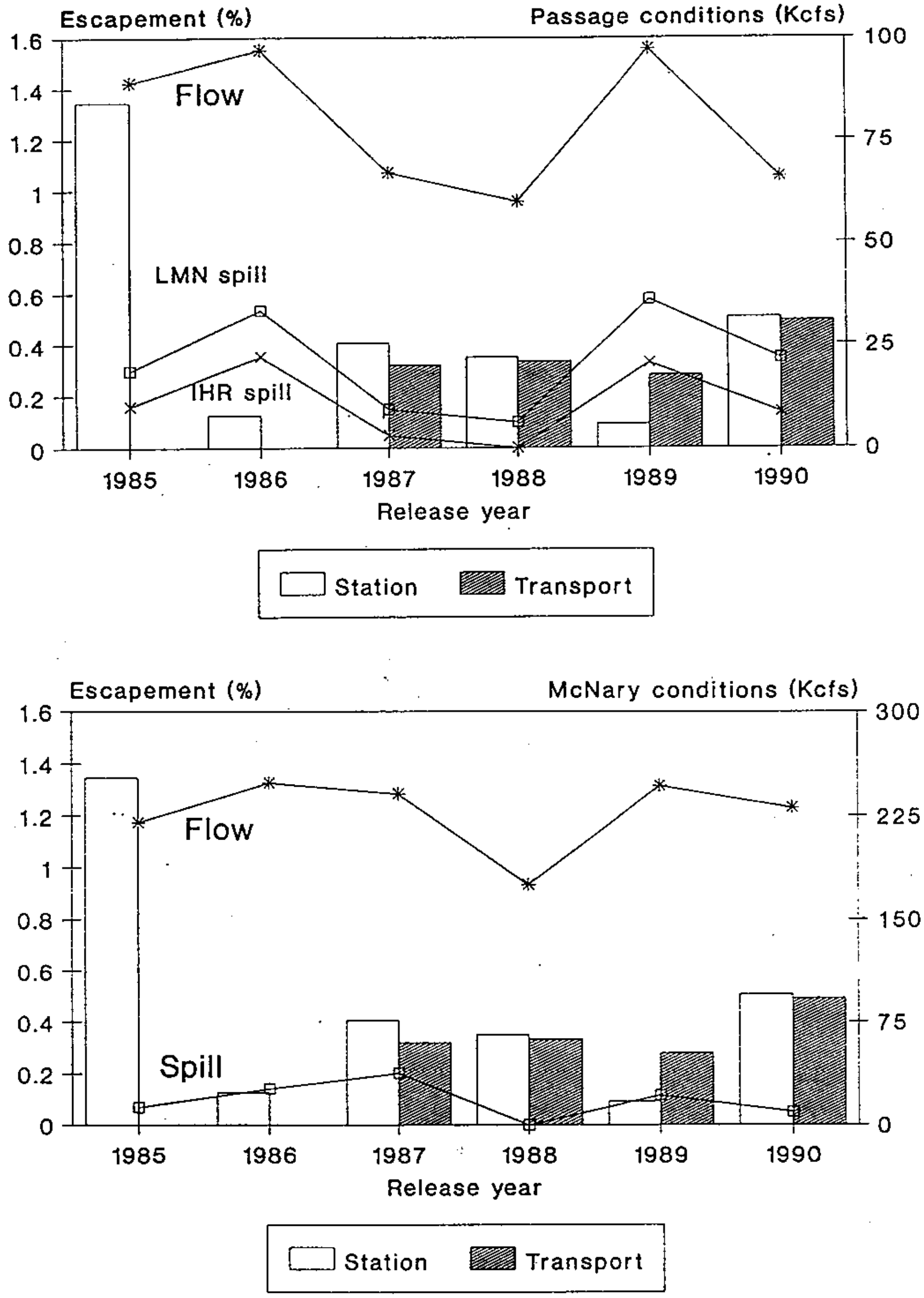


Figure 7. Yearling fall chinook salmon escapement from on-station and barged releases compared with downstream passage conditions for the year they were released from Lyons Ferry FH. The upper graph shows the average daily Snake River flow (at Lower Monumental Dam) and spills at both Lower Monumental and Ice Harbor dams during their middle 80th percentile of passage through each dam. The lower graph shows average daily flow and spill at McNary Dam during the middle 80th percentile of passage.

Yearly Variations

We saw a large difference in survivals among release years ($F=5.30$; $df=5, 12$; $P=0.008$; Table 4; Figure 4). The 1983 brood yearlings and 1984 brood subyearlings released in 1985 survived up to nearly 15 times more than on-station groups from the 1986 to 1990 release years. The 1989 release year, which consisted of the 1987 brood yearlings and 1988 brood subyearlings, had relatively low mean survival. Mean survival in 1989 was significantly lower ($P=0.04$) than survivals in 1987 and 1990. We saw no obvious differences in flow or spill (both magnitude and duration) in the Columbia and Snake rivers between 1985 and other release years that would account for this large difference in survival (Figures 6 and 7). Survivals of all treatment groups showed no apparent relation to flows on the Snake and lower Columbia rivers, which were respectively measured during the middle 80% percentile of branded fish passage at Lower Monumental and McNary dams. Water turbidity and temperature varied little in the Snake and lower Columbia rivers during these migration periods, hence no relation among survivals and these water conditions were apparent. Regardless of release year, no particular release group contributed more to fisheries in general than others. The average percentages of CWTs recovered from various fisheries relative to total recoveries for the four release groups were essentially the same between age groups (range: 70.26 to 80.28%). Ocean contribution for subyearlings released on-station or transported were 41.5% and 41.0%, respectively, and for yearlings it was 57.4% and 56.0%, respectively (Appendix B).

Homing Ability

All treatment groups showed high fidelity in homing to the Snake River. Of the 4.28 million coded-wire tagged salmon released from Lyons Ferry FH for this study, 9,910 were recovered as spawning escapement at inriver sampling locations (hatcheries, fish traps, and spawning grounds). Of these, 1.8% (177 total) were recovered in streams or hatcheries outside the Snake River (based upon sampling expansion); virtually all of these were recovered in the Priest Rapids/Hanford area of the mid-Columbia River upstream of the Snake River confluence (Figure 1; Table 5). Escapement to either the Snake or Columbia rivers was associated with release location (Chi-Square $\chi^2=335.34$, $df=1$, $P<0.001$). A higher than expected proportion of CWTs from transported salmon were recovered outside the Snake River Basin. However, escapement location was not independent of age at release ($\chi^2=32.21$, $df=1$, $P=0.001$) and subyearling releases produced higher escapement to the Columbia River and less in the Snake River. Within the Snake River Basin, 6.4% of the salmon were recovered upstream of the hatchery, although the area of recovery was associated with release location ($\chi^2=84.94$, $df=1$, $P=0.001$)

and age at release (χ^2=366.74, df=1, P<0.001). Based upon recoveries of 9,733 CWT, more salmon released on-station were found in locations upstream of Lyons Ferry FH than the transported treatment groups. Recent radio telemetry studies suggest that some returning salmon destined for Lyons Ferry FH have difficulty finding, or entering the hatchery, and pass upstream of Lower Granite Dam before decending to Lyons Ferry FH (Mendel et al. 1993, Mendel and Milks 1996). Regardless, the rates at which salmon released from Lyons Ferry FH strayed in freshwater within, and outside the Snake River Basin was quite low (8.1%).

Discussion

In every year of this study, yearling release groups had a substantial survival advantage over subyearling releases, regardless of release location. Similar results were seen in fall chinook salmon released at both ages from a Sacramento River hatchery (Sholes and Hallock 1979). In our study, the salmon released as yearlings had three advantages. First, the average release size of yearling salmon was 168 mm fork length and 45 g, while subyearlings were typically released at 88 mm and 6 g. The increased size may improve swimming performance (Raymond 1968; Park 1969), fish guidance efficiency at the dams (Raymond 1979), and predator avoidance (Rieman et al. 1991; Tabor et al. 1993). Second, mainstem flows (and attendant spill levels) were much higher in spring when the yearlings were released, while subyearlings released in summer generally migrated downstream when Columbia River flows were lower (Connor et al. 1992; Berggren and Filardo 1993) and temperatures were higher. Third, the foraging ability of larger salmonids may be higher, both in the Columbia River (Becker 1973) and in the estuary (Healy 1991).

Zaugg (1981) noted the importance of parr/smolt transformation in downstream migration of stream-type chinook salmon, yet we detected little difference in ATPase activity between the salmon released as subyearlings and yearlings from Lyons Ferry FH in 1987 and 1988. Since rearing conditions and size at release were essentially the same, we assume this trend to be indicative of smoltification in other years, and therefore, subyearlings and yearlings had no substantial difference in preparedness to migrate downstream.

Table 5. Escapement (excluding harvest) of fall chinook salmon released as four treatments from Lyons Ferry FH from 1985 to 1990. Escapement is estimated from coded-wire tags recovered at the hatchery, at Snake River sampling locations upstream of the hatchery, and at all sampling locations in the Columbia River Basin where Lyons Ferry tags were recovered. Values (with percent of escapement by release group) are expanded by sampling rate.

	Within Snake River Basin		Outside Snake River Basin		
Treatment	Lyons Ferry [a]	Upstream	Mid-Columbia [b]	Lower Columbia	Total Escapement
Subyearling on-station	543 (69.6)	237 (30.4)	0	0	780
Subyearling transport	591 (90.0)	14 (2.1)	52 (7.9)	0	657
Yearling on-station	6,198 (94.5)	332 (5.1)	22 (0.3)	3 (0.1)	6,555
Yearling transport	1,775 (92.6)	43 (2.2)	100 (5.2)	0	1,918
Totals	9,107 (91.9)	626 (6.3)	174 (1.7)	3 (0.1)	9,910

[a] Includes fish captured at Ice Harbor Dam and transported to Lyons Ferry Hatchery.

[b] McNary Dam and upstream.

Transportation Benefits

Over the six years encompassed in this study, no consistent benefit of transporting salmon downstream of Ice Harbor and Lower Monumental dams was apparent, regardless of the levels of flow and spill. This trend was evident for both subyearlings and yearlings. Based upon the relatively poor passage conditions for subyearlings (Berggren and Filardo 1993), we suspected that transportation would benefit this release group more than yearlings, and that both age groups would benefit during years with low flow (Park 1985). In 1987, when limited flow and little Snake River spill was available, transported subyearlings appeared to survive nearly three times better than those released on-station (Table 4). Transported yearlings did not show any benefit over on-station releases that year. This survival advantage is an isolated comparison, however, and probably would not exist now that juvenile bypass systems have been installed at both Ice Harbor and Lower Monumental dams.

Previous research showed benefits of transportation past all mainstem dams. For studies on 1978 to 1980 outmigrants, the transport:control ratios at McNary Dam were highest in fall chinook salmon (Park 1985), which were transported as subyearlings. Matthews (1992) noted that transport:control ratios for yearling spring/summer chinook were higher in drought years. The response of transporting yearlings in drought conditions were not clearly evident in our study, because the average flows and spill available during the middle 80% outmigration in their study were fairly consistent from year to year. The subyearlings in our study were subjected to more variable river conditions, yet the advantages of transporting them past two dams without installed bypass systems were not evident.

Homing

Salmon from all release groups showed high levels of homing back to the Snake River, and to the hatchery itself. We suggest this high fidelity was a result of three possible factors: 1) a stock endemic to the Snake River was used throughout the study (Bugert et al. 1995), 2) both the on-station released and transported salmon were allowed some downstream migration in their natal river, and 3) the study fish appeared to be in active parr/smolt transformation when released from the hatchery. McIsaac and Quinn (1988) and Slatick et al. (1988) found the homing tendency of fall chinook salmon increased with decreasing distance between the release and rearing site. Since Lyons Ferry FH is within 78 km of Ice Harbor Dam (the release site of transported groups), the effects of transportation on stray rates was minimal.

Several investigators compared adult returns of salmon allowed to migrate downstream through Columbia and Snake river dams with returns of salmon transported past the dams to the estuary. Some studies indicated that transportation of smolts collected while passing Columbia River dams have little, if any, effect upon adult homing (Ebel et al. 1973; Slatick et al. 1975; Ebel 1980). Results from other transportation studies however, suggested that homing could be impaired by transportation, especially where fish were transported directly from hatcheries on tributary streams (Ellis and Noble 1960; Vreeland et al. 1975). Bjornn and Ringe (1984) found Snake River fall chinook salmon transported directly from Hagerman FH to the estuary had lower release-to-adult survivals than those first allowed to migrate in the Snake River and then collected at Lower Granite Dam (the first dam encountered in downstream migration) for transportation. They concluded that fish which migrate a short distance before being transported downstream had better homing success than fish transported from the hatchery without any voluntary migration. The comparable homing rates of salmon released directly from Lyons Ferry FH, and those transported to the lower 17 km of the Snake River are consistent with this hypothesis. Similarly, Zaugg et al. (1985) concluded that some active migration in the river was important to parr/smolt transformation.

Stress Responses

Handling and crowding have been shown experimentally to be stressful to salmonids (Barton et al. 1980; Strange et al. 1977; 1978), which may affect the survival of transported groups (Congleton et al. 1984). Maule et al. (1988) determined that the most stressful event to fish in transportation was the loading operation. They found that fish recovered from the stress of loading while in route, and thus recovered more fully on longer trips (i.e., barge) than they did on short trips (i.e., truck).

A portion of the juveniles transported from Lyons Ferry FH to the Snake River downstream of Ice Harbor Dam were probably also intercepted at McNary Dam for transport through the lower Columbia River projects. It is plausible therefore, that the fish transported below Ice Harbor Dam did not recover from the initial stress of loading prior to their release from the barge, and some were then subjected to this same handling stress when collected for transport at McNary Dam. Recovery time for handling stress (measured through plasma cortisol concentrations) is 12-48 h if held in freshwater (Maule et al. 1988; Congleton et al. 1984). Any benefits of transportation in this study may have been offset by the multiple stressors those salmon encountered. Sigismondi and Weber (1988) suggested that the effect of stresses on juvenile chinook salmon is cumulative. We feel this should be an important consideration in any interpretation of the results from this study. Salmon collection from the run at large for transportation may not receive this cumulative handling stress.

Three factors probably reduced the transport groups' susceptibility to cumulative stress: 1) the salmon were allowed to acclimate to the barge after being transferred from the raceways, 2) the salmon were not held with steelhead or other salmon during transport, which has been shown to affect stress levels of spring chinook salmon (Maule et al. 1988), and 3) the salmon transported from Lyons Ferry FH were held in lower densities than those collected and transported from mainstem hydroelectric projects. Maule et al. (1988) suggested that stress recovery may be faster in low transport densities and high turnover rates of river water during barge transport.

Yearly Variations

We documented substantial yearly variation in release-to-adult survival rates within the Snake River Basin. These variations showed little or no relation to river conditions or type of release. Three examples show this lack of trend: 1) The 1986 releases (which include the 1984 yearling and 1985 subyearling broods) had lower survival rates than those released in 1987 (Table 4). Compared to 1987, both age classes released in 1986 experienced higher flows, more Snake River spill, and higher water turbidity during their middle 80% passage through Ice Harbor, Lower Monumental, and McNary dams (USACE 1987, 1988). 2) In 1989, Snake River flows and spill were relatively high when both the subyearlings and yearlings were released (USACE 1990), yet neither age class performed well. Ironically, this was the only release year that transported yearlings appeared to survive better than those released on-station. 3) Most notable were the high rates of escapement and overall survival in the 1985 releases, compared to the 1986 through 1990 releases. The 1983 brood, released on-station as yearlings in 1985, showed at a nearly threefold survival advantage over the next highest survival of other yearling releases. Likewise, the 1984 subyearlings released in June 1985 demonstrated a higher survival rate than other subyearling releases, excluding the 1987 transported group. We saw no obvious differences in flow, spill (both magnitude and duration), water temperature, turbidity, or dissolved gas levels in the Columbia and Snake rivers between

1985 and other release years that would account for this large difference in survival. Factors other than downstream migration may have affected the survival of fall chinook treatment groups. Oceanic conditions play a critical role in overall survival (Chelton 1984; Mathews 1984; Nickelson 1986; Beamish 1993; Beamish and Bouillon 1993).

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APPENDIX A

Coded-wire tag recoveries of Lyons Ferry fall chinook (1983-1989 broods, 46 tag codes) from PSMFC on 24 May 1995 and supplemented with Snake River recoveries through December 1994.

Brood year	Release age	Release type	CWT code	Number marked	SNAKE RIVER BASIN ONLY Observed recovery	Estimated recovery	Percent survival	ESCAPEMENT AND HARVEST Observed recovery	Estimated recovery	Percent survival
1983	one	station	633218	83,611	1,143	1,183	1.415	2,626	6,497	7.771
1983	one	station	632152	250,831	3,219	3,316	1.322	7,249	18,152	7.237
			MEAN				**1.345**			**7.370**
			SUM	334,442	4,362	4,499		9,875	24,649	
1984	zero	station	633226	78,417	98	122	0.156	212	531	0.677
1984	zero	station	633227	78,064	82	95	0.122	191	503	0.644
1984	zero	station	633228	78,504	99	119	0.152	196	454	0.578
			MEAN				**0.143**			**0.633**
			SUM	234,985	279	336		599	1,488	
1984	one	station	632841	258,355	313	326	0.126	766	1,935	0.749
1985	zero	station	633638	49,325	22	25	0.051	45	144	0.292
1985	zero	station	633639	49,325	25	30	0.061	48	111	0.225
1985	zero	station	633640	49,325	19	23	0.047	36	91	0.184
1985	zero	station	633641	49,325	18	19	0.039	37	81	0.164
1985	zero	station	633642	49,325	20	23	0.047	42	105	0.213
			MEAN				**0.049**			**0.216**
			SUM	246,625	104	120		208	532	
1985	zero	transport	633633	49,112	13	13	0.026	35	100	0.204
1985	zero	transport	633634	49,112	18	18	0.037	38	81	0.165
1985	zero	transport	633635	49,112	14	14	0.029	26	56	0.114
1985	zero	transport	633636	49,112	13	13	0.026	30	101	0.206
1985	zero	transport	633637	49,112	16	16	0.033	34	79	0.161
			MEAN				**0.030**			**0.170**
			SUM	245,560	74	74		163	417	
1985	one	station	634156	152,479	597	619	0.406	1,301	3,166	2.076
1985	one	transport	634159	156,036	489	498	0.319	1,225	3,201	2.051
1986	zero	station	634259	126,076	73	74	0.059	165	386	0.306
1986	zero	station	634261	125,570	72	73	0.058	161	371	0.295
			MEAN				**0.058**			**0.301**
			SUM	251,646	145	147		326	757	
1986	zero	transport	634401	128,283	201	205	0.160	353	747	0.582
1986	zero	transport	634262	127,715	189	193	0.151	332	679	0.532
			MEAN				**0.155**			**0.557**
			SUM	255,998	390	398		685	1,426	
1986	one	station	634413	58,970	203	214	0.363	374	794	1.346
1986	one	station	634411	58,735	193	198	0.337	384	826	1.406
			MEAN				**0.350**			**1.376**
			SUM	117,705	396	412		758	1,620	

Appendix A (Continued).

Brood year	Release age	Release type	CWT Tagcode	Number marked	SNAKE RIVER BASIN ONLY Observed recovery	Estimated recovery	Percent survival	ESCAPEMENT AND HARVEST Observed recovery	Estimated recovery	Percent survival
1986	one	transport	634407	60,523	190	193	0.319	391	928	1.533
1986	one	transport	634408	60,281	205	209	0.347	391	840	1.393
			MEAN				**0.333**			**1.464**
			SUM	120,804	395	402		782	1,768	
1987	zero	station	635214	124,345	9	11	0.009	14	27	0.022
1987	zero	station	635216	124,394	17	19	0.015	22	35	0.028
			MEAN				**0.012**			**0.025**
			SUM	248,739	26	30		36	62	
1987	zero	transport	635211	122,850	4	4	0.003	7	9	0.007
1987	zero	transport	635213	122,899	4	5	0.004	8	28	0.023
			MEAN				**0.004**			**0.015**
			SUM	245,749	8	9		15	37	
1987	one	station	634752	57,756	45	46	0.080	84	182	0.315
1987	one	station	634756	57,594	54	60	0.104	92	187	0.325
			MEAN				**0.092**			**0.320**
			SUM	115,350	99	106		176	369	
1987	one	transport	634755	59,609	159	167	0.280	304	641	1.075
1987	one	transport	634750	59,608	160	166	0.278	319	693	1.163
			MEAN				**0.279**			**1.119**
			SUM	119,217	319	333		623	1,334	
1988	zero	station	630226	113,193	14	15	0.013	21	34	0.030
1988	zero	station	630228	113,285	15	16	0.014	17	22	0.019
			MEAN				**0.014**			**0.025**
			SUM	226,478	29	31		38	56	
1988	zero	transport	635204	116,935	12	13	0.011	16	79	0.068
1988	zero	transport	635207	117,168	6	6	0.005	8	12	0.010
			MEAN				**0.008**			**0.039**
			SUM	234,103	18	19		24	91	
1988	one	station	630235	55,922	252	271	0.485	400	723	1.293
1988	one	station	630237	56,597	277	301	0.532	429	784	1.385
			MEAN				**0.508**			**1.339**
			SUM	112,519	529	572		829	1,507	
1988	one	transport	630231	58,988	285	301	0.510	471	854	1.448
1988	one	transport	630232	58,989	267	284	0.481	452	836	1.417
			MEAN				**0.496**			**1.432**
			SUM	117,977	552	585		923	1,690	

Appendix A (Continued).

Brood year	Release age	Release type	CWT Tagcode	Number marked	SNAKE RIVER BASIN ONLY Observed recovery	Estimated recovery	Percent survival	ESCAPEMENT AND HARVEST Observed recovery	Estimated recovery	Percent survival
1989	zero	station	635547	123,233	41	43	0.035	57	95	0.077
1989	zero	station	635544	123,640	60	73	0.059	86	145	0.117
			MEAN				**0.047**			**0.097**
			SUM	246,873	101	116		143	240	
1989	zero	transport	635550	119,941	58	58	0.048	81	134	0.112
1989	zero	transport	635549	118,104	47	47	0.040	68	104	0.088
			MEAN				**0.044**			**0.100**
			SUM	238,045	105	105		149	238	

Appendix B. Overall recoveries (expanded) of CWTs by recovery area (AK=Alaska, BC=British Columbia, CA=California, OR=Oregon, WA=Washington) for four treatments of Lyons Ferry fall chinook salmon released 1985-1990.

Age	Release Type	Number Released	Snake R.	Columbia R.	Total Freshwater	AK	BC	CA	OR	WA	NMFS[a]	Total ocean
subyearling	station	1,455,346	780	840[b]	1,620	121	863	43	234	248	6	1,151
subyearling	transport	1,219,455	605	699[c]	1,304	116	526	32	84	145	2	905
yearling	station	1,090,850	6,534[d]	7,617[e]	14,151	189	7,799	934	5,460	4,474	239	19,095
yearling	transport	514,034	1,818	1,699[f]	3,517	115	1,852	89	956	1,422	43	4,477
		4,279,685	9,737	10,855	20,592	541	11,040	1,098	6,734	6,289	290	25,992

[a] National Marine Fisheries Service high seas recovery off CA, OR, WA, except two recoveries (expanded) in the Gulf of AK from yearling on-station releases.

[b] All harvest, no spawning escapement included.

[c] Includes 52 (expanded) Hanford Reach spawners.

[d] Includes four sport recoveries (expanded) from the lower Snake River, all others are spawning escapement.

[e] Includes one fish each at the N. Bonneville and Umatilla River fish traps, one fish at Turtle Rock Hatchery, one fish at Spring Creek Hatchery, and 21 fish spawning in the Hanford Reach (expanded).

[f] Includes one fish at Priest Rapids Hatchery and 99 spawned fish in the Hanford Reach.