Truck Transportation of Juvenile Salmonids at U.S. Army Corps of Engineers Dams

by

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Introduction

In response to a growing concern over high mortalities of anadromous salmonid juveniles migrating through the lower Snake and Columbia River hydropower system in the 1970s, collection and transportation of the run-at-large began at Lower Granite and Little Goose Dams in 1977. The collection of downstream-migrating smolts was conducted with minimal oversight of National Marine Fisheries Service researchers who were conducting concurrent transportation studies. In 1981, collection and transportation of fish became operational under a region-wide program. The program is operated annually by the U.S. Army Corps of Engineers (COE) and the fisheries agencies, and is one of several strategies currently utilized in an attempt to maximize the survival of out-migrating juvenile anadromous salmonids in the Columbia River Basin.

At Lower Granite and Little Goose Dams on the lower Snake River, the program typically commences in March, when the leading edge of the spring/summer chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) smolt migrations arrive (Baxter et al. 1996, Spurgeon et al. 1997, Hetherman et al. 1998). When the numbers of collected smolts are low, they are trucked from the lower Snake River to a release site below Bonneville Dam. As smolt numbers increase (generally about 10-12 days into the migration), barges replace trucks to transport the bulk of the out-migration, usually until mid-June, when trucks are again employed to transport small numbers of smolts until the program is terminated in late autumn. For subyearling chinook salmon (fall chinook salmon), which migrate from mid-June through late autumn, virtually all fish collected at Snake River dams are trucked.

At McNary Dam on the Columbia River, small numbers of subyearling chinook salmon are usually collected and trucked during the first 2 weeks of June. Barges then replace trucks to transport the bulk of fish until mid- to late-July, when trucks again replace barges to continue the transportation process until termination in late autumn.

These schedules, while efficient and logical in an operational sense, result in a disproportionate application of transportation methodologies to different species or life history types. From 1995 through 1997, for example, trucking accounted for only 2-3% of all Snake River spring/summer chinook salmon and steelhead that were transported (Hetherman 1998). Conversely, of the totals transported, 98% of Snake River subyearling chinook salmon were truck-transported, whereas at McNary Dam, 36% were truck-transported.

Research to evaluate transportation of smolts around Snake and Columbia River dams (Fig. 1) began in the late 1960s (Ebel et al. 1973). On the lower Snake River, transportation of yearling chinook salmon and steelhead was evaluated at Ice Harbor, Little Goose, and Lower Granite Dams over a period of 13 years from 1968 through 1980. On the lower Columbia River, transportation of yearling and subyearling chinook salmon and steelhead was evaluated at McNary Dam from 1978 through 1983.

Results of initial studies conducted at Ice Harbor and Little Goose Dams from 1968 through 1973 were reported in the literature by Ebel et al. (1973), Slatick et al. (1975), and Ebel (1980). Results from ensuing studies were reported in a series of annual research reports to the COE, and all studies conducted through 1983 were summarized in a research report by Park (1985). More recently, Ward et al. (1997) reviewed and assessed transportation research conducted on Snake River spring/summer chinook salmon by the National Marine Fisheries Service from 1968 through 1989.

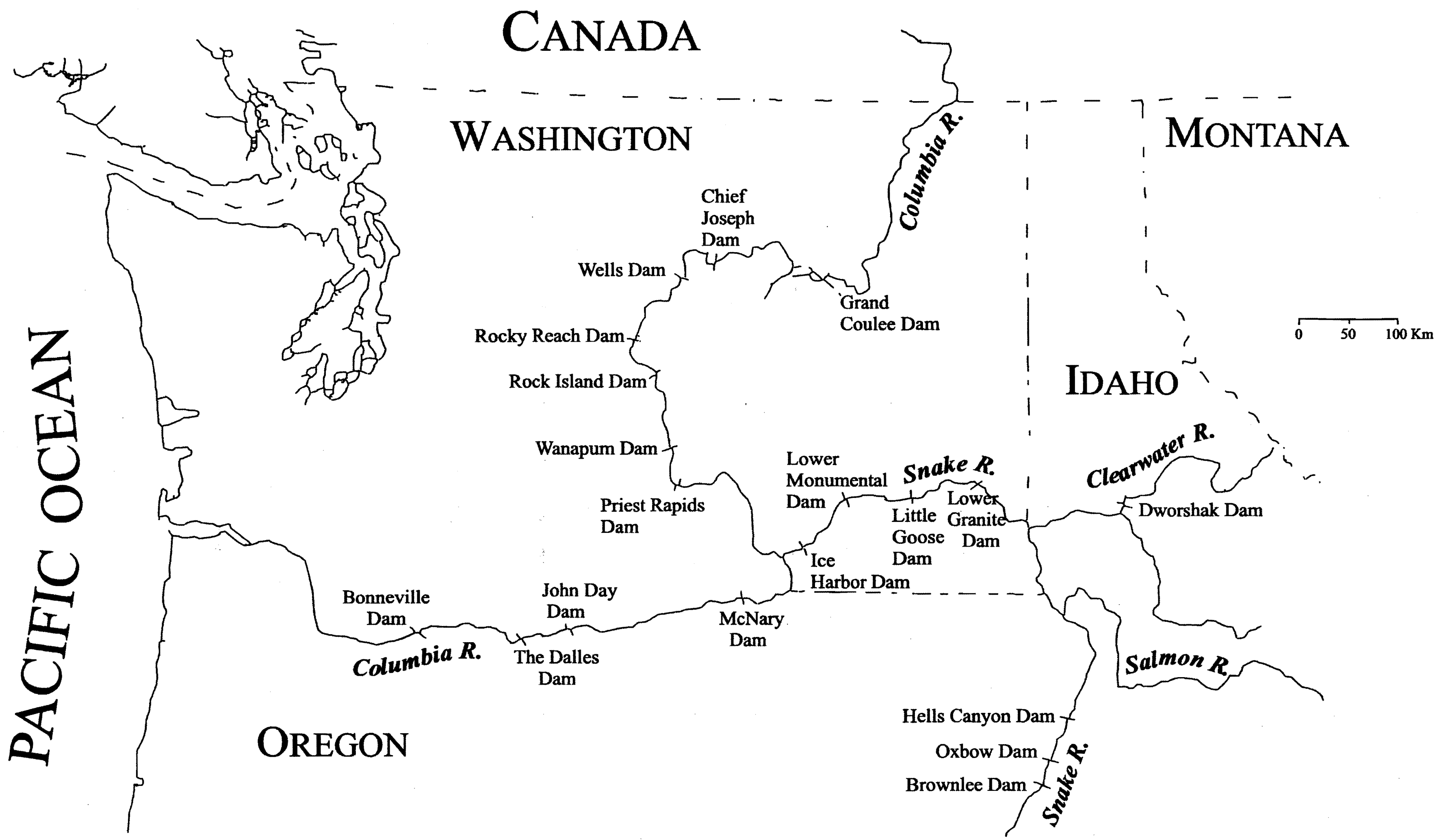

Figure 1. Map of the Columbia River hydropower system.

From 1968 through 1976, only trucks were used to evaluate the potential benefits of transportation because barges were not yet in use. Beginning in 1977, both barges and trucks were tested, but not at all locations simultaneously. The final truck study was conducted on fall chinook salmon at McNary Dam in 1983.

No recent studies have evaluated transportation of fish by truck even though collection systems have been modified extensively. Further, even with truck transportation, Snake River fall chinook salmon populations have remained low. Finally, in a recent review of the smolt transportation program, the Independent Scientific Advisory Board (ISAB) advised against the continued use of trucks in the smolt transportation program (R. Williams et al. 1998). Thus the question arises: Are some species, life history types, or subpopulations disadvantaged in some way because a higher proportion are trucked rather than barged? In this report, I review results of pertinent truck-transport studies, provide insight regarding factors that affected results of those studies, and offer a framework for analysis of the above question.

General Study Protocols

Mark/recapture methods were the principal tools used to evaluate the effects of truck transportation. Juvenile salmon and steelhead were collected from gatewells at Ice Harbor Dam (Ebel et al. 1973, Slatick et al. 1975) or from holding raceways within the smolt collection facilities at Little Goose and Lower Granite Dams (Matthews et al. 1977). Each study fish was anesthetized, coded-wire tagged (CWT), freeze branded, and adipose-fin clipped and then randomly assigned to a downstream-migrant control group or a truck-transport test group. In all years, study fish were batched marked, with the sizes of the release groups varying considerably within and between years. Also, batch marks were changed periodically during all study years; however, replication strategies and marking periods were inconsistent among years. All control and test groups were composites of hatchery and wild fish, which were indistinguishable when marked.

Downstream-migrant control groups were released above the dams where they were marked in each study year from 1968 through 1976 at all dams and through 1977 at Lower Granite Dam only. Thereafter, fish were released below the dams where marked. Transported fish were hauled in 18,900-L or 13,200-L tanker trucks equipped with recirculating water, refrigeration, and oxygenation systems. Transport groups were released from a truck through a hose into the Columbia River just downstream from Bonneville Dam or approximately 10 km farther downstream at Dalton Point, depending upon the study year.

Marked adults, recovered primarily at dams at or near where the smolts were marked, were used to evaluate smolt-to-adult return rates (SARs), and the efficacy of truck transportation. Generally the recoveries were expressed as transport-to-inriver (downstream migrant) adult-return ratios (T/Is), which were derived from SARs. Additional recovery information was gathered from ocean fisheries; Snake and Columbia River hatcheries; natal spawning areas; and river commercial, tribal, and sport fisheries.

Contingency table analyses using the chi-square or G-statistic, student's t-tests, and analysis of variance were used for statistical treatment of the adult-return data through the 1973 study year (Ebel et al. 1973, Ebel 1980, Park 1985); thereafter, only the G-statistic was used. In all cases, significance was set at $P < 0.05$.

Spring/Summer Chinook Salmon (Stream-Type)

Research Overview

From 1968 through 1980, 16 truck transport tests were conducted in 13 studies of spring/summer chinook salmon yearlings transported as yearling smolts from Snake River dams and released below Bonneville Dam (Table 1) (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985). Five additional studies using various concentrations of saltwater (NaCl) as a transport medium were also conducted. However, results from the saltwater studies were not considered in this review because SARs were too low for reasonable statistical accuracy, and the technique was never used again. Results of tests conducted at McNary Dam from 1978 through 1980 were also excluded, again because few adults returned and unusually high numbers of tag recoveries from ocean fisheries indicated that test groups likely contained relatively large numbers of marked subyearling chinook salmon.

In the 16 Snake River tests considered, overall T/Is varied considerably, ranging from 0.7 to 18.1, with three T/Is of 1.0 or lower. Results from seven of these tests indicated that significantly greater adult returns resulted from juvenile fish trucked to below Bonneville Dam compared to juveniles that migrated downstream through the hydropower system, while one study reported the opposite. In two studies, no adults from either group were recovered.

Particularly poor conditions at the release site below Bonneville Dam (a boat ramp along the Washington shoreline) in 1976 likely led to a significantly higher percentage of adults returning from control juveniles that migrated through the hydropower system compared to trucked juveniles. A changed shoreline configuration resulting from initial construction of the

Table 1. Results of truck transportation studies on spring/summer chinook salmon at Ice Harbor, Little Goose, or Lower Granite Dams from 1968 through 1980. Adults were recovered at the dams (SAR = smolt-to-adult return rate).

	Downstream-migrant release groups			Transport release groups			
Study year	No. juveniles released	No. adults recaptured	Observed SAR	No. juveniles released	No. adults recaptured	Observed SAR	T/I
			Ice Harbor Dam				
1968	80,335	117	0.14	42,420	128	0.30	2.1*
1969	24,217	47	0.19	13,529	33	0.24	1.3
1970	8,624	17	0.20	10,173	29	0.29	1.5
			Little Goose Dam				
1971	20,673	52	0.25	30,637	119	0.39	1.6*
				35,252	147	0.42	1.7*
1972	32,836	25	0.08	51,499	44	0.09	1.1
				54,906	45	0.08	1.0
1973	88,170	20	0.02	57,758	241	0.42	18.1*
				83,606	261	0.31	13.5*
1976	42,046	10	0.02	68,605	29	0.04	1.8
1977	38,346	0	0.00	41,677	0	0.00	----
1978	36,441	5	0.01	49,391	5	0.01	0.8
			Lower Granite Dam				
1975	43,902	138	0.30	68,550	436	0.64	2.0*
1976	28,686	11	0.04	72,918	18	0.03	0.7**
1978	36,441	5	0.01	43,855	33	0.08	5.8*
1980	21,876	0	0.00	32,722	0	0.00	----

*Indicates significantly more transport than downstream-migrant study fish were recovered as adults ($P < 0.05$).
**Indicates significantly more downstream-migrant than transport study fish were recovered as adults ($P < 0.05$)

Bonneville Dam Second Powerhouse and proximity to the spillway at Bonneville Dam created eddy conditions at this boat ramp, whereby wave action washed smolts back onto shoreline rocks a short distance downstream from the release site. These detrimental conditions were particularly pronounced during periods of spill or high winds, which intensified the wave action. Since smolts were released after dark, the situation went unnoticed for an extended time. When discovered in early May, the release site was abandoned in favor of a site just downstream from the Bonneville Dam First Powerhouse. In his research review, Park (1985) combined adult returns from juvenile releases at both sites for analysis and reported that adult return percentages of the downstream-migrant control group were significantly greater than those of the trucked group. Treatment of the data in this way was ill-advised in that it failed to show that SARs were twice as high for fish released at the powerhouse as for those released earlier at the boat ramp, and that the same was true for the test conducted from Little Goose Dam during the same year. The degree to which poor release conditions at the boat launch ramp may have impacted trucked fish in years prior to 1976 is unknown. However, since T/Is were lower than expected in many years (based on concurrent estimates of downstream migrant survival), trucked fish released from the shoreline were likely impacted to some degree in all years.

For all study years, results were sensitive to numbers of returning adults. Study years from which the largest number of adults returned also tended to have higher SARs and higher T/Is, which consistently showed a significant survival advantage for trucked release groups. Conversely, in study years in which lower SARs occurred, the differences in SARs between trucked and downstream migrants were usually less and often not statistically different. In some cases, low adult returns were due to inadequate numbers of juveniles marked, while in others they were due to abysmally low SARs of fish from both the control and the test groups.

Numbers of adults returning from the majority of the 16 tests described above were few. Ten of the 16 tests produced 80 or fewer returning adults in the downstream-migrant and trucked groups combined, and seven produced fewer than 50 total returning adults. In these 10 tests, even though trucked fish often had higher SARs than downstream-migrant fish, there were no statistically significant differences in the SARs between either group. However, in six of these tests, total adult returns ranged from 171 to 574 fish, and in each case, significantly higher percentages of adults returned from fish trucked as juveniles than those that migrated downstream through the hydropower system.

I could discern no apparent seasonal trends in SARs among these early truck studies. However, marking strategies were not designed to provide this type of information. Smolt marking activities began and ended at different times in different years, and replication strategies were inconsistent among years.

Truck vs. Barge Transportation

Barges were first used in the Snake River transportation program in 1977, after most truck transport studies were completed. Therefore, opportunities to directly compare truck vs. barge transportation were limited. On the Snake River, a single study comparing the two techniques on spring/summer chinook salmon was conducted at Lower Granite Dam in 1978. Park (1985) reported high overall T/Is for both test groups, with 5.8 for trucked fish and 8.9 for barged fish (99 adult returns for both transport test conditions combined), and with each transport group compared to the same downstream-migrant control group; however, results differed significantly between the two test groups. In his report, Park appropriately concluded "This comparative test should be repeated because it was done for only 1 year, and similar comparisons with steelhead and fall chinook salmon have shown no significant benefit for barging" [over trucking]. Unfortunately, the study was never repeated.

Barge vs. truck tests were also conducted on yearling chinook salmon at McNary Dam in 1978 and 1979. However, as stated above, the results were not considered usable.

Homing

Loss or impairment of homing in adult spring/summer chinook salmon was not reported as a problem in any of the truck-transport studies (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985). During all studies, T/Is calculated from CWTs recovered from hatcheries or spawning grounds were equal to or higher than those calculated from recoveries at downstream dams.

Excessive straying of adults from groups transported as smolts would also indicate a transportation-induced homing impairment, yet results from transport studies indicate no such impairment. No straying was reported for the Ice Harbor Dam studies (Ebel et al. 1973, Slatick et al. 1975). For the 1971 through 1973 Little Goose Dam studies, 10 adult returns from truck-transported juveniles and 2 adult returns from the downstream-migrant juveniles were recovered at Pelton Dam on the Deschutes River (Ebel 1980). Nevertheless, the T/I calculated from the small Deschutes River sample was nearly identical to the overall T/I calculated from adults recovered at Little Goose Dam (954 total adults), suggesting that adults from downstream-migrant juveniles may have strayed into the Deschutes at the same rate as those adults from the groups transported by truck as juveniles. For the truck-transport studies conducted from 1975 through 1980 at Little Goose and Lower Granite Dams, 11 adults from the juveniles transported by truck were identified as strays in the Deschutes River. However, 1,182 adults from the same groups were identified as having returned to expected areas (Park 1985). These straying rates are well below levels of natural straying reported elsewhere for anadromous salmonids (Chapman et al. 1991).

Steelhead

Research Overview

From 1968 through 1980, 16 studies were conducted to evaluate differences in SARs between groups of smolts transported by truck to below Bonneville Dam and those that migrated downstream through the hydropower system (Table 2) (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985). Of these tests, 13 were conducted from Ice Harbor (1970), Little Goose (1971-78), or Lower Granite (1975-78) Dams on the Snake River and 3 were conducted from McNary Dam (1978-80) on the Columbia River. A few additional studies were also conducted from Snake River dams to test various concentrations of saltwater as a transport medium. I do not discuss these results because the procedure was never used again.

In all of these Snake River studies, a significantly higher percentage of adults returned from juvenile fish transported to below Bonneville Dam compared to fish that migrated downstream through the hydropower system. T/Is ranged from 1.5 to 13.5. At McNary Dam, significantly higher percentages of adults returned from juveniles transported by truck than for those that migrated downstream in two of the three studies, with T/Is ranging from 1.4 to 3.4.

Table 2. Results of truck transportation studies on steelhead at Ice Harbor, Little Goose, Lower Granite or McNary Dams from 1970 through 1980. Adults were recovered at the dams (SAR = smolt-to-adult return rate).

Study year	Downstream-migrant release groups			Transport release groups			T/I
	No. juveniles released	No. adults recaptured	Observed SAR	No. juveniles released	No. adults recaptured	Observed SAR	
			Ice Harbor Dam				
1970	18,347	71	0.39	31,282	178	0.57	1.5*
			Little Goose Dam				
1971	33,243	199	0.60	35,967	367	1.02	1.7*
				44,939	464	1.03	1.7*
1972	32,488	132	0.41	22,831	318	1.39	3.6*
				27,362	346	1.27	3.1*
1973	42,461	61	0.14	26,650	517	1.94	13.5*
				36,802	708	1.92	13.4*
1976	29,414	89	0.30	43,287	497	1.15	3.8*
1977	22,204	4	0.02	24,272	28	0.12	6.4*
1978	30,364	67	0.22	35,375	365	1.03	4.7*
			Lower Granite Dam				
1975	49,601	222	0.45	60,475	977	1.62	3.6*
1976	41,987	149	0.35	54,696	307	0.56	1.6*
1978	30,364	67	0.22	47,899	514	1.07	4.4*
			McNary Dam				
1978	15,580	76	0.49	20,416	337	1.65	3.4*
1979	8,595	43	0.50	15,379	166	1.07	2.1*
1980	21,291	49	0.23	22,362	67	0.33	1.4

*Indicates significantly more transport than downstream migrant study fish were recovered as adults ($P < 0.05$)

Observed SARs for study fish were considerably higher for steelhead than for spring/summer chinook salmon during the early truck studies. Part of the reason was that trapping efficiency was higher for steelhead because freeze brands were more legible on this species. As a result, only a single study (Little Goose Dam 1977) returned fewer than 100 total study adults to the dam. In contrast, the study conducted from Lower Granite Dam in 1975 returned nearly 1,200 total adults. Nonetheless, based upon survival estimates for juveniles that migrated downstream through the hydropower system, trucked fish returned at comparatively lower rates in some cases than would have occurred if trucked fish had no differential mortality. The lower than expected SARs may have been related to less than optimal release locations for trucked fish or as a result of trucking fish that would have died in any case or both.

As in trends observed for spring/summer chinook salmon, seasonal trends in trucked steelhead SARs were difficult to assess, primarily due to a lack of consistency in replication strategies among years during these early studies. However, over the course of all studies over all years, we have generally noticed that earlier-migrating steelhead smolts tended to have higher SARs than later-migrating smolts. This was true for both transported and downstream-migrant smolts.

In this regard, it is noteworthy that wild steelhead smolts tended to arrive at the dams earlier in the migration than did hatchery steelhead smolts. SARs are higher for wild than hatchery fish (Raymond 1988). Moreover, unlike chinook salmon, steelhead smolts are susceptible to parr-reversion as water progressively warms during spring (Hoar 1976). Steelhead juveniles that reverted to parr would not have had the capability of osmoregulating in seawater, and therefore would not survive whether they were transported or migrated downstream through the hydropower system. Only reverted fish that survived winter in the reservoirs and then re-smolted the following spring would have had a chance to survive.

Truck vs. Barge Transportation

Opportunities to conduct truck vs. barge studies were also limited for steelhead. Three studies were conducted: one at Lower Granite Dam in 1978 and two at McNary Dam in 1979 and 1980. For the Lower Granite Dam study, T/Is were 4.4 for trucked fish and 5.2 for barged fish. For the McNary Dam studies, T/Is were 2.1 and 3.0 for trucked and barged fish respectively in 1979; in 1980, T/Is were identical for both groups at 1.4. Adult returns did not differ significantly between the two transport-type groups in any of the three studies (Park 1985).

Homing

As was the case for spring/summer chinook salmon, loss or impairment of homing was not reported as a problem in any of the studies from 1969 through 1980 (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985). No homing loss was reported for studies at Ice Harbor Dam in 1969 and 1970. Ebel (1980) reported returns of adult steelhead to various locations for truck studies at Little Goose Dam from 1971 through 1973. Returns were monitored extensively at Dworshak National Fish Hatchery and Pahsimeroi Hatchery, as well as downstream at Little Goose Dam. The T/Is were somewhat lower at the hatcheries than at the dam in the two tests from 1971 but were higher at the hatcheries than at the dam in the four tests from 1972 and 1973. However, statistical comparisons were not provided by the author.

Straying was also monitored during the early steelhead truck transport studies, with no indication of homing impairment for transported fish. No straying was reported during the early Ice Harbor Dam studies (Ebel et al. 1973, Slatick et al. 1975). From the 1971-73 Little Goose

Dam studies, Ebel (1980) reported that three CWT adult steelhead had strayed to Pelton Dam on the Deschutes River; all three had been transported as juveniles from Little Goose Dam. However, 2,720 adult steelhead (not adjusted upward for trapping efficiency), were identified at Little Goose Dam from the same release groups, thus indicating straying rates well within the expected range (Chapman et al. 1991).

In studies at Lower Granite, Little Goose, and McNary Dams from 1975 through 1980, Park (1985) identified as strays 16 of 9,800 returning adult steelhead that were transported as juveniles. None of the strays were from the McNary Dam studies. Moreover, 11 of the 16 strays were from the 1976 Lower Granite and Little Goose Dam studies. As for spring/summer chinook salmon, these levels of straying are below levels considered typical (Chapman et al. 1991).

A delay in the upstream migration of adults transported as juveniles might also suggest that truck transport had influenced homing behavior. This was reported to have occurred from 1971 through 1976 for approximately 10% of the fish trucked as juveniles relative to downstream-migrant juveniles that originated from Dworshak Hatchery (Park 1985). The small percentage of affected Dworshak steelhead returned to the hatchery in time to spawn successfully.

Fall Chinook Salmon (Ocean-Type)

Research Overview

Transportation of subyearling chinook salmon was evaluated exclusively at McNary Dam (Park 1985, Matthews et al. 1988). The earliest truck evaluation was initiated in 1978, and evaluations continued annually through 1983, yielding six total truck evaluations (Table 3). Releases of downstream-migrant fish were made directly below the dam during all evaluations.

Annual T/Is ranged from 2.7 to 8.6 for adults returning to Bonneville, McNary, Priest Rapids, and Lower Granite Dams combined. Adult recoveries at the dams ranged from 137 to 234 fish per test, and a significantly higher percentage of adults returned from groups trucked as juveniles compared to groups that migrated downstream through the hydropower system in all studies (Park 1985, Matthews et al. 1988). The studies were not designed to detect seasonal trends in subyearling SARs or T/Is.

Truck vs. Barge Transportation

As with spring/summer chinook salmon and steelhead, opportunities to directly compare truck vs. barge transportation on subyearling chinook salmon were limited. A single study was conducted at McNary Dam in 1983, where overall T/Is were 4.4 and 4.0 for adult returns from juveniles that were trucked and barged, respectively. There were no significant differences in adult recoveries between the two test groups, either overall or among early, middle, or late segments of the juvenile out-migration (Park 1985, Matthews et al. 1988).

Table 3. Results of truck transportation studies on fall chinook salmon at McNary Dam from 1978 through 1983. Adults were recovered at Bonneville, McNary, Priest Rapids, and Lower Granite Dams (SAR = smolt-to-adult return rate).

	Downstream-migrant release groups			Transport release groups			
Study year	No. juveniles released	No. adults recaptured	Observed SAR	No. juveniles released	No. adults recaptured	Observed SAR	T/I
1978	38,137	23	0.06	40,361	154	0.38	6.2*
1979	112,718	16	0.01	132,919	121	0.09	6.4*
1980	84,587	19	0.02	80,213	152	0.19	8.6*
1981	42,580	39	0.09	42,924	195	0.45	5.0*
1982	38,663	38	0.10	39,693	105	0.26	2.7*
1983	40,301	30	0.07	35,279	115	0.33	4.4*

*Indicates significantly more transport than downstream-migrant study fish were recovered as adults ($P < 0.05$).

Homing

As described for spring/summer chinook salmon and steelhead, truck transport of subyearling chinook salmon did not appear to influence homing behavior (Park 1985). Over the course of the studies, T/Is were virtually identical for adult study fish recovered in ocean and freshwater fisheries compared to those recovered from upriver hatcheries and spawning grounds (Park 1985, Matthews et al. 1988).

From all six studies and all freshwater areas combined, 1,640 adults returned from juveniles that were transported by truck to below Bonneville Dam compared to 450 adult returns from downstream-migrant subyearling chinook salmon. Of these totals, only three trucked and one downriver-migrant fish were recovered at an unexpected location and that was at Bonneville Hatchery. Very small numbers of study fish from both groups were also recovered at Dworshak, Ringold, and Wells Hatcheries. However, since these hatcheries only release spring chinook salmon, presumably these fish were spring/summer chinook salmon that were mistaken for fall chinook salmon when marked as juveniles at the dam.

Stress Studies Related to Truck Transportation

External and internal stimuli (stress) elicit a complicated series of physiological responses in fish (Mazeaud et al. 1977). The initial or primary response involves an increase in circulating corticosteroids (plasma cortisol) and catecholamines (adrenaline), which precipitate a wide array of secondary responses including increases or decreases in white blood cells, muscle protein, liver glycogen, plasma glucose, plasma lactate, electrolytes, melanocytes, heart rate, and plasma fatty acids.

Researchers have measured many of these stress indices while attempting to characterize the physiological effects of collecting and transporting salmonid smolts. In this section, I focus primarily on the dynamics of plasma cortisol not only because it was used as an index of stress in most studies, but also because as an indicator of primary stress, its levels are generally considerably more dynamic than those associated with secondary responses (Mazeaud et al. 1977). With regard to cortisol as a stress indicator, I address only studies that involved collection and transport by truck.

In a comprehensive 3-year study of the effects of collection and transport on subyearling chinook salmon, Maule et al. (1988) reported that plasma cortisol concentrations increased significantly during the collection process but returned to base levels during the 12 to 48 hours of raceway residence immediately following collection. Loading into trucks elicited another significant increase in plasma cortisol followed by a net decrease after 3-4 hours of truck transport. Furthermore, truck loading densities, which ranged from 0.02 to 0.36 kg/L did not influence plasma cortisol dynamics.

Congelton et al. (1984) reported similar results for yearling chinook salmon at Lower Granite Dam. Plasma cortisol increased during collection and decreased during raceway residence. The loading process elicited another increase in circulating plasma cortisol that generally remained unchanged or declined during the 8-9 hours of subsequent truck transport. Truck loading densities did not affect final plasma cortisol concentrations upon arrival at Bonneville Dam.

To evaluate the stress effects of a 3-hour truck transport on experimental fish, Matthews et al. (1987) measured plasma cortisol in groups of yearling smolts prior to and after marking at

Lower Granite Dam and after truck transport to Little Goose Dam. The numbers of smolts sampled in each of five tests were nearly triple the numbers sampled in individual tests in the studies reported above. In each test, plasma cortisol increased significantly after handling and marking and decreased significantly after truck transport, usually reaching levels measured prior to handling and marking.

From 1984 through 1986, Matthews et al. (1987) held yearling chinook salmon smolts sampled from various areas of the Lower Granite Dam collection and transport system in an artificial seawater recirculating system at the dam for long-term observation. In all 3 years, the 43-day mortality was significantly higher for smolts that had passed through the collection system than for those that had not. However, there was no significant difference in mortality between those that had passed through the collection system and those that passed through the system and experienced transport by truck. These findings implied that conditions associated with smolt collection were more important than those associated with truck transport relative to primary stress during the collection and transport process.

In all studies to date, various components of the collection and handling process were shown to elicit a physiological response in juvenile salmonids, as measured by plasma cortisol. However, in nearly all cases, truck transport did not elicit an additional response. On the ontrary, circulating plasma cortisol generally decreased during transportation.

Discussion

Results of the mark/recapture studies differed by life history type. For steelhead and fall chinook salmon (subyearlings), numbers of returning study fish were consistently high, and tag return information consistently demonstrated that significantly more truck-transported than downstream-migrant fish returned as adults to the dams from which they were transported as juveniles. Results for spring/summer chinook salmon (yearlings) were more variable. The initial 6 years of research (1968-73) indicated that truck transportation increased adult returns to the Snake River. The increase demonstrated during the 1973 low-flow year was particularly substantial. No research was conducted in 1974; in 1975, a single study was conducted at Lower Granite Dam. A substantial number of adults (574) returned from this study, supporting earlier findings.

Truck-transport research during the next 5 years (1976-80) coincided with a severe decline in the numbers of returning adult study fish, resulting in mixed or inconclusive results from tests of spring/summer chinook salmon. Williams and Matthews (1995) discussed some of the factors that reduced the numbers of returning adults during this period. None were related to the transport process itself.

Small numbers of returning adult spring/summer chinook salmon diminished the precision of studies from 1976 through 1980. The low numbers of adult returns did not provide sufficient power to determine if statistically significant differences in SARs existed between fish transported as juveniles vs. those that migrated downstream through the hydropower system.

Even in most years prior to 1977 when significant differences were detected between fish trucked as juveniles vs. those that migrated downstream through the hydropower system, fish from the trucked groups returned at lower rates than expected compared to downstream-migrant fish. This implied higher mortality in trucked fish after release below Bonneville Dam relative to downstream-migrant fish. Trucked fish were released from shoreline areas below the dam prior to 1977, most notably from a boat ramp on the Washington shoreline. Ledgerwood et al. (1991) later found that fish released from shoreline areas downstream from Bonneville Dam were vulnerable to significant predation. Moreover, in mid-1976, it was discovered that hydraulic conditions at the boat-ramp release site caused many smolts to wash ashore downstream from the release site. A new release site was subsequently established at the Bonneville Dam First Powerhouse. At this site, smolts were released in high flows, well offshore.

It is evident that the extra mortality many now ascribe to truck transportation was likely due to naivety regarding the importance of release strategies during the early studies. Much has been learned from past mistakes. Today, great care is taken to minimize any potential problems associated with fish releases from both trucks and barges. Unfortunately, the only truck studies with reasonable SARs were conducted early in the smolt-transport program, so no data have been generated using contemporary methods. Because of known and presumed problems with early truck-release strategies, it is highly likely that early truck-transport results were biased against the transport groups. However, the early data simply do not represent extant or future conditions.

Opportunities to directly compare truck vs. barge transportation were rare. Only five tests were conducted: one on spring/summer chinook salmon, three on steelhead, and one on fall chinook salmon. Trucked fish were released at the offshore Bonneville Dam First Powerhouse release site during these studies. Although no statistically significant differences were detected between return rates of trucked and barged fish, barged fish appeared to return at higher rates in most cases. This may have resulted from differences in the release locations for the two groups. The barged fish were released 4-5 km downstream from Bonneville Dam vs. the tailrace of Bonneville Dam for the trucked fish. Under present transportation procedures, nearly all trucked fish are now taken by a ferry into the river downstream from Bonneville Dam for release. Nonetheless, regardless of species or life history type, study fish from both transport procedures returned at significantly higher rates compared to downstream migrants.

A concern exists that some individual stocks or life history types are potentially disadvantaged when truck transportation is implemented at dams. The ISAB (R. Williams et al. 1998) reported that Imnaha River wild spring/summer chinook salmon exhibited a relatively late and protracted timing of migration, with up to one-third of the population migrating past the dams in September. They concluded that a high proportion of this population was more likely to be trucked than barged downstream. However, this hypothesis is based on a false premise about the late run-timing of this population: Achord et al. (1997) demonstrated that virtually all wild yearling smolts (including wild Imnaha River fish) from all streams moved past the dams between early April and early July, and that Imnaha River fish were among the earliest, not the latest, to migrate. If future spring transportation schedules remain comparable to those of the past 3 years, then it is highly likely that, of the fish collected and transported, more than 90% of all individual populations will be transported by barge in any given year. In most years, the percentage will be much higher. Even though no information exists about truck returns under present operation scenarios, it does not appear that the small percentages of fish trucked will have much of an influence on SARs of any individual wild population.

Detailed smolt migrational timing data are unavailable for specific wild steelhead populations. However, Raymond (1979) demonstrated that the migrational distribution of the composite wild population was also protracted, albeit to a lesser degree than for wild spring/summer chinook salmon. Since the wild steelhead migration is concentrated nearer the middle of the spring out-migration period, it is likely that an even smaller fraction of any specific wild steelhead population are transported by truck rather than barge in any given year.

In contrast, a large fraction of fall chinook salmon juveniles is transported by truck rather than barge each year. Of this fraction, nearly all Snake River subyearlings, and roughly one-third of the subyearlings arriving at McNary Dam, are transported by truck. Previous research at McNary Dam has consistently demonstrated high T/Is for fish trucked from that dam. There was no significant difference in adult returns in the single study that directly compared truck and barge transport of these fish. Transport studies that specifically targeted Snake River fall chinook salmon were never conducted. However, since wild Snake River subyearlings are more developmentally advanced at time of transport than the bulk of wild subyearlings arriving at McNary Dam, a proportional difference in transport effects seems a reasonable assumption between fish from the two areas.

No consistent evidence of homing impairment emerged during the early transport studies conducted at COE dams, nor was there any evidence from these studies that trucked fish strayed at higher rates than barged fish, contrary to findings reported by the ISAB (R. Williams et al. 1998). The reason for this discrepancy was that the ISAB's conclusion was not based upon results of NMFS studies conducted at COE mainstem dams. The studies cited by the ISAB that suggested homing impairment primarily involved direct transport by trucks from hatcheries, transport after short-distance migrations, or transport from mid-Columbia River dams. Straying and other homing disruptions commonly occur when salmonid juveniles are transported either directly from hatcheries or after abbreviated migrations (Hisata 1980, Bjornn and Ringe 1984, Harmon and Slatick 1984). Moreover, Chapman et al. (1997) specifically advised against extrapolation of results from transport studies conducted at mid-Columbia River dams.

Adult PIT-tag detection systems will be installed in mainstem Columbia River dams in the near future. These systems will provide data from which to compare adult homing efficacies of fish with differing juvenile migration histories. Until these data are accumulated and assessed, judgments relative to transportation from COE mainstem dams should be weighted heavily to results of the studies conducted in situ.

Stress in relation to smolt collection and transportation has been studied extensively since the early 1980s, and these evaluations continue today. Various components of the smolt collection process consistently elicited a primary stress response in juvenile salmonids. However, primary stress indices consistently declined during truck transport, regardless of the hauling densities tested. Truck transport appears relatively benign as measured by primary stress indicators.

From a thorough review of the literature, I concluded that truck-transported steelhead and fall chinook salmon juveniles returned as adults at significantly higher rates than did juveniles allowed to migrate inriver from 1968 through 1980. Because I imparted considerable weight to studies that yielded high rather than low numbers of returning adults (and subsequently more accurate statistical comparisons), I concluded the same for spring/summer chinook salmon. Early T/I point estimates lacked precision, however. Further research will be necessary before valid scientific conclusions can be drawn concerning potential differences in effectiveness between truck and barge transportation from mainstem dams. For now, any judgments or conclusions in this area must necessarily be based on conjecture rather than fact.

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