ISSUE PAPER

POTENTIAL OF SHORT-HAUL BARGING AS A BYPASS RELEASE STRATEGY

by

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INTRODUCTION

On-site bypassing of juvenile salmonids around turbines for subsequent release into tailrace areas of dams is a developing strategy for increasing survival of these fish. All of these systems use single-site, fixed-location exit structures. Recent studies at Bonneville Dam have shown that survival of bypassed subyearling fall chinook salmon (*Oncorhynchus tshawytscha*) was not increased over fish passing through the second powerhouse turbines at that dam (Ledgerwood et al. 1991). Furthermore, Ledgerwood et al. (1991) suggested that predation at the bypass exit was likely responsible for the lower than expected survival of fish using this passage conduit.

Recent research at dams upstream from Bonneville Dam has demonstrated that piscivorous fishes, particularly northern squawfish (*Ptychocheilus oregonensis*), concentrate heavily in the tailrace area of dams and consume large numbers of juvenile salmonids (Beamesderfer and Rieman 1991, Poe et al. 1991, Vigg et al. 1991). Avian predators, particularly ring-billed gulls (*Larus delawarensis*), also concentrate heavily in the immediate vicinity of dams. It is becoming increasingly apparent that the benefits of bypassing juvenile salmonids around turbines may be nullified by heavy predation at the bypass release sites. It is possible that even multiple random or mass postbypass release strategies would still result in unacceptable levels of predation in these highly restricted, predator-infested areas.

In contrast, open areas downstream and distant from dams pose a lower risk of predation-related mortality, particularly to yearling smolts. Northern squawfish prefer low-velocity microhabitats that

normally occur near shore or around dams. It is believed that yearling smolts, on the other hand, migrate in the reservoirs below dams in faster-flowing open water (Beamesderfer and Rieman 1991). It is likely that release of bypassed juvenile salmonids into these areas, little used by predators, would substantially reduce predation-related mortalities.

It is important to consider all options for increasing survival of bypassed juvenile salmonids. Short-haul transfer or barging of bypassed juvenile salmonids for release into down-reservoir areas offers a potential solution to this problem. Release points could be varied randomly in space and time over several miles of open reservoir. Smolts could also be released in mass, offering protection in numbers--a basic survival strategy of schooling fishes.

The short-haul barging concept shares many features with the long-haul transportation program which has been studied in detail over the past 24 years. Throughout the last decade, long-haul barging has been used extensively to avert mortalities associated with passage through the series of dams and reservoirs on the lower Columbia and Snake Rivers. The potential benefits and risks associated with short-haul barging as a postbypass release strategy are explored in this paper by examining the results of previous long-haul transportation studies under the assumption that they represent the long-term effects of transporting juvenile salmonids following short-haul transportation. The short-term effects of collection and transportion are also discussed in terms of physiological indices of stress and the prevalence of disease.

LONG-TERM EFFECTS OF TRANSPORTING JUVENILE SALMONIDS

Long-haul transportation of juvenile salmonids by truck or barge has been studied extensively since the late 1960s. On the Snake River, transportation of steelhead (*Oncorhynchus mykiss*) and yearling chinook salmon (*O. tshawytscha*) was evaluated at Ice Harbor, Little Goose, and Lower Granite Dams over a period of 13 years from 1968 through 1980. More recently at Lower Granite Dam, marking of barge-transported groups only was revisited from 1983 through 1985, and a re-evaluation of long-haul transportation of these species was initiated in 1986. On the Columbia River, long-haul transportation of steelhead and subyearling and yearling chinook salmon was evaluated at McNary Dam from 1978 through 1983. In addition, transport of subyearling and yearling chinook salmon was re-evaluated at McNary Dam from 1986 through 1988. Transportation of sockeye salmon (*O. nerka*) and yearling chinook salmon was studied at Priest Rapids Dam during 1984-88 and 1984-86, respectively. Few, if any, survival enhancement techniques for anadromous salmonids of the Columbia River have received more intense scientific scrutiny over such a protracted period.

Mark/recapture methods have been, and continue to be, the principal tools for evaluating the long-term effects of long-haul transportation on juvenile salmonids. Groups of downstream migrating salmonids collected at an upstream dam receive distinctive coded wire tags and freeze brands. One group is then transported and released below Bonneville Dam while the other is returned to the river as experimental controls to continue the downstream migration through the hydropower complex. Recoveries of adults from these

experimental groups from various areas including ocean and river fisheries, fish ladders at dams, hatcheries, and spawning grounds are compared to evaluate the effectiveness of the technique. Generally, these recoveries are expressed as a transport to control ratio (T/C).

The T/Cs also provide indirect information on the effect of transportation of juveniles on the homing ability of returning adults. Assuming no differential mortality occurred between groups, a steadily decreasing T/C from marked adults sampled as they progress upstream implies a loss of homing ability. Homing impairment would also be indicated if excessive numbers of adults returned to inappropriate locations.

The effects of transportation on anadromous salmonid populations can also be evaluated indirectly by examining trends in population abundance over time for populations that have undergone extensive (mass) transportation. This type of analysis must be viewed with perspective as other phenomena outside of transportation can affect population abundance, particularly short-term trends in abundance. Examples are annual variations in ocean survival, ocean and freshwater fisheries, and freshwater environmental conditions that can influence survival over the entire period of freshwater residency. Severe annual drought or extended drought are examples of the latter. Also, transportation has been used extensively for only about two to four generations depending upon the species. This is a relatively short period considering the depressed status of all stocks at the time that mass transportation of smolts was initiated, and the potential for stochastic processes, unrelated to smolt

transportation, to negatively impact small populations in the short term.

Over the last 24 years, transportation research has provided a considerable volume of direct information concerning the long-term effects of transportation on several anadromous salmonid species of the Columbia and Snake Rivers. Over a shorter time, observations of the responses of populations that have undergone extensive transportation have provided additional indirect knowledge of long-term effects. In the following sections, the state of knowledge of the effects of smolt transportation on adult returns is summarized by species or stock.

Steelhead

Overview of Research

From 1969 through 1980, 22 separate transportation studies were conducted using juvenile steelhead as the target species (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985). Of the studies, 17 were conducted at various Snake River dams and 5 were conducted at McNary Dam on the Columbia River. Both truck and barge transportation were tested. In all of the Snake River studies, significantly more transported than control steelhead were recovered as returning adults from the fish ladders at the dams. The T/Cs ranged from 1.3 to 17.5. For the McNary Dam studies from 1978 through 1980, significantly more transported than control fish were recovered as adults from traps in fish ladders in all but one study in which a trucked group returned at a slightly higher rate than the paired in-river control. The T/Cs ranged from 1.3 to 3.0.

In 1986 and 1989, transportation of juvenile steelhead was re-evaluated at Lower Granite Dam using state-of-the-art collection, handling/marking, and barge transport techniques. In-river controls for these studies were released below Little Goose Dam. Complete returns for the 1986 study year show that the T/C back to the dam was 2.0 with a 95% confidence interval (CI) of (1.4, 2.7). Returns for the 1989 study year are incomplete; to date, the T/C is 1.9.

Ebel (1980) examined differences in the size and age of returning adult steelhead released during juvenile transportation studies at Little Goose Dam during 1971-73. No significant differences were found in either of these variables between adults that were transported as juveniles and those that were not.

Homing Behavior

Loss or impairment of homing ability in adult steelhead previously transported as juveniles was not considered a serious problem in any of the studies conducted from 1969 through 1980 (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985). No homing loss was reported in the studies conducted at Ice Harbor Dam in 1969-70 (Ebel et al. 1973, Slatick et al. 1975). Ebel (1980) provided an extensive coverage of returns of adult steelhead to various locations for studies conducted at Little Goose Dam from 1971 through 1973. Returns were monitored at Dworshak National Fish Hatchery (NFH) and Pahsimeroi Hatchery as well as downstream at Little Goose Dam. The T/Cs at the hatcheries were somewhat lower than at the dam in the 1971 studies, but higher than at the dam in the 1972 and 1973 studies. The author did not provide an

explanation for these conflicting results; statistical comparisons, however, were not provided between the recovery locations.

Returns are complete for the most recent study (1986) at Lower Granite Dam. The T/Cs measured at the dam and at hatcheries above the dam were identical (Matthews et al. 1990), suggesting no loss of homing ability between these areas.

Excessive straying of adults from groups transported as juveniles would also indicate that the transportation affected homing behavior. Ebel et al. (1973) and Slatick et al. (1975) reported no straying of adult steelhead that were transported as juveniles during the Ice Harbor Dam studies. From the 1971-73 Little Goose Dam studies, Ebel (1980) found that three marked steelhead had strayed to Pelton Dam on the Deschutes River in Oregon. All three had been previously transported as juveniles from Little Goose Dam. However, 2,720 adult steelhead were identified at Little Goose Dam from the same release groups. In the 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 fish transported during the McNary Dam studies were identified as strays. Also, 11 of the 16 strays were from the 1976 study year. In the most recent studies at Lower Granite Dam (1984 through 1989), to date, only 2 of 2,205 recovered adult steelhead that were transported as juveniles have been identified as strays (Matthews et al. 1990). These levels of straying are below the levels reported elsewhere for spring/summer chinook salmon (Chapman et al. 1991).

Furthermore, of the millions of juvenile steelhead that were coded-wire-tagged at hatcheries in the Snake River Basin during the past 15 years, there is no evidence that these fish returned to inappropriate locations above the dams, even though the majority were transported as smolts to below Bonneville Dam during that time.

A delay during the upstream migrations of adults transported as juveniles would also suggest that transportation had influenced homing behavior. This phenomenon was reported to have occurred from 1971 through 1976 for approximately 10% of the adult steelhead that originated at Dworshak NFH but not for other hatchery populations in the Snake River (Park 1985). The stock reared at Dworshak NFH is termed the "B" run of Snake and Columbia River summer steelhead, while all other summer steelhead are considered the "A" run. The adult run-timing of the A run is earlier than the B run. Adult steelhead in the Snake River cease migrating upstream when the water temperature decreases toward winter. As the water temperature increases the following spring, the migration continues upstream to the spawning areas. Park (1985) observed a higher T/C in the population moving past Little Goose and Lower Granite Dams in the spring than in the fall. He attributed this observation to a delay in about 10% of the transported fish relative to the controls. Furthermore, from jaw-tag recoveries, he determined that the spring migrants were steelhead from the B run population only. I propose that the phenomenon that Park observed and attributed to delay was more likely due to a slightly later timing of adults returning from groups that were transported as juveniles. This was not observed in the A run fish because most were above the dams when the migrations

ceased the previous fall; hence, they would not have been observed at the dams during the spring migration. Because the B run migrates later, the latest segment of that population would over-winter in the reservoirs below the dam. This later segment would then be observed at the dams the following spring when the migrations continued. A slightly higher proportion of transported adults in this later segment of the B run would account for the slightly higher T/C measured in the spring than in the fall. This may have been occurring in the A run as well, but it simply was not observed. There appears to be a tendency for T/Cs to increase during the year in all studied stocks. However, marked returns are generally small relative to the populations they represent and the tendency is slight. Therefore, the phenomenon is difficult to quantify. In any event, the slight difference in run-timing, if it is real, does not appear to affect the ability of steelhead to return to the hatcheries in time to spawn successfully.

Currently, there are no data suggesting that transportation of juvenile steelhead causes a delay during their adult migrations. Recent data indicate that adult spring/summer chinook and sockeye salmon transported as juveniles do not delay during their upstream migrations (J. Harmon[1]). These data are from fish that were jaw tagged at Bonneville Dam and subsequently recovered at Priest Rapids or Lower Granite Dams. There was virtually no difference in the median travel time of transported and nontransported adults between those dams. Thus, data for other salmonid species suggest that a

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[1]Jerrell R. Harmon, National Marine Fisheries Service, Rt. 3, Box 53, Pomeroy, WA 99347. Pers. commun., October 1991.

significant delay during adult migrations is not likely to be an effect attributable to transportation of juvenile anadromous salmonids.

Mass Transportation

Mass transportation of steelhead (transporting all collected smolts, not only those marked for research purposes) began at Little Goose Dam in 1975 and was expanded to include smolts collected at Lower Granite Dam in 1976. During the first 2 years, less than 20% of the estimated total outmigration arriving at Lower Granite Dam was transported (Koski et al. 1986). From 1977 through 1985, an average of 65% (range 44 to 79%) of the annual outmigrants arriving at the dam were transported. Since then, the abundance of smolts arriving at the first dam has not been estimated annually. However, hatchery production increased and, presumably, the percentage transported was higher than in the past due to improvements in the fish guidance capabilities of submerged travelling screens.

Prior to the initiation of mass transportation in the mid-1970s, record low runs of adult steelhead were recorded in the Snake River. Only 17,311 and 23,017 adults were counted at Lower Granite Dam in 1975 and 1976, respectively (USACE 1990). However, after mass transportation, annual adult counts began to increase. From 1977 through 1980, adult counts averaged 37,000 fish, about double the average of the previous 2 years. Over the last 10 years, adult counts have more than doubled again, averaging 90,000 fish with a modern record of over 134,000 adults counted in 1986.

It is appropriate to note that the quality of hatchery-reared steelhead smolts collected at the dams in the mid-1970s was poor,

particularly for those originating at Dworshak NFH. Fungal infections were typical, suggesting that the physiological status of the smolts was inferior. By the late 1970s and early 1980s, fungal infections were rare and severe fin erosion, also typical of the earlier smolts, had declined substantially.

Summary

Past research demonstrated conclusively that long-haul transportation of steelhead smolts by truck and/or barge resulted in substantially more returning adults when compared to smolts that migrated downstream through the hydropower complex. Ongoing research continues to substantiate the earlier observations. In addition, transportation of steelhead smolts does not appear to negatively influence the homing behavior of returning adults, at least to a degree that has been detectable with the methods used. The strong recovery of these runs and their present abundance is a testimonial to the potential effectiveness of transporting quality smolts around dams.

Spring/Summer Chinook Salmon (Stream Type)

Overview of Research

From 1968 through 1980, 24 separate transportation studies were conducted at dams on the Snake River using spring/summer chinook salmon as the target species (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985, Chapman et al. 1991). Studies were conducted at Ice Harbor Dam in 1968-70, at Little Goose Dam in 1971-73 and again in 1976-78, and at Lower Granite Dam in 1975-80. A few additional studies were attempted on the Columbia River at McNary

Dam in 1978-80 and at Priest Rapids Dam in 1984-86, but results were inconclusive due to insufficient adult returns. Both truck and barge transport were tested. In a few of the truck tests, a saltwater transport medium was tested, but results were inconclusive due to poor adult returns. In 10 (42%) of the Snake River tests, significantly more transported than control fish were recovered as returning adults from traps in the fish ladders at dams where the studies originated. In five of the tests, more, but not significantly more, transported than control fish were recovered as adults in the traps. In another five tests, returns of both groups were so low that results were meaningless. In two tests (1977), no fish of either group returned. In one test (1976), Park (1985) and Chapman et al. (1991) reported significantly more control than transported fish were recovered as adults. In this test, adult returns from two truck transport release sites were combined to provide sufficient returns for statistical analysis. The intent of the study was to compare the two release sites with each other as well as each with the control. If the data had been treated in this way, as I believe is appropriate, then the adult return rates for each group were too low for meaningful comparisons. Over the course of the 24 studies, T/Cs ranged between 0.7 and 18.1, with 3 of the studies reporting T/Cs below 1.0. All three of these studies were associated with extremely poor adult returns of both experimental groups, which resulted in insufficient returns for analysis or nonsignificant differences in the returns.

Marking of juvenile spring/summer chinook salmon barge transport groups only was reinitiated at Lower Granite Dam in 1983

and paired in-river controls were also marked in 1986 and 1989 (Matthews et al. 1990). As with steelhead, the in-river controls were released below Little Goose Dam. Adult returns for the 1986 study year are complete and show a T/C estimate back to the dam of 1.6 with a 95% CI of (1.01, 2.47). While adult returns for the 1989 study year are incomplete, the T/C is currently 2.1.

Ebel (1980) examined the returns of adult spring/summer chinook salmon from control and transported smolt groups released each year at Little Goose Dam during 1971-73 to determine if transportation as juveniles influenced the size and age of return of adults. Transportation did not influence the size of returning adults. However, there was a slight, but statistically significant, difference in the age of return of adults between the two groups. Relative to the control groups, transported fish tended to return more as 2- than 3-ocean adults. Adult returns in subsequent studies have been insufficient to verify or refute this earlier observation.

It is also possible that factors other than transportation could account for Ebel's (1980) observation that transported fish tended to return more as 2- than 3-ocean adults. For example, wild fish originating from areas of the Salmon River other than the South Fork tend to produce higher numbers of adults returning as 3- than 2-ocean fish relative to other areas including hatcheries (Howell et al. 1985, Matthews and Waples 1991). If the control groups included slightly higher numbers of wild smolts originating in the Salmon River than the transported groups, then the former groups might be expected to produce proportionately more adults returning as 3-ocean fish regardless of transportation effects.

Viewing the mixed results of the earlier studies (1968-80) "on the surface" is, I believe, one of the primary reasons for the current reluctance of the Columbia Basin Fish and Wildlife Authority to fully endorse transportation of spring/summer chinook salmon. This is in spite of the fact that more or significantly more transported than control fish returned as adults in most tests. Moreover, individual tests that produced the highest adult return rates of both experimental groups always resulted in significantly more fish returning as adults from the transported than non-transported test groups. The principal pattern evident from the earlier studies is a deterioration in the quality of the study results due to a deterioration of adult return rates for both release groups through time. A more detailed, chronological examination of these studies is, therefore, warranted.

The first and most successful study to evaluate transportation of Snake River spring/summer chinook salmon was conducted at Ice Harbor Dam in 1968 by Ebel et al. (1973). Smolts were dipped directly from unscreened gatewells, marked as appropriate, and either transported by truck to below Bonneville Dam or released as controls above the dam. According to Raymond (1988), the 1968 smolt outmigration was composed of nearly 80% wild fish. Moreover, the minority of the smolts that originated from Rapid River Hatchery returned as adults nearly as well as the wild fish. Study results for that first year reflected the uncomplicated collection and handling procedures (for that time) and also the survival capability of the study population. Significantly more transported than control fish returned to the dam as adults. The observed (sampled)

adult return rate was 0.14% for the control group and 0.30% for the transported group resulting in a T/C of 2.0. By retagging with jaw tags all observed adults at the dam and subsequently examining the hatchery and wild populations after spawning, Ebel et al. (1973) estimated total adult returns of 4.3% for the control group and 9.0% for the transported group.

The study was repeated at Ice Harbor Dam in 1969 and 1970 (Slatick et al. 1975) with, again, a higher abundance of wild than hatchery fish in the population and a high survival to adulthood of both hatchery and wild smolts in the general population (Raymond 1988). As for the 1968 study year, significantly more transported fish returned to the dam as adults than controls for both study years. The T/Cs were 1.3 and 1.5 for 1969 and 1970, respectively. However, while the observed adult return rates were similar to the rates observed for the 1968 study year, the estimated total returns for both groups were much lower for both 1969 and 1970. During these two study years, smolts were not dipped from the gatewells prior to marking as was the case in 1968. Instead, an orifice/wooden flume bypass system, installed in the ice and trash sluiceway, was used to collect smolts for marking. An inclined-screen trap was located at the terminus of the flume and was used to collect and hold fish. A fish pump was incorporated into the system to pump the smolts against 15 m of hydraulic head to the intake deck for marking. Also, smolts had to pass through two new dams (Lower Monumental Dam in 1969 and, in addition, Little Goose Dam in 1970) before arriving at Ice Harbor Dam. Slatick et al. (1975) reported a high incidence of gas bubble disease in smolts collected for marking

at Ice Harbor Dam in 1969 and 1970 due to spilling excess flow at the either or both upstream dams in 1969 and 1970. These operational differences during the latter 2 years of study resulted in the experimental groups being comprised of smolts in poorer physical condition than during the first study year; hence, adult return rates of both experimental groups were also poorer. This, I believe, was the first indication of one of two principal reasons that adult return rates of study fish deteriorated drastically as the studies progressed through time--the level of physical abuse suffered by smolts comprising both experimental groups increased through time.

Beginning in 1971 and continuing through 1978, transportation research was conducted at Little Goose Dam. The collection of fish was facilitated by incorporating intake guidance screens, an orifice bypass system, and collection raceways into the dam (Smith and Farr 1975). A fish pump was again used to move fish from the collection raceways into the sorting and marking building. Adult return rates for the first year were similar to those observed at Ice Harbor Dam in 1969 and 1970 (Ebel 1980). Significantly more adults returned to the dam from those groups that were transported as juveniles by truck than from those groups that were not. The T/Cs for the two truck release site test groups were 1.6 and 1.7. In the second year of study (1972), adult return rates suddenly plummeted. More adults returned from the transported than the control groups, but the differences were not significant. The third year (1973) of study coincided with a period of severe drought and attendant low river flows. Significantly more adults returned from the transport test

groups than the control. The T/Cs for the two truck release site test groups were 13.5 and 18.1. From 1976 through 1978, truck transportation research continued at Little Goose Dam. Adult return rates for both study groups continued to be very poor resulting in inconclusive results for all 3 years (Park 1985).

As the transportation research continued at Little Goose Dam, additional research began upstream in 1975 at the newly constructed Lower Granite Dam. A complete juvenile fish diversion, bypass, and fish holding system was incorporated during construction of this dam (Matthews et al. 1977). The new system utilized gravity-flow exclusively to transfer fish, and it was hoped that this would help alleviate much of the physical trauma experienced by fish in the more archaic system at Little Goose Dam. For reasons discussed below, this was not to be the case even though adult return rates for the first study year were similar to earlier return rates at Ice Harbor Dam during 1969-70 and at Little Goose Dam in 1971. Significantly more adults returned from the truck transported study group than the control group for the 1975 study year with a T/C of 2.0. From 1976 until these studies were completed in 1980, adult return rates for both study groups were poor. Even so, in 1978 and 1979, significantly more adults returned from both truck and barge transported groups than the corresponding control groups.

The second major factor that I submit contributed to the chronological deterioration of study results began to emerge during the earlier studies (1971-73) at Little Goose Dam--the ratio of wild to hatchery smolts shifted as outmigrant populations began to be predominated by hatchery fish. From 1970 through 1974, the smolt

population emigrating from the Snake River changed from one predominated by wild fish to one that was composed of nearly equal numbers of wild and hatchery-reared fish (Raymond 1988). Adult return rates for hatchery and wild fish in the general population remained high for the first 2 years of this period. However, in 1972, coincidental with the sudden decline of adult returns of study fish in both experimental groups at Little Goose Dam, adult return rates of hatchery fish in the general population suddenly declined about sevenfold from the average of the previous five years (Raymond 1988). With the exception of 1975, adult return rates of hatchery-reared fish in the general population continued to decline or remained very low through the late 1970s. Also during this period, the smolt population changed again from one composed of roughly equal numbers of wild and hatchery-reared fish to one predominated by the poorly surviving hatchery component. It has been noted elsewhere that as hatchery production increased through time in the Columbia River Basin, the rate of return of adults decreased (McIntyre 1987, Chapman et al. 1991).

As the studies progressed through the 1970s and the overall survival potential of the population in general declined drastically, the physical abuse suffered by study fish during collection increased. Based upon descaling and delayed mortality measurements, Ebel (1980) reported that poorer fish condition at the time of release was most likely a major factor contributing to the lower adult return rates for study fish during the earlier studies at Little Goose Dam compared to the original studies at Ice Harbor Dam. The problem was to worsen. At Lower Granite Dam during the

late 1970s, a massive debris accumulation in the forebay of the dam provided a continual supply of woody material that clogged trashracks (Smith et al. 1980) and accumulated in the gatewells and fish facility. Gatewell orifices were continually obstructed by this material as were all other components of the collection system. Also, the fish separator was a "dry" type typical of earlier models. Today's models are of the "wet" design where the grader bars are submerged in water. Debris continually accumulated between the exposed grader bars of the older models. In addition, the plumbing in the system was undersized for transferring fish safely and expeditiously and was highly susceptible to partial or complete blockage by debris. For example, during peak collection periods, it typically required 1 hour, and at times up to 3 hours, to transfer fish from one of the five raceways into a fish transport barge. Occasionally, the 6-inch transfer lines would completely plug with debris. It was not unusual for the system mortality rate to be so high that total enumeration was impossible--counts were often attempted by estimating the number of smolts in full or partially full dip nets of fish removed from the raceway tailscreens. In retrospect, considering the inferior capacity for survival of the population as a whole combined with the detrimental effects of collection in terms of physical abuse, it is remarkable, in my opinion, that any study fish returned as adults during this period.

From 1981 through 1984, the Corps of Engineers and fisheries agencies took major steps to correct the problems in the smolt collection systems at dams, particularly at Lower Granite Dam. Since then, additional improvements have been incorporated into the

systems annually. The modifications and improvements are detailed by facility in a series of annual reports by the Fish Transportation Oversight Team. A summary of these improvements are documented by Chapman et al. (1991). Moreover, the preanesthesia system of handling and marking smolts (Matthews et al. 1986) was introduced at Lower Granite Dam in 1983 and at McNary Dam in 1987. This system virtually eliminated the major physical traumas associated with the handling and marking process. All indications suggest that the modifications and improvements increased survival substantially. For example, at Lower Granite Dam, Matthews et al. (1988) reported an average tenfold decrease in postmarking delayed mortality rates for spring/summer chinook salmon smolts from 1983 through 1986 compared to the average from 1976 through 1980. Furthermore, in contrast to results from earlier studies, delayed mortalities for spring/summer chinook salmon smolts were lower than for steelhead smolts during the recent years. Major improvements in the observed adult return rates of marked and transported fish were also noted. Compared to the earlier study years noted above, observed adult returns back to the dam were four to seven times higher for the 1983 through 1985 study years. This was in spite of the fact that, relative to the 1976 through 1980 study years, the smolt populations of the most recent years were comprised of higher percentages of the poorer surviving hatchery component (Raymond 1988).

Homing Behavior

As with steelhead, impairment of homing behavior in returning adult spring/summer chinook salmon that were previously transported as smolts was not detected during the 1968-70 Ice Harbor Dam and

1971-73 Little Goose Dam studies (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985). During all studies, the T/Cs for spring/summer chinook salmon at the hatcheries and on spawning grounds were either equal to or higher than at the dams downstream. More recently, adult returns for the study conducted at Lower Granite Dam in 1986 are complete. Although too few adults were recovered from the hatcheries or spawning grounds to allow precise statistical comparisons with the T/C estimate at Lower Granite Dam, it is worth noting that at Rapid River Hatchery, where the largest number of study fish was recovered (26), the T/C was higher than at Lower Granite Dam (Matthews et al. 1990).

Reported incidences of straying of adult spring/summer chinook salmon that were transported as smolts were similar to the incidences reported for steelhead. No straying was reported for the Ice Harbor Dam studies (Ebel et al. 1973, Slatick et al. 1975). For the 1971-73 Little Goose Dam studies, 10 adults from the transported groups and 2 controls were recovered at Pelton Dam on the Deschutes River (Ebel 1980). Nevertheless, 857 adults from the same test groups were identified at Little Goose Dam. Park (1985) identified as strays 11 of 1,182 returning adult spring/summer chinook salmon that were transported as juveniles from Lower Granite, Little Goose, and McNary Dams from 1975 through 1980. All strays were recovered in the Deschutes River and, as for steelhead, none of the strays were from the studies conducted at McNary Dam. In the most recent studies at Lower Granite Dam (1983-89), 13 (10 were recovered from the Deschutes River) of 824 recovered adult spring/summer chinook salmon that were transported as juveniles have been identified as

strays so far. Again, these incidences of straying are generally below the incidences of natural straying of anadromous salmonids reported elsewhere (Chapman et al. 1991).

During the last decade, millions of spring/summer chinook salmon juveniles were coded-wire-tagged at hatcheries in the Snake River drainage. Even though many of these smolts were transported to below Bonneville Dam during this period, only two returning adults were recovered at inappropriate locations (Chapman et al. 1991). Moreover, it is not known if these two fish were even transported as juveniles. Also, a localized incidence of straying was reported in the Grande Ronde River drainage in recent years. Several adults released as juveniles at Lookingglass Creek Hatchery were recovered from two nearby streams. Strays of this type are rare and may not have any relationship to prior transportation as smolts.

Mass Transportation

Mass transportation of spring/summer chinook salmon smolts was initiated at Lower Granite and Little Goose Dams in 1976. In the first year, only 15% of the smolt population estimated to have arrived at Lower Granite Dam was transported from both dams combined to below Bonneville Dam (Koski et al. 1986). From 1977 through 1985, an average of 47% (range 26 to 68%) of the annual smolt populations estimated to have arrived at Lower Granite Dam were transported from both dams combined. Since 1985, the annual abundance of smolts arriving at Lower Granite Dam has not been estimated. However, hatchery production has nearly doubled since then, and the numbers transported have steadily increased.

In contrast to steelhead populations, demonstrating the positive influence of mass transportation on the general population of Snake River spring/summer chinook salmon is problematic. This is particularly true if only total adult returns to the river (dam counts, which include both hatchery and wild fish) are considered. For example, from 1975 through 1978, annual adult returns (including jacks) averaged 39,204 fish at Lower Granite Dam. Over the next 6 years (1979 through 1984) counts declined considerably, averaging only 16,932 fish and including the lowest returns on record of 11,111 and 10,205 fish in 1979 and 1980, respectively. I believe that these poor returns were primarily attributable to the previously described problems associated with the smolt collection systems at dams during this period and the devastating impact of the 1977 drought. After the major modifications and improvements were incorporated into the smolt collection systems in the early 1980s, annual adult counts improved to an average of 31,268 fish from 1985 through 1988. During the last 3 years (1988 through 1991), however, annual adult counts declined again, averaging 17,975 fish. Considering the total number of spring/summer chinook salmon smolts that were transported over the last 11 years, these return statistics are unimpressive. However, hatchery production roughly doubled during the early 1980s and then roughly doubled again from 1987 to present. At the same time, the abundance of wild fish in the population was the lowest in modern history (Matthews and Waples 1991). Therefore, the totals transported were increasingly predominated by fish with dubious survivability, regardless of any influence from smolt transportation. Perhaps more important was the

fact that wild populations were at such low levels of abundance at the beginning of the decade that even a relatively good response by these fish might be obscured if only the composite population were viewed through dam counts.

Redd counts in index areas provide the best indicator of trends in abundance of wild fish in the Snake River Basin (Matthews and Waples 1991). Since redd counts were initiated in the late 1950s, trends in all areas have followed the same basic pattern. For simplicity, I focus on redd counts in the Middle Fork of the Salmon River--a primary production area for wild spring chinook salmon in Idaho. I examine the temporal trend in redd production in this drainage as a redd recruitment ratio (R/R) progressing through 5 year population segments (generations). From 1960 through 1979, the R/R declined steadily through four reproductive cycles of salmon (White and Cochnauer 1989). For the successive generations the R/Rs were 0.8, 0.6, 0.5, and 0.3. Suddenly, however, the R/R for the 1980-84 spawning generation increased dramatically to 3.4. Smolts of this generation migrated downstream from 1982 through 1986 and returned as adults from 1984 through 1988. The smolt migration period was coincidental with the aforementioned initiation of major modifications and improvements in the smolt collection systems at dams. Particularly impressive was the performance of wild smolts in the 1985 outmigration. In that year, over 50% of the smolts arriving at Lower Granite Dam were estimated to have been transported (Koski et al. 1986). Fish from this outmigration predominated ensuing adult returns as 2-ocean fish in 1987 and

3-ocean fish in 1988 (Fryer and Schwartzberg 1991). In 1988, the total redd count in the Snake River drainage was the highest since 1978 and, in the Middle Fork of the Salmon River, the highest since 1973 (Matthews and Waples 1991). It is noteworthy that river flows in the Snake River during the spring and early summer of 1985 were the lowest of the 5-year period 1982-86 (USACE 1985) and would likely be considered somewhat below average overall.

Adult returns are incomplete for the most recent reproductive cycle (1985-89); however, returns to date indicate that the R/R will again fall somewhat below 1.0 for that generation. Several complicating factors, unrelated to smolt transportation, may be negatively impacting this most recent generation of wild fish. In 1987, the Snake River drainage entered an extended period of drought (5 years to date) characterized by minimal snowpacks and periods of extreme cold during mid-winter. Water discharge from all streams has been reduced substantially. These types of severe environmental conditions are known to negatively impact the survival of juvenile salmonids in freshwater ecosystems (Edmunson et al. 1968, Seelbach 1987). In addition, as previously mentioned, hatchery production increased substantially beginning in 1987. Chapman et al. (1991) provided a meticulous review of the potential adverse impacts of hatchery fish on wild populations. Yet, progressively more were released and production is scheduled to increase even more in the near future. Finally, the 1989 outmigration of both spring/summer chinook salmon and steelhead survived very poorly. Recent adult return rates of NMFS transportation study fish of both transport and control groups of both spring/summer chinook salmon and steelhead

were well below the expected return rates as were the populations in general for both species. This implies that the 1989 outmigrations of both species survived poorly during their first year after passage through the river, regardless of transportation. It is also noteworthy that river flows in the Snake River in the spring/summer period of 1989 were the highest of the past 5 years and very similar to flows in 1985--the year that produced the highest adult return of wild fish since the mid-1970s.

Summary

Past research to evaluate transportation of spring/summer chinook salmon smolts was less successful overall than for steelhead. Nevertheless, in nearly all studies, more or significantly more adults returned from groups transported as smolts than from those that migrated downstream through the hydropower complex. The most recent studies continue to strongly support transportation of this species. As with steelhead, no transportation-induced homing impairment has been detected so far. The strong recovery of wild populations during the mid-1980s in concert with improvements in the collection systems at dams, favorable environmental conditions, and much reduced levels of hatchery production provides evidence that transportation of this species is beneficial and should be maximized. Smolt transportation, however, will not and should not be expected to mitigate for progressive overproduction of hatchery populations with grossly inferior survival capabilities.

Summer/Fall Chinook Salmon (Ocean Type)

Overview of Research

The earliest evaluation of transportation of subyearling chinook salmon was initiated at McNary Dam in 1978 and continued for 6 consecutive years finishing in 1983. Truck transport was evaluated exclusively with the exception of 1983 when transport by both truck and barge was tested. Beginning in 1986 and continuing for three consecutive years, juvenile transportation by barge was re-evaluated using state-of-the-art facilities and methodologies. In all studies, in-river controls were released directly below the dam.

In all of the earlier studies (1978-83), significantly more adults were recovered from the transported than the control groups from all recovery areas (Park 1985, Matthews et al. 1988). The T/Cs ranged from 1.8 to 8.0, depending upon recovery area and study year. Adult returns for the studies begun in 1986 are incomplete; however, preliminary adult returns to all recovery areas continue to strongly favor the transported groups.

Homing Behavior

As for steelhead and spring/summer chinook salmon, previous transportation as juveniles did not appear to affect the homing capability of adult summer/fall chinook salmon. In the studies conducted from 1978 through 1983, T/Cs in the ocean and river fisheries were very similar to T/Cs on the spawning grounds and at hatcheries (Park 1985, Matthews et al. 1988). Likewise, no strays

have been recovered at inappropriate locations during any studies to date.

Mass Transportation

Mass transportation of subyearling chinook salmon began at McNary Dam in 1979. Only 670,000 juveniles were transported the first year, but the number transported increased to approximately 2 million in 1980. Since then, the numbers transported annually have steadily increased, peaking at 7.0 million fish in 1990.

Annual counts of adult fall chinook salmon passing McNary Dam increased substantially after mass transportation of juveniles was initiated (USACE 1990). Counts increased steadily from a low of 33,148 in 1981 to over 240,000 in 1986. Since 1987, counts have receded gradually to 80,692 in 1990. This is still two to four times more adults than were counted just prior to initiation of mass transportation of this stock. It should be noted that factors other than juvenile transportation can have a profound effect on the numbers of adult fall chinook salmon returning annually to spawn. For example, although the stock is heavily fished both in the ocean and the lower Columbia River, variable annual fishing pressure can result in variable annual spawning escapements. In addition, because the collection efficiency of this stock is low, a high percentage of the juveniles are not protected by transportation during their feeding migrations and are thus exposed to potentially wide annual variations in survival.

Summary

As with steelhead, past research demonstrated conclusively that this stock benefitted from transportation as juveniles, and the current studies continue to support the earlier findings. Moreover, the procedure does not appear to affect the homing ability of returning adults which have increased in number substantially since the advent of mass transportation.

Sockeye Salmon

Overview of Research

Transportation of sockeye salmon smolts from Priest Rapids Dam to below Bonneville Dam was evaluated for five consecutive years from 1984 through 1988 (Dell et al. 1985; Carlson et al. 1987a,b, 1988, 1989, 1991a,b). Transport by truck was tested in all years; however, in 1987 and 1988 a combination of trucking and barging was also tested. In these tests, smolts were trucked to McNary Dam where they were transferred to a barge for subsequent transport to below Bonneville Dam. The information from these studies must be viewed with caution because statistical analysis of the adult return data has not been reported.

A review of the preliminary data indicates that the studies produced mixed results. For two of the years (1984 and 1986), T/Cs for truck transport studies were less than 1.0 to all adult recovery areas. Return rates of both test and control groups were very poor for those years. In the other years (particularly the 1985 study year), return rates of study fish were improved and T/Cs to all recovery areas were equal to or greater than 1.0 (range 1.0 to 2.9).

However, T/Cs for the trucked and barged groups for the 1987 and 1988 study years were lower than for the trucked only test groups. I suspect that most of these studies were encumbered by mechanical flaws during the release of the trucked groups, a poor truck release site, or both.

One interesting result was the consistent observation of a temporal difference in the adult return rates of marked smolts. Throughout the studies, smolts marked and transported earlier in the outmigration returned at lower rates than their corresponding controls whereas just the opposite occurred in later marked groups. Presumably this reflects a difference in stock performance as spawning ground surveys showed that the earlier test groups were composed of fish from the Wenatchee stock and the later test groups were composed of fish from the Okanogan stock. Wenatchee stock smolts were much smaller than their Okanogan stock counterparts when they migrated past Priest Rapids Dam.

Homing Behavior

Carlson et al. (1988) provided a nonstatistical analysis that implied a transportation-induced homing disruption for returning adult sockeye salmon. The primary precept for this inference was the observation of a consistently higher T/C measured at Bonneville Dam than upstream at Priest Rapids Dam. Again, whether the T/Cs are statistically different has not been reported to date. At Bonneville Dam, only the fish ladder near the Washington shoreline was used to recover adults. The majority of returning sockeye salmon use the other fish ladders when passing the dam. A propensity for adults that were transported as juveniles to use this

ladder at a higher rate than controls would result in a sample bias in favor of the transported groups. Results for the 1985 study year suggested that this scenario was not only possible but probable. Adults returning from that outmigration year were sufficient in number to provide commercial harvests in the river below and above Bonneville Dam. The T/Cs in these fisheries were very similar to the T/C at Priest Rapids Dam while the T/C from recoveries in the north ladder at Bonneville Dam was much higher. Moreover, if adults from the transported groups were disoriented or lost after passing Bonneville Dam, they would likely mill in this area of the river, thereby increasing their susceptibility to harvest in the tribal fishery above the dam. This should have resulted in a higher T/C in this fishery. It is unlikely that confused adults would simply stop moving altogether at the upstream face of Bonneville Dam.

Summary

In my view, it is likely that a statistical analysis of these data will prove inconclusive overall. With the exception of the 1985 study year, adult recoveries were low in all areas. This is primarily because the studies were encumbered by difficulties in collecting adequate numbers of smolts for marking. Therefore, in nearly all cases, statistical significance will be difficult to establish.

Results of these studies to date do not support or refute juvenile transportation as a survival enhancement technique for sockeye salmon. Additional, well-designed, and tightly supervised studies will likely be necessary in the future to provide precise

and reliable information concerning the effects of transportation on this species.

SHORT-TERM EFFECTS OF TRANSPORTING JUVENILE SALMONIDS

Over the last 10 years, considerable research has provided insight concerning the short-term effects of collection and transportation on juvenile sockeye and chinook salmon. A large body of these studies focused primarily upon characterizing the fishes' response to various components of the collection and transportation process using physiological indices of stress (primarily plasma cortisol). In addition, the incidence and severity of bacterial kidney disease (BKD) infections in yearling chinook salmon smolts has also received substantial attention. Although these types of studies provide no knowledge that can be related directly to adult abundance, they do provide information that is useful in appraising and correcting potential problems for juveniles in an attempt to enhance the probability that they will survive to maturity.

Stress Studies

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 (cortisol) and catecholamines (adrenaline) which, in turn, influence 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 indices while attempting to characterize the effects of collection and transportation on salmonid smolts. In this review, I focus primarily on the dynamics of plasma cortisol not only because the hormone was used as an index of stress in most of the studies discussed, but because it is a primary stress response and, as such, is generally more dynamic than secondary responses (Mazeaud et al. 1977). Furthermore, I address only those studies that involved collection and transportation of salmonid smolts on a large scale at dams.

In a comprehensive, 3-year study of the effects of collection and transportation on juvenile fall chinook salmon at McNary Dam, Maule et al. (1988) reported that plasma cortisol concentrations increased significantly during the collection process but returned to base levels after 12-48 hours of raceway residence. Loading of fish into trucks or barges elicited another significant increase in plasma cortisol, but there was a net decrease in this stress index after 3-4 hours of transport in both trucks and barges. During barging, plasma cortisol concentrations remained low throughout the 15 hours of transport. Furthermore, loading densities in trucks ranging from 0.02 to 0.36 kg/l did not influence plasma cortisol dynamics.

Congelton et al. (1984) reported similar results for spring/summer chinook salmon during collection and transportation from Lower Granite Dam. Plasma cortisol levels increased during collection and decreased during raceway holding. As in the McNary Dam study, the loading process elicited a plasma cortisol response that generally remained unchanged or declined during the 8 to 9

hours of truck transport. However, in one test, plasma cortisol levels increased significantly during the final hours of transportation. Truck loading densities did not affect the final plasma cortisol concentrations upon arrival at Bonneville Dam. During barging, plasma cortisol remained unchanged or declined during the initial 8 hours of transportation but tended to increase in later samples. In seven of eight groups, plasma cortisol values were higher upon arrival at Bonneville Dam than they were at departure from Lower Granite Dam. (It is noteworthy that even though absolute plasma cortisol values changed during barging, 95% confidence intervals overlapped for all serial samples.) The timing of the increase in plasma cortisol in the sampled fish corresponded to the arrival of the barges at the confluence of the Snake and Columbia Rivers, and the authors offered this observation as a plausible explanation for the increase. That is, the fish may have been responding to the change in water circulating through the barges. I have witnessed abnormal behavior (frantic swimming and jumping) in salmonid smolts when they were transitioned immediately to different water, even when temperatures are nearly the same. The physical response may be more subdued or unnoticeable during a gradual transition (as in the barges), but a physiological response might not be unusual. On the other hand, heavily smolted salmonids held in small tanks of fresh water for 24 to 48 hours also demonstrate a frenzied behavior and jump frequently in an attempt to escape. Whether the confinement in large barges during the longer trip from Lower Granite Dam to below Bonneville Dam elicits a similar but less physical response is unknown.

Over a 5-year period, the stress response of spring chinook and sockeye salmon smolts to collection, handling and marking, and transport was evaluated at Priest Rapids Dam (Dell et al. 1985; Carlson et al. 1987a,b, 1988, 1989). During all study years, plasma cortisol levels increased in both spring chinook and sockeye salmon after collection and marking. During truck transport, plasma cortisol levels decreased or remained unchanged in all but one sample of spring chinook salmon. Annual results during truck transport were more variable for sockeye salmon; however, in most individual samples and over all years, a net decrease in plasma cortisol was measured.

To evaluate the effects of a 3-hour truck transport on experimental controls for transportation research, Matthews et al. (1987) measured plasma cortisol in groups of spring/summer chinook salmon smolts prior to and after marking at Lower Granite Dam and after truck transport to Little Goose Dam. The numbers of smolts sampled during each of five tests were nearly triple the numbers sampled during individual tests in the studies reported above. As with all previous studies, plasma cortisol levels increased significantly after handling and marking. However, in each individual test, plasma cortisol levels decreased significantly during truck transport to the levels measured prior to handling and marking at Lower Granite Dam.

From 1984 through 1986, spring/summer chinook salmon smolts were sampled from different areas of the collection and transportation system at Lower Granite Dam and subsequently held for observation in an artificial seawater recirculation system at the

dam (Matthews et al. 1987). 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 system and those that had both passed through the system and had undergone truck transport. The findings implied that the stress associated with smolt movement through the collection system was the most important factor affecting short-term survival of collected and transported smolts.

In all of these studies, various components of the collection and handling processes have been shown to elicit a physiological response in salmonid smolts as measured by plasma cortisol. However, in nearly all cases, short-term transportation did not elicit an additional response. On the contrary, plasma cortisol levels generally declined during transportation.

Disease

Transportation requires concentrating salmonid smolts in relatively small volumes of water. This procedure enhances the risk of disease transmission if contagious pathogens are extant in the population. Many factors can influence the level of risk. These factors include, but are not limited to, the pathogenicity of the disease or diseases involved, the susceptibility of the host population, and the initial level of infection in the population. One such pathogen that has received considerable attention in relation to smolt transportation in recent years is *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease (BKD)

in salmonids. It is worth noting that spring/summer chinook salmon are considered to be more sensitive to the disease than most other salmonids (Bullock and Wolf 1986).

In 1976, the spring/summer chinook salmon smolt population collected for transportation at Lower Granite Dam was examined for the presence of disease organisms (Park et al. 1977). Thirty mortalities and 90 randomly sampled smolts were necropsied and examined using standard procedures. Gram stains of kidney smears revealed massive concentrations of BKD organisms (gram-positive diplobacilli) in nine of the mortalities and one of the randomly sampled smolts. However, the gram-stain method is sufficiently sensitive to detect *R. salmoninarum* only in heavily infected fish. With the exception of a few nematodes and trematodes, no other disease organisms were reported in this study.

At Lower Granite Dam in 1985, Park et al. (1986) held several groups of spring/summer chinook salmon smolts sampled from various areas of the smolt collection system in an artificial seawater recirculation system for 21 weeks. By the end of the test, mortalities ranged between 60.3 and 75.9%, depending upon the sample area. Using an indirect fluorescent antibody technique, BKD organisms were identified in 98.8% (range 97.5 to 100% depending upon sample area) of the mortalities. Furthermore, 94.9% of the survivors were infected although the levels of infection were considerably lower. These results implicated BKD as a possible major factor influencing the survival of hatchery-reared spring/summer chinook salmon whether collected and transported or not.

Following up on these findings in 1987, Matthews et al. (1988), in cooperation with disease researchers from the U.S. Fish and Wildlife Service (USFWS), profiled the daily incidence and severity of BKD in spring/summer chinook salmon smolts collected at Lower Granite Dam. *R. salmoninarum* was quantified using a fluorescent antibody technique (FAT) and an enzyme-linked immunosorbent assay (ELISA) specific for *R. salmoninarum* (Pascho et al. 1988). Of 1,525 fish sampled throughout the outmigration, 18.8 and 46.5% were identified as BKD positive using the FAT and ELISA techniques, respectively.

These findings led to an ongoing, comprehensive research effort by the USFWS to examine BKD in relation to Columbia River salmonid smolts with particular emphasis on collected and transported spring/summer chinook salmon smolts (Pascho and Elliott 1989, Elliott and Pascho 1991). Results for the first study year (1988) indicated that 86 to 96% of spring/summer chinook salmon smolts sampled from the Columbia and Snake Rivers were infected with BKD as determined by the ELISA. Although the prevalence of BKD was high, over 65% of the smolts had ELISA values indicative of very low infection levels. For the other salmonid species, all sockeye salmon tested and 95% of the coho salmon (*O. kisutch*) tested were infected and, depending upon the sample site, 56 to 100% of the steelhead tested were infected. Infection levels in these fish were similar to those reported for spring/summer chinook salmon. Three-fish tissue pools from wild spring/summer chinook salmon parr from two streams in the Snake River were also examined by ELISA for *R. salmoninarum*. All samples were positive, but infection levels

were also very low. Finally, at McNary Dam, water samples from the river just upstream from the dam, from the collection raceways, and from a transport barge were concentrated and examined by FAT for presumptive *R. salmoninarum*. The bacteria was identified in the water samples from all three areas with cell counts ranging from 29 to 40 bacteria/ml. Results from tests the following year were similar. However, the incidence of BKD in spring/summer chinook salmon smolts was higher, ranging between 97 and 100%. In addition, live-box studies indicated that horizontal transmission of *R. salmoninarum* can occur among salmonids collected for transportation.

To date, these studies have demonstrated that *R. salmoninarum* is pervasive among all salmonid smolts emigrating from the Columbia and Snake Rivers. While the exact impact of the disease remains obscure, it is my view that short-term transportation will result in little, if any, additional impact since it appears that nearly all salmonid smolts involved will already have been infected.

DISCUSSION AND CONCLUSION

Previous research involving smolt bypass systems at dams on the Snake and Columbia Rivers was concerned primarily with improving collection efficiencies and evaluating the condition of smolts during bypass. Holistic studies designed to examine the short- and long-term consequences of passing salmonid smolts through individual bypass systems and to define potential problem areas are just beginning. Even so, evidence is mounting that postbypass release of smolts into the predator-infested tailrace areas of dams might prove counterproductive. In contrast, studies to evaluate the short- and

long-term effects of long-haul smolt transportation operations have been ongoing for over 2 decades and have provided a large volume of information relative to this procedure. Presumably, this knowledge is applicable in a conservative sense to short-haul smolt transportation operations as well because these types of operations would be considerably less extreme both spacially and temporally.

Based upon adult returns, results of the transportation studies varied by species. For steelhead and summer/fall chinook salmon, the latter migrating as subyearlings, tag return information from transportation research indicated a benefit. Also, adult returns of the general populations increased substantially after the initiation of mass transportation. For sockeye salmon, transportation studies conducted at Priest Rapids Dam on the Columbia River were inconclusive. This resulted from difficulties in collecting adequate numbers of juveniles for marking, and possibly by problems at the transport release site.

For spring/summer chinook salmon, migrating as yearling smolts, study results were less consistent. The initial 6 years (1968-73) of research on a small proportion of the population indicated that transportation would substantially increase adult returns. However, research during the next 6 years (1975-80) coincided with a severe decline in the adult return rates of all fish in the population, and results from marked transport and control fish were mixed or inconclusive. The structure of the general population had changed from one with a mean of 62% wild fish from 1968 through 1973 to one with a mean of 61% hatchery fish from 1975 through 1980 (Raymond 1988). Concomitantly, the juvenile outmigrants were exposed to high

levels of physical trauma due to structural inadequacies and debris accumulations within the smolt collection systems at the dams. After these problems were corrected in the early 1980s, the most current complete adult returns from juveniles marked during the 1986 study indicated a significant benefit for fish transported as juveniles. Incomplete returns from juveniles marked during the 1989 study continue to show benefits for transported fish. The overall adult return rate of the population, however, has remained low. I attribute this to poor survival of the hatchery component, which accounted for greater than 85% of the smolts arriving at Lower Granite Dam during this period. In contrast to hatchery fish returns during the mid-1980s, wild populations recovered substantially from near extinction levels. This strong recovery coincided with a period when the majority of smolts were transported.

Recently, the Northwest Power Planning Council has used mathematical modeling of the 1986 study to imply that transportation does not maximally benefit spring/summer chinook salmon smolts (McConnaha 1991). Under a typical scenario, mortality was calculated at 15% per project for inriver controls under average conditions. This led to the conclusion that if 100% of the transported fish had survived relative to the inriver controls released below Little Goose Dam, the T/C should have been 3.1. If the computer modeling predicts actual conditions, and since the measured T/C from transport research was only 1.6, the modeling results suggested that approximately 50% of the transported fish must have perished relative to the controls. Furthermore, the

computer modeling implied that no benefit would be gained from transportation at McNary Dam if the T/C from Little Goose Dam was only 1.6.

In developing the model for this analysis, the various parameters acting on juvenile migrant survival were adjusted so that model results would match results from juvenile mark/recapture experiments by Sims and Ossiander (1981) conducted at Snake and Columbia River dams during the 1970s. As indicated earlier in this report, 48-hour post-marking delayed mortalities were high during this period due to the problems attendant at collection dams and with methods of fish handling. As a result, many smolts marked and released at an upstream dam did not arrive at downstream sites since large numbers obviously died after release simply due to the physical traumas of collecting and marking. During the mark/recapture studies (Raymond 1979, Sims and Ossiander 1981) to estimate flow/travel time and flow/survival, release numbers were not adjusted to reflect even the short-term 48-hour delayed mortalities, much less those that likely occurred over a longer period. Further, all smolts released from upstream sites and not recovered at downstream sites were assummed to have died as a result of passage through the hydropower complex, with survivals varying due to changes in river discharge. These analyses did not consider smolt condition and undoubtedly resulted in artificially high in-river mortality estimates which were attributed entirely to changes in flow and dam passage conditions. Passage conditions at dams and fish handling techniques have improved substantially over those during the 1970s. Thus, models based upon conditions during the

1970s probably underestimate in-river survival of marked juvenile fish used in recent transportation studies.

Another problem with the model for estimating in-river survival was the assumption that per project mortality was the same for all projects. Our preliminary review of the data collected during the 1970s indicated that fish mortality was much higher at the first dams encountered by smolts after they were marked. This was particularly true for fish arriving at Lower Granite and Little Goose Dams because debris from the Snake River accumulated at these projects and negatively influenced fish condition.

Use of the measured T/C estimate without considering the statistical error bound may lead to conclusions that do not reflect reality. All measured T/Cs have very broad 95% CIs. A seemingly small difference in the T/C estimate could make a large difference in the inferences drawn from the model.

Finally, the argument that spring/summer chinook salmon populations have not rebounded because smolt transportation does not work is inconsistent with results for steelhead. The T/Cs measured for steelhead have been similar to those measured for spring/summer chinook salmon. Both species face the same conditions during passage through the hydropower system. Steelhead populations have recovered substantially under the transportation program. Although hatchery fish dominate the juvenile outmigrations of both stocks, the spring/summer chinook salmon hatchery component has a very low survival compared to steelhead.

No consistent evidence exists to indicate that long-haul transportation of salmonid smolts negatively influences the homing

capabilities of returning adults or affects overall survival. If any effect of smolt transportation on homing behavior has occurred, the methodologies used to date were not sufficiently sensitive to accurately quantify them. New research designed to precisely evaluate the effects of long-haul smolt transportation on adult homing behavior has been proposed for the future. However, it is highly improbable that short-haul transportation, involving only a few miles of river, would affect homing behavior to any degree.

The impacts of smolt collection and transportation operations in terms of stress and disease received considerable attention during the 1980s, and evaluation of these factors continues into the 1990s. The collection and bypass systems were shown to stimulate a primary stress response in fish that receded during raceway residence. Loading operations stimulated a second response that generally receded during transport regardless of the densities tested. This should not be too surprising since, for all practical purposes, a transport barge is nothing more than a floating raceway and a transport truck is not much different. The only disease that has been reported as a potential problem so far is BKD. The exact relationship between the disease and smolt transportation is yet to be determined. However, because virtually all salmonid smolts are already infected, transmission during transport, even if it occurs, should not be a major negative factor. Eventually, the disease will have to be curtailed or controlled at its primary source--the hatcheries.

The overwhelming majority of evidence indicates that long-haul smolt transportation is not harmful to salmonid smolts. On the

contrary, by providing a means of avoiding high-risk areas, the method is a valuable tool for increasing the survival of juvenile salmonids. Transportation operations are not without risk, however. Loading and unloading operations and methods are critical to the well-being of smolts and must receive considerable attention and be conducted properly. Reliable and properly operated life support systems are also critical. With these cautions, I conclude that either short- or long-haul transportation operations are associated with high potential benefits and minimal risks.

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