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SNAKE RIVER SPRING AND SUMMER CHINOOK SALMON: CAN THEY BE SAVED?

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ABSTRACT

Spring and summer chinook salmon *Oncorhynchus tshawytscha* populations from the Snake River have declined precipitously from historical levels. Declines initially were the result of overfishing, but since the late 1950s they have been primarily the result of hydroelectric dams that blocked access to spawning areas, created slack water, and caused mortalities of juvenile outmigrants. Mitigation hatcheries and juvenile collection and bypass systems at dams, transportation of juveniles from upriver dams to a release site on the lower Columbia River, a water budget, allocated spill for fish at main-stem dams have not increased these populations appreciably. Ocean conditions may have been a factor in the low returns from 1976 through 1984, but the factors currently considered as controlling the viability of the run are the low genetic variability, lack of stress tolerance, and incidence of bacterial kidney disease inherent in the stock. With control of disease, reduced stress at main-stem projects, and continued efforts to maintain genetic variability, the chinook salmon populations should increase and their long-term viability should be assured.

KEY WORDS Chinook salmon Snake River Hydroelectric dams Genetic variability

INTRODUCTION

The Columbia River watershed historically produced more chinook salmon *(Oncorhynchus tsawytscha)* than any other river system in the world (Netboy, 1980), with the majority of the spring chinook salmon coming from the Snake River system (Fulton, 1968). In the early 1880s, spring and summer chinook salmon provided commercial fisheries in the lower Columbia River with average annual catches of 17·7 million kilograms (Craig and Hacker, 1940). The heavy exploitation of these fisheries, however, caused a substantial depletion of the dominant summer stock; the fisheries then concentrated on the spring and fall stocks (Craig and Hacker, 1940; Gangmark, 1957). Summer chinook salmon populations from the mid- and upper Columbia river continued to decline such that by 1964 the inriver commercial fishery for all summer run fish was closed. By this time, Snake River Basin spring and summer chinook salmon accounted for approximately 78 per cent of the remaining upper river populations (Fulton, 1968).

A commercial and sport fishery in the lower Columbia River was maintained for spring chinook salmon through the mid-1970s; however, the numbers of Snake River spring chinook salmon adults declined dramatically after 1975, with the result that all inriver fishing for spring chinook salmon was halted in 1978. In this paper I will speculate on the decline of Snake River stocks and the directions necessary to preserve and enhance this species.

CAUSES FOR THE DECLINE

Although overfishing substantially depleted some stocks in the early years, it has been direct and indirect losses due to environmental modifications that have had the greatest and permanent effect on chinook salmon stock viability.

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Loss of Spawning Habitat

In its pristine state, the main-stem Snake River and its tributaries contained an estimated 12,540 km of habitat for anadromous salmonids. At present this habitat has been reduced by one-half to an estimated 6 770 km. Dams caused most of the habitat losses; however, other causes of loss or degradation include water diversion by irrigation projects and siltation, debris, or pollution from sewage, farming, logging, and mining (Pacific Fishery Management Council, 1979).

Loss of Migrating Fish Past Main-stem Dams

Dams built by the U.S. Army Corps of Engineers (COE) on the Snake and lower Columbia Rivers reduce survival of migrating juvenile salmonids and, to a much lesser extent, adults passing upstream. They reduce juvenile salmonid abundances in three ways:

1. Passage of juveniles through Kaplan turbines is estimated to cause direct mortalities between 8 per cent and 19 per cent (Bell, 1981).
2. Passage of juveniles through spillways is estimated to cause direct mortalities between 1 per cent and 5 per cent, with mortalities higher under very turbulent conditions (Bell and DeLacy, 1972).
3. Passage of juveniles through impoundments increases travel time, which increases the probability of predation on smolts (Raymond, 1979) and may disrupt timing for optimal entry into seawater (Mahnken *et al.*, 1982).

The dams present a physical barrier to upstream migrants; however, evaluation of adult collection systems constructed as part of each project indicated that the general effect of a dam is to increase upstream passage time by 1 to 3 days per project (Shew *et al.*, 1985). Under conditions of little or no spill, no direct adult mortality was associated with the projects (Liscom and Steuhrenberg, 1983). Mortalities of adult fish were found under high spill conditions, but the losses were not sufficient to affect the overall viability of chinook salmon stocks (Junge, 1966; Merrell *et al.*, 1971; Gibson *et al.*, 1979). Because adverse impacts on the inriver survival of adults are minimal when compared with the impacts on juvenile survival, I limit my subsequent discussion to affects on juveniles.

Prior to 1968, yearling chinook salmon smolts (spring and summer stocks) from the upper Snake River drainage negotiated four dams during their outmigration (Figure 1). Although there was a dam-related loss of fish, these stocks migrated during high spring flows so that most fish passed the projects via spillways rather than through the turbines. Chinook salmon stocks were only minimally influenced by the early losses sustained at the projects, but conditions changed dramatically between 1965 and 1979. Storage capacity in the Columbia and Snake Rivers was 40·2 km^3 in 1965 but nearly doubled to 75·5 km^3 in 1973. This increase in storage capacity decreased peak flows during the spring outmigration. In addition, three additional dams on the lower Snake River and one on the lower Columbia River were completed between 1968 and 1975 (Figure 1), and cumulatively began to substantially affect the juvenile outmigration. The effects of these additional dams were as follows:

1. Initially, considerable spill occurred under high flow conditions with a concomitant increase in atmospheric gases supersaturated in water. This was partially a consequence of a lack of flow control, but to an even greater extent, the result of constructing the new Snake River projects without a full complement of turbines. Additionally, new projects with higher head and deeper spilling basins led to more gas entrainment. Exposure time of migrants to supersaturated conditions was also increased by the continuous series of reservoirs where equilibration of gases with the atmosphere was minimal. Between 1970 and 1972, estimated total mortalities to juvenile salmonids from nitrogen supersaturation ranged from 18 per cent to 35 per cent (Ebel and Raymond, 1976). Spillways probably created some conditions of water supersaturated by gases in earlier years, but the distance between the few dams allowed sufficient time for dissipation of the gases to the atmosphere.
2. By 1979, all of the Snake River projects had a full complement of turbines. As control over the river flow increased and forced spill decreased, the percentage of fish passing through the turbines consequently increased. Although not all fish were subjected to turbine passage (as discussed later), the survival of fish that passed through turbines at the eight Snake and Columbia river projects was estimated at approximately 30 per cent [$(0{\cdot}86)^8$ if 86 per cent turbine survival is assumed per project—an average value from Bell, 1981].

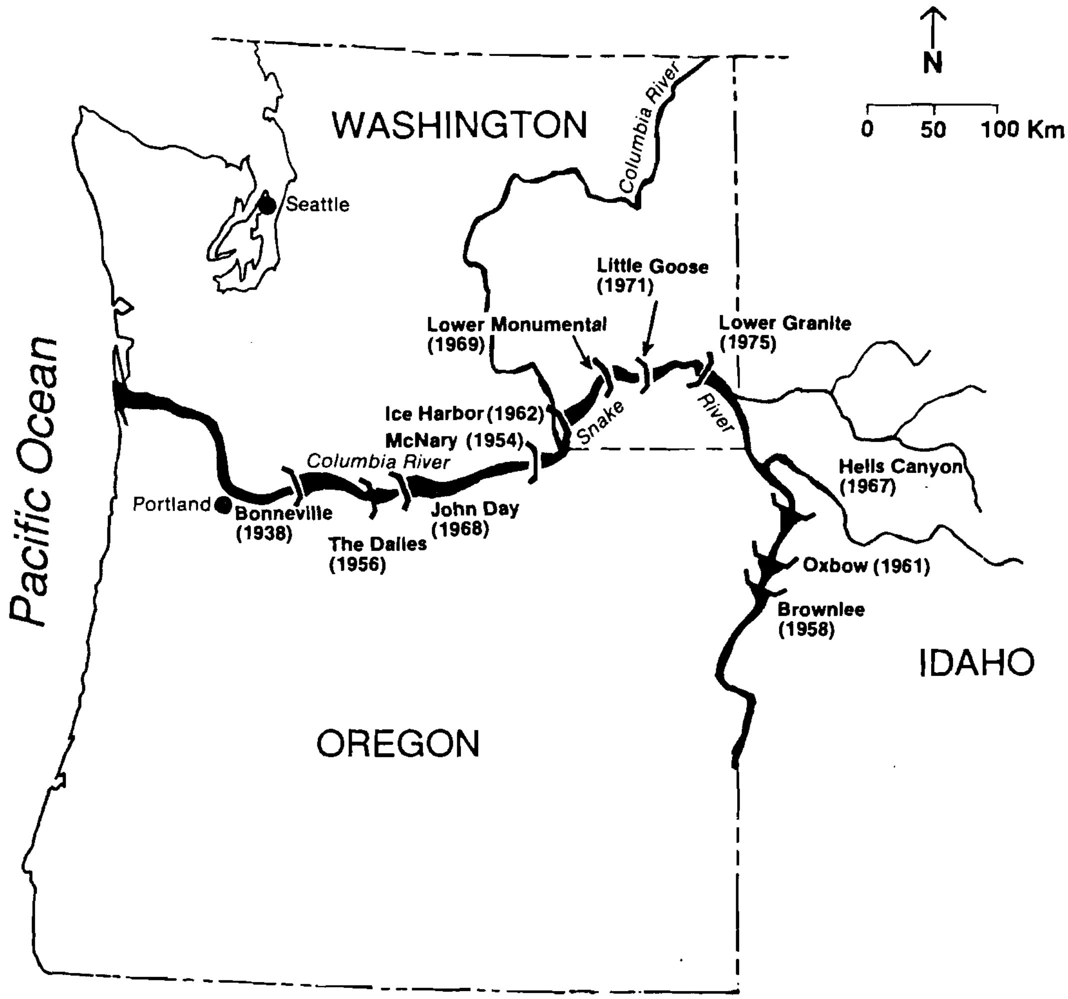

Figure 1. Hydroelectric projects on the lower Columbia and Snake Rivers with (completion dates).

3. Finally, the increased number of impoundments added travel time and subjected salmonid smolts to a greater exposure to potential predators. Estimated survival of juveniles from the uppermost Snake River Dam to below Bonneville Dam in the critically low flow year of 1973 was only 4–5 per cent (Raymond, 1979). This estimate included both turbine and reservoir mortalities.

EFFORTS TO DECREASE MORTALITIES

Modification and Use of Spillways

Spillways were modified at most COE projects to prevent water from plunging into the tailrace and to decrease nitrogen supersaturation. Deflectors were built at the base of the spillways to direct spill horizontally into the tailrace. Since modification of the spillways in 1976, mortalities due to 'gas-bubble disease' are minimal (W. J. Ebel, U.S. National Marine Fisheries Service (NMFS), Seattle, personal communication). However, turbulence at modified spillways under high spill conditions has increased, and no recent survival studies have been conducted to evaluate the condition. Since survival through spillways was generally high (Bell and DeLacy, 1972), the fishery agencies and tribes managing Columbia River fisheries developed a plan to optimize spill. The purpose of this plan is to provide spill during downstream fish passage at projects where no, or less than adequate, turbine bypass systems are in place.

This spill of water is preferably provided with a concomitant decrease in turbine generation (B. J. Brown, NMFS, Portland, personal communication).

Water Budget Implementation

As a result of flow/travel/survival time studies (Raymond, 1979; Sims and Ossiander, 1981), the Northwest Power Planning Council (NWPPC) established a water budget and a group to implement it. The water budget is a volume of water that can be used to increase flows in the Snake and Columbia Rivers and thereby decrease migration time and increase survival of salmonid smolts during periods when flows would otherwise be low (NWPPC, 1987). The first year to have low flows since the Water Budget was established was 1987; confirmation of the benefits of this plan are unavailable because adults that allegedly benefitted will not return for several years.

Construction of Collection, Transportation, and Bypass Facilities

The largest expenditures in money and research effort have been for installing juvenile salmonid collection and transportation systems at COE hydroelectric projects. This is a consequence of information gained from the Fish Passage Research Program implemented by the Bureau of Commercial Fisheries (BCF) in 1960 (now the NMFS) and the ongoing Fishery Engineering Research Program of the COE. These two programs are responsible for the majority of juvenile fish passage research on the Snake and Columbia Rivers. One of the initial efforts of the BCF program was to determine if it was possible to make turbines safe. Concurrent studies indicated that losses of fish due to increased migration time (Raymond, 1979) and predation after passing through turbines (Long *et al.*, 1968) had a large impact on

Table 1. Adult returns of chinook salmon by year of outmigration from estimated number of smolts arriving at uppermost dam on the Snake River

Year of outmigration	Number of smolts (10^6)*	River flow (1000 m^3/s)†	Percentage transported	Total adult return (1000 s)‡	Total % return
66	3.0	2100	0	132.0	4.4
67	2.2	2300	0	97.0	4.4
68	2.6	1600	§	104.0	4.0
69	2.5	3300	§	87.0	3.5
70	5.4	2800	§	162.0	3.0
71	4.0	4700	3	90.0	2.2
72	5.0	3500	5	41.0	0.8
73	5.0	1980	7	18.0	0.4
74	3.5	4420	0	43.0	1.2
75	4.0	3910	10	104.0	2.6
76	5.0	3080	15	28.0	0.6
77	2.0	1120	68	4.0	0.2
78	3.2	2960	51	13.0	0.4
79	4.3	2380	49	24.0	0.6
80	5.4	3080	58	23.0	0.4
81	3.2	2630	46	13.0	0.4
82	2.0	3350	28	13.0	0.7
83	3.8	3050	26	32.0	0.8
84	4.6	3480	28	34.0	—¶

*Data 1966–1975 (Raymond, 1979); 1976–84 (Koski *et al.*, 1985)
†Data 1966–1972 estimated from Raymond (1979); 1973–84 (Sims *et al.*, 1984)
‡Data 1966–1975 (Raymond, 1979); 1976–1984 (S. Huffaker, Idaho Department of Fish and Game, Boise, Idaho, personal communication)
§Experimental transport only, no unmarked groups of fish transported
¶Through 2-ocean returns only

the runs even if successful passage at dams was possible. Consequently, efforts were concentrated to determining if a substantial decrease in downstream mortalities was feasible by collecting fish at the upper-most dams on the Snake River and subsequently transporting the fish to the Columbia River below Bonneville Dam for release.

Early transportation research by NMFS was encouraging. Juveniles had a very high survival, and coded-wire tag (CWT) returns from adults were as high as 9 per cent of the CWT-marked juveniles (Ebel *et al.* 1973). Based upon the encouraging transportation research results, mass transportation of juveniles from the Snake River began in 1975. Although Snake River steelhead and fall chinook salmon (subyearlings) from the mid Columbia River enjoyed large benefits from the transportation program, adult returns for Snake River chinook salmon have remained low since the 1976 outmigration (Park, 1985). Prior to 1968, adult returns of spring and summer chinook salmon were 4 per cent or more of the juvenile outmigration; however, in the past 10 years returns dropped to less than 0·7 per cent, although there is a slight upturn in returns from the 1983 and 1984 outmigrations (Table 1). These depressed returns remained relatively constant despite a wide range in the percentage of the outmigrating fish being transported.

POSSIBLE FACTORS PREVENTING RECOVERY OF STOCKS

The most apparent difference between the present yearling chinook salmon outmigration as compared to those of earlier years is that the populations changed from 100 per cent wild stocks in 1965 to 75 per cent hatchery stocks by 1975 (Raymond, 1979). The successful early transportation research on yearling juvenile chinook salmon was conducted with almost 100 per cent wild stocks, but subsequent mass transportation efforts have involved predominantly hatchery stocks. Thus, it appears that decreased survival is related in large degree to the hatchery component of the transported population. Too few wild fish have been marked during recent research studies to determine if they have maintained the benefits from transportation found in earlier years (D. L. Park, NMFS, Seattle, personal communication).

The Snake River stocks of hatchery chinook salmon, at present, apparently are not able to withstand the conditions they encounter during their juvenile outmigration, either with transportation or inriver passage. Outside of the obvious problems of reservoir and turbine mortalities encountered inriver by juvenile outmigrants, there are four areas that potentially control the survivability of the hatchery chinook salmon stocks: early ocean survival, genetics, the ability to withstand stress, and disease.

Ocean Survival

Ocean survival is extremely important in the viability of salmonid stocks. Returns to the same hatchery from outmigrations in different years with relatively constant release sizes can vary by a factor of 6 or more (Wahle and Vreeland, 1978). There are a number of ocean conditions that probably influence survival, and it is likely that some combination of all of them determines the success of a particular year class. The following are some of the major factors hypothesized as controlling survival: time of ocean entry as related to size of fish at release and their ability to adjust to seawater (Mahnken *et al.*, 1982; Gowan and McNeil, 1984); density dependence and carrying capacity of the nearshore ocean waters for smolts, particularly because the number of smolts arriving at the ocean has increased tremendously due to hatchery releases (McGee, 1984); ocean warming during 1967–1983, with large increases in 1982–1983 due to El Niño phenomena (McLain, 1984); ocean upwelling (Nickelson and Lichatowich, 1984); and predation on smolts (R. Gowan, Anadromous, Inc., Corvallis, Oregon, personal communication).

No work has been conducted on ocean survival of juvenile yearling chinook salmon from the Columbia River. This may be partially because these fish are apparently in the nearshore coastal waters for only a short time (Miller *et al.*, 1983). Nonetheless, the decrease in adult returns of Snake River chinook salmon stocks between 1976 and 1984 occurred when ocean survival factors were implicated in decreases of other Pacific coast salmon populations. Also, the increase in total adult chinook salmon returns to the Snake River from the 1983 and 1984 outmigrations (Table 1) corresponds with a substantial increase in both Snake River steelhead and upriver bright fall chinook salmon (Jensen, 1987). I consider this important as it indicates there may be some combination of ocean factors affecting many stocks. Although yearly returns of adult spring chinook salmon probably fluctuate with variable ocean conditions, the percentage returns from the Snake River in earlier years exceeded those in the past 10 years. Thus, I do not consider ocean conditions to be the only factor that controls the strength of the stocks.

Genetics of Chinook Salmon Stocks

A basic concept in biology is that the greater the genetic diversity of a species, the greater its chances of survival under variable environmental conditions. Construction of Brownlee Dam on the main-stem Snake River in 1958 blocked all spawning areas above that point. Adult spring chinook salmon collected at Oxbow Dam from a population dominated by a stock from Eagle Creek, a tributary to the Powder River in northeast Oregon, provided eggs for mitigation hatcheries in Idaho. Consequently, present hatchery brood stock are primarily the offspring of this one stock of fish. Subsequent studies of Idaho hatchery spring chinook salmon and remaining Snake River wild stocks showed them to have approximately 50 per cent lower genetic diversity than other stocks of spring chinook salmon in the Columbia River basin (Winans, in press). This low genetic diversity in Snake River chinook salmon populations may affect their future survival. No direct evidence exists to confirm this speculation.

Stress in Yearling Chinook Salmon Stocks

Stress levels were evaluated on Snake River chinook salmon smolts used for transportation research studies in 1972. Some stress was associated with the marking and transportation process, but adult returns were not apparently severely affected (Ebel *et al.*, 1973). By 1981, however, sufficient data were collected on adults in transportation studies to determine that decreased return rates correlated with stresses in the collection–transportation system. NMFS recommended that future research define where stresses were occurring in the system and develop means for alleviating the stress (Park *et al.*, 1981).

Seawater challenge stress studies began at Lower Granite Dam in 1981 and continued through 1984 (Park *et al.*, 1982, 1983, 1984; Matthews *et al.*, 1985). Beginning in 1982, stress studies were expanded to include plasma cortisol measurements on yearling chinook salmon smolts at Lower Granite and McNary Dams and on subyearling chinook salmon smolts at McNary Dam during the fish collection and transportation process and after release from barges below Bonneville Dam (Congleton *et al.*, 1984, 1985; Schreck *et al.*, 1985). The results from these studies were relatively similar. Increased stress, as measured by elevated levels of plasma cortisol (Barton *et al.*, 1986) or increased mortalities when fish were placed in seawater (Matthews *et al.*, 1985), was observed in yearling chinook salmon sampled from different areas of the collection systems at the projects. On the other hand, subyearling chinook salmon had much lower stress levels, as measured by only small increases in cortisol and little delayed mortality, compared to spring chinook salmon (Schreck *et al.*, 1985). After subyearlings or yearlings were held in raceways at the projects from 48 to 72 hours, their stress levels decreased to precollection levels. The process of loading fish from raceways into the transport vehicles increased stress indicators in fish equal to levels observed during the collection process, but little or no increase in stress occurred during actual transportation.

The increased stress indicators observed during collection and transportation or passage through a bypass system suggest an increased likelihood that yearling chinook salmon smolts, while stressed, will have impaired swimming ability (Schreck *et al.*, 1985) and will be more vulnerable to predator attack (Congleton *et al.*, 1985). This may be particularly significant for fish diverted through bypasses, as the tailraces of hydroelectric projects have large predator populations (Nigro *et al.*, 1985) and salmonids are a significant part of their diet (Gray *et al.*, 1984).

In an attempt to answer questions on the long-term survival of unstressed and stressed yearling chinook salmon, Park *et al.* (1986) and Matthews *et al.* (1987) began extended seawater holding experiments in 1985. Data from 45 days of seawater holding suggested that stress was an important factor influencing smolt survival. In one study where fish were held 120 days, bacterial kidney disease (BKD) was the major cause of mortality in all treatment groups including the controls that were least stressed. It was suspected that stress worked to lower the immune system's ability to respond, and disease, specifically BKD, was responsible for low survivals in yearling chinook salmon smolts.

Studies are also in progress by the Idaho Cooperative Fishery Research Unit (ICFRU) to determine the survival to adulthood of yearling chinook salmon smolts subjected to varied levels of stress before release from a hatchery (T. J. Bjornn, ICFRU, Moscow, Idaho, personal communication). As ICFRU scientists suspected BKD to be the agent of mortality, some of their release groups were fed erythromycin during hatchery rearing as a possible prophylaxis against BKD.

Eliminating stressful conditions does not appear feasible as most fish are either bypassed or transported from the hydroelectric projects. There was no appreciable difference in stress levels measured between fish that were bypassed at one dam and those that were transported. Fish that migrate through the entire river system will be subjected to a series of stresses during bypass at each project, whereas transported fish are subjected to stressful conditions only once. As more projects incorporate bypass systems, the number of stressful incidents will increase. I believe that development of hatchery fish that can tolerate stressful conditions could significantly increase the total return of spring and summer chinook salmon stocks.

Disease in Yearling Chinook Salmon Stocks

Bacterial kidney disease is a chronic, systemic disease present in virtually every salmonid stock in the northeast Pacific basin and considered to be more severe in spring chinook salmon than in other salmonids (Bullock and Wolf, 1986). When direct fluorescent antibody techniques (DFAT) were used in 1982 and 1983 for screening some hatchery spring chinook salmon in the Snake River basin, 35–53 per cent were assumed to be BKD-free; however, 35 per cent of those testing negative were found to be BKD-positive when enzyme-linked immunosorbent assay (BKD-ELISA) tests were used (Bjornn *et al.*, 1984). Researchers from the U.S. Fish and Wildlife Service (USFWS) National Fishery Research Center, Seattle, Washington, found that over 90 per cent of the fish from Snake River hatcheries were BKD-positive when tested with ELISA whereas with DFAT tests, infection levels were considerably less (R. Pascho, USFWS, Seattle, personal communication).

It is common hatchery practice to treat disease with antibiotics; however, BKD is found intracellularly and antibiotics only inhibit its growth (Bullock and Wolf, 1986). Research findings suggest that the failure of control methods to eliminate BKD from hatchery populations may ultimately result in reduced ocean survival of fish released from the hatchery. Bacterial kidney disease infections acquired in fresh water may impair the ability of salmonid smolts to acclimate to seawater, and entry into seawater may actually accelerate mortality among infected fish (Fryer and Sanders, 1981; Banner *et al.*, 1983). Thus, keeping fish alive in the hatchery with antibiotics will not likely decrease subsequent BKD-related mortality. Antibiotics allow highly infected fish to live, at least temporarily, and may increase the probability of keeping a high disease incidence in the population.

Sensitivity of salmonids to BKD is perhaps a result of sensitivity to stress. Since yearling chinook salmon smolts from the Snake River appear to be particularly sensitive to stress as compared with smolts of subyearling chinook salmon and steelhead, it may be that no successful enhancement of Snake River chinook salmon will occur until either stress can be controlled or levels of BKD in the population decreased. While no solution to the BKD problem is at hand, a potential means of control has been proposed. The proposal is to separate adult fish by their level of BKD infection, determined microbiologically, and to cross-fertilize only those with the lowest levels of BKD. Progeny from fish with very low levels of BKD may be able to withstand the stresses they will endure during their juvenile outmigration and acclimation to seawater without developing lethal infections (R. Pascho, USFWS, Seattle, personal communication). Tests of this hypothesis have yet to be conducted.

OUTLOOK FOR SNAKE RIVER STOCKS

Although a Water Budget has been implemented and bypass systems are either in place or scheduled to be completed at all main-stem dams on the Snake and lower Columbia Rivers, the problems identified with reservoir mortality and turbine mortalities for migrating fish at dams still exist. Transportation has been successful for subyearling chinook salmon and steelhead (Park, 1985) and was promising in the initial studies with yearling chinook salmon (Ebel, 1980). Thus, it appears that transportation has great potential for increasing adult returns to the Snake River, as it provides the largest number of smolts to below Bonneville Dam. Although in recent years transportation has not provided large adult returns of Snake River chinook salmon, nonetheless, in 17 out of 26 studies, transported marked juvenile yearling chinook salmon returned as adults at equal or higher rates than marked juvenile yearling chinook salmon released at the dams as controls. In six of the studies there were insufficient returns to make a determination and in only three did control fish return at a higher rate than the transported fish (Ebel, 1980; Park, 1985).

At present, the emphasis on saving the stocks is centred on providing adequate spill, transport, and bypass systems at hydroelectric projects. Based on results to date, it would appear that these efforts will not be sufficient to fully restore spring chinook salmon runs. Even with the construction of new bypass systems and improvements in present facilities to decrease stress, the survival of spring and summer chinook salmon is not equal to that observed for both subyearling chinook salmon and steelhead. I do not believe that the chinook salmon populations from the Snake River can be increased substantially until additional emphasis is placed on providing a more robust hatchery component of the population through the following actions:

1. Monitoring levels of genetic diversity in the stocks;
2. Practicing sound genetic hatchery husbandry to ensure maintenance of this diversity (Winans in press); and,
3. Most importantly, developing an effective means for decreasing the incidence or severity of BKD in the population.

I hypothesize that low stress tolerance coupled with a high incidence of BKD in yearling chinook salmon smolts is the most crucial factor in the low adult returns to the Snake River basin. Research with wild stocks of chinook salmon in the 1960s indicated that successful returns were possible (Raymond, 1988). Therefore, in addition to work on improving hatchery populations, a concentrated effort must maintain and increase the wild (or possibly naturally spawning) component of the stock.

When hardy salmonid juveniles were transported around dams, adult survivals and returns were substantially increased. I believe that with efforts to improve the quality of fish, as identified above, a long-term increase in populations of upper river chinook salmon is obtainable. Favourable ocean conditions will accelerate the process.

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