June 1993

FACTORS AFFECTING THE SURVIVAL OF UPSTREAM MIGRANT ADULT SALMONIDS IN THE COLUMBIA RIVER BASIN

Recovery Issues for Threatened and Endangered Snake River Salmon
Technical Report 9 of 11

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Recovery Issues for Threatened and Endangered Snake River Salmon
Technical Report 9 of 11

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June 1993

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EXECUTIVE SUMMARY

The Bonneville Power Administration (BPA) is developing conservation planning documentation to support the National Marine Fisheries Service's (NMFS) recovery plan for Columbia Basin salmonid stocks that are currently listed under the Endangered Species Act (ESA). Information from the conservation planning documentation will be used as a partial scientific basis for identifying alternative conservation strategies and to make recommendations toward conserving, rebuilding, and ultimately removing these salmon stocks from the list of endangered species. This report describes the adult upstream survival study, a synthesis of biological analyses related to conditions affecting the survival of adult upstream migrant salmonids in the Columbia River system. This effort supports the recovery planning process associated with stocks listed as threatened or endangered under the ESA.

The objective of the adult upstream survival study was to analyze existing data related to increasing the survival of adult migrant salmonids returning to the Snake River system. Salmonid stocks considered include stocks listed under the ESA: Snake River sockeye salmon (*Oncorhynchus nerka*), and fall, spring, and summer runs of chinook salmon (0. *tshawytscha*). The fate and accountability of each stock during its upstream migration period and the uncertainties associated with measurements of escapement and survival were evaluated. Operational measures that affected the survival of adult salmon were evaluated including existing conditions, augmented flows from upstream storage release, and drawdown of mainstem reservoirs. The potential impacts and benefits of these measures to each ESA stock were also described based on considerations of species behavior and run timing.

Anadromous salmonids must pass up to eight hydroelectric dams during their upstream migration to Snake River spawning grounds. The physical barriers created by these dams result in delays in migration and may influence reproductive success. Operation of the dams (i.e., changes in flow regimes) influence survival of adult salmonids by affecting migration rates, passage, fallback, and exposure to dissolved gases. Other mortality factors occurring during the upstream migration period of ESA-listed stocks include harvest, and environmental conditions such as temperature, pollutants, and marine mammal predation.

The primary measure for survival during upstream migration is adult passage counts at mainstem dams. Thus, hatchery returns, escapement to natural areas, and straying behavior must also be estimated to account for mortalities occurring during migration. Counts of spring chinook salmon were found to provide a better measure of escapement and "loss" caused by dam passage than counts for the other ESA-listed stocks, at least in the lower mainstem Columbia and Snake rivers, because 1) spring chinook salmon do not appear to stray and wander as much as fall chinook salmon, 2) our ability to accurately count summer chinook salmon is complicated by definitive cutoff dates at the beginning and the end of the run, and 3) sockeye salmon numbers are too low to obtain accurate estimates of interdam loss in the Snake River.

Our analysis indicates that we can isolate most of the causal factors affecting the survival of adult salmonids during their upstream migration in the Columbia and Snake rivers. However, because of uncertainties in measurement variables, we are generally limited in our ability to accurately predict the benefits that specific changes in operational or environmental factors could have on adult survival of ESA-listed stocks.

There is some error associated with each measure of mortality and estimates of run size. Thus, the potential error associated with estimates of adult mortality through the system increases as fish pass by each additional vector of mortality. The magnitude of error in these estimates is also different for each stock.

Our analysis also included a qualitative comparison of our ability to accurately measure interdam loss and considers the general operational strategies. The major difference among potential operations is that adult passage counts would not be possible under some drawdown scenarios and accountability of run size to adults during all drawdown scenarios are unknown. Among stocks, fall chinook salmon appear to provide the least accurate measurements for run reconstruction and estimates of mortality.

There is little evidence that passage contributes to measurable direct mortality of any of the four salmonid stocks. Fall chinook salmon may be more vulnerable to passage mortality because of excessive delays at some dams during upstream migration and because of the relatively high rate of fallback noted for some projects. The risk to stocks during passage would be similar for each operational condition except for drawdown scenarios. Effects to salmon during passage would be reduced under the natural river option for all stocks, while other drawdown scenarios could have adverse effects on passage of spring and summer chinook salmon.

The risk to ESA-listed stocks from both commercial and sport harvest is reduced by the extensive planning associated with harvest of listed stocks (CRTS 1992, 1993a, 1993b). Relative risk of commercial harvest by stocks would be fall chinook salmon > sockeye salmon > spring chinook salmon > summer chinook salmon. Relative risk of sport harvest would be fall chinook salmon > spring chinook salmon > summer chinook salmon > sockeye salmon. The risk due to harvest would be similar under each of the three operational conditions discussed.

Temperature is an important environmental condition influencing the survival of adult upstream migrant salmon returning to the Snake River basin. Stocks most vulnerable to increased temperature in the mainstem Columbia and Snake rivers include sockeye salmon, fall chinook salmon, and summer chinook salmon. Flow augmentation practices that reduced mainstem temperatures to below 21° C would reduce the risk to these populations. Spring chinook salmon are sometimes exposed to high temperatures in tributary streams. This is a concern if it occurs during the spawning period. Drawdown operations are likely to have little influence on temperature in the lower Snake River. However, temperatures need to be monitored if drawdown conditions extend into August and September.

Dissolved gases currently impose a moderate risk on spring and summer chinook salmon because they migrate during the spring spill period. This risk would be reduced under the natural river option because there would be little or no spill over the Snake River dams. However, relative risk at the lower Columbia River dams could be higher if increased flows and higher spill were encountered there. Because of their migration timing, there is little or no risk to fall chinook salmon from high concentrations of dissolved gases.

There presently appears to be a low risk for pollutants to impact any of the ESA-listed stocks. Several pulp mills and metal extractions plants release effluents containing metals, halogenated compounds, and aromatic hydrocarbons, and occur mainly in the lower Columbia River. However, effluent discharge limitations appear to be adequate to maintain fish populations. Certain tributaries formerly used for spawning by spring and summer chinook salmon have been adversely impacted by changes in water quality from mining activities. There is a potential for moderate risk to spring chinook salmon from suspended sediments expected during the different drawdown options.

Predation by marine mammals was also considered as an ecosystem-level effect that occurs in the hydroelectric complex. This mortality factor is restricted to the lower Columbia River and affects stocks migrating upriver in the spring. Thus, the only ESA-listed stocks with risk from marine mammals are spring and summer chinook. There is no change in relative risk to these stocks under the different operational conditions analyzed in this study.

Several research needs were identified as a result of our analysis. Our recommendations were directed at two general research areas. The first area of research relates to better accountability of run size and inter-dam loss. For example, studies are needed to determine the potential for increasing accuracy of dam counts, to identify problems with run reconstruction methods, and to examine the relationship between operation of mainstem project and adult passage conversion rates. The second research area relates to mitigating potential mortality factors. Recommended studies include determining the extent and cause of fallback, determining the impacts of migration delay on reproductive success and pre-spawning mortality, and better documentation of behavioral attributes that affect returns to natural and artificial production areas, e.g., straying and mainstem spawning.

ACKNOWLEDGMENTS

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The Bonneville Power Administration (BPA) is developing conservation planning documentation to support the National Marine Fisheries Service's (NMFS) recovery plan for Columbia Basin salmonid stocks that are currently listed under the Endangered Species Act (ESA). Information from the conservation planning documentation will be used as a partial scientific basis for identifying alternative conservation strategies and to make recommendations toward conserving, rebuilding, and ultimately removing these salmon stocks from the list of endangered species. This report describes the adult upstream survival study, a synthesis of biological analyses related to conditions affecting the survival of adult upstream migrant salmonids in the Columbia River system. This effort supports the recovery planning process associated with stocks listed as threatened or endangered under the ESA.

The objective of the adult upstream survival study was to analyze existing data concerning biological issues and enhancement measures for hydroelectric operations related to increasing the survival of adult migrant salmonids returning to the Snake River system. Salmonid stocks considered include Snake River sockeye salmon (*Oncorhynchus nerka*), and fall, spring, and summer runs of chinook salmon (0. *tshawytscha*). Operational measures evaluated include existing conditions, augmented flows from upstream storage release, and drawdown of mainstem reservoirs. The fate and accountability of each stock during their upstream migration period and the uncertainties associated with measurements of escapement and survival are discussed. The potential impacts and benefits of these measures to each ESA-listed stock are also described based on considerations of species behavior and run timing.

Certain mortality factors, including those relating to passage at the dams and environmental conditions, can be expected to change if operational conditions are altered. Other mortality factors, such as harvest impacts, are not likely to change relative to operation of hydroelectric facilities. This report describes these mortality factors and associated methods used to account for loss of adult salmon during their upstream migration to the Snake River.

2. BACKGROUND

This section summarizes existing and planned dam operational measures that may affect the survival of ESA-listed salmonid stocks during their upstream migration to the Snake River. The ESA-listed salmonid stocks may pass up to eight dams before they reach their spawning grounds or return to hatchery facilities (Figure 1). Operational measures may be grouped into three general categories: 1) existing operational conditions, 2) flow control, and 3) reservoir drawdown.

2.1 EXISTING OPERATIONAL CONDITIONS

Within other uses of the system, operation of all major dams and reservoirs in the Columbia River system, except for Brownlee Dam, is coordinated to maximize the power benefits provided by storage. Historically, the major functions of the reservoir system have been navigation, power generation, and flood control. Recently added functions include maintaining seasonal high flows to aid downstream migration of juvenile salmon and steelhead and maintenance of adequate reservoir levels for resident fish and recreation (COE 1992c). Basic operating guidelines are set each year based on meeting the following related, yet sometimes conflicting, objectives:

- provide adequate flood storage space
- maintain an acceptable probability for annual reservoir refill
- provide flows during juvenile fish migration intervals
- maximize power generation.

General operation of the system can be organized into three seasons. During August through December, storage reservoirs are operated according to predetermined rule curves. These rule curves specify reservoir water levels that are desirable for each month. During January through March, the operation of the reservoirs is guided by the runoff forecasts. Water from reservoirs is released to provide flood control space and meet power needs. During April through July, the reservoirs store spring runoff and water is released to assist the downstream migration of juvenile salmon and steelhead.

2.2 FLOW CONTROL

One alternative to continuing existing operations is to augment the flow through storage release. Augmenting flows on the Snake and Columbia rivers to facilitate the spring migration of

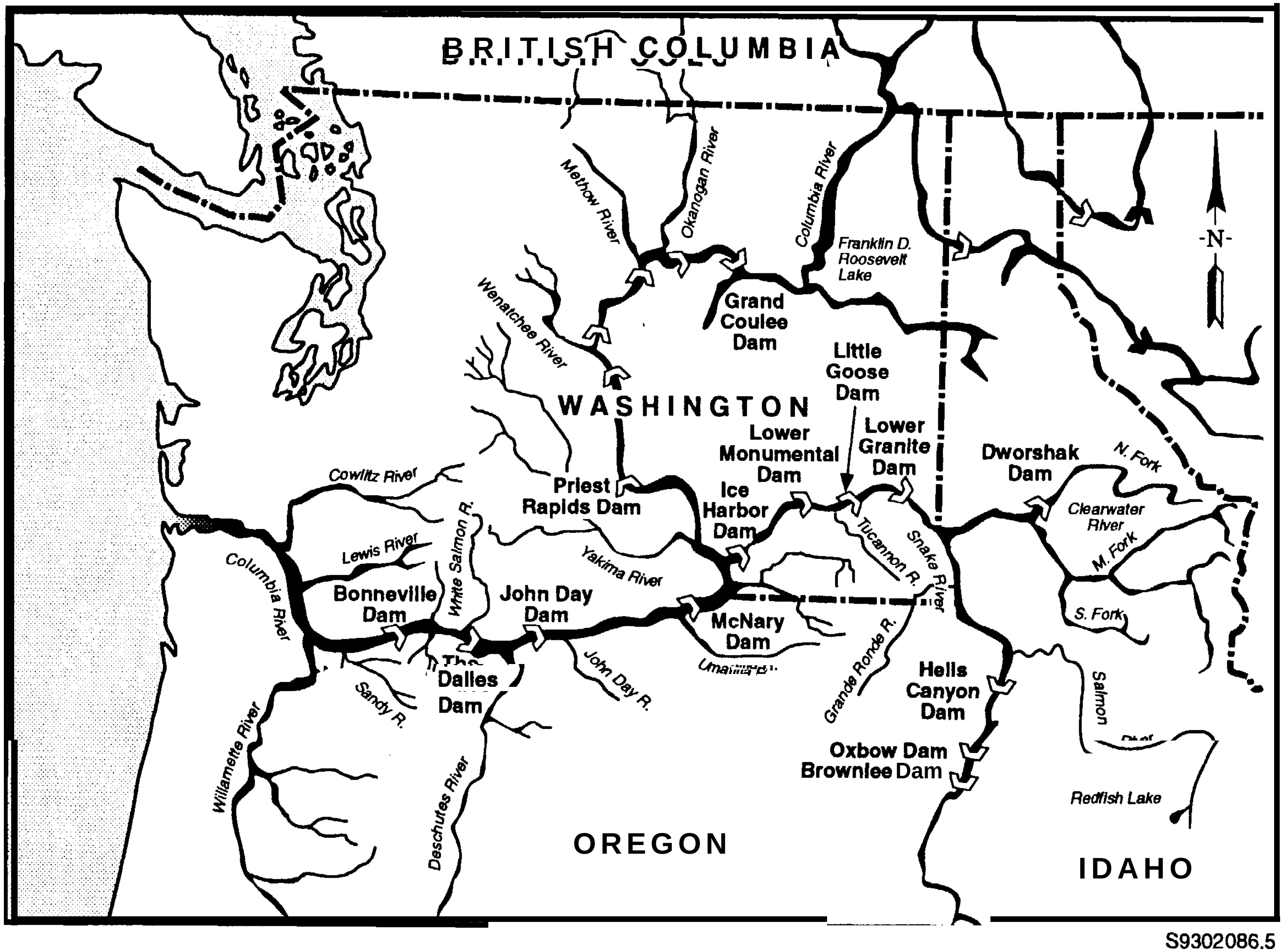


Figure 1. The Lower Columbia and Snake River Drainages and Locations of Hydroelectric Dams that Affect Migration and Survival of Adult Salmonids

juvenile salmonids originating from the Snake River drainage may be accomplished by modified operation of Dworshak Dam on the North Fork of the Clear-water River and Brownlee Dam on the Snake River. Additional upstream storage is being considered at the Galloway site (Weiser River Basin), and other locations in the Middle Snake, Clear-water, and Palouse basins.

Spring flows are augmented to levels greater than those required for dam functions when conditions must be improved for the outmigration of juvenile salmonids. This is accomplished within the Water Budget Program, which is part of the Northwest Power Planning Council's (NPPC) Fish and Wildlife Program. Each winter, the U.S. Army Corps of Engineers (COE) develops a Coordinated Plan of Operations (CPO) to implement the amount and timing of the Water Budget Program releases. The CPO is developed in cooperation with BPA, Bureau of Reclamation (BOR), fisheries agencies, tribes, and power interests, and submitted to NPPC in late March. The Water Budget Program releases are usually implemented from April 15 to June 15. Water from storage reservoirs is released after considering requests from the Fish Passage Center, which represents the fisheries agencies and tribes. The total volume for the Water Budget Program includes up to 1.19 million acre feet (MAF) on the lower Snake River and up to 3.45 MAF on the middle and lower Columbia River (COE 1992c). The Water Budget Program is used to achieve target flows at specific points along the river, with Lower Granite Dam as the monitoring point on the Snake River. A river management plan was developed in 1991 to supplement the Water Budget Program with additional releases of stored water during the spring outmigration period.

In September 1990, a flow augmentation study was initiated to determine if releases of cold water from Dworshak Reservoir would lower temperatures in the lower mainstem Snake River (Karr et al. 1991). The need for the study was based on elevated water temperatures that occurred during the upstream migration of adult fall chinook salmon and steelhead into the Snake River. Results of this study were promising enough that additional studies were conducted in 1991. The COE Columbia Basin temperature model (COLTEMP) was selected to predict water temperatures at downstream locations and to analyze different release options. A complex monitoring network was then established to track temperature profiles from the Snake River upstream from its confluence with the Clearwater River to the Columbia River downstream from its confluence with the Snake River. Cold water releases were detected as far downstream as Ice Harbor Dam, with a gradual diminishing cooling of ambient conditions noted with distance. Temperatures were 16.6' C at Lower Granite Dam, 17.7' C at Lower Monumental Dam, and 18.9' C at Ice Harbor Dam after the cold water releases were fully mixed at each site (Karr et al. 1991). Effects of the reduced water temperature on fisheries resources have not been determined and will require additional studies.

The Idaho Power Company (IPC) regulated flows during fall chinook salmon spawning in the fall of 199 1 to encourage redd construction below a water level that could be maintained throughout the incubation and fry emergence period. This policy was part of a proposed interim operation plan to aid recovery of fall chinook salmon stocks in the free-flowing reach of the Snake River downstream of Hells Canyon (IPC 1991). The IPC is currently conducting a series of studies within the Hells Canyon area to gather information on the flow requirements of fall chinook salmon and other fisheries resources.

2.3 RESERVOIR DRAWDOWN

Another alternative to continuing existing operations is to draw down certain reservoirs. The objective of reservoir drawdown is to lower pool elevations in one or more of the four lower Snake River dams, thus increasing river velocities through the affected reach. The assumption is that increased river velocities during the spring outmigration period will increase the survival of migrating salmonid smolts. Each of the proposed drawdown scenarios would require significant modifications to the dams and existing facility operations, including adult fish passage facilities. Possible drawdown levels range from normal minimum operating pool (MOP) to a complete river bypass of the dams. During drawdown, all lower Snake River reservoirs may be operated at some lowered pool elevation, ranging from about 19 to 52 ft below MOP. The drawdown rate would occur at the rate of 2 ft/d, and drawdown conditions would be maintained during the juvenile outmigration period, or from April 15 to as late as August 3 1. Refill times could range from 4 to 84 days, depending on inflow rates and when refill commences.

There are various dam modifications proposed to facilitate operation at any drawdown pool elevation. For example, the drawdown condition can be achieved by passing water through the powerhouse, over the spillway, or both. Once the drawdown is achieved, pool levels may be maintained at near-constant levels or could be allowed to fluctuate with river flows. The various modes of operation that could occur once drawdown is achieved are usually divided into five general groups: natural river option, variable pool with existing powerhouse operation, variable pool with modified powerhouse operation, constant pool with existing powerhouse operation, and constant pool with modified powerhouse operation. Additional modifications to spillway operations could result in up to nine different drawdown options being considered.

For the natural river option, bypass structures will be designed so that velocities through the structures are suitable for adult fish passage (less than an average of 9 ft/sec) at all river flows up to 225,000 cfs. Adult fish facilities will require modification to operate during the period between normal operations and drawdown/refill operations. Facilities would function at pool elevations between normal pool and spillway crest. For other drawdown options, the existing adult fish ladders would have to be modified to work under the lowered or variable water levels. For example, auxiliary exits would be required to allow adult passage during the transition between full and lowered pool at Lower Monumental, Little Goose, and Ice Harbor dams. Lower Granite Dam would require modification to accommodate a range in pool fluctuation. A secondary low-level ladder exit with a vertical slot control section could be employed to provide a gravity feed operation for ladder operation. When all reservoirs are operating in drawdown mode, each, with the exception of Ice Harbor Reservoir, will be lowered to maintain tailwater depths that allow for operation of fish ladder entrances.

The reservoir drawdown concept was tested in March 1992 using Lower Granite and Little Goose dams on the lower Snake River. The test was designed to collect information on the effects of lowering existing reservoirs. Water in Lower Granite and Little Goose reservoirs was lowered to 36 and 12.5 ft below MOP, respectively, before being refilled. Dam and reservoir facilities and structures, water resources, biological resources, and cultural resources were monitored for potential effects from the drawdown (COE 1992a). Specific studies were conducted to determine the effects of spill on tailrace flow patterns, movement of adult steelhead through Lower Granite Reservoir, and passage of adult steelhead through the Lower Granite Dam fish ladder.

Two other options currently considered include drawdown of John Day Reservoir and drawdown of Lower Granite Reservoir only (Idaho Plan). Drawdown of John Day Reservoir would occur concurrently with drawdown of lower Snake River reservoirs and the downstream smolt migration period for juvenile salmonids. The change to current dam operation would be to operate the John Day Reservoir at minimum flood control pool, an elevation of 257 ft, from May 1 through August 31, annually. This operational change would decrease the average normal spring pool elevation by 12 ft, except when accommodating flood flows (COE 1992b). The Idaho Plan is being considered as a compromise to a drawdown of all reservoirs in the lower Snake River.

3. FATE OF RETURNING ADULTS

Salmon returning to the Snake River system may migrate as far as 1000 km from the time they enter the mouth of the Columbia River to when they reach their spawning grounds in the upper basin. Artificially reared fish may either return to hatcheries or to natural production areas in the mainstem Snake River and tributaries. Obstacles to the safe return of adult salmonids include commercial and sport fisheries, hydroelectric dams, industrial pollution, and predators. Relative number and survival of returning adults during their inriver migration is estimated based on a combination of measures including dam passage counts, harvest records, hatchery returns, and spawning ground surveys. Factors that contribute to unaccounted for mortality of ESA-listed stocks include dam passage, fallback, illegal fishing activities, mammalian predators, disease, and environmental factors such as pollutants, elevated temperatures, and excess concentrations of dissolved gases (Figure 2). Primary measures affecting our ability to account for ESA-listed stocks include relative accuracy of dam counts, incidence of fallback, lack of knowledge concerning mainstem and tributary spawning, and degree of straying. This section describes mortality factors of ESA-listed stocks (effects from dam operations, losses from the commercial and sport harvests, and environmental factors) and discusses other variables that affect the accuracy and precision of survival estimates (returns to hatcheries and natural production areas).

3.1 EFFECTS OF DAM OPERATIONS ON ADULT SURVIVAL

Anadromous salmonids must pass up to eight hydroelectric dams during their upstream migration to Snake River spawning grounds (Table 1). The design of each mainstem dam is different, including locations and number of fish ladders. Operation of the dams (extent of spill, etc.) affects conditions at the entrance to each ladder and the subsequent ability of fish to find and navigate the fishway. Although there is no upstream passage in the mainstem Snake River upstream from Hells Canyon Dam, water storage practices related to Oxbow and Brownlee reservoirs may also affect survival of adult salmonids.

There are various fishway pool designs at Columbia and Snake River dams. Every dam fishway has over-fall weirs with submerged orifices. There are also various forms of vertical slots (usually a series of these is found at the upper end of the ladder) and non-overflow sections. An example of a non-overflow section can be found in the fishway at Ice Harbor Dam. The non-overflow section has submerged orifices for passage. Migrating adult salmon are attracted into the fish ladders by flows out of the fishways. In addition, there are adult collection passageways at the base of the spillway and the powerhouse, which lead migrating adults to the fishway. When spill occurs, the amount of spill and its distribution across the spillway can affect passage rates.

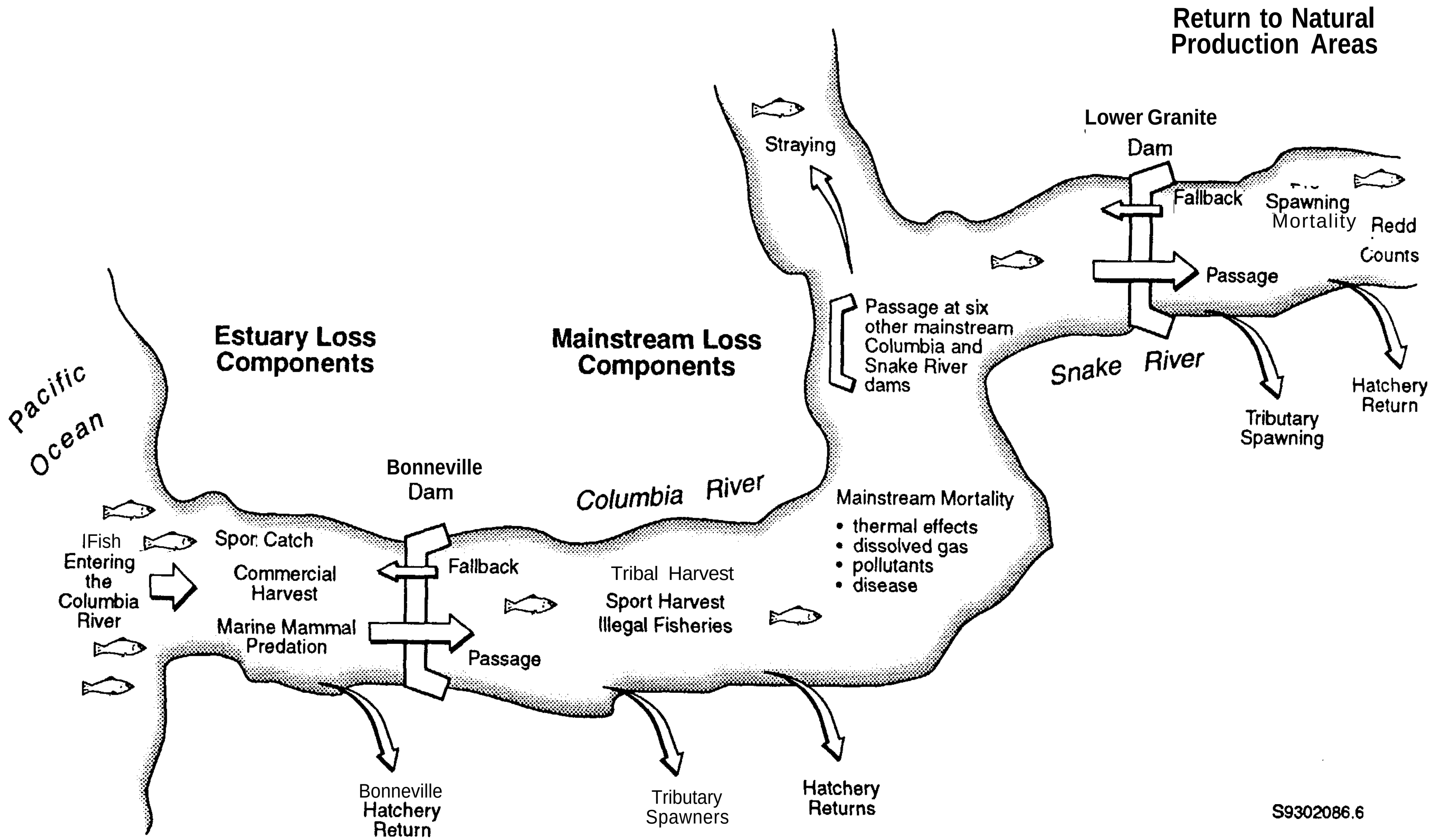


Figure 2. Conceptual Diagram of Factors that Affect the Survival and Accountability of Salmon Stocks that Return to the Snake River Drainage

Table 1. Hydroelectric Dams on the Columbia and Snake Rivers Affecting Migration of Snake River ESA-Listed Stocks

Dam	Year in Service	Miles to Mouth	Miles of Reservoir	Adult Handling Facilities	Number of Ladders
Bonneville	1938	146	45	Yes	3
The Dalles	1957	192	31	None	2
John Day	1968	216	76	None	2
McNary	1953	292	61	None	2
Ice Harbor	1961	334	32	Temporary	2
Lower Monumental	1969	366	29	None	2
Little Goose	1970	395	37	None	1
Lower Granite	1975	432	39	Off ladder	1
Hells Canyon	1967	571	22	None	0
oxbow	1961	597	12	None	0
Brownlee	1958	609	57	None	0

A generic design of a hydroelectric facility in the Columbia River system indicating location of fishway entrances, fish ladders, spillway, and powerhouse is shown in Figure 3.

Adult salmonids at the eight dams are counted during passage through fishways. Although adult fish passage facilities are operated year-round, fish counting normally extends from March 1 through November 30 (COE 19926). Counting intervals are 16 hr/d (0400 to 2000 hours Pacific Standard Time) from April 1 through October 3 1, and 8 to 10 hr/d during other periods. Counts are extrapolated to daily totals based on a 50-min counting period every hour. A video monitor detector is also used at Little Goose Dam to monitor total dam passage from April 15 to October 15.

Chinook salmon are separated into spring, summer, and fall runs, based on their period of adult migration (Table 2). These dates vary by dam because of the distance that fish must migrate before ascending the next facility. Run timing for the ESA-listed stocks past Bonneville, McNary, and Lower Granite dams is compared in Figure 4. The following subsections discuss current methods for monitoring adult passage over the dams and the effect of alternative operations on passage and migration of ESA stocks.

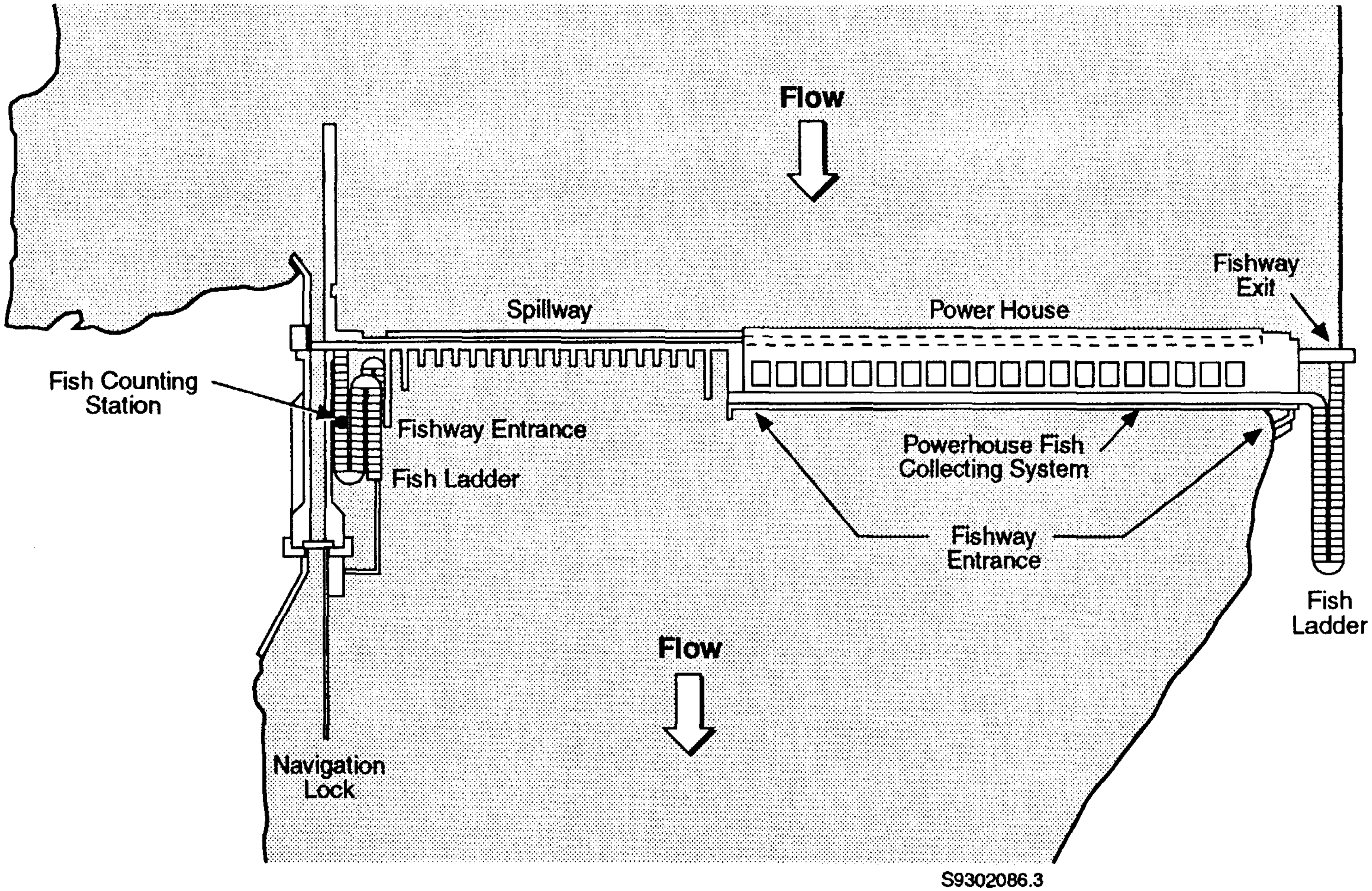
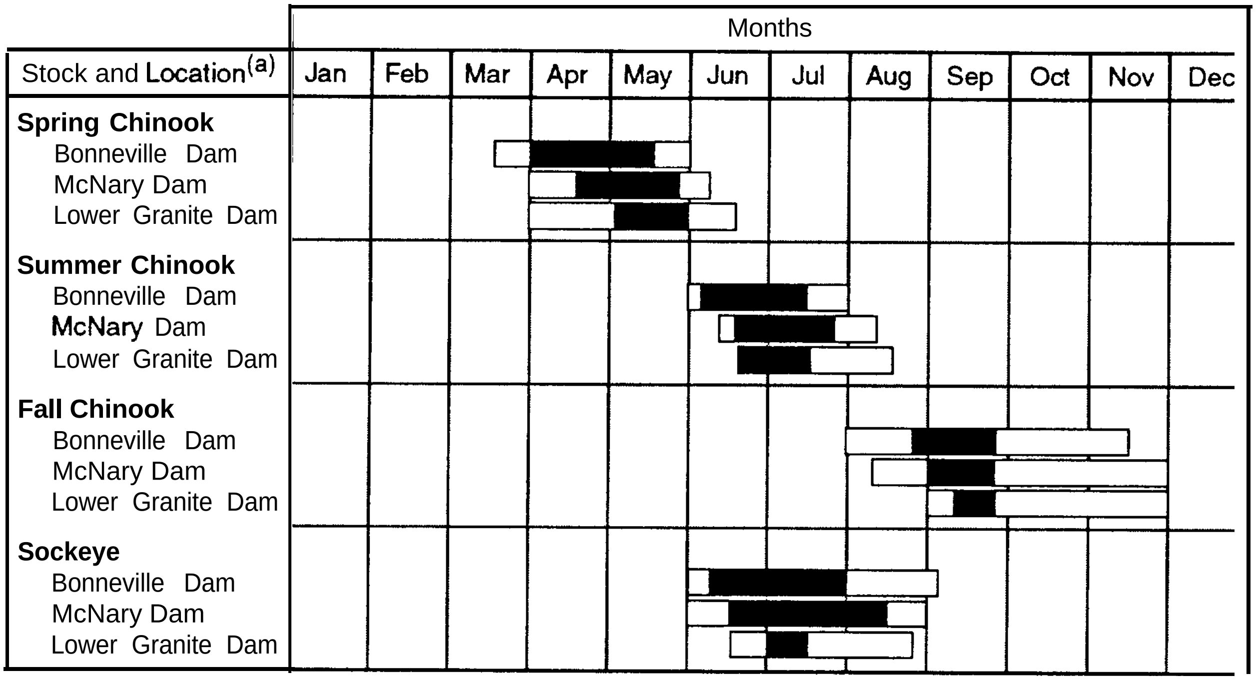


Figure 3. Generic Design of a Hydroelectric Facility in the Columbia River System and Location of **Fishways**



(a) Migration period range and peak annual counts shown as darker central region,

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Figure 4. Run Timing for ESA-Listed Stocks Passing Bonneville, McNary, and Lower Granite Dams. The migration period range (open) and peak (dark portion) are shown.

Table 2. Dates Used to Classify Spring, Summer, and Fall Chinook Salmon at Dams on the Columbia and Snake Rivers. Initial dates for spring chinook salmon and final dates for summer chinook salmon vary by dam and among years (WDF/ODFW 1992).

Dam	Spring Chinook Salmon	Summer Chinook Salmon	Fall Chinook Salmon
Bonneville	March 15 - May 31	June 1 - July 31	Aug 1 - Nov 31
The Dalles	March 18 - June 3	June 4 - Aug 3	Aug 4 - Nov 31
John Day	April 1 - June 5	June 6 - Aug 5	Aug 6 - Nov 31
McNary	April 1 - June 8	June 9 - Aug 8	Aug 9 - Nov 31
Ice Harbor	April 1 - June 11	June 12 - Aug 11	Aug 12-Oct31
Lower Monumental	April 1 - June 13	June 14 - Aug 13	Aug 14 - Oct 31
Little Goose	April 15 - June 15	June 16 - Aug 15	Aug 16 - Oct 31
Lower Granite	April 15 - June 17	June 18 - Aug 17	Aug 18 - Dec 15

3.1.1 Existing C˙ȯn -

Losses of up to 15% of fish per dam, fallback rates up to 35% over the spillway at Bonneville Dam, and substantial delays in passage at darns sometimes result in high overall losses of adult salmonids that migrated upstream through the darn system to spawn (Junge and Carnegie 1976; Monan and Liscom 1976). In high-flow years, adult loss rates between dams may have been similar to those for smolts. Since 1975, passages of adults have been markedly enhanced by better-formed spills, better attraction facilities at ladders and powerhouse collection entrances, and reduced powerhouse generation next to ladder entrances. Also, added power generation at dams reduced the spill levels and, in turn, reduced adult fallback and losses associated with dissolved gas supersaturation (Raymond 1988). The effects of existing conditions on passage and migration are discussed below.

3.1.1.1 Passage Effects

Two general passage effects that may result in mortality to adult migrant salmonids include delay and fallback. Passage delay is related to problems with fish finding the entrance to the fishway and could lead to prespawning mortality. In contrast, fallback can result in direct or immediate mortality because fish pass back downstream, either over the spill or through mechanical structures (i.e., juvenile bypass or dam turbines). Wagner and Hilsen (1992) reported that injury rates of fall chinook salmon that passed back at McNary Dam in 1991 were highest for larger fish, with bruises being the most common injury. This study also documented fallback through the turbines, a route that is known kill adult salmonids.

Dam-related or physical injuries resulting in mortality to adult salmonids are difficult to separate from other types of injuries that occur during migration through the reservoirs. Further, loss rates at each dam can be expected to vary among years, depending on fish stock, environmental conditions, and dam operations. For example, mortality rates (i.e., interdam loss) for upstream migrant adult salmonids were estimated at 12% to 13% for each dam in 1970 (INPFC 1977). Based on more recent studies, planners have estimated interdam losses at 5% of adult spring and summer chinook salmon for each darn on the lower Columbia and Snake rivers (Chapman et al. 1991). Bjomn et al. (1991) estimated that passage success for spring and summer chinook salmon from the Ice Harbor Dam tailrace to the forebay at Lower Granite Dam (past four dams) was 87% in 1991.

The passage conversion rates are a method used to account for mortality or apparent loss of adult fish as they migrate past dams in the Columbia River hydroelectric system. Adult dam counts are the primary measure for these values, with known losses due to tributary spawning and harvest also factored into reconstruction of run size. Adult passage conversion rates were summarized for each of the ESA-listed stocks using data summarized in biological assessments developed by the Columbia River Technical Staffs (CRTS 1992; 1993a). These run reconstruction methods accounted for hatchery returns plus redd counts, and included adjustments for tributary turnoffs and commercial catch. There was no apparent adjustment for fallback. Per dam conversion for spring chinook salmon ranged from 0.750 to 0.948 for passage past the lower Columbia River dams and from 0.873 to 0.979 for the lower Snake River dams during 1977 to 1992 (Table 3). Passage conversion rates for summer chinook salmon were more variable and ranged from 0.651 to 1.037 from Bonneville Dam to Ice Harbor Dam and 0.750 to 1.588 from Ice Harbor Dam to Lower Granite Dam during 1979 to 1992 (Table 4). Per dam conversions for fall chinook salmon ranged from 0.908 to 0.984 for passage past lower Columbia River dams and 0.707 to 0.845 for lower Snake River dams during 1986 to 1991 (Table 5). Adult passage conversion rates for sockeye salmon were also highly variable, particularly in recent years when the run size was small. Passage rates for sockeye salmon ranged from 0.770 to 1.501 at lower Columbia River dams during 1965 to 1992 and from 0 to 2.0 at the lower Snake River dams during 1975 to 1992 (Table 6).

Conversion rates of the different stocks are affected by run reconstruction techniques that apply definitive cutoff dates at each dam when separating the spring, summer, and fall runs of chinook salmon. Variations in actual versus defined run timing during upstream migration can result in differences in true allocation of fish among the spring, summer, and fall components. Differences in migration rate could result in conversion rates higher or lower than the true rates, i.e., rates based on known stock origin in relation to date of upstream passage over dams. Run reconstruction results in the largest variation in accounting for summer chinook salmon stocks because they have an early cutoff date that may overlap with the latter part of the spring chinook salmon run and a late cutoff date that may overlap with the early part of the fall chinook salmon run.

Passage Delay-- The ability of a salmon to find the fishway entrance will influence the amount of time it spends in the tailrace or the amount of "delay" in the migration interval. Migration delay is a concern during upstream passage of adult salmonids because a lengthened migration period could deplete energy reserves and result in increased prespawning mortality or reduced reproductive success for returning adults. Bjomn et al. (1991) recently reported that the time required for spring and summer chinook salmon to pass the four Snake River dams ranged from 7.9 days at Ice Harbor Dam, to 1.8 days at Little Goose Dam in 1991. Mendel et al. (1992) found that delay times for fall chinook salmon in the lower Snake River ranged from an average of 2.2 days at Lower Monumental Dam to 17.8 days at Lower Granite Dam, also in 1991. One factor that could

Table 3, Adult Passage Conversion Rates for Spring Chinook Salmon in the Lower Columbia and Snake Rivers, 1977 to 1992

Year	Bonneville to McNary Dam(a)	Conversion Per Project	McNary to Ice Harbor	Ice Harbor to Lower Granite(b)	Conversion Per Project	Bonneville to Lower Granite
1977	0.769	0.916	1.005	0.857	0.950	0.662
1978	0.635	0.859	1.005	0.833	0.941	0.558
1979	0.512	0.800	0.858	0.814	0.934	0.358
1980	0.421	0.750	1.011	0.686	0.882	0.292
1981	0.608	0.847	1.142	0.864	0.953	0.600
1982	0.486	0.786	1.009	0.880	0.958	0.432
1983	0.746	0.907	0.835	0.804	0.930	0.500
1984	0.663	0.872	1.006	0.828	0.939	0.552
1985	0.852	0.948	1.087	0.814	0.934	0.754
1986	0.812	0.933	0.952	0.845	0.946	0.653
1987	0.852	0.948	0.931	0.937	0.979	0.743
1988	0.787	0.923	1.045	0.900	0.965	0.740
1989	0.621	0.853	0.970	0.864	0.952	0.520
1990	0.781	0.921	0.875	0.887	0.961	0.606
1991	0.614	0.850	1.053	0.666	0.873	0.430
1992	0.813	0.933	0.967	0.859	0.95 1	0.675
average	0.686	0.878	0.987	0.834	0.944	0.567

(a) Values based on Bonneville Dam counts minus McNary Dam counts minus Zone 6 harvest minus estimated tributary turnoff.

(b) Values based on Ice Harbor Dam counts minus Lower Granite Dam counts minus hatchery returns.

Table 4. Adult Passage Conversion Rates for Summer Chinook Salmon in the Lower Columbia and Snake Rivers, 1979 to 1992 (CRTS 1993a)

Year	Bonneville to Ice Harbor Dam	Ice Harbor to Lower Granite
1979	0.824	1.588
1980	0.709	1.174
1981	0.706	1.000
1982	0.692	1.000
1983	0.723	0.907
1984	0.982	0.982
1985	0.882	1.244
1986	0.903	0.886
1987	0.65 1	0.894
1988	0.689	0.824
1989	0.808	0.914
1990	0.849	0.911
1991	1.037	0.809
1992	0.831	0.750
average	0.806	0.992

Table 5. Adult Passage Conversion Rates for Fall Chinook Salmon in the Lower Columbia and Snake Rivers, 1986 to 1991 (CRTS 1992)

Year	Bonneville to McNary Dam	Conversion Per Proiect	McNary to Ice Harbor	Ice Harbor to Lower Granite	Conversion Per Proiect	Bonneville to Lower Granite
1986	0.952	0.984	0.854	0.379	0.724	0.309
1987	0.852	0.948	0.856	0.444	0.763	0.324
1988	0.92 1	0.973	0.840	0.353	0.707	0.273
1989	0.856	0.949	0.859	0.455	0.769	0.334
1990	0.788	0.924	0.884	0.604	0.845	0.421
1991	0.750	0.908	0.818	0.384	0.727	0.235
average	0.798		0.852			0.297

contribute to long delay times is the location of spawning grounds or hatchery facilities. For example, some fall chinook salmon might “overshoot” the Lyons Ferry Hatchery and appear to delay below Little Goose Dam. Adult salmon that chose to spawn in the dam tailrace area might also move around in the vicinity of the dam.

The choice of fishways used by adult chinook salmon and the rate of passage past a dam are influenced by spill patterns, the effectiveness of the attraction flows at the entrance to the

Table 6. Adult Passage Conversion Rates for Sockeye Salmon in the Lower Columbia and Snake Rivers, 1965 to 1992 (from CRTS 1993a)

Year	Bonneville to Ice Harbor Dam	Ice Harbor to Lower Granite
1965	0.987	
1966	1.117	-
1967	1.135	-
1968	1.061	-
1969	0.826	-
1970	1.174	-
1971	1.125	-
1972	1.501	
1973	0.945	-
1974	0.814	
1975	0.953	0.860
1976	0.770	0.689
1977	0.982	0.787
1978	0.820	1.430
1979	0.870	0.833
1980	0.894	2.667
1981	0.947	1.535
1982	0.823	1.213
1983	0.927	2.000
1984	0.898	0.448
1985	1.019	1.458
1986	0.839	0.750
1987	0.988	2.23 1
1988	1.051	1.046
1989	1.139	0.500
1990	0.982	0.000
1991	0.974	0.889
1992	0.977	0.500
average	1.019	1.102

fishway, the number and placement of entrances, and current and water velocity (Bjomn and Perry 1992). Delays in adult migration can be reduced by perfecting operation of spillways and turbines at the dam to provide optimum attraction flows for entrance of fish to the spillways. When there is little or no spill, few fish use the fishway entrances near the spillway. Small amounts of spill may increase use of entrances near spillways, but large spills can completely block a fishway for upriver passage of fish. During periods of power peaking, usually during daylight hours and on weekends, decreased passage rates have been observed. In a 1966-to-1970 study on Columbia River dams, Junge (197 1) found that weekend passage rates at The Dalles and Priest Rapids dams were 14% to 83% higher than during weekdays that had higher powerhouse discharge. Haynes and Gray (1980) concluded that passage delays at Little Goose Dam in 1976 and 1977 were related to heavy spilling, turbine operations, and trapping operations in the ladder. They also found that passage delays at Little Goose Dam averaged 153 hours, and adult salmon were delayed about 50 hours at Lower Granite Dam.

Generally, passage rates are lower when high flows and spills make it difficult for fish to find fishway entrances. In a related study, Gray and Haynes (1977) observed that spring chinook salmon migrated at greater depths when they encountered supersaturated water below Little Goose Dam. The risk of passage delays would increase during periods of spilling because fishway entrances are located near the surface.

Adult steelhead depend on the downstream current for orientation during upstream migration, a characteristic common to most species of anadromous salmonids. Under “zero” flow conditions, when only limited amounts of water (about 200 cfs) passed Little Goose Dam, upstream migration of approximately 15% to 20% of steelhead and summer chinook salmon were delayed (Liscom et al. 1985). Up to 75% of the tagged steelhead swam downstream from the dam during “zero” flow conditions. As a result, the proposed extension of the “zero” flow period from 2200 to 0700 hours during August to April in the lower Snake River was not recommended when adult salmonids were actively migrating.

Once chinook salmon enter the fishways, passage is relatively rapid, usually a matter of a few hours. Reported passage rates at Lower Monumental Dam in spring 1973 ranged from 0.7 to 0.8 hr and 2.3 to 3.5 hr at the north and south fishways, respectively (Monan and Liscom 1974). The migration rate of adult chinook salmon through the Lower Granite Dam fishway was about 4 hr (Liscom and Monan 1976). Shew et al. (1985) reported a mean ladder travel time at McNary Dam (i.e., entrance to exit) for spring chinook salmon, summer chinook salmon, and sockeye salmon, of 2.4, 3.9, and 2.9 hr, respectively.

<u>Fallback</u>-- Passage counts of adult salmon cannot be considered as absolute measures of escapement to a particular reach of the river because of inaccuracies in counting methods and because of fallback, i.e., some adults pass the fish ladder and are counted, then drop back below the dam after passing through the spill, turbines, or juvenile bypass system. Fish that pass back may display a variety of behaviors, including reascending the fishway, remaining below the dam, or even migrating downstream and entering another river. Different forms of fallback behavior may include 1) that related to the spring freshet or high flows, 2) the “overshoot” syndrome or when fish ascend a dam only to drop back to spawn in the Columbia River or in tributaries, and 3) migration cessation (common with some steelhead stocks that migrate to upper reaches of the Snake River and then pass back to over-winter in deep water areas).

The rate of fallback over a dam varies with flow and spill, by dam, and by fish species (Table 7). Homer and Bjomn (1981a) found that fallback rates were related to dam and fishway design and were positively correlated with increasing flows. Wagner and Hilsen (1992) found that fallback of fall chinook salmon was positively correlated to the number of fish passing the dam and to dam discharge. Fallback rates increased from two fish per hour at 80,000 cfs to 11 per hour at 125,000 cfs in 1991. Spring and summer chinook salmon have fallback rates of up to 30% or more at some dams in the middle Columbia and lower Snake rivers (Bjomn and Perry 1992). Studies by Mendel et al. (1992) showed that 53% of 15 fall chinook salmon fell back after crossing Lower Granite Dam. This group included fish radiotagged and released downstream from both Ice Harbor and Lower Granite dams. A portion of the adult fall chinook salmon run **is also known** to pass back after they pass Lower Monumental and Little Goose dams (Liscom et al. 1985). In contrast, Bjomn et al. (1991) reported that only 18 of 370, or 4.9%, of spring chinook salmon passing Lower Granite Dam passed back in 1991, a low-flow year.

There is recent evidence that the migration behavior of fall chinook salmon entering the Snake River is different than that of other ESA stocks. In 1991, 95 fall chinook salmon were radiotagged near Ice Harbor Dam in an attempt to understand disparities between fall chinook salmon counts at Ice Harbor Dam and those at Lower Granite Dam. The radiotagged fish exhibited a wide range of behavior. For example, 57% of the fish were found outside the Snake River drainage, mainly in the Columbia River. Seven of the 95 fish crossed Lower Granite Dam, of which only one remained upstream to spawn (Mendel et al. 1992). The study was repeated in 1992 with similar results. These studies suggest that the differences between adult fall chinook salmon counts at Ice Harbor and Lower Granite dams may be largely attributed to straying and fallback (or natural wandering), rather than interdam mortality. Migrating fall chinook salmon exhibit a wide range of behavior before spawning in the Snake River. Thus, results of the radiotagging studies indicate that numbers of adult fall chinook salmon returning to the Snake River Basin cannot be reliably accounted for by dam passage counts. Once these recent studies are completed, it may be possible to apply an additional adjustment factor to dam counts that account for fallback behavior and provide more accurate estimates of escapement and interdam loss.

3.1.1.2 Inriver Migration

Existing operational conditions at dams also affect inriver migration. Adult chinook salmon have been known to migrate in free-flowing rivers at rates up to 24 km/d (OFC 1960). However, reducing discharge from dam powerhouses to zero at night had no observable effect on the migration rates of adult chinook salmon and steelhead (McMaster et al. 1977). Migration rates in reservoirs range from 16 km/d for fall chinook salmon in Brownlee Reservoir, a large storage

Table 7. Summary of Fallback for Adult Upstream Migrant Salmonids in the Columbia River System

Dam	Species	Sample Size	Fallback Rate, %	Period of Study	Reference
Bonneville	sockeye salmon	9	22.2	summer 1982	Ross 1983
	spring chinook salmon	146	13.0	spring 1984	Shew et al. 1988
	summer chinook salmon	331	0.6	summer 1973	Young et al. 1974
	summer chinook salmon	?	39.2	summer 1977	Young et al. 1978
	fall chinook salmon	40	0.0	fall 1982	Ross 1983
The Dalles	fall chinook salmon	146	14.6	1974	Monan and Johnson 1974
	spring chinook salmon	14	13.6	1980	Johnson et al. 1982
	fall chinook salmon	200	1.0	1982	Liscom and Stuehrenberg 1983
John Day	spring chinook salmon	40	7.5	1982	Johnson et al. 1982
	spring chinook salmon	83	6.0	1984	Shew et al. 1985
	spring chinook salmon	47	8.5	1985	Shew et al. 1985
	sockeye salmon	24	4.2	1985	Shew et al. 1985
McNary	spring chinook salmon	45	2.2	1985	Shew et al. 1985
	summer chinook salmon	34	5.9	1985	Shew et al. 1985
	fall chinook salmon	133	1.5	1982	Liscom and Stuehrenberg 1983
	sockeye salmon	9	22.2	1985	Shew et al. 1985
Ice Harbor	spring chinook salmon	43	9.3	1982	Turner et al. 1984
	spring chinook salmon	223	10.3	1964	Johnson 1964
	fall chinook salmon	29	13.7	1991	Mendel et al. 1991
Lower Monumental	summer/fall chinook salmon	13	7.7	1981	Liscom et al. 1985
	summer/fall chinook salmon	32	9.3	1981	Liscom et al. 1985
	fall chinook salmon	36	11.1	1982	Turner et al. 1984
	fall chinook salmon	25	4.0	1991	Mendel et al. 1991
Little Goose	spring chinook salmon	35	4.0	1976, 1977	Haynes and Gray 1980
	spring chinook salmon	22	4.5	1981	Turner et al. 1983
	fall chinook salmon	9	44.4	1991	Mendel et al. 1991
Lower Granite	spring chinook salmon	17	17.6	1975	Liscom and Monan 1976
	spring chinook salmon	25	4.0	1981	Turner et al. 1983
	fall chinook salmon	7	71	1991	Mendel et al. 1991
	fall chinook salmon	20	30	1992	Mendel[(a)]
	spring chinook salmon	370	4.9	1991	Bjornn et al. 1991

(a) Mendel, G., Washington Department of Fisheries, personal communication with D. D. Dauble. Pacific Northwest Laboratory, March 1993.

pool, to 56 km/d for spring chinook salmon in Ice Harbor and Little Goose reservoirs, both run-of-the-river pools (Bjomn and Perry 1992). Studies conducted in the Snake River between Little Goose and Lower Granite dams determined that summer chinook salmon travel up to 38.6 km/d (Liscom and Monan 1976). Rates of travel for fish migrating from Ice Harbor Dam to Little Goose Dam averaged 16.7 km/d (McMaster et al. 1977). Migration rates were lower at night and after storm events when rivers were turbid.

In one of the most extensive studies conducted to date, Bjomn et al. (1991) tracked 531 spring and summer chinook salmon past the four lower Snake River dams and into tributaries of the Snake River drainage. They found that migration through the reservoirs was rapid (i.e., 55 km/d or 1.4 to 1.8 days per reservoir), while the rate of migration in the free-flowing rivers ranged from 15 to 3 1 km/d. These migration rates were conducted under favorable conditions (i.e., low flow, low turbidity, and no spill) and were at the high end of the range reported in a major review of migration behavior (Bjomn and Perry 1992).

3.1.2 Upstream Storage/Flow Augmentation

Upstream storage releases related to fisheries management are primarily used to augment flows in the spring to aid the outmigration of juvenile salmonids and provide cooler water during the late summer migration period when thermal barriers to upstream migration may exist. These conditions (i.e., increased flows and temperature alterations) could influence the behavior and survival of some ESA stocks. How this alternative affects passage and inriver migration is discussed below.

3.1.2.1 Passage Effects

Passage effects to adult salmonids during upstream storage releases would be determined by spill and discharge variables, except for those related to changes in temperature that occurred during flow augmentation practices. Releases of cooler water could encourage upstream movement of fish if high water temperatures were adversely affecting the behavior or survival of adult migrants. For example, a decrease in water temperatures could stimulate upstream migration for fish that are holding over because river temperatures exceed critical threshold values. Thermal blocks to migration could occur during passage if temperatures in the fish ladders are higher than those in the tailrace below each dam. Temperature studies conducted during summer and fall 1991 showed that water discharged from the turbines (tailrace) was sometimes 1° to 3° C cooler than water at the tops or lower ends of the fishways (Bjomn et al. 1991). Water temperatures in the fish ladders reached a peak of 23” to 25° C during mid to late August; these temperatures are known to be lethal to adult salmonids for extended exposures,

3.1.2.2 Inriver Migration

Water temperatures also influence the migration behavior and passage timing of summer and fall chinook salmon in the Columbia and Snake rivers. During the late summer, water temperature in the Snake River is usually warmer than in the Columbia River. This difference results in a distinct thermal gradient at the confluence of these two rivers, just downstream from Pasco, Washington. Some summer chinook salmon and steelhead hold up in the Columbia River near the mouth of the Snake River until temperatures decline to less than 21°C (Stuehrenberg et al. 1978).

In September 1990, a flow augmentation study was initiated to determine if releases of cold water from Dworshak Reservoir would lower temperatures in the lower mainstem Snake River (Karr et al. 1991). Cool water releases had a measurable affect on tailrace temperatures at Lower Granite Dam in late August, and cooling may have extended to early or mid-September. However, a similar reduction in water temperatures was not recorded for the Ice Harbor Dam tailrace (Bjomn et al. 1991), suggesting that further studies are required before benefits to adult upstream migration can be attributed to the augmented flows.

3.1.3 Reservoir Drawdown

Reservoir drawdowns are proposed to be implemented annually from April 15 to as late as August 3 1. Because the subsequent refill period cannot be predicted, all ESA-listed stocks could be affected by changes in reservoir level and discharge volume. Possible effects on passage and migration are discussed below.

3.1.3.1 Passage Effects

Adult fish passage would not be possible at Snake River dams if all reservoirs were lowered to near spill crest (COE 1992c). Thus, all drawdown alternatives require that the present adult fish facilities be modified to operate during the period between normal operations and the drawdown/refill operations. Under the natural river option, the bypass structure and river channel around each dam would need to be designed so that velocities through the structures are suitable for adult passage (< 9 ft/sec at river flows up to 225,000 cfs). Modeling studies are currently under way at the COE’s Waterways Experiment Station to design these bypass structures.

Drawdown alternatives that utilize the existing spillway would require that adult fish ladders be modified to work under the forebay fluctuations and lowered tailwater depths. For example, auxiliary exits with false weirs and return flumes will be required for adult passage during the transition drawdown and refill periods. The lower-level spillway alternatives require that existing fish ladder exits be modified and secondary low-level adult ladder units and vertical barrier gates be constructed. This modification would allow adult ladder operation during the transition period from normal operation to drawdown pool elevations. At all dams except Ice Harbor Dam, the adult collection system would be lowered and adult ladder facilities, including entrances and auxiliary water supply, would have to be modified.

Adult passage could also be affected by dissolved gas concentrations. Dissolved gas concentrations increased from about 105% to 135% as the tailwater elevation was decreased and spill increased during the test drawdown of Lower Granite Reservoir in March 1992 (COE 1992a). Spillway deflectors designed to reduce dissolved gas concentrations were ineffective at these low tailwater elevations. Based on these findings, adult passage would be affected by high gas concentrations in the tailrace. Further, the risk of passage delay caused by increased turbulence would be increased at Ice Harbor and Lower Monumental dams because fishway entrances are located near the spill.

Adult passage will also likely be affected by construction activities proposed for the natural river option. For example, increases in turbidity could decrease migration rates during any of the required construction activities and during early periods of drawdown implementation. However, passage delays or impacts to migration timing should be minimized during the natural river option, unless velocities through the headgate (alternate route past the dam) are excessive.

3.1.3.2 Inriver Migration

Depending on the magnitude of increased velocities resulting from reservoir drawdown, drawdown could decrease the rate of migration for adult salmonids (i.e., increase the amount of time they take to pass through each affected reach to the fishway entrance) (Table 8). For example, the natural river option would result in increased velocities through the entire lower Snake River system. However, adult salmon would not have to pass through fishways at the dams, thus eliminating or at least reducing the delay time associated with finding a passage route past the dam. Adult migration rates would likely decrease during the other drawdown alternatives because salmon would encounter increased velocities through the newly created free-flowing section of the river. Actual delay at each dam would depend on operating conditions and the ability of fish to navigate fish ladder entrances located at the lower pool elevations. Adult passage would

Table 8. Estimated Travel Time (Days) for Adult Chinook Salmon to Migrate from the Confluence of the Snake and Columbia Rivers to Cleat-water River. Estimates are based on relative migration rates in free-flowing versus reservoir environments[(a)] and passage delays at dams.@)

	Flow Scenario		
Operation	25 kcfs	60 kcfs	140 kcfs
existing conditions	15.1	20.8	29.6
drawdown - natural river option	9.3	9.3	9.3
drawdown - lowered	16.2-17.3	23.3-26.1	29.6-33.6

(a) Assumed a migration rate of 56 km/d in Snake River reservoirs (Turner et al. 1983, 1984) and 24 km/d in free-flowing portions of the Snake River (OFC 1960). Note: these rates are similar to those reported by Bjomn et al. (1991) for chinook salmon in 1991.

(b) Passage delays were assumed to be: Ice Harbor - 4.9 days under all conditions (Turner et al. 1983, 1984); Lower Monumental - 1.8 days at 25,000 cfs, 2.6 days at 60,000 cfs and 3.5 days at 140,000 cfs (Monan and Liscom 1974); Little Goose - 2.2 days at 25,000 and 60,000 cfs (Turner et al. 1983) and 9.0 days at 25,000 cfs and 8.2 days at 60,000 and 140,000 cfs (Turner et al. 1984).

not be possible during the transition periods when reservoirs are being lowered to drawdown conditions and again when the reservoirs are being refilled. Thus, upstream migration of spring and summer migrating species would be blocked for about 2 weeks during initial drawdown and >2 weeks during the refill interval, depending on upstream flows.

3.1.4 Summary

Counts of spring chinook salmon provide a better measure of escapement and “loss” caused by dam passage than counts of the other ESA-listed stocks, at least in the lower mainstem Columbia and Snake rivers, because 1) spring chinook salmon do not appear to stray and wander as much as fall chinook salmon, 2) our ability to accurately count summer chinook salmon is complicated by definitive cutoff dates at the beginning and the end of the run, and 3) sockeye salmon numbers are too low to obtain accurate estimates of interdam loss in the Snake River.

Adult passage conversion rates are less for spring chinook salmon that migrate by the four lower Snake River dams when compared to rates for the lower Columbia River dams (average of 0.944 versus 0.878 per dam). In contrast, recent fall chinook salmon conversion rates were higher for the Columbia River dams than for the Snake River dams (average of 0.948 versus 0.756 per dam). The lower conversion rate for fall chinook salmon in the lower Snake River is largely attributable to fallback and straying. The high incidence of fallback for fall chinook salmon at the lower Snake River darns is a cause for concern because of the potential for turbine mortality. However, in the absence of knowledge indicating stock origin and because of the high incidence of straying, any mortality associated with fallback can only be considered a cumulative loss to the system rather than loss to a specific upriver production area.

Certain operations associated with power peaking and high spills delay the passage of migrating adults past hydroelectric dams. Studies conducted to improve passage efficiency at dams have resulted in changes in the position and number of fishway entrances and the addition of attraction flows. The main concern with delays to migration is increased energy expenditure and associated stress that may contribute to reduced reproductive success or prespawning mortality. However, there is currently no evidence that migration delay, although substantial at some dams, results in measurable mortality to adult salmonids.

Each of the three general operational measures evaluated would affect the amount and rate of discharge during inriver migration periods of the ESA-listed stocks. The primary difference among measures is the timing and duration of these flow manipulations. Existing conditions are directed at increasing flows during the spring outmigration period of smolts, and changes in operations would mainly affect the survival of spring chinook salmon. Flow augmentation could result in an increased rate of migration for adult fall chinook salmon in the late summer if high temperatures were restricting migration and if sufficient temperature decreases were realized in the lower Snake River system. Reservoir drawdown could result in a small increase in the upstream migration rate of adult spring and summer chinook salmon, with the exception of implementing the natural river option, which should substantially decrease travel time of these stocks through the lower Snake River. The potential for any of the measures to increase survival of adult upstream migrant salmon is limited by the amount and seasonal availability of water present in the Columbia and Snake river basins.

3.2 LOSSES FROM COMMERCIAL AND SPORT HARVEST

Harvest is a significant mortality factor for adult salmonids returning to the Columbia River and is a major outcome that must be accounted for in management of ESA-listed stocks. For example, the shortening of the commercial fishing season for summer chinook salmon to allow greater escapement was the major reason for restoration of these runs between 1945 and 1955 (Raymond 1988). Commercial and sport catches are monitored by fisheries management agencies, and these harvest statistics provide accurate harvest estimates. However, a precise measure of this mortality factor cannot be obtained because of limitations in monitoring the total catch.

A Columbia River Fish Management Plan (CRFMP) was adopted in 1988 to help restore runs and allocate harvest of fish in the mainstem Columbia River and tributaries. The CRFMP was agreed to by the United States, States of Oregon and Washington, and four treaty Native American tribes (Yakima, Warm Springs, Umatilla, and Nez Perce). Since 1988, management of Columbia River fish runs and fisheries has been principally based on the CRFMP. Each of the state fisheries management agencies has regulatory authority over sport and commercial fisheries within their boundaries. In addition, the tribal governments have the authority to regulate the conduct of the tribal fishery.

Current harvest goals vary by stock. For example, the goal for sockeye salmon is to allow no commercial harvest downstream from the confluence of the Snake River with the Columbia River. Limited tribal ceremonial and subsistence harvest is also recommended (NPPC 1991). Spring chinook salmon harvest goals are set at whatever the tribes catch plus 4% of upriver runs. Further, it is recommended that the ocean fishery be monitored to ensure incidental harvest remains at 2% or less of the upriver run. Current summer chinook salmon goals are to limit the tribal and non-tribal catch to 1000 and 100 fish, respectively, and to manage the Columbia River harvest of summer chinook salmon according to U.S. vs. Oregon. The goal for fall chinook salmon is to reduce ocean and inriver harvest to 55% of annual runs. Sport fishery regulations are designed to adopt catch-and-release regulations for weak stocks and closures for depressed stocks.

Areas open to commercial fishing of ESA-listed stocks in the mainstem Columbia River are shown in Figure 5. The commercial fishery downstream from Bonneville Dam (Zones 1 through 5) consists of gillnets. The number of fishing days allowed for the commercial mainstem fishery has declined from over 270 in 1943 to 45 per year since 1980 (WDF/ODFW 1992).

The commercial fishery upstream from Bonneville Dam (Zone 6) was open to fishing by both tribal and non-tribal interests up to 1956. From 1957 to 1968, Zone 6 was closed to commercial fishing, and harvest was restricted to treaty fisheries that occurred by tribal ordinances. In 1968, commercial fishing was reestablished exclusively for treaty fishers in the mainstem upstream from Bonneville Dam and extending to the mouth of the Umatilla River near McNary Dam. The number of days open to commercial salmon fishing upstream from Bonneville Dam has ranged from 48 to 120 days from 1968 to 199 1. The commercial fishery is conducted mainly with set gill nets, with some dip netting. Treaty fishers also catch anadromous fish during noncommercial, ceremonial, and subsistence fisheries. Subsistence fishing is usually open year-round and is conducted primarily with dip net and hook and line. Reporting of ceremonial and subsistence fisheries are tribal responsibilities.

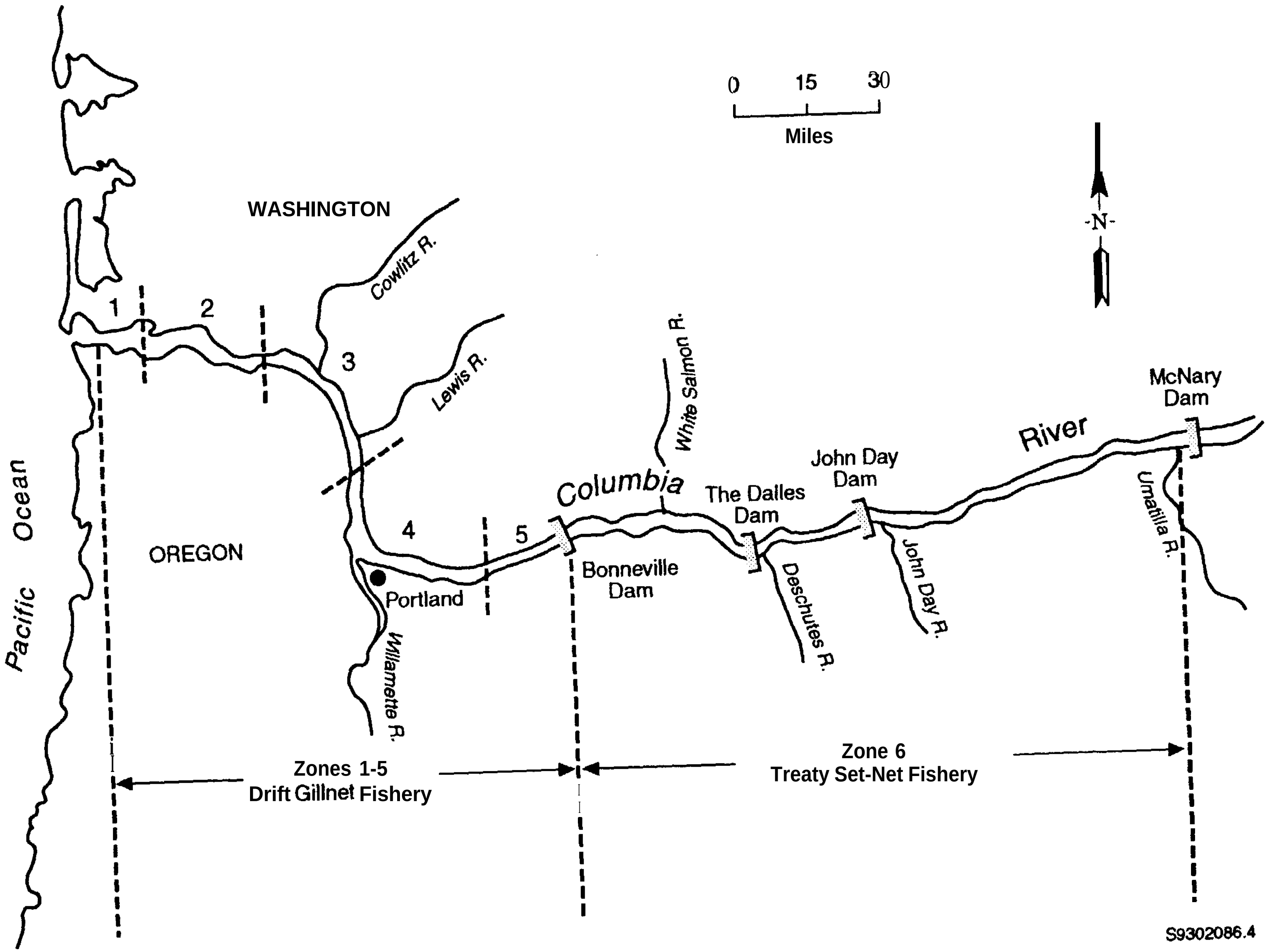

Figure 5. Location of Commercial Fishing Zones for the Lower Columbia River

The primary recreational fisheries for ESA-listed stocks in the lower mainstem Columbia River include the area from Bonneville Dam downstream to the Astoria-Megler Bridge and the estuary fishery from Astoria-Megler Bridge to Buoy 10 or the “Buoy 10” fishery. Target species include spring/summer and fall chinook salmon. Estimates of angler catch and effort are determined each year by a statistical sampling program from February to October.

The CRFMP does not address any specific escapement goals or harvest guidelines for the Snake River Basin, other than to define a natural/wild spring chinook salmon interim management escapement goal at Lower Granite Dam of 25,000 fish. Instead the CRFMP directs the affected parties to develop tributary harvest and production plans for each of the subbasins. Treaty and non-treaty fishers have not fished commercially in the Snake River since the early 1900s. Sport fisheries in the Snake River do not target adult chinook salmon or sockeye salmon. However, treaty tribal ceremonial and subsistence fisheries occur at various locations throughout the Snake River Basin. These fisheries generally target surplus hatchery stocks near hatcheries, with the exception of fisheries in the upper Salmon River Basin, which harvest some wild fish while targeting hatchery stocks (CRTS 1993b). Since 1986, treaty fisheries have generally targeted hatchery spring and summer chinook salmon during May and June. There have been no known treaty fisheries of fall chinook salmon and sockeye salmon in recent years.

Additional harvest impacts can be expected to occur during nontarget fisheries. For example, low numbers of chinook salmon and sockeye salmon may be caught during the early summer gill net fishery for shad. Additionally, test fisheries conducted by management agencies to help predict upriver run size may result in a low catch of spring chinook salmon (USFWS/TAC 1992). No impacts to ESA-listed stocks are anticipated from smelt, sturgeon, or anchovy fisheries.

3.2.1 Spring Chinook Salmon Harvest

Spring chinook salmon are separated into lower river and upriver runs. Lower river fish enter the Columbia River from January through May and are destined mainly for the Willamette and Cowlitz rivers. Upriver stocks originate from hatchery and natural production areas upstream of Bonneville Dam, including mainstem tributaries between Bonneville and McNary dams, upper Columbia River tributaries upstream from Priest Rapids Dam, and the Snake River system. Upriver fish begin entering the Columbia River in March, and current runs are mainly hatchery fish. The upriver run size entering the Columbia River is determined by combining the count for commercial and sport catches of upriver fish made in the lower Columbia River in February through May and the Bonneville Dam count. Interim management goals are currently 115,000 and 35,000 (25,000 wild/natural) fish passing Bonneville and Lower Granite dams, respectively. Each of the harvest components that affect adult upstream survival of spring chinook salmon are discussed below.

3.2.1.1 Commercial Harvest (downstream from Bonneville Dam)

No spring season (late April and May) has been allowed since 1977. Some incidental catch occurs during the winter season (late February and early March). In 1989, the winter catch included about 1500 of the upriver adult run, or 1.8% of the total.

3.2.1.2 Tribal Harvest (upstream from Bonneville Dam)

No spring season has been allowed since 1977. However, low numbers (<500 per year) of spring chinook salmon have been harvested in the Zone 6 commercial tribal fishery during the winter season since 1983. The combined fisheries harvest rate for the winter season (February 1 to March 31) is not to exceed the 1983 to 1985 harvest average or 15%. The Columbia River treaty tribes also have a minimum mainstem ceremonial and subsistence entitlement of 10,000 spring and summer chinook salmon through a platform fishery. The majority of the harvest is to be taken from the spring chinook salmon run. Mainstem ceremonial and subsistence gill net fisheries for spring chinook salmon are managed according to inriver run size and are not to exceed 7% of runs >50,000 over Bonneville Dam. The gill net fishery for ceremonial and subsistence is only by agreement at run sizes <25,000. The total ceremonial and subsistence spring chinook salmon catch in 1991 was 3994, or 6.7%, of the actual upriver run size of 59,800.

Treaty ceremonial and subsistence fisheries for spring and summer chinook salmon occur mainly in the Clearwater, Salmon, and Grande Ronde river subbasins. Tribal fisheries in the Tucannon and Imnaha river subbasins have not occurred in recent years. The Nez Perce tribe has conducted ceremonial and subsistence fisheries for Dworshak Hatchery spring chinook salmon annually since 1987, except in 1991 when the hatchery return was poor. Tribal harvest of Dworshak Hatchery spring chinook salmon in the North Fork Clearwater River has ranged from 160 to 514 during that interval. Ceremonial and subsistence fisheries have also been conducted in Clear Creek for Kooskia Hatchery spring chinook salmon. Annual take from 1987 to 1990 ranged from 50 to 130 spring chinook salmon. Treaty catches during 1985 to 1992 at the Rapid River Hatchery (Salmon River drainage) ranged from 544 to 3540 spring chinook salmon. For the period 1981 to 1992, the Shoshone-Bannock fishery harvested from 0.1% to 0.7% of the wild spring and summer chinook salmon escapement over Lower Granite Dam (CRTS 1993a). In 1992, 73 hatchery and 33 wild spring and summer chinook salmon were caught in the Shoshone-Bannock fishery in the upper Salmon River Subbasin. Umatilla tribal ceremonial and subsistence fisheries for spring chinook salmon have occurred in the upper Grande Ronde River and Catherine Creek from 1986 to 1989 and in 1992. Catches ranged from 8 to 125 fish during that interval, with about 80% of the fish being hatchery origin. In 1992, the Nez Perce tribe caught an additional 120 fish in their ceremonial and subsistence fishery that targeted Lookingglass Hatchery spring chinook salmon.

3.2.1.3 Recreational Harvest

The lower Columbia River sport fishery has closures timed to protect upriver stocks of spring chinook salmon. On March 19, 1991, angling was closed upstream from the interstate (I - 5) bridge. The traditional closure date for the portion of the river below that bridge has been March 31 since 1975. The February-through-March sport catches in the lower Columbia River are mostly Willamette River fish. The fishery was extended into April for several years during the late 1980s. Of the 5600 spring chinook salmon in the sport catch 1500, or 2.6%, were considered to be Snake River fish and only 180 of these were estimated to be wild fish. Incidental catches (annual average of 650 fish) of upriver chinook salmon occurred in the lower Columbia fishery from 1978 to 1991. This total comprised about 10% of the upriver run (WDF/ODFW 1992).

There is no sport harvest allowed for any chinook salmon in the Snake River and tributaries. The sport fisheries target only hatchery steelhead, and retention of chinook salmon is not allowed. The sport fisheries for steelhead are not open during migration or spawning periods of spring chinook salmon.

3.2.2 Summer Chinook Salmon Harvest

Summer chinook salmon enter the Columbia River in June and July and are nearly all of upriver origin. The run comprises an earlier migrating component destined primarily for the Salmon River drainage in Idaho and a later migrating component destined for the upper Columbia River and tributaries upstream from Priest Rapids Dam. The minimum run size entering the Columbia River is determined by combining the commercial and sport catches of upriver fish made in the lower Columbia River in June and July and the Bonneville Dam count. The minimum spawning escapement goal is 80,000 to 90,000 over Bonneville Dam. Each of the harvest components that affect adult upstream survival of summer chinook salmon are discussed below.

3.2.2.1 Commercial Harvest (downstream from Bonneville Dam)

Summer chinook salmon have not been harvested as a target species since 1963. Incidental harvest was allowed from 1967 to 1973 during shad, steelhead, and sockeye salmon seasons and no harvest has occurred since 1974, except for jacks during the 1984 to 1988 sockeye salmon seasons. The total incidental harvest is not to exceed 5% of the inriver run size for each of the treaty and non-treaty fisheries. Impacts on Snake River summer chinook salmon during the fall season fishery should be negligible because most of the Snake River fish have migrated upstream out of the mainstem fishing areas by the time the fall fisheries begin (CRTS 1992).

3.2.2.2 Tribal Harvest (upstream from Bonneville Dam)

Summer chinook salmon have not been harvested as a target species since 1964. The estimated ceremonial and subsistence harvest of adult wild Snake River summer chinook salmon is estimated to have ranged from 0 to 353 fish since 1979, with 1989 to 1991 catches less than 20 fish per year (CRTS 1992). The treaty allocation by platform and gill net is 10,000 fish, but this total includes only a small proportion of summer chinook salmon. The estimated tribal commercial harvest of summer chinook salmon has ranged from 0 to 152 fish from 1979 to 1991, with fish reported in only 5 of 13 years. Incidental harvest of summer chinook salmon (up to 100 fish annually) has occurred during shad and sockeye salmon seasons and during ceremonial and subsistence fisheries for spring chinook salmon.

3.2.2.3 Recreational Harvest

No recreational harvest of adult summer chinook salmon has been allowed in the Columbia River since 1974. The taking of jacks has been permitted since 1977, and up to 100 fish are estimated to have been taken, some of which may be spring chinook salmon.

There is no sport harvest allowed for chinook salmon in the Snake River and tributaries. The sport fisheries target only hatchery steelhead, and retention of chinook salmon is not allowed. These fisheries are not open during migration and spawning periods of summer chinook salmon.

3.2.3 Fall Chinook Salmon Harvest

Fall chinook salmon entering the Columbia River include both lower river and upriver runs that enter the Columbia River from early August through November. The lower river run is destined for hatchery and natural production areas downstream of Bonneville Dam. The upriver run comprises those fish destined for production areas upstream of Bonneville Dam. This run consists of the Bonneville Pool Hatchery (BPH) and upriver bright (URB) stocks. BPH stocks are produced primarily at the Spring Creek National Fish Hatchery, while URB fall chinook salmon originate primarily from natural production in the Hanford Reach. Small numbers of URB also return to the Deschutes River and to the middle Snake River. The escapement goal of 45,000 URB adults passing McNary Dam has been exceeded annually since 1983. An additional group of fall chinook salmon, the mid-Columbia bright (MCB), corresponds to a group of URB stock fish reared and released in mid-Columbia River areas below McNary Dam. These fish are mid-Columbia stock and are nearly all from hatchery production. Because run timing of most fall chinook salmon stocks overlaps during migration into the lower Columbia River, harvest of these mixed stocks may affect the survival of fish destined for the Snake River. A significant proportion of Snake River fall chinook salmon are harvested in the lower Columbia River. The harvest rate for adult Snake River fall chinook salmon ranged from 26.8% to 55.4% from 1986 to 1991 (CRTS 1992). Each of the harvest components that affect adult upstream survival of the URB component of fall chinook salmon are discussed below.

3.2.3.1 Commercial Harvest (downstream from Bonneville Dam)

The non-treaty harvest allocation is 50% of the run size exceeding 45,000 adults over McNary Dam. Run size of URB stocks ranged from 66,600 to 419,400 adults from 1980 to 1989. Commercial catch (Zones 1 to 5) ranged from 2400 to 104,300 adults during that same interval and 3.6% to 24.5% of the total estimated adult run size. The total nontreaty catch of upriver fall chinook salmon was 19,200 adults in 1991, of which 13,800, or 71%, were URB.

3.2.3.2 Tribal Harvest (upstream from Bonneville Dam)

The tribal harvest allocation is 50% of the run size exceeding 45,000 adults over McNary Dam. The tribal commercial harvest ranged from 2800 to 120,000 adults from 1980 to 1989 and 3.5% to 28.5% of the total adult run size. The 1991 Zone 6 fishery was 20 fishing days. The tribal harvest in 1991 was 51,000 adults, including 22,600 URB.

No known mortalities of wild or hatchery fall chinook salmon have occurred in the mainstem Snake River as a result of the tribal subsistence fishery (CRTS 1993b). Treaty ceremonial and subsistence fisheries in the Snake River Basin that target hatchery spring and summer chinook salmon are conducted in areas and during times when wild fall chinook salmon are not present. Tribal fisheries for wild fall chinook salmon that spawn in the Tucannon and Imnaha river subbasins have not occurred in recent years.

3.2.3.3 Recreational Harvest

Sport catch includes both estuary recreational (Buoy 10) and terminal (i.e., upper mainstem and tributary) totals. Sport catches ranged from 200 to 18,200 fish from 1980 to 1989 and 0.2% to 4.8% of the total adult run size. Currently, the two primary sport fisheries for URB stock are the Buoy 10 and the Hanford Reach areas. The Buoy 10 sport fishery harvest was 11,500 chinook salmon, of which 800 were URB. The lower river fishery caught 3200 fish, of which 800 were URB. The fishery between Bonneville and McNary dams consisted of 1100 URB. The total URB catch downstream from McNary Dam was 2700 adult fish, or 5.7% of the McNary Dam URB adult count in 199 1. The Hanford Reach fishery occurs upstream from the confluence of the Snake and Columbia rivers and does not affect Snake River stocks.

There is no sport harvest allowed for chinook salmon in the Snake River and tributaries. Even though the steelhead sport fishery is open when fall chinook salmon are migrating to their spawning grounds, retention of chinook salmon is not allowed. Mortality of fall chinook salmon during steelhead sport fisheries is considered to be nonexistent (CRTS 1993b).

3.2.4 Sockeye Salmon Harvest

Sockeye salmon runs in the Snake River have severely declined from historical levels. From 1989 to 1992, annual numbers of returning adults ranged from 0 to 4 fish. Sockeye salmon enter the Columbia River in June and July and are destined for natural production areas upstream from Priest Rapids Dam in the Wenatchee and Okanogan river basins. At present, the minimum harvestable run size is 75,000 sockeye salmon passing Bonneville Dam, and the escapement goal is 65,000 sockeye salmon passing Priest Rapids Dam. The current harvest management provisions for sockeye salmon are shown in Table 9. Each of the harvest components that affect adult upstream survival of sockeye salmon are discussed below.

3.2.4.1 Commercial Harvest (downstream from Bonneville Dam)

Target commercial fisheries for sockeye salmon have occurred in the mainstem Columbia River annually since 1984. However, because recent run sizes have been relatively small, no commercial season on sockeye salmon has been allowed since 1988. Sockeye salmon were commercially harvested in only 5 of 8 years previous to 1988, and landings ranged from a high of 31,900 fish in 1985 to 1800 fish in 1986. Because their run timing does not coincide with the fall season fishery for chinook salmon, sockeye salmon have not been taken in the lower river fall

Table 9. Summary of US. vs. Oregon Harvest Management Provisions for Sockeye Salmon

Run Size	Ceremonial and Subsistence	Treatv	Nontreatv
<25,000	**only with** agreement	None	None
25,000 to 50,000	**<5%**	None	None
50,000 to 75,000	**c7 %**	None	None
75,000 to 100,000	Yes	**75%** of surplus >75,000	**25%** of surplus >75,000
>100,000	Yes	**50%** of surplus >100,000	**50% of surplus** >100,000

season commercial fisheries since at least 1983. During 1989 to 1991, it was estimated that harvest was in fractions of one Snake River sockeye salmon (CTRC 1992).

3.2.4.2 Tribal Harvest (upstream from Bonneville Dam)

Depending on escapement, substantial numbers of sockeye salmon may be harvested in the Zone 6 commercial tribal fishery. Landings ranged from 1800 fish in 1983 to 49,400 fish in 1985. Only about 3300 sockeye salmon (4.3% of the total run) were harvested in the 1991 ceremonial and subsistence fisheries. Recorded landings of sockeye salmon in the Zone 6 treaty commercial fall season fishery from 1983 to 1991 ranged from 0 to 370 and averaged 60 sockeye salmon (CRTS 1992). The chance of intercepting a Snake River sockeye salmon in these fisheries is extremely low. Since 1974, the total number of Snake River sockeye salmon estimated in the ceremonial and subsistence and Zone 6 tribal fisheries was <30 fish annually and was estimated to be <1 fish for 10 of 17 years (CRTS 1992).

No sockeye salmon are expected to be caught in the mainstem Snake River because **no** tribal fishing effort is known during their migration period. The only subbasin with sockeye salmon returning is the Salmon River and tributaries. Although sockeye salmon may be present in the mainstem Salmon River during the time the Shoshone-Bannock chinook salmon fishery takes place, there are no recent records of sockeye salmon being caught in this fishery (CRTS 1993b).

3.2.4.3 Recreational Harvest

The recreational harvest of sockeye salmon is negligible (<100 fish). Anglers do not target sockeye salmon in the Columbia River. The sport fishery was closed on the lower Columbia by emergency regulation effective July 3, 1991, to protect Snake River sockeye salmon.

There is no sport harvest allowed for sockeye salmon in the Snake River and tributaries. The sport fisheries that target hatchery steelhead are not open during migration and spawning periods of sockeye salmon.

3.2.5 Summary of Harvest Impacts

The potential of each ESA stock to be affected by commercial or harvest species varies, depending on the total run size and the harvest management objectives for that year. Fall chinook salmon stocks that return to the Snake River are most vulnerable to impacts from commercial harvest because up to 50% of the total run may be harvested in the mixed-stock fishery that occurs in Zones 1 to 6. The potential for impacts to the summer chinook salmon is extremely low because there is no fishing during their migration interval. Mainstem ceremonial and subsistence fisheries are the primary harvest impact (about 7% per year) for ESA-listed stocks of spring chinook salmon. Terminal ceremonial and subsistence fisheries in tributaries of the Snake River take <1% of the escapement of spring chinook salmon over Lower Granite Dam. Depending on whether escapement goals are met at Bonneville and Priest Rapids dams, up to 30% of the adult run of sockeye salmon could be harvested. However, if these minimum run size objectives are not met, there would be no impact to Snake River sockeye salmon from harvest. Recreational fisheries are not a mortality factor for sockeye salmon or summer chinook salmon, but may remove up to 10% of the upriver run of spring and fall runs of chinook salmon.

3.3 ENVIRONMENTAL FACTORS CONTRIBUTING TO ADULT LOSSES

Besides dam operations and harvest, environmental factors also contribute to adult mortality. Significant human-caused changes have occurred to many water quality parameters in the Snake and Columbia river systems during the last century. These changes have included shifts in seasonal temperature regimes because of irrigation practices and reservoir storage, increases in dissolved gases from entrainment of air during spill operations at hydroelectric facilities, and addition of nutrients and pollutants from domestic and industrial sources. Dissolved gas levels and water temperature are routinely monitored at the dams. However, input of pollutants from nonpoint sources such as irrigation and grazing is of concern, and impacts to fish more difficult to estimate. This section discusses changes in water quality parameters and other ecosystem components, such as marine mammal predation, that may contribute to mortality of adult salmon that return to spawn in the Snake River Basin.

3.3.1 Temperature

Elevated temperatures may affect the behavior and survival of ESA-listed salmon stocks if temperatures exceed a lethal threshold for a species and if exposures are long enough. It is important to understand that the occurrence of high water temperatures reported to be lethal to adult salmon does not always mean that losses will occur. Fish may also respond to temperatures that are outside their preferred range by seeking acceptable conditions (i.e., cooler refuge areas) and or by ceasing to migrate upstream past a thermal barrier. Upstream migration may continue after ambient temperatures decline to acceptable limits. Increased temperatures that occur in the late summer may also affect the abundance of disease pathogens, such as columnaris, and increase the potential for infectious disease and prespawning mortality.

Cool temperatures can also slow migration of adult salmonids. Before construction of Dworshak Dam, the temperatures of flows leaving the North Fork Clearwater River were similar to those of the mainstem. In late July and early August 1976, water released from Dworshak Dam was 0.6” to 3.9” C cooler than in the mainstem Cleat-water River. These flows may have caused tagged fish to hold up in the North Fork Clearwater between 7 hours and 10 days, thus delaying their migration up the mainstem Clear-water (Stabler 1981).

Available literature suggests water temperature should be in the range of 10.6” to 19.4” C during migration for fall chinook salmon, 3.4” to 13.3” C for spring chinook salmon, and 13.3” to 20.0” C for summer chinook salmon (Table 10). However, these temperature limits are not physiological limits to survival. The ultimate upper lethal temperature for juvenile spring chinook salmon and sockeye salmon are 25.1” C and 24.4” C, respectively (Brett 1952). Adult salmon are generally less tolerant of high water temperatures. For example, Becker reported that the incipient lethal temperature (median mortality of exposed groups after 7-day exposures) for jack chinook salmon was near 21° to 22” C. Other investigators have reported that although temperatures above 20” C are not directly lethal to migrating adult chinook salmon, prolonged exposure to high water temperatures can delay migration or cause stress-related mortality (McCullough 1991).

Adult run timing past lower Columbia and Snake river dams and the period when water temperatures were ≥ 2 1 ° C (199 1 data) are compared in Figure 6. Sockeye salmon have the highest potential to encounter high temperatures during migration, while summer and fall chinook salmon may also encounter high water temperatures during a portion of their run. The following

Table 10. Water Temperature Criteria for Salmon, Degrees Centigrade (NPPC 1992)

Species/Run	Upstream Migration	Spawning	Incubation	Preferred	Optimum
Chinook					
Fall	10.6-19.4	5.6-13.9	5.0-14.4	7.2-14.4	12.2
Spring	3.4-l 3.3	5.6-13.9	5.0-14.4	7.2-14.4	12.2
Summer	13.3-20.0	5.6-13.9	5.0-14.4	7.2-14.4	12.2
Sockeye	7.2-15.6	10.6-12.2			

subsections briefly summarize available temperature data relating to conditions expected to be encountered during migration and spawning of the ESA-listed stocks.

3.3.1.1 Chinook Salmon Thermal Tolerance

Chinook salmon have been shown to avoid thermal plumes when encountering above optimum temperature conditions. For example, migrating adult chinook salmon will avoid temperatures greater than 21.1’ C (EPA and NMFS 197 1). Hallock et al. (1970) also found that water temperatures of 19° C were a partial block to adult migrating chinook salmon. Adult chinook salmon have congregated in cold creeks near Rock Island and Bonneville dams when temperatures were 21.7’ to 23.9’ C, respectively, in the mainstem Columbia River (Fish and Hanavan 1948). The selection of chinook salmon migration routes was examined by the U.S. Fish and Wildlife Service from 1965 to 1968. Fish sought cooler water when temperatures exceeded 21.1’ C, while no preference or avoidance was evident from temperatures between 10° and 21.1’ C (EPA and NMFS 1971).

Available literature also indicates that temperatures of 21° C and above are directly lethal to 50% of the salmon and steelhead populations exposed for >7 days. The upper lethal threshold for chinook salmon was 21° to 22° C for 1- to 2-year-old chinook salmon jacks acclimated at 15.4° to 19.7’ C (Coutant 1970). Warm temperature in combination with other stresses, such as disease through pathogenic agents, and nitrogen supersaturation can increase the rate of prespawning mortality (McCullough 199 1). These indirect effects could influence the production potential of adult salmon returning to hatcheries and natural spawning areas.

During the summer, Snake River water temperatures are usually higher than those in the Columbia River. This temperature difference may cause chinook salmon to delay their upstream

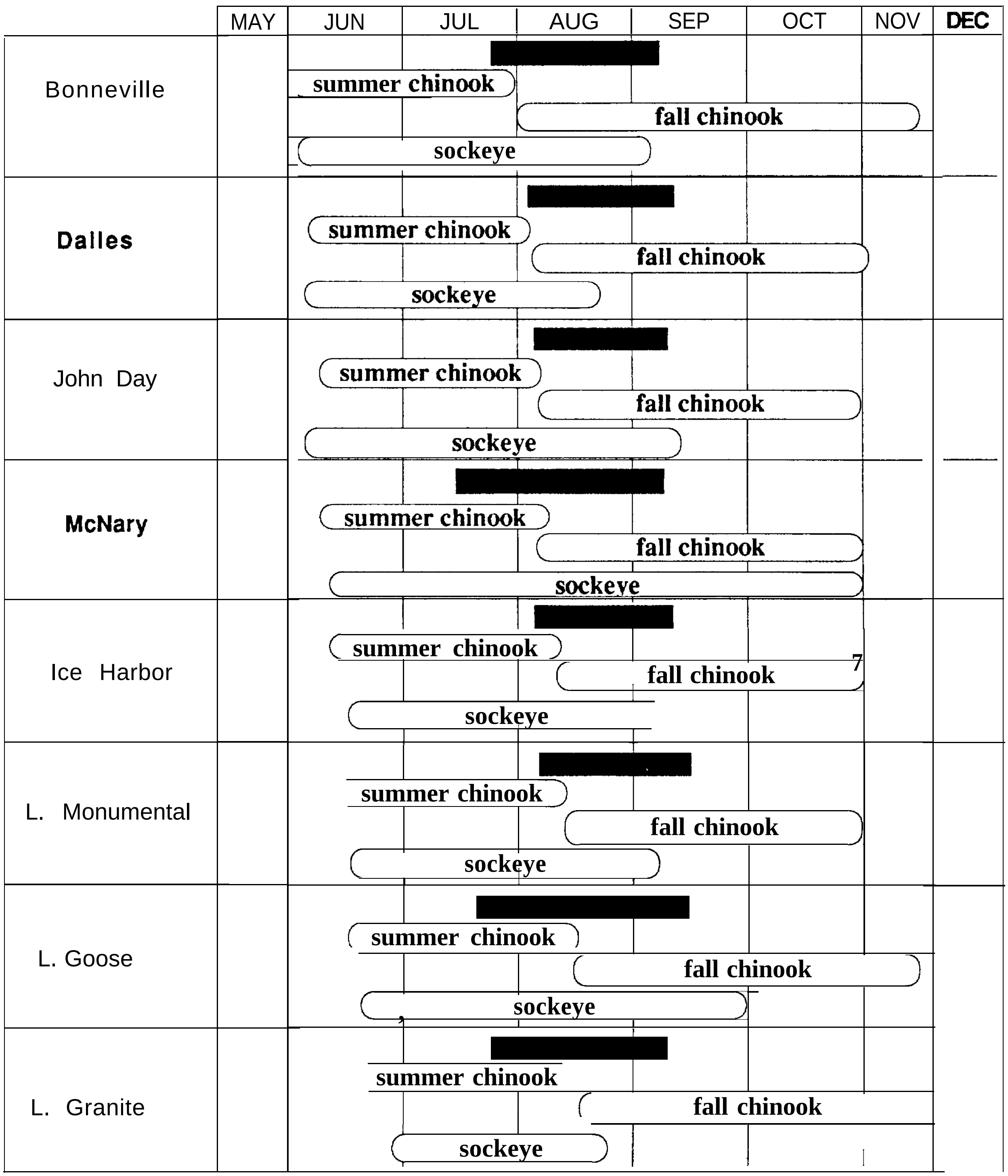

Figure 6. Adult Salmon Migration Timing (open bars) and Period of Water Temperature ≥ 21.1 °C (black bars) at Lower Columbia and Snake River Dams in 1991

migration into the Snake River in the late summer and early fall (Stuehrenberg et al. 1978). When fish began to congregate near the mouth of the Snake River in July, Snake River temperatures were 22° C while the Columbia River temperatures were 17° C. By early August 1967, the water temperatures were 26° C in the Snake River and 17° C in the Columbia River. Migration resumed in late August when water temperatures had reached 21” C in both rivers. High water temperatures have slowed the upstream migration of adult salmonids into the lower Snake River during August and September, and perhaps affected their migration rate in the lower Columbia River (Bjornn and Perry 1992).

Recent temperature monitoring studies on the mainstem Snake River indicated temperatures were well above 21.1’ C at Ice Harbor Dam from mid-August to mid-September. *Mean* temperatures at Lower Granite Dam from 1985 to 1989 ranged from 21.1’ to 22.3’ C in mid-July through August. During the same period, temperatures in Lake Sacajawea were between 22.3° and 26. 1° C. During 1990, reservoir temperatures at Lower Granite Dam, as measured in the turbine scroll case, equaled or exceeded the upper resistance temperature of the fish (21.1” C) for 69 consecutive days from July 10 through September 17, reaching 26. 1° C on August 13 (Karr et al. 1991). Lower Granite Reservoir temperatures exceeded the upper tolerance levels for salmonids most of the time from June 16 to October 29.

There is evidence that historical temperatures in the Snake River also sometimes exceeded lethal thresholds for chinook salmon. Thus, current reservoir storage practices are not the only influence on water temperatures. Mean water temperatures at Clarkston in 1958 were above 21.1’ C from July 10 to August 12 (DOI 1960).

Temperature effects from habitat alterations also occur in tributaries to the Columbia and Snake rivers and may reduce the spawning success of spring and summer chinook salmon in natural production areas. The loss of cover along the stream banks may result in elevated summer temperatures, which in turn create thermal barriers to migrating adults and increase their rate of energy expenditure (Fry 1971). Loss of riparian vegetation and irrigation return flows in the lower Tucannon River contribute to elevated water temperatures and increased sedimentation (Theurer et al. 1985). Summer water temperatures in the lower Tucannon River are above the preferred range for migrating spring chinook salmon from July to mid-August..

3.3.1.2 Sockeye Salmon Thermal Tolerance

Elevated temperatures have been reported to affect adult sockeye salmon migration. For example, Fish and Hanavan (1948) reported that sockeye salmon congregated on cold water creeks near Bonneville and Rock Island dams when Columbia River temperatures were 21.6’ to 24.9’ C. Migration blockage from elevated temperatures was implicated in delayed migrations of sockeye salmon into the Okanogan River when temperatures exceeded 21.1' C, while falling temperatures caused migration to resume (Major and Mighell 1966). Migration delay from temperature blocks may reduce adult survival by increasing exposure of sockeye salmon to other factors that affect them adversely. The acutely lethal temperature limit for adult sockeye salmon was determined to be 22.1' C based on studies that indicated sockeye salmon survived 3.2 days at 22.1' C and 11.7 days at 20° C (McCullough 1991).

Secondary effects may also result from exposure to elevated temperatures. For example, the incidence of disease may be increased if adult salmon are exposed to elevated temperatures (reviewed in McCullough 1991).

3.3.2 Dissolved Gases

Spilling large volumes of water is the underlying cause of gas supersaturation at dams (Meekin and Allen 1976). Spillway deflectors are somewhat effective in degassing incoming water from forebays at dams. When flow over the spillways is low to moderate, a small increase in supersaturation is likely to occur (Park 1993). On the Columbia and Snake rivers, spillway deflectors are in operation at Bonneville, McNary, Chief Joseph, Lower Granite, Little Goose, and Lower Monumental dams (Chapman et al. 1991). A lo-year spill agreement was made in 1989 to aid downstream migrating juveniles in the spring. The provisions provided for a 70% spill at Lower Monumental Dam, 10% at The Dalles Dam, and 25% at Ice Harbor Dam.

During the spring and summer of 1968, supersaturation in the tailrace of John Day Darn was 123% to 143% while all water was spilled over the darn This condition persisted during most of the spring migration, with 365 chinook salmon and 13 sockeye salmon adults recovered dead below the darn in a single day (Ebel et al. 1975). During May 29, 1990, an emergency situation at John Day Dam caused total flow to be spilled, with water in the tailrace supersaturated to 145% (Chapman et al. 1991).

Nitrogen supersaturation in conjunction with elevated temperatures causes greater problems for adult salmon (Bouck et al. 1970). During years of high nitrogen levels, delayed effects of gas supersaturation on adult survival are extremely important with many observations of "blisters" on spring chinook salmon in hatcheries and spawning grounds. When large reaches of the Columbia and Snake rivers have gas supersaturation levels of 125%, mortality should be expected (Chapman et al. 1991).

The Dissolved Gas Monitoring Program has operated every year from mid-April through Labor Day since 1984. Seventeen stations are monitored below dams, covering the Columbia and Snake rivers. The current standard is 110% saturation below dams. Values recorded in 1991 ranged from 110% at Lower Monumental Dam to 137% at the international boundary. Lower Granite Dam total dissolved gas levels were monitored during spill, with the levels rising to 138%

within a 4-hr period at standard recording depth of 15 ft. The gas levels dissipated by the time the water reached Little Goose Reservoir. Recordings at Little Goose Dam forebay increased slightly from 106% to 109%, lasting about a half day. Total dissolved gas in 1991 exceeded the 110% saturation standard, caused in part by implementing the lo-year spill agreement.

The 1991 spill dates and the relative proportion of each ESA-listed stock that passed each dam during the spill interval is shown in Figure 7. The potential for each stock to encounter high dissolved gas concentrations because of spill decreases as they migrate past the lower Columbia River dams because of the Snake River dams have a much shorter period of spill. Fall chinook salmon are not likely to encounter spill conditions because they migrate later in the year.

There is little information available on how much time fish spend above a 3-m (10-ft) depth, which is the depth range of interest for most observations of supersaturation in the Columbia and Snake rivers. Bubble formation does not occur when the hydrostatic pressure is greater than the total dissolved gas pressure. Because the total dissolved gas pressure rarely exceeds 130% saturation, fish cannot experience bubble formation in their blood and tissues at depths below 3 m. Gray and Haynes (1977) showed that swimming depths of adult chinook salmon that migrated in normally saturated water were shallower and differed significantly from those of fish migrating in supersaturated water. In 1976, chinook salmon were recorded at least 2 m below the surface about 89% of the time. During the study, fish deeper than 1.5 to 2.0 m were below the critical zone. Adult chinook salmon swam deeper in supersaturated water than in normally saturated water and thus avoided potentially lethal conditions. Above 111% total gas pressure, coho salmon increased their mean depth to compensate for increased gas supersaturation, while below these concentrations the fish no longer remained below the compensation depth (Shrimpton 1985).

From the information summarized above, it is evident that supersaturation conditions do sometimes occur downstream of dams on the Columbia and Snake rivers. Supersaturation values as high as 137% can occur at the dams, particularly after spilling, and these conditions are potentially lethal to salmonids migrating within the top 3 m of water. Both natural and engineered mechanisms are in place to reduced levels of gas supersaturation during spill. For example, spillway deflectors present at the lower Snake River dams reduced supersaturation by 10% to 15% at moderately high flows (Park et al. 1977). Levels of dissolved atmospheric gases may dissipate between dams after turbine and spill flows become more completely mixed, depending on the rate of equilibration toward atmospheric conditions.

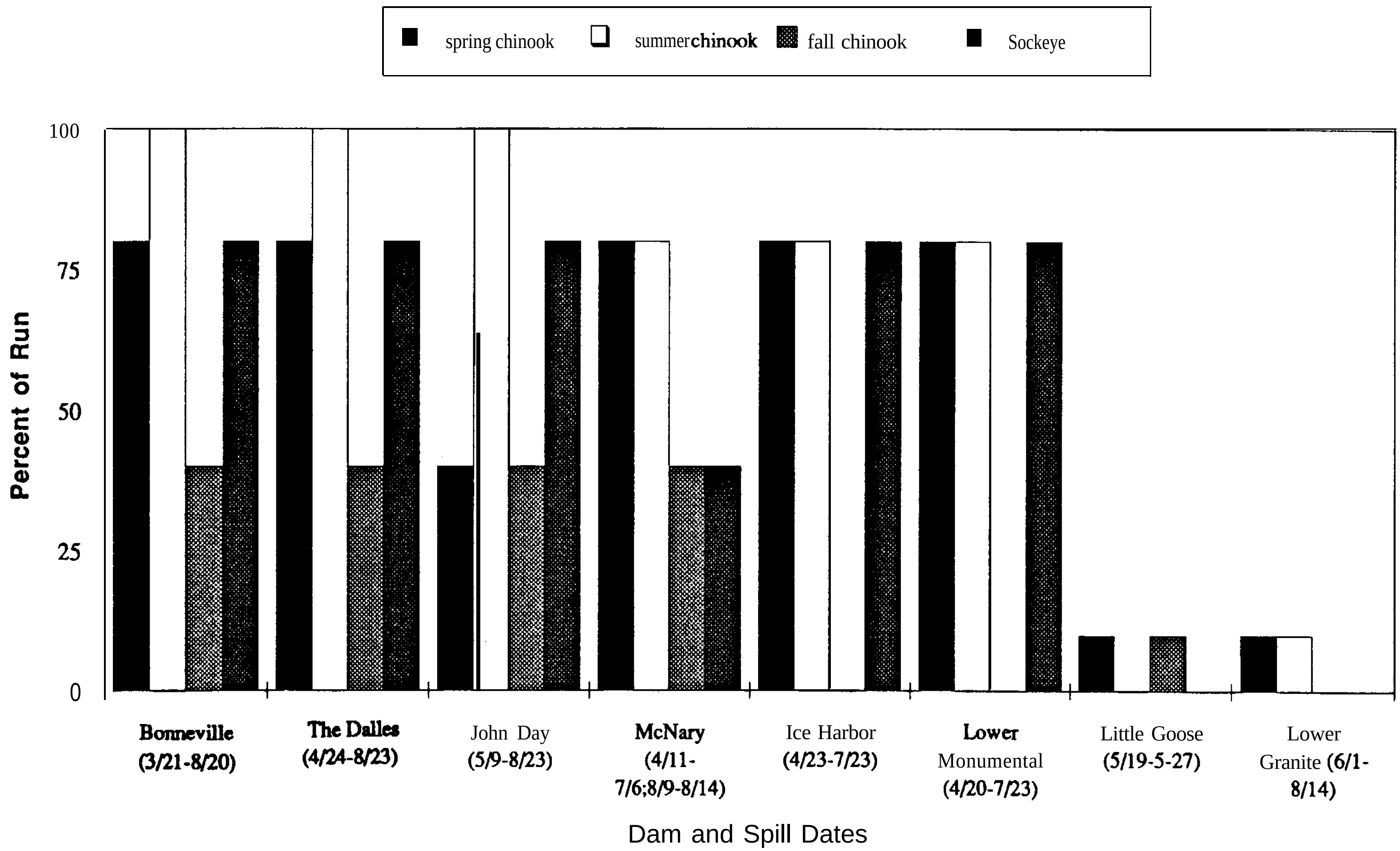

Figure 7. Potential Adult Run Exposure to Supersaturated Water in 1991

3.3.3 Pollutants

Anthropogenic input of pollutants may affect the survival of adult upstream migrant salmonids if concentrations exceed the lethal tolerance limit of a species or if exposures result in indirect effects such as stress, disease, or increased susceptibility to predators. This section briefly summarizes some known point source inputs of pollutants to the Columbia River system and potential impacts to adult upstream migrant salmonids. A more detailed discussion, including sources and impacts of nonpoint pollutants, was beyond the scope of this study.

Major sources of industrial contaminants in the lower Columbia and Snake rivers include discharges from pulp and paper mills and metals-processing plants. Six pulp mills operate between Columbia River mile 42 and 121 (downstream from Bonneville Dam), and another mill is located upstream from McNary Dam, just downstream of the Snake River confluence with the Columbia River. Contaminants released into the Columbia River from the pulp and paper mills include adsorbable organic halogens and dioxins. Three metals-processing plants also operate and discharge into the Columbia River at miles 63,102, and 120. Contaminants of concern include aluminum, nickel, cyanide, and benzo(a)pyrene. Two major facilities discharge regulated waste into the Snake River Basin near Lewiston, Idaho: Potlatch Corporation and the City of Lewiston. Potlatch Corporation is a pulp and paper mill, and the City of Lewiston discharges domestic waste. Each of the identified facilities have strict discharge limitations established by the Washington State Department of Ecology, the Oregon Department of Environmental Quality, or the U.S. Environmental Protection Agency.

In 1982, fluoride concentrations of 0.3 to 0.5 mg/L were recorded at John Day Dam, and the main source of contamination was traced to an aluminum plant, located immediately upstream of John Day Dam. From 1983 to 1986, fluoride discharges from the plant were greatly reduced to approximately 0.10 to 0.15 mg/L. During mid-April 1986, a problem occurred with the pollutant storage system at the aluminum plant, with fluoride concentrations of 1.21 mg/L recorded at the outfall of the plant. By October of the same year, the concentrations were reduced to approximately 0.16 to 0.17 mg/L. Bioassays suggested that migration of adult salmon could be adversely affected by fluoride concentrations of 0.5 mg/L and that direct morality to rainbow trout resulted at concentrations between 2.3 and 5.5 mg/L. Fish passage delays and interdam losses of adult salmon decreased concurrently with the decreases in fluoride concentration near the dam from 1983 to 1986 (Damaker and Day 1984, 1985).

Aromatic hydrocarbons and heavy metals occur at elevated levels at John Day Dam. Aromatic hydrocarbon concentrations in the sediments near John Day Dam (8300 µg/L) approach those found in the Duwamish Waterway (Puget Sound), which is considered to be among the most polluted areas in the USA. Effects to fish from these aromatic hydrocarbons are unknown.

Failures of tailings ponds containing mining wastes have occurred in Idaho. The impacts of large releases of these toxic wastes into tributaries are known to deter adult salmonids from migrating and spawning in affected areas. The primary areas in the Snake River Basin that are affected by mining include Bear Valley Creek, Panther Creek, Crooked Creek, and the South Fork Clear-water River (Chapman et al. 1991).

Continued irrigation practices reduce stream flow in which adult salmonids need to reach spawning areas. Stream flow diversion in the upper Salmon River Basin have reduced the summer chinook salmon capacity from July to September. In the Lemhi and Pahsimeroi rivers, irrigation diversions leave little water for fish migration. Irrigation returns also contribute to water quality degradation by increasing suspended sediments and turbidity (Chapman et al 1991). In addition to reducing stream flows, many older diversions do not provide adequate fish passage facilities for adult fish.

3.3.4 Marine Mammals

Another environmental factor related to adult mortality is predation by marine mammals. Recent observations of severe injuries to spring chinook salmon at Bonneville and Lower Granite dams indicate that marine mammals may be a significant contributor to direct and indirect mortality as well as delays downstream from Bonneville Dam The rate of injuries is a concern because of the recent expansion of the seal herd size in the Columbia River resulting from the Marine Mammal Protection Act. For example, studies conducted at Lower Granite Dam during the last 3 years reported that 14% to 20% of Snake River spring and summer chinook salmon may have been wounded by seals (Park 1993). Chapman et al. (1991) estimated an average loss of 3640 Snake River spring chinook salmon caused by seal bites. It is speculated that up to 70% of the seal-wounded fish which arrive at Lower Granite Darn die before spawning. Thus, predation by marine mammals would affect escapement estimates to natural spawning grounds.

The fact that summer chinook salmon receive fewer seal bites than do spring chinook salmon suggests seals may leave the estuary or switch to other prey items after the spring migration period. The presence of these mammals in areas which salmon are known to use as staging and resting areas may also contribute to delays and indirect mortality as fish pass upstream dams.

3.3.5 Summary of Environmental Factors

Temperature and dissolved gas concentrations appear to be the primary environmental parameters influencing the survival of adult upstream migrant salmonids in the Columbia and Snake river systems. Stocks most vulnerable to elevated temperatures in the mainstem Columbia and Snake rivers include sockeye salmon, fall chinook salmon, and summer chinook salmon. These stocks all migrate during mid-summer, when temperatures known to stress adult salmonids exist, Elevated temperatures could result a number of effects, including migration delay, increased incidence of disease, and even direct mortality. Flow augmentation practices that reduced main-stem temperatures to below 21° C would reduce the potential for mortality to these populations. Measures that maintain water temperatures in the fish ladder at levels near those in the tailrace would benefit fish passage. Spring and summer chinook salmon may be exposed to high temperatures in tributary streams. This could contribute to reduced reproductive success and could result in prespawning mortality. Drawdown operations are likely to have little influence on temperature in the lower Snake and Columbia rivers.

High concentrations of dissolved gases probably result in a small, yet unknown, mortality to spring and summer chinook salmon because they migrate mainly during the spring spill period. The addition of fliplips to several mainstem dams has reduced concentrations of dissolved gases occurring during the spill period and has probably increased survival and rates of migration of adult salmonids during the upstream migration period. The potential for mortality from high concentrations of dissolved gas would be reduced under the natural river option when compared to other drawdown alternatives because there would be no spill over the Snake River dams under the natural river option scenario.

There is little evidence of pollution-related mortality occurring to any of the ESA-listed stocks during their inriver migration period. Several pulp and paper mills and metals-processing plants discharge into the lower Columbia River, but effluents are monitored according to state and federal regulations. However, certain tributaries formerly used for spawning by spring and summer chinook salmon have been adversely impacted by alterations to water quality. These changes include releases of heavy metals from mine tailings and land use activities that reduce stream flow and increase sediment loading. There is a potential for increased turbidity to affect ESA-stocks that migrate in the Snake River during operation of any of the drawdown options.

Predation by marine mammals (i.e., harbor seals and sea lions) on ESA-stocks is restricted to the lower Columbia River and occurs mainly during the spring migration period, A high incidence of bite marks has been reported in recent years, coincident with increases in the marine mammal population. Losses of Snake River spring chinook salmon because of harbor seal predation were estimated to ranged from about 4100 to 9700 annually from 1990 to 1992.

3.4 RETURNS TO NATURAL PRODUCTION AREAS

Although not a mortality factor, uncertainties in survival estimates influence our knowledge of adult returns. Factors affecting our ability to accurately determine escapement to natural production areas include relative accuracy of dam passage counts, straying behavior, ptespawning mortality, and spawning survey methods. This section includes a brief description of natural spawning areas of ESA stocks and methods used to estimate adult escapement. Additional detail on spawning of these stocks is contained in Chapman et al. (1990, 1991) and Homer and Bjomn (1981a, 1981b).

3.4.1 Spring/Summer Chinook Salmon Spawning

Natural production of spring and summer chinook salmon takes place in the lower and upper tributaries of the Salmon, Tucannon, Grande Ronde, and Xmnaha river basins. Escapement totals between these runs are difficult to separate because both migration and spawning times overlap (Matthews and Waples 1991). Thus, it is difficult to accurately account for losses of these stocks from the estuary to the spawning grounds.

The recorded status of wild and natural spring and summer chinook salmon is based for the most part on redd counts in streams. Redd surveys are used to estimate the extent of spawning and are the best indicator of escapement to a particular stream. However, redd counts are assumed to be only indicators of total escapement and not exact abundance estimates (Chapman et al. 1991). In the mid-Columbia River, each redd represents approximately 2.4 adult fish (Mullan 1990). This number is also assumed to be accurate for Snake River spring and summer chinook salmon. Redd counts for spring and summer chinook salmon are considered to provide a good estimate of escapement because spawning occurs in tributary streams and the number of spawning adults can be estimated using a variety of techniques, including aerial surveys, ground surveys, and carcass surveys.

Since 1982, redd counts for summer chinook salmon in the Salmon River Basin have been conducted using a 1-day helicopter survey before the peak of summer chinook salmon spawning (Chapman et al. 1991). Redd counts have increased from a minimum of 620 in 1980 to high of 3395 in 1988. In 1990, redd counts for spring and summer chinook salmon in the Salmon River Basin were 1224. Wild spring chinook salmon redd counts upstream from Lower Granite Dam decreased from 2000 in 1988 to 500 in 1991.

Spawning surveys on spring chinook salmon in the Tucannon River showed a average adult female-to-redd ratio of 1.37: 1.00 from 1986 to 1987. This ratio included the total number of spawners upstream from the Tucannon Hatchery. Adult-to-redd ratios that included spring chinook salmon spawning downstream from the hatchery averaged 1.25 in the Tucannon River from 1989 to 1991. In 1990,180 redds and 302 wild plus hatchery adults were counted during spawning surveys (Bugert et al. 1990b). In 1991, 90 redds with 181 adults were counted (Bugert et al. 1991).

Prespawning mortality for wild spring chinook salmon was estimated to be 40% to 50% in the Salmon River Basin (Bjornn 1990). Losses of prespawning summer chinook salmon in Idaho were 30% to 40% (Chapman et al. 1991). Wounds caused by marine mammals and other injuries to wild spring chinook salmon are likely to result in greater prespawning mortality than fish held in broodstock collection facilities (Chapman et al. 1991).

Escapement of wild fish to spawning grounds upstream of Lower Granite Dam is estimated using two methods. The first method subtracts all hatchery returns from the dam counts. This number is subject to considerable error because it does not account for prespawning mortality. The second method uses an expansion factor based on dam counts and redd indexes before hatchery influence. This estimate also is considered biased because only a few years of data are available and because dam counts and redd counts were high during that time period (Matthews and Waples 1991). Thus, improvements to estimating escapement are needed.

3.4.2 Fall Chinook Salmon th a w -

Numbers of fall chinook salmon migrating over Lower Granite Dam have dropped from over 1000 in the mid-1970s to less than 100 in 1990. The majority of the natural production takes place from Hells Canyon Dam to 100 miles downstream. A few fall chinook salmon have been known to spawn in the lower reaches of the Imnaha, Grande Ronde (none before 1981), Tucannon, Palouse, lower Salmon and Clearwater rivers. Arnsberg (1992) counted 24 redds and 12 carcasses in the mainstem Cleat-water River in 1992. Spawning ground surveys of the lower Tucannon River showed 50 redds in 1991. Fall chinook salmon redd densities ranged from 2.8 to 8.8 redds/m from 1988 to 1991 (Mendel et al. 1991). In addition, limited spawning may be taking place in the tailrace sections of the lower Snake River dams.

The number of redds reported downstream from Hells Canyon Dam and in the Imnaha River in 1967 and 1969 was 188 and 568, respectively. The count of fall chinook salmon at Lower Granite Dam for those years was 14,000 and 6200 (Irving and Bjomn 1981). Additional redds were found in the Imnaha, Grande Ronde, and Clearwater rivers. The final dam count at Lower Granite Dam in 1990 was 391 adults and 185 jacks. However, trapping by NMFS reduced that number to 342 adults and 91 jacks. The total redd count upstream from Lower Granite Dam in 1990 was 46, resulting in a ratio of about 7 adults per sighted redd, compared to red&fish rations of 10 in 1989 and 8 in 1988 (Bugert et al. 1990a). The redd:fish ratio for fall chinook salmon spawning in the Hanford Reach of the Columbia River has averaged 9.4: 1 (range 3.1 to 16.1) from 1964 to 1988 (Dauble and Watson 1990). The variability associated with this value indicates relative accuracy of escapement could be as poor as ±50% when using a fixed redd:fish ratio for estimating fall chinook salmon spawning.

Redd counts conducted by aerial survey are limited by the clarity of the water and the depth of water over the redd. Thus, some redds may not be visible (and not counted) because fish spawn in deep water or because the water is too turbid Maximum depth that fall chinook salmon redds could be observed in the Hanford Reach of the Columbia River were estimated at 2.7 m by Chapman et al. (1983) and 4 m by Dauble and Watson (1990). Swan et al. (1988) reported that some fish spawned in midchannel locations of the Hanford Reach exceeding 5 m deep. Redd counts do not provide reliable indexes of fall chinook salmon in the mainstem Snake River because of the depth of the redds (up to 9 m) according to Waples et al. (1991a). This may explain why the ratio of adult escapement to redd counts of Snake River fall chinook salmon ranged from 8:1 to 14:1 during 1987 to 1989. In 1991, the U.S. Fish and Wildlife Service compared fall chinook salmon redd counts in the mainstem Snake River (river km 261) determined by aerial survey to those obtained by ground truthing and scuba surveys. The ground surveys located 20 redds compared to 14 during aerial surveys (Conner et al. 1993). Collectively, these studies indicate the red&fish ratio could vary widely, depending on the relative numbers of fish that spawned in shallow versus deepwater locations and the redd survey method used.

An additional variable affecting stock accountability is whether fall chinook salmon spawn in the tailraces downstream from the lower Snake River dams. The URB fall chinook salmon is known to spawn in the mainstem Columbia River downstream from Wanapum and Rock Island dams (Homer and Bjomn 1979; Rogers et al. 1989). Additionally, Bennett (1983) reported that O-age chinook salmon occurred in Little Goose reservoir in the spring of 1980, before collection of juveniles at the Lower Granite Dam juvenile collection facilities. Suitable spawning habitat for fall chinook salmon may be present downstream from Lower Granite Dam (Dauble and Geist 1992); however, attempts to locate redds by scuba or aerial survey techniques have been unsuccessful.

3.4.3 Sockeye Salmon Spawning

Natural production of the Snake River sockeye salmon is limited to Redfish Lake, in the Stanley Basin in Idaho, which has a potential to produce 1500 adults (Chapman et al. 1990). The returns of sockeye salmon destined for Redfish Lake have been less than 1000 fish annually since 1970, and less than 100 since 1981. Based on counts past Ice Harbor Dam, escapement averaged less than 20 fish from 1985 to 1988 and declined to less than 5 fish in the last 3 years. Adults were trapped for a captive broodstock program beginning in 1991 and 1992, and natural spawning has been restricted to kokanee populations (Waples et al. 1991b).

From 1962 to 1966, counts at Ice Harbor Dam were compared to weir counts at Redfish Lake to estimate prespawning mortality (Chapman et al. 1990). During this period, the weir count ranged from 5% to 35% of the Ice Harbor Dam counts. Based on Snake River dam counts and number of sockeye salmon that returned to the Redfish Lake weir from 1981 to 1991, inriver mortality from Lower Granite Dam to Redfish Lake was as high as 100% for 5 of 11 years, but as low as 0% in 3 of 11 years (Table 11). The wide range in survival suggests that stock accounting is poor.

The higher numbers of occurrences at Lower Granite Dam than at Ice Harbor Dam are probably the result of fish misidentified or fish that may have used navigation locks to bypass dams. Sockeye salmon fallback is not documented, and counts at McNary and Priest Rapids dams do not support fallbacks at Ice Harbor Dam. Currently, no other natural spawning of sockeye salmon is thought to occur other than Redfish Lake. Warren (1988) reported 45% prespawning mortality in adult sockeye salmon trapped at Redfish Lake weir and held to ripen at Sawtooth Hatchery.

3.4.4 Summary of Natural Production

When monitoring is done over several years and at regular intervals during the spawning season, redd counts are useful for indicating time of spawning and relative distribution of spawners, and for providing an index of the number of spawning adults. However, redd counts and other spawning ground surveys such as carcass counts cannot be considered as absolute measures of escapement to a spawning area. The redd:adult ratio is used to estimate total escapement to natural spawning grounds. However, this value is subject to error associated with both dam counts and redd counts. The redd:adult ratio calculated for spring and summer chinook salmon typically ranges from about 1.3 to 2.4, while values reported for fall chinook salmon are more variable, ranging from about 3 to 16. The primary difference is that spring and summer chinook salmon are tributary spawners and redds are easier to locate. Escapement of sockeye salmon is based on counts of adults over the weir at Redfish Lake, the only known remaining spawning site.

Prespawning mortality of natural populations of spring and summer chinook salmon in the Snake River Basin can be quite high, ranging from 30% to 50%. The prespawning mortality of sockeye salmon also appears to be high, based on the difference in counts over Lower Granite Dam and the weir at Redfish Lake during 1981 to 1991.

3.5 ADULT RETURN TO HATCHERIES

This section summarizes current hatchery practices of ESA-listed stocks and factors affecting the accountability of returning adults. Two factors contribute to the loss of fish returning to hatcheries: straying and pre-spawning mortality. Both of these factors would decrease the

Table 11. Estimated Prespawning Mortality for Adult Sockeye Salmon (numbers of fish) Based on Dam Counts and Adult Returns to Spawning Grounds, 1981 to 1992

Year	Ice Harbor	L. Granite	Redfish Weir	Inriver Mortality, %
1981	142	218	26	12
1982	174	211	50	23
1983	216	122	0	100
1984	105	47	22	47
1985	24	35	--	100
1986	20	15	--	100
1987	13	29	--	100
1988	22	23	29	0
1989	4	2	2	0
1990	1	0	0	0
1991	9	8	4	50

production potential of ESA-stocks that include hatchery production as a strategy for rebuilding. Location of major hatcheries for chinook salmon in the lower Columbia and Snake rivers is shown in Figure 8. Fall chinook salmon hatcheries are directed at enhancing stocks in the lower Columbia and Snake rivers, while spring and summer chinook salmon hatcheries are located in tributary streams. There are no sockeye salmon hatcheries in the Columbia and Snake river systems. However, there is currently a captive broodstock program for sockeye salmon and kokanee at the Sawtooth Hatchery in Idaho (DOE 1992).

3.5.1 Spring/Summer Chinook Salmon Hatcheries

Several hatcheries and satellite facilities exist in the upper Snake River Basin for the trapping, release, and rearing of summer and spring chinook salmon. Rapid River and Sawtooth hatcheries are the largest producers and may release up to 5.5 million spring chinook salmon annually (Table 12). McCall and Pahsimeroi hatcheries can produce up to 1 million summer chinook salmon smolts each.

Snake River spring and summer chinook salmon stray very little throughout the Columbia River Basin compared to fall chinook salmon. Of the tagged fish released at Rapid River, McCall, Sawtooth, and Hyden Creek hatcheries, none were recovered by carcass surveys in streams outside their release streams. Straying has been recorded in the Grande Ronde River, with up to 60% of Lookingglass/Carson stock found spawning in the Wenaha and Minam rivers in 1986 and 1987 (Chapman et al. 1991). In a related study from 1974 to 1977, 98.6% of the 41,085 escapement returned to the Cowlitz River. Some strays entered other hatchery traps, but only 85,

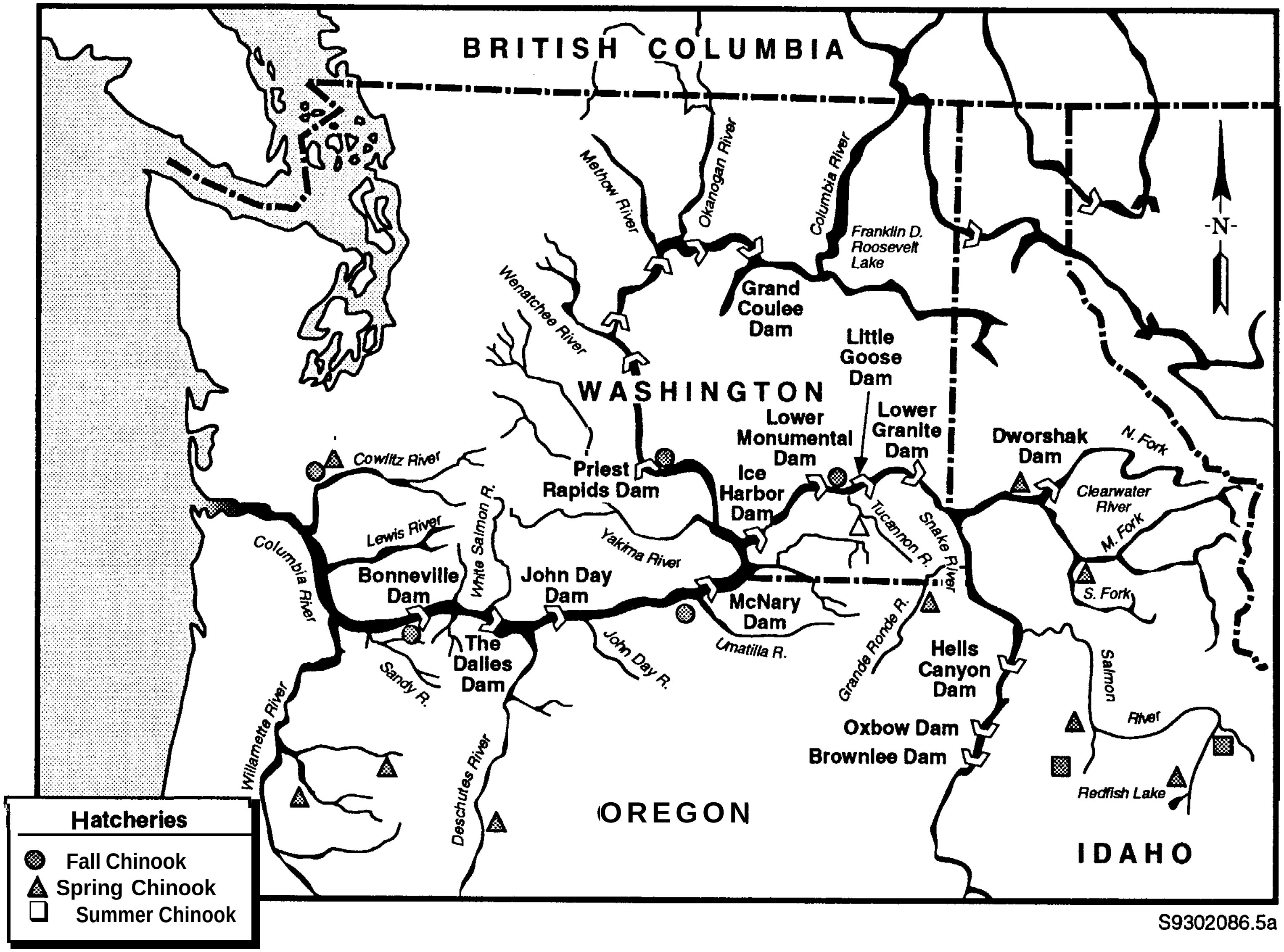

Figure 8. Location of Major Chinook Salmon and Sockeye Salmon Hatcheries in the Lower Columbia and Snake River Systems

Table 12. Summary of Spring and Summer Chinook Salmon Hatcheries and Satellite Facilities Operating in the Snake River Basin

Hatchery	Initial Brood Year	Agency[a]	Run	Production Design, No. Fish	Satellite Facility
McCall	1978	IDFG	Summer	1,000,000	South Fork Salmon Trap
Dworshak	1981	USFWS	Spring	1,050,000	
Sawtooth	1978	IDFG	Spring	2,235,000	East Fork Salmon Trap
Lookingglass	1981	OFW	Spring	1,390,000	Imnaha Ponds Big Canyon Ponds Wallowa Fish Hatchery
Lyons Ferry	1987	WDF	Spring	132,000	Tucannon Fish Hatchery
Clearwater	1991	IDFG	Spring	1,369,500	Red River Ponds Crooked River Powell Ponds
Pahsimeroi	1967	IDFG	Summer	1,000,000	Pahsimeroi Trap
Kooskia	1966	USFWS	Spring	800,000	Clean Creek
Rapid River	1964	IDFG	Spring	3,000,000	Rapid River Trap Oxbow Fish Hatchery

(a) IDFG = Idaho Department of Fish and Game; USFWS = U.S. Fish and Wildlife Service; OFW = Oregon Department of Fish and Wildlife; WDF = Washington Department of Fisheries.

or 0.2%, spawned in non-natal streams. Straying rates ranged between 1% and 13% (Quinn and Fresh 1984).

Prespawning mortality of female hatchery brood spring chinook salmon averaged 19.7% at Sawtooth Hatchery (Moore 1983, 1985; Rogers 1984, 1989). At the Pahsimeroi Hatchery, the prespawning mortality rate of female spring chinook salmon was 36% from 1982 to 1987 (Moore 1983, 1984, 1988, 1989). Summer chinook salmon losses ranged from 11% at the Sawtooth Hatchery to 23% at Pahsimeroi Hatchery. Prespawning mortality for hatchery spring and summer chinook salmon is presumed to be less than that of natural spawners because hatchery fish are vaccinated for disease during the holding interval before egg take.

3.5.2 Fall Chinook Salmon Hatcheries

Lyons Ferry Hatchery, located near the mouth of the Tucannon River and between Lower Monumental and Little Goose dams, is the only facility producing fall chinook salmon in the Snake River basin. Its initial brood year was 1984, and it has a production capacity of over 9 million fish. Voluntary returns to Lyons Ferry Hatchery averaged 8 12 adults from 1987 to 1991, of which 82% were estimated to originate from the facility. The Lyons Ferry Hatchery also collects broodstock from trapping facilities at Ice Harbor and Lower Granite dams.

Fall chinook salmon appear to wander or stray in far greater numbers than do spring and summer chinook salmon. Of the total run at Ice Harbor Dam in 1991, 80% originated from the Snake River and 48% of these were of Lyons Ferry Hatchery origin (LaVoy 1992). Extensive straying of fish planted in the Umatilla River has been noted at the Ice Harbor Dam and Lyons Ferry Hatchery traps. The number of strays from this stock increased from 70 in 1977 to 790 in 1989 and averaged 31% of the strays at Ice Harbor Dam, 15% at Lyons Ferry Hatchery, and 24% at Lower Granite Dam from 1990 to 1992. Other strays collected at Ice Harbor Dam included fish from the Bonneville and Priest Rapids hatcheries, and from releases in the Yakima River (Mendel et al. 1991). Umatilla River releases have also been recovered from carcass surveys in the Hanford Reach, according to Chapman et al. (1991), who calculated a minimum stray estimate of 2% with an expanded rate of 33%. These data suggest that hatchery stocks of fall chinook salmon do not home well to their release locations. Contributing factors may include lack of attraction flows at the hatchery, high temperatures, and poor passage conditions in the lower Umatilla River. Additional flows provided by the Columbia River water exchange project, scheduled for completion in 1993, may help reduce the number of strays.

There are few data available on the rate of prespawning mortality for fall chinook salmon. Prespawning mortality of adult fall chinook salmon collected for broodstock at the Lyons Ferry Hatchery was 28% in 1990 and 1991 (Mendel et al. 1991).

3.5.3 Sockeye Salmon Hatcheries

Sockeye salmon have not been supplemented in the Snake River Basin. All sockeye salmon in the Columbia River system are natural stocks because no hatchery operation currently exists. However, in 1991 and 1992, adult Snake River sockeye salmon returning to Redfish Lake were trapped and held at the Sawtooth Hatchery near Stanley, Idaho, for spawning and the rearing of their offspring. These progeny and juvenile sockeye salmon migrating out of Redfish and Alturus lakes are being held as captive broodstock for stock enhancement activities (DOE 1992).

3.5.4 Summary of Hatchery Returns

Straying of chinook salmon returning as hatchery broodstock appears to be extensive for some stocks. Although it may not result in direct mortality, it does affect our ability to account for escapement to natal spawning areas or to the hatchery release location. In general, the incidence of straying is less for spring and summer chinook salmon than for fall chinook salmon. Extensive straying has been noted for some hatchery stocks of fall chinook salmon, particularly those originating from Umatilla River releases. Prespawning mortality estimates for spring and summer hatchery broodstock range from 11% to 36%, and are about 30% for fall chinook salmon. Prespawning mortality is thought to be higher in the natural environment. Wounds by marine mammals contribute to prespawning mortality of spring chinook salmon.

4. DISCUSSION

Our analysis of available information indicates that we can isolate most of the causal factors affecting the survival of adult salmonids during their upstream migration period in the Columbia and Snake rivers. However, we are generally limited in our ability to accurately predict the benefits that specific changes in operational or environmental factors could have on adult survival of ESA-listed stocks. This discussion suggests a process and specific studies directed at resolving some of these issues.

4.1 UNCERTAINTY RESOLUTION

This section includes a brief summary of uncertainties associated with improving the survival of adult upstream migrants and a discussion of how measurement variables affect the accuracy of survival and escapement estimates. We identified several factors that contribute to uncertainties associated with improving the survival of adult salmon returning to the Snake River Basin. These factors affect our ability to accurately measure the interdam loss of adult upstream migrant salmonids, and include:

- incidence of fallback
- accuracy of passage counts--species identification, expansion of data
- definitive cutoff date for run timing
- spawner counts--visibility, redd count expansion factor
- overlap of spring and summer chinook salmon spawning areas
- unreported harvest--incidental harvest, illegal harvest
- catch estimate expansion for commercial and sport harvest statistics
- lack of evidence of mortality resulting from operational conditions.

There is some error associated with each measure of mortality and estimates of run size. Thus, the potential error associated with estimates of adult mortality through the system increases as fish pass by each additional vector of mortality. The magnitude of error in these estimates is different for each stock. For example, fall chinook salmon generally have a higher incidence of fallback than do spring chinook salmon, they have a high rate of harvest, and spawning counts are more difficult to determine than other stocks because they are primarily mainstem spawners. Thus, any estimates of mortality for fall chinook salmon would have a higher degree of uncertainty than those for spring chinook salmon. Summer chinook salmon have similar mortality factors as spring chinook salmon, except they are not harvested. However, their passage estimates are based on a fixed migration interval that does not provide a true measure of run size. Because accurate passage counts are the basis for all estimates of relative run size, there is a low confidence in estimates of mortality for summer chinook salmon. This potential error is supported by a wide range in adult passage conversion values. Run size of sockeye salmon in recent years is too small to accurately measure the effects of incremental changes in mortality vectors and operational conditions on their survival during upstream passage.

Figure 9 summarizes the primary measures that are used for run reconstruction and to create adult passage values. This matrix provides a qualitative comparison of our ability to accurately measure interdam loss and considers the general operational strategies. The major difference among potential operations is that adult passage counts would not be possible under some drawdown scenarios and accountability of run size to adults during all drawdown scenarios is unknown. Among stocks, fall chinook salmon appear to provide the least accurate measurements for run reconstruction and estimates of mortality.

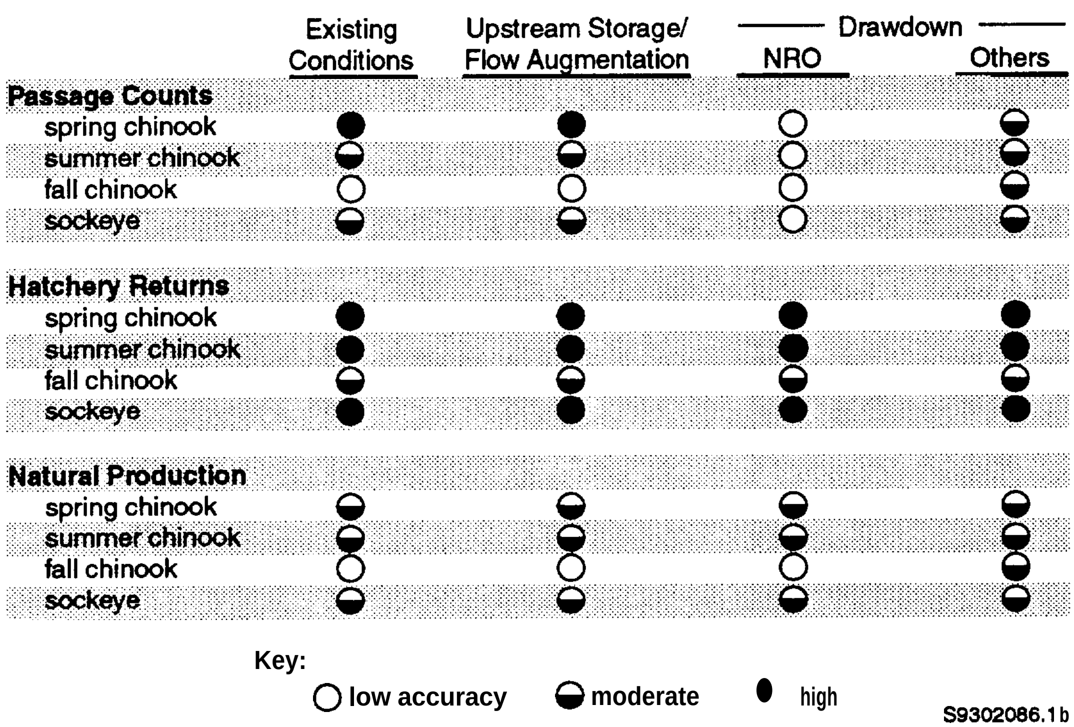

Figure 9. Relative Accuracy of Measurements used to Estimate Adult Survival and Relationship to Operational Conditions in the Columbia River System

4.2 RELATIONSHIP AMONG BIOLOGICAL ISSUES AND OPERATIONAL MEASURES

This section contains a summary of the relative risk by stock for each of the operational strategies and a detailed summary of the primary mortality factors for each ESA stock. The relative risk to the ESA-listed stocks to each of the major mortality components discussed in this report are summarized in Figure 10.

There is little evidence that passage contributes to measurable direct mortality of any of the four ESA stocks. Fall chinook salmon may be more vulnerable to passage mortality because of excessive delays at some dams during upstream migration and because of the relatively high rate of fallback noted for some dams. The risk to stocks during passage would be similar for each operational condition except drawdown scenarios. Impacts to salmon during passage would be reduced under the natural river option for all stocks, while other drawdown scenarios could adversely affect salmon passage. For example, passage of spring chinook salmon would be restricted during the spring drawdown interval, while sockeye salmon and fall chinook salmon would be restricted during the summer/fall refill interval because fishways would not be functional.

The risk to ESA-listed stocks from both commercial and sport harvest is reduced by the extensive planning associated with harvest of listed stocks (CRTS 1992, 1993a, 1993b). Relative risk of commercial harvest by stocks would be fall chinook salmon > sockeye salmon > spring chinook salmon > summer chinook salmon. Relative risk of sport harvest would be fall chinook salmon > spring chinook salmon > summer chinook salmon > sockeye salmon. The risk from harvest would be similar under each of the three operational conditions discussed.

Temperature is an important environmental condition influencing the survival of adult upstream migrant salmonids returning to the Snake River Basin. Stocks most vulnerable to temperature extremes in the mainstem Columbia and Snake rivers include sockeye salmon, fall chinook salmon, and summer chinook salmon. Flow augmentation practices that reduced mainstem temperatures to below 21° C would reduce the risk to these populations. Spring chinook salmon are sometimes exposed to high temperatures in tributary streams. This is a concern if it occurs during the spawning period. Drawdown operations are likely to have little influence on temperature in the lower Snake River. However, temperatures need to be monitored if drawdown conditions extend into August and September.

Dissolved gases currently impose a moderate risk on spring and summer chinook salmon because they migrate during the spring spill period. This risk would be reduced under the natural river option because there would be little or no spill over the Snake River dams. However, relative risk at the lower Columbia River dams could be higher if increased flows and higher spill were

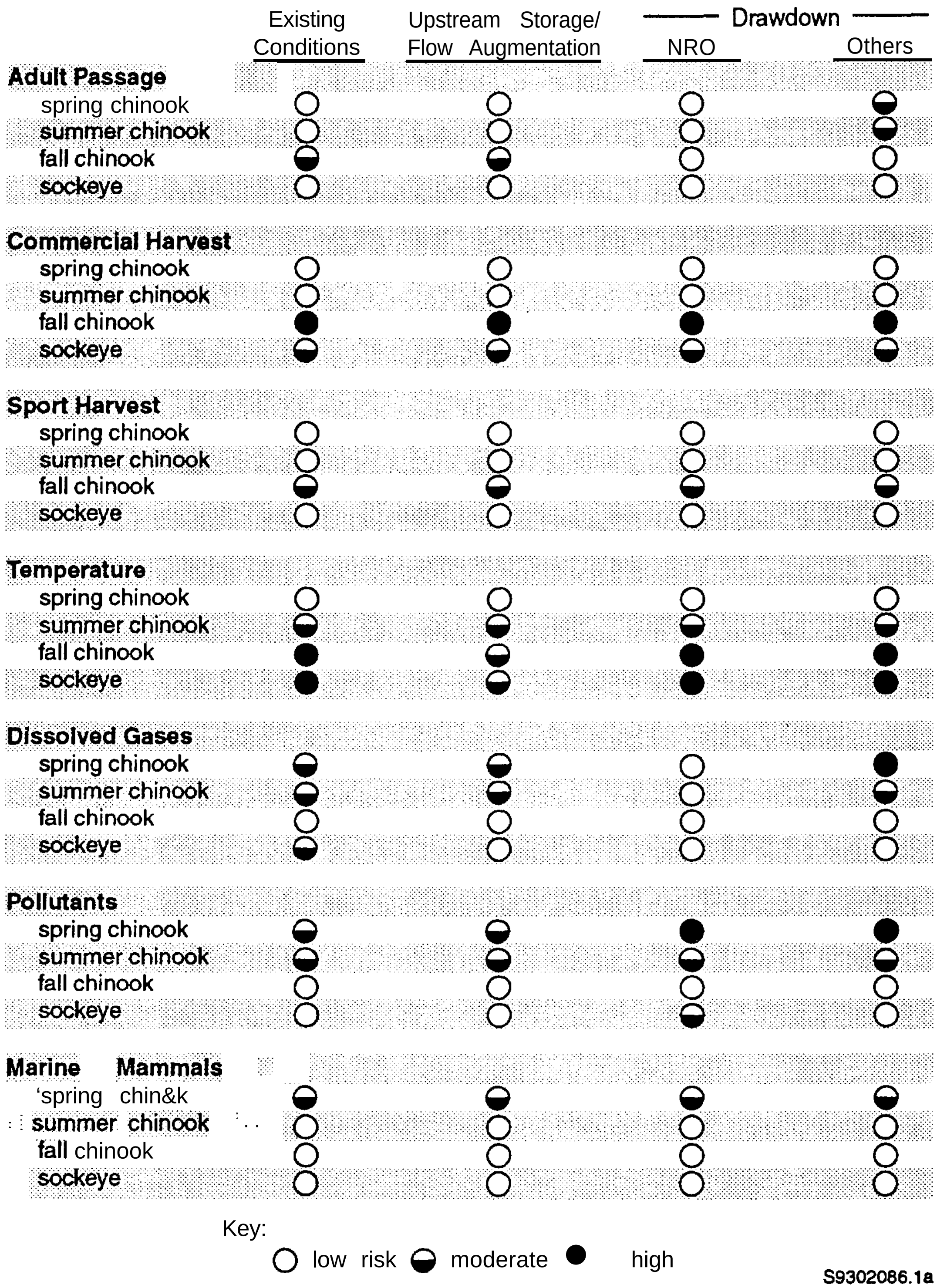

Figure 10. Relative Risk of ESA-Listed Stocks to Different Mortality Components Present in the Lower Columbia and Snake River Systems

encountered there. Because of migration timing, there is little or no risk to fall chinook salmon from high concentrations of dissolved gases.

There currently appears to be a low risk for pollutants to impact any of the ESA-listed stocks. Several pulp mills and metals-processing plants release effluents containing metals, halogenated compounds, and aromatic hydrocarbons, and occur mainly in the lower Columbia River. However, effluent discharge limitations appear to be adequate to maintain fish populations. Certain tributaries formerly used for spawning by spring and summer chinook salmon have been adversely impacted by changes in water quality from mining activities. There is a potential for moderate risk to spring chinook salmon from suspended sediments expected during the different drawdown options.

Predation by marine mammals was also considered as an ecosystem-level effect that occurs in the hydroelectric complex. This mortality factor is restricted to the lower Columbia River and affects stocks migrating upriver in the spring. Thus, the only ESA-listed stocks with risk from marine mammals are spring and summer chinook salmon. There is no change in relative risk to these stocks under the different operational conditions analyzed in this study.

4.3 CRITICAL RESEARCH NEEDS

Two general areas of research were indicated as a result of our analysis, i.e., those designed to mitigate known losses and those directed at improving the accountability and accuracy of determining run size. A summary of research needs includes:

- A thorough analysis is needed to determine the potential for increasing accuracy of dam counts. This analysis should involve a comparison of ocular estimates versus video monitoring, an analysis of random versus stratified observational periods, and an evaluation of the effects of fixed counting intervals on estimates of run size for stocks like summer chinook salmon.

- More detailed analysis of adult passage conversion rates between mainstem dams is needed. For example, are there certain areas (i.e., reservoir or dam) where higher mortality occurs and can any correlations be made between conversion rates and operating conditions? This study should include identification of problems with run reconstruction methods that result in higher variation in measures of run size, survival, or accountability.

- Additional site-specific studies are needed to determine if fallback and delays are due to passage or current operating conditions at dams, e.g., at Lower Granite Dam for fall chinook salmon and Ice Harbor Dam for spring/summer chinook salmon. These studies should be directed at designing optimum passage for adult salmon during critical passage intervals and for a drawdown condition, if implemented.

- Current studies directed at determining the extent and cause of fallback for fall chinook salmon should be continued. Relationships between the incidence of fallback for all species and causal factors (i.e., discharge volume and operations) need to be quantified. Information is also needed to determine mortality rates for adults that pass downstream through the turbines, spill, and bypass.

- Although delays ranging from a few hours to several days occur at hydroelectric dams, the impact of migration delay on the reproductive success of salmon is not known. Thus, studies are needed to determine the energy requirements of adult salmon during their migration period. Certain operational measures could be implemented to enhance the migration rate of adult salmon, particularly if their energy requirements changed during the latter stages of the reproductive cycle. Prespawning mortality is also a concern, and factors contributing to it need additional study.

- Increased knowledge of mainstem spawning, particularly in tailrace locations, is needed to provide more accurate estimates of escapement for fall chinook salmon. This information should be combined with improvements in the redd index to provide better estimates of escapement to spawning areas upstream from Lower Granite Dam. Data on incidence of fallback and prespawning mortality should also be applied to run accounting of fall chinook salmon.

- Research is needed on imprinting mechanisms and environmental and physiological factors influencing the homing behavior of both hatchery and wild stocks. Widespread straying of some hatchery stocks (e.g., Umatilla releases) affects the accuracy of dam counts and other measures used to account for survival of adult salmon that return to hatcheries or to natural production areas.

- Studies are needed to assess present conditions in tributary streams used for oversummering and spawning and to determine if habitat improvement measures can be implemented to increase survival and reproductive success of spring and summer chinook salmon that return to natural spawning areas.

- More data are needed to determine the relationship among storage releases, meteorological, and hydrological conditions, and temperature of the lower Snake River before flow augmentation for temperature control during high water temperature periods is implemented. This information could be used to refine the COLTEMP model or to develop a more refined model.

4.4 POTENTIAL ENHANCEMENT MEASURES

Several measures have been adopted by the NPPC to improve the survival of adult upstream migrant salmonids (NPPC 1992). Although water flow and spill guidelines have been adopted to assist in the passage of adults through fishways, there are still problems with delayed passage and mortality at some facilities. For example, flow and spill conditions designed to enhance migration and passage of juvenile salmonids may impede passage of adult salmonids. One significant source of mortality may be adult salmon that fall back through the powerhouse. Thus, the NPPC has asked the COE to leave juvenile fish screens in to provide protection for adult salmon during upstream migration. This could result in a significant increase in survival at some dams for stocks like fall chinook salmon that show a high incidence of fallback.

Other measures directed at enhancing adult salmonid migration are directed at operating conditions in the fishways (NPPC 1992) and include evaluating the need for improvements in fishway operation and spill criteria, monitoring adequately to ensure operating criteria are met, and evaluating the movement of fish during low flow conditions.

The impacts of high temperatures on returning adults is a major concern that needs to be addressed. High temperatures in mainstem fish ladders may delay migration, and means for decreasing temperatures when they are elevated above preferred conditions needs to be implemented The efficacy of releasing cool water from Dworshak Dam and Hells Canyon needs to be further evaluated For example, can these releases be used to decrease water temperatures at Ice Harbor Dam to temperatures that improve fish passage and survival during the late summer? Studies of tributary streams also need to be conducted to determine the relationship between habitat variables and water use on tributary temperatures. Additional meteorological and hydrological data are needed to characterize tributary watershed management and the influence of resulting inflow temperatures on mainstem Snake River temperatures (NPPC 1992).

A resource management plan directed at decreasing the incidence of marine mammal predation needs to be developed. This predation is of particular concern at locations where salmon concentrate (i.e., downstream from Bonneville Dam) and are vulnerable to predators. Preparing this plan may involve taking measures directed at reduction of predator populations or measures designed to spread out salmon passage over time or space.

Habitat enhancement measures designed to improve conditions in tributary streams used for oversummering and spawning by spring and summer chinook salmon need to be implemented. Water use is a major concern and improved passage for upstream migration and additional irrigation screens for downstream migration would benefit affected populations. Other habitat and water quality improvement measures include riparian restoration, reduction in point and nonpoint pollutant sources, maintenance of adequate instream flows, and reduction in practices that contribute to silt loading.

5. REFERENCES

Amsberg, B. D. 1992. Fal[redacted]hinook[redacted]almon A[redacted]ial Redd Surveys on the Clearwater, S. F. Clearwater, and Lower Salmon Rivers. Nez Perce Tribe Department of Fisheries Management, Orofino, Idaho.

Becker, C. D. 1973. "Columbia River Thermal Effects Study:Reactor Effluent Problems." J. Water P[redacted]tion Control Fed. 45(5):850-869.

Bennett, D. H., P. M. Bratovich, W. Knox, D. Palmer, and H. Hansel. 1983. Status of the Warmwater Fisher-y and the Potential of Improving Warmwater Fish Habitat in the Lower Snake Reservoirs. Completion report no. DACW68-79-C-0057. U.S. Army Corps of Engineers, Walla Walla, Washington.

Bjornn, T. C. 1990. An Assessm[redacted]t Losses, Production Rates [redacted]Escapements for Wild Spring and Summer Chinook Salmon in the Snake River. Spring Chinook Salmon Workshop, sponsored by Coastal Zone and Estuarine Studies, National Marine Fisheries Service, November 8-9, 1989, Pasco, Washington.

Bjornn, T. C., and C. A. Perry. 1992. A Review of Literature Related to Movements of Adult Salmon ahd Steelhead Past Dams and Through Reservoirs in the Lower Snake River. U.S. Army Corps of Engineers Tech. Rep. 92-1, Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho.

Bjomn, T. C., R. R. Ringe, K. R. Tolotti, P. J. Keniry, and J. P. Hunt. 1991. Migration Past Dams and Through Reservoirs in the Lower Snake River and into Tributaries. 1992 Annual Report to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Bouck, G. R., G. H. Chapman, P. W. Schneder Jr., and D. G. Stevens. 1970. Observations on Gas Bubble Disease in Adult Columbia River Sockeye Salmon (*Onchorhynchus nerka*). U.S. Environmental Protection Agency, Western Fish Toxicology, Corvallis, Oregon.

Brett, J. R. 1952. "Temperature Tolerance in Young Pacific Salmon, Genus *Oncorhynchus*." J. Fish Res. Bd. Canada 9(6):265-323.

Bugert, R., C. Busack, G. Mendel, K. Petersen, D. Marbach, L. Ross, and J. Dedloff. 1990a. Lyons Ferry Fall Chinook Salmon Hatchery Evaluation Program. Washington Department of Fisheries 1990 Progress Report, U.S. Fish and Wildlife Service, Boise, Idaho.

Bugert, R., C. Busack, G. Mendel, L. Ross, K. Petersen, D. Marbach, and J. Dedloff. 1990b. Tucannon River Spring Chinook Supplementation Studies Washington Department of Fisheries 1990 Progress Report, U.S. Fish and Wildlife Service, Boise, Idaho.

Bugert, R., K. Petersen, G. Mendel, L. Ross, D. Milks, J. Dedloff, and M. Alexandersdotlii. 1991. Tucannon River Sp ' g Chinook Hatchery Evaluation Program Washington Department of Fisheries 1% Progress Report, U.S. Fish and Wildlife Service, Boise, Idaho.

Chapman, D. W., D. E. Weitcamp, T. L. Welsh, and T. H. Schadt. 1983. Effects of Minimum Flow Regimes on Fall Chinook Spawning at Vemita Bar 1978-1982. Prepared for Grant County Public Utility District No. 2, Ephrata, Washington, by Don Chapman Consultants, Inc., McCall, Idaho, and Parametrix, Inc., Bellevue, Washington.

Chapman, D. W., W. S. Platts, D. Park, and M. Hill. 1990. Status of Snake River Sockeye Salmon. Prepared for Pacific Northwest Utilities Conference Committee by Don Chapman Consultants, Inc., Boise, Idaho.

Chapman, D. W., A. Giorgi, M. Hill, A. Maule, S. McCutcheon, D. Park, W. Platts, K. Pratt, J. Seeb, L. Seeb, and F. Utter. 1991. Status of Snake River Chinook Salmon. Prepared for Pacific Northwest Utilities Conference Committee by Don Chapman Consultants, Inc., Boise, Idaho.

COE (U.S. Army Corps of Engineers). 1992a. Lower Granite and Little Goose Projects. 1992 Reservoir Drawdown Test Report, Draft October 1992, U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

COE (U.S. Army Corps of Engineers). 1992b. Columbia River Salmon Mitigation Analysis System Configuration Study Phase I Interim Status Report, Technical Appendix B. John Day Reservoir Minimum Operating Pool, U.S. Army Corps of Engineers, Portland, Oregon.

COE (U.S. Army Corps of Engineers). 1992c. Columbia River Salmon Flow Measures Options Analysis Environmental Impact Statement. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

COE (U.S. Army Corps of Engineers). 1992d. Fish Passage Plan for 1992, Corps of Engineers Projects. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Conner, W. P. A. P., H. L. Burge, and R. H. Taylor. 1993. "Fall Chinook Salmon Spawning in Free-Flowing Reaches of the Snake River." In Identification of the Spawning, Rearing, and Migratory Requirements of Fall Chinook Salmon in the Columbia River Basin. D. W. Rondorf, and W. H. Miller, eds. Annual Progress Report Draft, August 1991-July 1992, Prepared for Lower Snake River Compensation Plan Office, Boise, Idaho, and Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon.

Coutant, C. C. 1970. Thermal Resistance of Adult Coho and Jack Chinook Salmon, and Steelhead Trout from the Columbia River. BNWL-1508, Pacific Northwest Laboratory, Richland, Washington.

CRTS (Columbia River Technical Staffs). 1992. Biological Assessment of the Impacts of Anticipated 1992 Summer and Fall Season Columbia River Fisheries on Listed Snake River Species Under the Endangered Species Act. Portand, Oregon.

CRTS (Columbia River Technical Staffs). 1993a. Biological Assessment of the Impacts of Anticipated 1993 Winter, Spring, and Summer Season Columbia River and Tributary Fisheries on Listed Snake River Species Under the Endangered Species Act. Portand, Oregon.

CRTS (Columbia River Technical Staffs). 1993b. Biological Assessment of Impacts of Anticipated 1992 Fisheries in the Snake River Basin on Listed Species Under the Endangered Species Act. Portand, Oregon.

Damaker, D. M., and D. B. Day. 1984. Adult Fish Delay at John Day Dam. National Marine Fisheries Service report to the U.S. Army Corps of Engineers, Northwest and Alaska Fisheries Center, Seattle, Washington.

Damaker, D. M., and D. B. Day. 1985. Effects of Water-Borne Pollutants on Salmon Passage at John Dav Dam. Columbia River (1982-1984). National Marine Fisheries Service report to the U.S. Army Corps of Engineers, Northwest and Alaska Fisheries Center, Seattle, Washington.

Dauble, D. D., and Watson, D. G. 1990. Spawning and Abundance of Fall Chinook Salmon *(Oncorhynchus tshawytscha) in* the Hanford Reach of the Columbia River, 1948-1988. PNL-7289, Pacific Northwest Laboratory, Richland, Washington.

Dauble, D. D., and D. R. Geist. 1992. Impacts of the Snake River Drawdown Experiment on Fisheries Resources n Little Goose and Lower Granite Reservoirs. 1992. PNL-8297, Pacific Northwest L&oratory, Richland, Washington.

Ebel, W. J., H. L. Raymond, G. E. Monan, W. E. Farr, and G. K. Tanonaka. 1975. Effect of Atmospheric Gas Supersaturation Caused by Dams on Salmon and Steelhead Trout of the Snake and Columbia Rivers. National Marine Fisheries Service, Seattle, Washington.

EPA and NMFS (U.S. Environmental Protection Agency and National Marine Fisheries Service). 1971. Columbia River Thermal Effects Study, Volume 1. Biological Effects Study. U.S. Environmental Protection Agency and National Marine Fisheries Service, Washington, D.C.

Fish, F. F., and M. G. Hanavan. 1948. A Report upon the Grand Coulee Fish Maintenance Project (1939-1947). U.S. Fish and Wildlife Special Scientific Report 55.

Fry, F. E. J. 1971. "The Effect of Environmental Factors on the Physiology of Fish." In Fish Physiology, Vol. VI : Environmental Relations and Behavior, eds., W. S. Hoar and D. J. Randall, pp. l-98. Academic Press, Inc., San Diego, California.

Gray, R. H., and J. M. Haynes. 1977. "Depth Distribution of Adult Chinook Salmon in Relation to Season and Gas Supersaturated Water." Trans. Am. Fish. Soc. 106:617-620.

Hallock, R. J., Elwell, R. F., and D. H. Fry, Jr. 1970. "Migration of Adult King Salmon *(Oncorhynchus tshawytscha)* in the San Joaquin Delta." Fish Bull. 151:92.

Haynes, J. M., and R. H. Gray. 1980. "Influence of Little Goose Dam on Upstream Movements of Adult Chinook Salmon, *Oncorhynchus tshawytscha.*" Fish. Bull. 78:185-190.

Homer, N., and T. C. Bjomn. 1979. Status of Upper Columbia River Fall Chinook Salmon. Prepared for the U.S. Fish and Wildlife Service, Boise, Idaho.

Homer, N., and T. C. Bjomn. 1981a. Status of Upper Columbia and Snake River Spring Chinook Salmon in Relation to the Endangered Species Act. Prepared for the U.S. Fish and Wildlife Service, Idaho Coop. Fish. Res. Unit, University of Idaho, Moscow, Idaho.

Homer, N., and T. C. Bjomn. 1981a. Status of Upper Columbia and Snake River Summer Chinook Salmon in Relation to the Endangered Species Act. U.S. Fish and Wildlife Service, Boise, Idaho, by the Idaho Cooperative Fisheries Research Unit, University of Idaho, Moscow, Idaho.

IPC (Idaho Power Company). 1991. Idaho Power Fall Chinook Interim Recovery Plan and Study. Presented to the Northwest Power Planning Council and the National Marine Fisheries Service,

INPFC (International North Pacific Fisheries Commission). 1977. "Additional Information on the Exploitation, Scientific Investigation and Management of Salmon Stocks on the Pacific Coast of the United States in Relation to the Abstention Provisions of the North Pacific Fisheries Convention." Bulletin 36, International North Pacific Fisheries Commission, Vancouver, B.C.

Irving, J. S., and T. C. Bjomn. 1981. Status of Snake River Fall Chinook Salmon in Relation to the Endangered Species Act U.S. Fish and Wildlife Service, Idaho Cooperative Fisheries Research Unit, University of Idaho, Moscow, Idaho.

Johnson, G. A., J. R.. Kuskie, Jr., W. T. Nagly, K. L Liscom. and L. Stuehrenberg. 1982. The John Day Dam Powerhouse Adult Fish Collection System Evaluations, 1979-1980. U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Johnson, J. H. 1964. "Fallback of Adult Chinook Salmon (*Oncorhynchus tshawytscha*) at Ice Harbor Spillway-1964. Review of progress of the Fish Passage Research Program." U.S. Bureau of Commercial Fisheries Bulletin No. 41, Seattle, Washington.

Junge, C. O., and B. E. Carnegie. 1976. Spillway Studies, 1976. Oregon Department of Fish and Wildlife, Clackamas, Oregon.

Junge, C. 1971. Effects of Peaking Operations on Passage of Adult Salmonids over Columbia River Dams. U.S. Army Corps of Engineers, Portland District, Portland Oregon.

Karr, M., B. Tanovan, R. Turner, and D. Bennett. 1991. *1991 Snake River Water Temperature Control Project*. Columbia River Inter-tribal Fish Commission, U.S. Army Corps of Engineers, and University of Idaho, Portland, Oregon.

LaVoy, L. 1992. Age and Stock Composition of Fall Chinook at Lyons Ferry Hatchery, Ice Harbor Dam, and Lower Granite Dam in 1991. Columbia River Lab, Progress Report 92-7, Washington Department of Fisheries, Battle Ground, Washington.

Liscom, K. L., and G. E. Monan. 1976. Radio Tracking Studies to Evaluate the Effect of Spillway Deflectors at Lower Granite Dam on Adult Fish Passage. Final Report, National Marine Fisheries Service, Seattle, Washington.

Liscom, K. L., and L. C. Stuehrenberg. 1983. Radio Tracking Studies of Spring Salmon Between Bonneville and McNary Dams, 1982. National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle, Washington.

Liscom, K. L., L. C. Stuehrenberg, and F. Ossiander. 1985. Radio-Tracking Studies of Adult Chinook Salmon and Steelhead to Determine the Effect of "Zero" River Flow During Water Storage at Little Goose Dam on the Lower Snake River. Final Report. National Marine Fisheries Service, Northwest Fisheries Center, Seattle, Washington.

Major, R. L, and J. L. Mighell. 1966. "Influence of Rocky Reach Dam and the Temperature of the Okanogan River on Upstream Migration of Sockeye Salmon." Fishery Bull. 66: 131-147.

Matthews, G. M., and R. S. Waples. 1991. "Status Review for Snake River Spring and Summer Chinook Salmon." U.S. Dep. Commer. Natl. Oceanic Atmos. Admin. Tech. Memo.

McCullough, D. A. 1991. Snake River Temperature Control Project Review of Recommended Temperatures for Protection of Fall Chinook. Columbia River Inter-Tribal Fish Commission, Portland, Oregon.

McMaster, K. M., White, R. G., Ringe, R. R, and T. C. Bjomn. 1977. Effects of Reduced Nighttime Flows on Upstream Migration of Adult Chinook Salmon and Steelhead Trout in the Lower Snake River. University of Idaho Forest Wildlife Range Experimental Staion, Moscow, Idaho, Contribution 93.

Meekin, T. K., and R. L. Allen. 1976. Summer Chinook and Sockeye Salmon Mortality in the Upper Columbia River and its Relationship to Nitrogen Supersaturation. pp. 127-143, Washington Department of Fisheries. Tech. Rep. 12.

Mendel G., K. Petersen, R. Bugert, D. Milks, L. Ross, J. Dedloff, and L. Lavoy. 1991. Lyons Ferry Fall Chinook Salmon Hatchery Program, Washington Department of Fisheries 1991 Evaluation Report. U.S. Fish and Wildlife Service, Boise, Idaho.

Mendel, G., D. Milks, R. Bugert, and K. Petersen. 1992. Upstream Passage and Spawning of Fall Chinook Salmon in the Snake River 1991 Completion Report. Washington Department of Fisheries, Olympia, Washington.

Monan, G. E., and J. H. Johnson. 1974. Distribution of 1965 Fall Chinook Salmon Between the Dalles and McNary Dams, as Determined by Sonic Tagging. National Marine Fisheries Service, Northwest Fisheries Center, Seattle, Washington.

Monan, G. E., and K. L. Liscom. 1974. Radio Tracking of Spring Chinook Salmon to Determine Effect of Spillway Deflectors on Passage at Lower Monumental Dam, 1973. National Marine Fisheries Service, Northwest Fisheries Center, Seattle, Washington.

Monan, G. E., and K. L. Liscom. 1976. Radio Tracking Studies of Summer Chinook Salmon and Steelhead Trout at and Between Bonneville and The Dalles Dams, 1975 National Marine Fisheries Service, Northwest Fisheries Center, Seattle, Washington:

Moore, B. 1983. Sawtooth Salmon Trap Annual Report. Idaho Fish and Game Department, Boise, Idaho (cited in Chapman et al. 1991).

Moore, B. 1985. Sawtooth Salmon Trap Annual Report. Idaho Fish and Game Department, Boise, Idaho (cited in Chapman et al. 1991).

Mullan, J. W. 1990. "Status of Chinook Salmon Stocks in the Mid-Columbia River." Pages 45-55. In Park (Convenor) Status and Future of Spring Chinook Salmon in Columbia River Basin - Conservation and Enhancement. NOAA Technical Memorandum, NMFS F/NWC- 187, Seattle, Washington.

NPPC (Northwest Power Planning Council). 1991. Priority Salmon Habitat and Production Proposals Stock Analysis. Northwest Power Planning Council 91-12, Portland, Oregon.

NPPC (Northwest Power Planning Council). 1992. Strategy for Salmon. Volume II. Northwest Power Planning Council, 92-22 1 A, Portland, Oregon.

OFC (Oregon Fish Commission). 1960. Results of Tagging Program to Enumerate the Numbers and to Determine the Seasonal Occurrence of Anadromous Fish in the Snake River and its Tributaries. U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon.

Park, D. L. 1993. "Effects of Marine Mammals on Columbia River Salmon Listed Under the Endangered Species Act. Report No. 3." In Factors Affecting the Survival of Upstream Migrant Adult Salmonids in the Columbia River Basin. Bonneville Power Administration, Portland, Oregon.

Park, D. L., J. R. Smith, E. Slatick, G. A. Swan, E. M. Dawley, and G. M. Matthews. 1977. Evaluation of Fish Protective Facilities at Little Goose and Lower Granite Dams and Review of Nitrogen Studies Relating to Protection of Juvenile Salmonids in the Columbia and Snake Rivers, 1976. Processed Report 47, U.S. Army Corp of Engineers, Seattle, Washington.

Quinn, T. P., and K. Fresh. 1984. "Homing and Straying in Chinook Salmon from Cowlitz River Hatchery, Washington." Can. J. Fish. Aquatic Science 41: 1078-1082.

Raymond, H. L. 1988. 'Effects of Hydroelectric Development and Fisheries Enhancement on Spring and Summer Chinook and Steelhead in the Columbia River Basin." North American Journal of Fisheries Management S(1): l-24.

Rogers, L. E., P.A. Beedlow, D. D. Dauble, L. E. Eberhardt, and R. E. Fitzner. 1989. Ecological Baseline Study of the Yakima Firing Center Proposed Land Acquisition: A Status Report. PNL-6485, Pacific Northwest Laboratory, Richland, Washington.

Rogers, T. 1984. Sawtooth Hatchery Annual Report. Idaho Fish and Game Department, Boise, Idaho (cited in Chapman et al. 1991).

Ross, C. V. 1983. Evaluation of Adult Passage at Bonneville Dam, 1982. U.S. Army Corps of Engineers, Portland, Oregon.

Shew, D. M., R. D. Peters, R. J. Stansell, and L. M. Beck. 1985. Evaluation of Adult Fish Passage at McNary Dam and John Day Dam, 1985. U.S. Army Corps of Engineers, Portland District Fisheries Office, Oregon.

Shew, D. M., R. D. Peters, R. J. Stansell, D. R. Bryson, A. R. Case, and A. R. Turner, Jr. 1988. Evaluation of Adult Fish Passage at Bonneville and John Day Dams in 1984. U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Shrimpton, J. M. 1985. Response ... Salmon (Onco hynchus kisutch) to Different Levels of Gas Supersaturation. M.S. Thesis, Department of Biology, University of Victoria B.C.

Swan, G. S., E. M. Dawley, R. D. Ledgerwood, W. T. Norman, W.F. Cobb, and D. T. Hartman. 1988. Distribution and Relative Abundance of Deep-Water Redds for Spawning Fall Chinook Salmon at Selected Study Sites in the Hanford Reach of the Columbia River. National Marine Fisheries Service, Seattle, Washington, and Horton Dennis and Associates, Inc., Kirkland, Washington.

Stabler, D. F. 1981. Effects of Altered Flow Regimes, Temperatures, and River Impoundment on Adult Steelhead Trout and Chinook Salmon. M.S. Thesis, University of Idaho, Moscow, Idaho.

Stuehrenberg, L. C., G. E. Monan, and K. L. Liscom. 1978. A Study of Apparent Losses of Chinook Salmon and Steelhead Based on Count Discrepancies Between Dams on the Columbia and Snake Rivers, 1967-1968. U.S. Army Corps of Engineers, Portland, Oregon.

Theurer, F. D., I. Lives, and T. Nelson. 1985. "Interaction Between Riparian Vegetation, Water Temperature, and Salmonid Habitat in the Tucannon River." Water Resourc. Bull. 21(1) 53-64.

Turner Jr., A. R., J. R. Kuskie, Jr., and K. E. Kostow. 1983. Evaluation of Adult Fish Passage at Little Goose and Lower Granite Dams, 1981. U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Turner Jr., A. R., J. R. Kuskie Jr., and K. E. Kostow. 1984. Evaluation of Adult Fish Passage at Ice Harbor and Lower Monument Dams, 1982. U.S. Army corps of Engineers, Portland District, Portland, Oregon.

U.S. Department of Energy (DOE). 1992. Juvenile and Adult Trapping Program Snake River Sockeye Salmon Sawtooth Valley Project. Bonneville Power Administration, Portland, Oregon.

USFWS/TAC (U.S. Fish and Wildlife Service and Technical Advisory Committee). 1992. Biological Assessment of the Impacts of Proposed 1992 Winter and Spring Season River Fisheries on Listed Species and Species Proposed for Listing Under the Endangered Species Act. January 1993.

U.S. Department of Interior (USDOI). 1960. Fish and Wildlife Service, Portland Oregon.

Wagner, P., and T. Hilson. 1992. 1991 Evaluation of Adult Fallback Through the McNary Dam Juvenile Bypass System. Washington Department of Fisheries Habitat Management Division. U.S. Army Corps of Engineers, Contract DACW68-82-C-0077, Task Order Number 10,

Waples, R. S., R. P. Jones, Jr., B. R. Beckman, and G. A. Swan. 1991a. Status Review for Snake River Fall Chinook Salmon U.S. Department of Commerce, NOAA Tech. Memo, NMFS F/NWC-201, Seattle, Washington.

Waples, R. S., 0. W. Johnson, and R. P. Jones. 1991b. Status Review for Snake River Sockeye Salmon. U.S. Department of Commerce, NOAA Tech. Memo, NMFS F/NWC-195, Seattle, Washington.

Warren, C. 1988. 1986 Sockeye Salmon Brood Year Report. Idaho Department of Fish and Game Special Report, Boise, Idaho.

WDF/ODFW (Washington Department of Fisheries and Oregon Department of Fish and Wildlife). 1992. Status Report Columbia River Fish Runs & Fisheries, 1960-1990. Olympia, Washington, and Portland, Oregon.

Young, F. R., R. T. Michimoto, and G. Gibson. 1978. Passage Problems of Adult Chinook Salmon During 1976 and 1977 and Steelhead Trout During 1974 and 1975 in the Columbia River Between Bonneville and McNary Dams. Department of Fish and Wildlife, Fish Division, Portland, Oregon.

Young, F. R., R. T. Michimoto, G. G. Gibson, R. T. Westfall, H. E. Jensen, and D. W. Nichols. 1974. An Investigation of the Effects of Peakine Upon Adult Salmon in the Columbia River. Fish Commission of Oregon, Annual Progress Report, Portland, Oregon.