Redfish Lake Sockeye Salmon Captive Broodstock Rearing and Research

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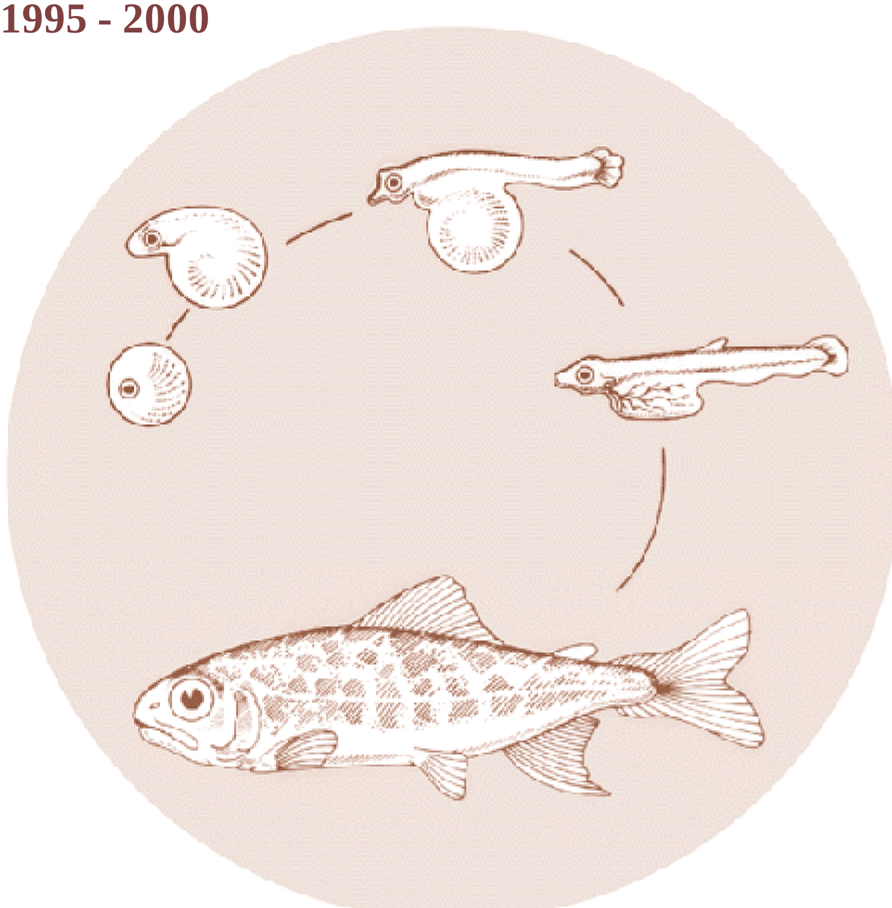

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REDFISH LAKE SOCKEYE SALMON CAPTIVE BROODSTOCK REARING AND RESEARCH, 1995-2000

by

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ABSTRACT

The National Marine Fisheries Service (NMFS) Northwest Fisheries Science Center, in cooperation with the Idaho Department of Fish and Game and the Bonneville Power Administration, has established captive broodstocks to aid recovery of Snake River sockeye salmon (*Oncorhynchus nerka*) listed as endangered under the U.S. Endangered Species Act (ESA). Captive broodstock programs are a form of artificial propagation and are emerging as an important component of restoration efforts for ESA-listed salmon populations. However, they differ from standard hatchery techniques in one important respect: fish are cultured in captivity for the entire life cycle. The high fecundity of Pacific salmon, coupled with their potentially high survival in protective culture, affords an opportunity for captive broodstocks to produce large numbers of juveniles in a single generation for supplementation of natural populations.

The captive broodstocks discussed in this report were intended to protect the last known remnants of this stock: sockeye salmon that return to Redfish Lake in the Sawtooth Basin of Idaho at the headwaters of the Salmon River. This report addresses NMFS research from January 1995 to August 2000 on the Redfish Lake sockeye salmon captive broodstock program and summarizes results since the beginning of the study in 1991. Since initiating captive brood culture in 1991, NMFS has returned 742,000 eyed eggs, 181 pre-spawning adults, and over 90,000 smolts to Idaho for recovery efforts. The first adult returns to the Stanley Basin from the captive brood program began with 7 in 1999, and increased to about 250 in 2000. NMFS currently has broodstock in culture from year classes 1996, 1997, 1998, and 1999 in both the captive broodstock program, and an adult release program. Spawn from NMFS Redfish Lake sockeye salmon captive broodstocks is being returned to Idaho to aid recovery efforts for the species.

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INTRODUCTION

The Snake River sockeye salmon (*Oncorhynchus nerka*) are a prime example of a species on the threshold of extinction. The last known remnants of this stock return to Redfish Lake in the Stanley Basin in Idaho (Fig. 1). In December 1991, the National Marine Fisheries Service (NMFS) listed Snake River sockeye salmon as endangered under the U.S. Endangered Species Act[1] (ESA) (Waples et al. 1991b). Since the listing, only a few wild sockeye salmon adults (0-8 per year, 16 total) have returned to Redfish Lake. NMFS is developing a recovery plan for Snake River sockeye salmon (SRSRP 1993, Schmitten et al. 1995). The goal of this recovery plan will be to rebuild listed Snake River sockeye salmon within its historic range. In the interim, recovery efforts are being coordinated through the Stanley Basin Sockeye Technical Oversight Committee (SBSTOC). Members on the committee includes representatives from NMFS, the Idaho Department of Fish and Game (IDFG), the Bonneville Power Administration (BPA), the Shoshone-Bannock Tribes, University of Idaho (UI), other state and federal agencies, and private groups interested in sockeye salmon restoration in Idaho.

On the basis of critically low population numbers, SBSTOC members implemented a captive broodstock project in 1991 as an emergency measure to save Redfish Lake sockeye salmon (Flagg 1993; Johnson 1993; Kline 1994; Spaulding 1993; Flagg and McAuley 1994, 1995, 1996, 1997, 1998; Flagg et al. 1994, 1995a, 1996, 1998, 1999; Teuscher et al. 1994, 1995; Kline and Younk 1995; Johnson and Pravecek 1995, 1996; Teuscher and Taki 1996; Kline and Lamansky 1997; Pravecek and Johnson 1997; Taki and Mikkelsen 1997; Kline and Heindel 1999). The Redfish Lake sockeye salmon captive broodstock project is intended as a stop-gap measure until migration and rearing habitat improvements can be implemented to increase survival of wild stocks.

In 1992, the NMFS Northwest Fisheries Science Center (NWFSC) entered into a cooperative project with BPA (Project 92-40, Contract DE-AI79-92BP41841) for involvement in Redfish Lake captive broodstock rearing. NMFS captive broodstock activities for Redfish Lake sockeye salmon were originally conducted under ESA Section 10 Propagation Permit 795 issued to IDFG. In 1996, the NWFSC was issued ESA Permit 1005 for the NMFS portion of Redfish Lake sockeye salmon captive broodstock propagation. In 1998, this captive broodstock work was reauthorized under ESA Permit 1148 to the NMFS NWFSC Resource Enhancement and Utilization Technologies (REUT) Division.

Captive broodstock programs are a form of artificial propagation. Captive propagation of animals to maximize their survival and reproductive potential has won acceptance in endangered

[1] Use of the term “species” in the context of ESA can refer to taxonomic species, subspecies, and distinct population segments. The definition of what constitutes a species under the ESA is addressed by Waples (1991b).

species restoration (Gipps 1991, Johnson and Jensen 1991, DeBlieu 1993, Olney et al. 1994). Currently, over 105 species of mammals, 40 species of birds, 12 species of reptiles, 29 species of fish, and 14 species of invertebrates are being maintained or enhanced through forms of captive breeding (CBSG 1991). The captive broodstock concept for salmon differs from that used in conventional hatcheries in that fish of wild origin are maintained in captivity throughout their life (Flagg and Mahnken 1995). Adults or offspring from captive broodstocks are released to supplement wild populations.

Captive broodstocks should be viewed as a short-term measure for gene pool protection, not as a substitute for recovering naturally spawning fish to the ecosystem. However, in concert with efforts to correct causes of decline in stocks at risk of extinction, this technology holds promise as a means of accelerating stock recovery by rapidly increasing the abundance of fish available for restocking suitable habitat (Flagg et al. 1995b, Schiewe et al. 1997). The relatively high fecundity of Pacific salmon, coupled with potentially high survival in protective culture, can allow captive broodstocks to produce large numbers of juveniles in a single generation. Maintenance of each year-class of broodstock in captivity for a single generation or a limited number of generations should help ensure that genetic integrity and adaptability to native habitats are preserved. Importantly, the relatively stable egg supply provided by a captive broodstock program can allow restoration efforts of depleted stocks such as Redfish Lake sockeye salmon to continue even when the numbers of wild spawners fall below critical levels.

The exact status of the Snake River sockeye salmon population was unknown at the time of ESA listing. Construction of impassable hydroelectric and irrigation dams on the Snake River system in the 1950s and 1960s had markedly reduced the geographic distribution of Snake River sockeye salmon to a single watershed in the Stanley Basin at the headwaters of the Salmon River in Idaho (Fig. 1). In addition, barriers to upstream migration were installed in the 1950s at three of the four remaining salmon-producing lakes in the Stanley Basin, and the lakes were poisoned. These alterations were made to promote trout (*Oncorhynchus* spp.) fisheries, but they further limited the range of Snake River sockeye salmon to a single lake--Redfish Lake. Eight major hydroelectric dams on the Columbia River system currently interfere with the almost 1,450-km migration to and from the ocean for Redfish Lake sockeye salmon.

No sockeye salmon returned to the Stanley Basin during 1990, the year of the ESA-mandated biological review. However, because redds (nests) were observed in Redfish Lake in 1988 and 1989, indicating that juveniles could still be in the lake or at sea, the NMFS Biological Review Team decided that the Snake River sockeye salmon population could still exist (Waples et al. 1991a). Subsequent collections of outmigrating juveniles and returns of wild anadromous adult sockeye salmon to Redfish Lake in 1991, 1992, 1993, 1994, 1996, and 1998 confirmed the persistence of this population.

Three life history forms of *O. nerka* are found in nature, all of which occur in Redfish Lake. They are:

- the anadromous form , which usually spends 1 to 2 years in its nursery lake before migrating to sea as a smolt during the spring and where it remains for 2 to 4 years before returning to the natal area to spawn (Bjornn et al. 1968, Foerster 1968, Burgner 1991).
- the residual form, which are progeny of anadromous fish that remain in fresh water until they mature and reproduce. The residual form produces mostly anadromous offspring (Foerster 1968, Burgner 1991). It was theorized that residual sockeye salmon helped maintain the Redfish Lake sockeye salmon population during historic population lows (Waples et al. 1991a).
- the more distinct kokanee form appears to have diverged from anadromous stock in recent geological time and is fully adapted to fresh water (Foerster 1968, Burgner 1991).

Anadromous and residual sockeye salmon in Redfish Lake were included together in the anadromous gene pool for ESA protection and are represented in the broodstock program, while the kokanee form was excluded (Waples et al. 1991a).

The following report focuses on the status of the NMFS Redfish Lake sockeye salmon captive broodstock program from January 1995 through August 2000 and summarizes results since the start of the project. NMFS Redfish Lake sockeye salmon captive broodstocks are complementary to those reared by IDFG (Johnson and Pravecek 1995, 1996; Pravecek and Johnson 1997; Kline and Heindel 1999) and are intended to reduce the risk of catastrophic loss of this valuable gene pool. Our efforts from 1995-2000 focused on maintaining “wild” genetic lineages for 1991-, 1993-, 1994-, and 1996-broods of Redfish Lake sockeye salmon, and on research using non-endangered Lake Wenatchee sockeye salmon to refine captive broodstock methods. In addition, NWFSC staff represented NMFS at SBSTOC meetings and visited IDFG fish culture and fish trapping operations for Redfish Lake sockeye salmon.

MATERIALS AND METHODS

NMFS is rearing Redfish Lake captive broodstock in circular tanks supplied with fresh well water at the NMFS facility at the University of Washington's Big Beef Creek (BBC) Research Station near Seabeck, Washington. In addition, NMFS is rearing fish in circular tanks supplied with filtered and ultraviolet light (UV) treated seawater at the NMFS Manchester Research Station (MRS) near Manchester, Washington.

The NMFS hatchery at BBC was designed as a protective rearing facility for salmonid captive broodstocks. The facility includes a 425-m^2 building and a 200-m^2 outdoor chain-link fenced fish-holding area. At present, the protected rearing area includes 12 4.1-m, 19 1.8-m and 6 2.1-m diameter circular tanks. A separate hatchery room accommodates down-flow incubators (Novotny et al. 1985) redesigned for isolated egg incubation. The hatchery is supplied with about 2,000 L/m of 10°C artesian well water. Before entering fish rearing tanks, the water is passed through degassing columns to remove excess nitrogen and boost dissolved oxygen levels. Water flow, fire, and intruder alarms are monitored through a security system linked to pagers and home and office telephones. The BBC system complies with Washington State Department of Fish and Wildlife (WDFW) quarantine certification standards. Effluent from the hatchery passes through a settling basin and UV treatment system (with back-up generator) to inactivate organic material prior to discharge.

The seawater laboratory at Manchester currently contains 6 4.1-m diameter circular fiberglass tanks and 20 6.1-m diameter circular fiberglass tanks enclosed in 2 separate buildings, and 4 3.7-m diameter covered circular fiberglass tanks in an outdoor fenced area. The 4,500 L/min (1,200 gpm) of ambient temperature (about 7°C winter low and 14°C summer high) seawater supplied to these tanks is processed to ensure quality. Filtering consists of sand filters containing number 20-grade sand that removes organic and inorganic material more than 20 microns in diameter. After sand filtration the water passes through cartridge filters which remove material more than five microns in diameter, then through UV-sterilizers to inactivate remaining organic material. Sensors monitor flow and water pressure in the seawater filtration/sterilization system. Before entering fish rearing tanks the processed seawater is passed through either 120-cm-long by 20-cm-diameter packed column degassers located at each 4.1-m and 3.7-m pool or a central degassing tower for the 6.1-m pools to strip excess nitrogen and to boost dissolved oxygen levels. Any interruption in water flow activates an emergency oxygen supply to all rearing containers. An alarm system monitors the pumps and electrical supply and is linked to an automatic dialer system to pagers and home and office telephones. An emergency generator is automatically activated in the event of a power failure. The Manchester system complies with WDFW quarantine certification standards. Effluent passes through a settling basin and ozone treatment system to inactivate organic material prior to discharge.

NMFS provides daily staffing for protective culture of fish during the work week, with electronic security and facilities monitoring at all times. The fish are reared using standard fish culture practices and approved therapeutics (for an overview of standard methods see Piper et al.

1982, Leitritz and Lewis 1976, Rinne et al. 1986). Fish are fed a commercial ration (e.g., Biodiet[2]). Appropriate prophylactic drugs are administered under supervision of a veterinarian during fish rearing. For instance, the diet may be modified under FDA Investigational New Animal Drug (INAD) 4333 to contain 0.45% erythromycin and fed at 2% of body weight/day for 28 days on a quarterly basis during rearing as a prophylactic against bacterial pathogens. Mortalities are examined by a fish pathologist to determine cause of death. Select mortalities are frozen or preserved as appropriate for genetic or other analyses. Specimens not vital to analysis or restoration are incinerated or buried. Because these fish are listed as endangered under ESA, husbandry research is not feasible and the fish are not routinely handled during rearing. This precludes documentation of parameters such as growth except as endpoint measurements. Therefore, survival and primary causes of death are the only data reported for these fish in this report.

Redfish Lake sockeye salmon are reared to maturity at NMFS Manchester and BBC facilities. Fish reared in seawater at Manchester are transferred to freshwater at BBC for final maturation and spawning. Prespawning adults, spawn, and juveniles are returned to Idaho for use in recovery programs for Snake River sockeye salmon. Spawners are analyzed for common bacterial and viral pathogens, including bacterial kidney disease (BKD), infectious hematopoietic necrosis virus, etc. NMFS obtains appropriate permits for interstate transport of eggs, fish, and progeny. NMFS coordinates their captive broodstock rearing activities through the SBSTOC.

During the reporting period NMFS also reared non-endangered Lake Wenatchee sockeye salmon captive broodstock at BBC and Manchester for husbandry research. Both 1990- and 1991-brood Lake Wenatchee (Washington) yearling sockeye salmon were donated to this study from the BPA-NMFS Cle Elum Lake study (Project 86-45). Both brood years of fish were progeny of wild adult spawners captured from the Wenatchee River during their adult upstream migration, spawned, and reared at the NMFS Montlake Hatchery in Seattle for Project 86-95 studies (Flagg et al. 1991, 2000). Replicate groups of Lake Wenatchee sockeye salmon were reared in either circular tanks supplied with fresh well water at BBC, circular tanks supplied with filtered and UV-treated seawater, or conventional seawater net-pens at Manchester. Lake Wenatchee fish were reared through age-4 spawning in 1994 (1990-brood) and 1995 (1991-brood). Husbandry evaluations focused on fish growth, health, survival, and reproductive success.

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[2] Use of trade names does not imply endorsement by NMFS.

RESULTS AND RESEARCH

I. Captive Broodstock Research Using Non-Endangered Lake Wenatchee Sockeye Salmon

One of the primary obligations when maintaining an endangered species in protective culture is ensuring the highest possible survival. At the time of ESA-listing of Redfish Lake sockeye salmon in 1991 (Waples et al. 1991a), very little was known regarding methods to ensure survival of these fish in captive broodstock culture. Nevertheless, as pointed out in the introduction of this report, the impending extinction of the stock left little choice except husbandry intervention. At that time, most past attempts at captive broodstock culture (McAuley 1983, Harrell et al. 1984, 1985, 1987, Peterschmidt 1991, C. Mahnken and T. Flagg, NMFS, unpublished data, C. Wood, Canada Department of Fish and Oceans, Pacific Biological Station, unpublished data) indicated that, for Pacific salmon, full-term culture in pathogen-free fresh water generally resulted in higher survival to spawning and higher percentages of viable gametes than culture in seawater. Therefore, full-term freshwater rearing in pathogen-free water was chosen for initiation of these endangered captive broodstocks.

At the initiation of our studies in 1991, it appeared probable that many past husbandry problems in seawater were related to culture in net-pens exposed to near-surface environmental conditions. Several factors critical to survival are more variable at the surface than in the deeper marine waters preferred by most salmonids. These include water temperature, water quality, and occurrence of toxic plankton blooms. In addition, fish held in net-pens are at risk of escape, natural catastrophes, and predation from marine mammals and birds.

In 1992, we initiated studies to determine if land-based facilities supplied with pumped, filtered, and ultraviolet (UV) treated seawater could provide the quality environment necessary for protective culture of salmonids in seawater (Flagg 1993, Flagg and McAuley 1994, Flagg et al. 1996). These studies were conducted with two year-classes (1990- and 1991-brood) of Lake Wenatchee (Washington) sockeye salmon so as not to jeopardize the endangered Redfish Lake sockeye salmon gene pool. This research allowed various sockeye salmon culture strategies to be evaluated prior to implementation with the Redfish Lake fish.

1.1-- 1990 Brood

As described in Flagg et al. (1996), three replicates of about 300 yearling smolt size fish each were set up in mid-May 1992 in each of the following environments:

1) 4.1-m diameter circular fiberglass tanks supplied with pathogen-free fresh water at BBC,

2) 4.1-m diameter circular fiberglass tanks supplied with pumped, filtered, and UV-treated seawater at Manchester, and

3) 4.9-m square seawater net-pens at Manchester.

Water depth in each rearing environment vessel was adjusted to provide about 12 m^3 of fish rearing space. All fish were injected with bivalent vibrio vaccine (0.15 cc/fish) and erythromycin (50 mg/kg of body weight) prior to transfer and again at the end of June 1992 (Flagg 1993).

Rearing, growth, and survival

As described in Flagg et al. (1996), inventory discrepancies were noted in all groups during rearing. The inventory discrepancies averaged about 5% in the freshwater tanks, 7% in the seawater tanks, and 17% in the seawater net-pen replicates. These losses were recognized at the first complete inventory in March 1993 and were probably due to bird predation of dead or moribund fish during the months just after transfer to the experimental environments. However, some fish may have escaped from the seawater net-pens. For purposes of analysis, inventory discrepancies were assigned as mortalities to the month following transfer to the experiment.

Survival for experimental groups of 1990-brood Lake Wenatchee sockeye salmon during the 28 months of rearing from the beginning of the experiment in May 1992 through August 1994 averaged as follows: about 32% for replicates held in circular tanks supplied with fresh well water, 35% for replicates in circular tanks supplied with pumped, filtered, and ultraviolet (UV) light-treated seawater, and 26% for replicates held in conventional seawater net-pens. ANOVA indicated no significant differences ($P > 0.05$) in the percentage of fish remaining in freshwater tanks, seawater tanks, and seawater net-pens to prespawning at the end of August 1994.

Mortalities in the seawater net-pen and seawater tank replicates appeared related to a combination of osmoregulatory distress and BKD during the months just after seawater transfer, and thereafter, mortalities were associated with BKD (Flagg and McAuley 1994). Most mortalities in the freshwater tank replicates also appeared related to BKD during this same period. Fish in all treatments were fed a medicated diet containing 0.45% erythromycin at 2% of body weight/day for approximately 28 days in December 1992 and April and December 1993. Erythromycin was fed at 1.25% of body weight/day in February, April, and June 1994. This medication may have helped arrest BKD incidence. Mortality stabilized (at about 60%) after 8 to 12 months of rearing (at about 2 to 2.5 years of age).

Growth differences were noted between the treatments. Size of fish averaged 2.26 kg in the freshwater tanks, 1.57 kg in the seawater tanks, and 1.49 kg in the seawater net-pens at the last measuring period prior to spawning (September 1994). ANOVA indicated significant differences ($P < 0.05$) between average weights of fish in the three treatments. The fish reared in fresh water were about 44% larger than fish reared in the seawater tanks and 52% larger than those reared in the seawater net-pens. Tukey's multiple comparison test indicated that average fish weight in the treatments ranked as follows: freshwater tanks > seawater tanks = seawater net-pens ($P < 0.10$).

The cause of these growth differences is unclear. Fish in all treatments received approximately the same percent ration in proportion to size. However, in the freshwater and seawater tanks, ration not immediately consumed in the water column could be (and often was) eaten from the bottom of the tanks by the fish. Ration falling through the net-pen bottom was lost to the fish, and may account for the smaller size of fish from seawater net-pens. However, this does not explain the size differences between fish reared in freshwater and seawater tanks. It is possible that stress related to a combination of seawater osmoregulatory problems and disease may have also suppressed growth in seawater treatments.

Spawning 1993

As described in Flagg and McAuley (1994), the faster growth rate of the freshwater replicates resulted in a few fish (15%) maturing at 3 years of age in late October 1993. Male spawners averaged 42.7 cm and 1.01 kg, and female spawners averaged 41.5 cm and 0.87 kg. Fecundity averaged 1,359 eggs/female and egg viability averaged about 36%. No fish from either seawater treatment matured in 1993.

Spawning 1994

As described in Flagg et al. (1996), the majority of the 1990-brood population matured as 4-year-old fish in the fall of 1994. As indicated above, survival of fish in the experimental groups from 1.5 years of age (at the start of the experiment in 1992) to prespawning in fall 1994 averaged about 32% in the freshwater tanks, 35% in the seawater tanks, and 26% in the seawater net-pens. A total of 79% of surviving fish in freshwater replicates, 70% of those in filtered seawater replicates, and 8% of fish surviving in the seawater net-pen replicates were spawned between 30 September and 26 October 1994. The low number of spawners from the seawater net-pen replicates appears to reflect river otter (*Lutra canadensis*) predation coincident with prespawning sorting of fish.

Because natural anadromous sockeye return to freshwater to spawn, fish in both seawater treatments were sorted according to reproductive state (mature vs. immature), and maturing adults were transferred to freshwater at BBC one month prior to spawning. Fish in the freshwater treatment group were also sorted for maturity. At the time of spawning, fecundity and egg size were determined, and gamete quality was monitored by evaluating fertilization rates. The quality of the gametes was further evaluated by monitoring survival to the eyed egg stage.

Female 1990-brood sockeye salmon from the freshwater tank replicates averaged 54.4 cm and 2.24 kg, while male spawners averaged 56.5 cm and 2.51 kg. Fecundity averaged 2,477 eggs/female (1,106 eggs/kg of female weight) for the 1990-brood Lake Wenatchee sockeye salmon spawned from the freshwater rearing treatment in our experiments in 1994. Eyed-egg survival for this treatment averaged 49.6%.

Female 1990-brood from the seawater tank replicates averaged 50.3 cm and 1.56 kg, while male spawners averaged 51.0 cm and 1.69 kg. Fecundity averaged 1,899 eggs/female (1,217 eggs/kg of female weight) with eyed-egg survival averaging 42.4% for the seawater tank replicates. Average length and weight for female spawners from the seawater net-pen treatment were 43.0 cm and 0.99 kg, while male spawners averaged 44.6 cm and 1.17 kg. Fecundity averaged 1,783 eggs/female (1,801 eggs/kg of body weight), with eyed-egg survival averaging 45.8% for this group.

Columbia River Basin female sockeye salmon normally mature as 4- and 5-year-old fish, at about 45-60 cm and 2-4 kg (Mullan 1986). The 4-year-old 1990-brood Lake Wenatchee sockeye salmon spawners from the freshwater tank rearing treatment were within the expected size range for Columbia River sockeye salmon. However, spawners from the seawater tank and net-pen rearing treatments were below expected size thresholds (see size discussion under rearing, growth, and survival section above). ANOVA indicated significance difference ($P < 0.002$) in both male and female spawner length and weight between the rearing treatments. Tukey's multiple comparison test indicated that average male and female spawner size (length and weight) in the treatments ranked as follows: freshwater tanks > seawater tanks > seawater net-pens ($P \leq 0.10$).

ANOVA also indicated significance differences ($P < 0.001$) in fecundities of female spawners between rearing treatments. Results from Tukey's multiple comparison test indicated that average female spawner fecundity in the treatments ranked as follows: freshwater tanks > seawater tanks = seawater net-pens ($P < 0.02$). However, ANOVA indicated no significant difference ($P > 0.10$) in eyed egg survival (viability) of female spawners from the three treatments.

The 42-50% average eyed-egg survival rate for 4-year-old spawners in this study was lower than the 70 to 90% often documented in hatchery-spawned wild sockeye salmon (Mullan 1986). However, the rate was higher than the 36% eyed-egg survival documented for 1990-brood 3-year-olds spawned in 1993.

1.2-- 1991 Brood

In mid-May 1993, three replicates of about 300 yearling smolt size fish each were set up in each of the following environments:

1) circular fiberglass tanks supplied with fresh water,

2) circular fiberglass tanks supplied with pumped, filtered, and UV-treated seawater at Manchester, and

3) seawater net-pens at Manchester (Flagg and McAuley 1994, Flagg et al. 1996).

Freshwater replicates were held at the NMFS Montlake hatchery (Seattle) in 1.8-m diameter circular fiberglass tanks until early November 1993 and then transferred to 4.1-m diameter circular fiberglass tanks at BBC for rearing to maturity. Seawater tank replicates were held in 1.8-m diameter circular fiberglass tanks until early November 1993 and then transferred to 4.1-m diameter circular fiberglass tanks for rearing to maturity. Seawater net-pen replicates were held in 2.4- by 4.9-m rectangular net-pens until early November 1993 and then transferred to 4.9-m square pens for rearing to maturity. Water depth in each rearing container in each rearing environment was adjusted to provide about 1.5 m^3 of fish rearing space from May to November 1993 and about 12 m^3 of fish rearing space thereafter. All fish were injected with bivalent vibrio vaccine (0.15 cc/fish) and erythromycin (50 mg/kg of body weight) at the initiation of the experiment.

Rearing, growth, and survival

Inventory records for experimental groups of 1991-brood Lake Wenatchee sockeye salmon during the 28 months of rearing (to prespawning as 4 year old fish at the end of August 1995) averaged about 88% for replicates held in circular tanks supplied with fresh (well) water, 61% for replicates in circular tanks supplied with pumped, filtered, and ultraviolet (UV) light-treated seawater, and 22% for replicates held in conventional seawater net-pens. A replicate was lost from the seawater tank treatment in November 1993 due to mechanical failure of the inflow line feeding the tank, and a replicate was lost from the seawater net-pen treatment in September 1994 due to river otter predation. In addition, inventory discrepancies were noted in all treatments in August 1993 and were substantially greater in the seawater net-pen treatments (about 6%) compared to the seawater tanks (3%) and freshwater tanks (0%). A subsequent inventory of freshwater replicates in March 1994 revealed a 5% discrepancy, which was most likely due to bird predation, despite bird-netting covers on the tanks. Higher inventory discrepancies for fish in seawater net-pens were also noted for 1990-brood Lake Wenatchee sockeye salmon (described above). These losses were probably due to bird predation on dead or moribund fish during the months just after transfer to the experimental treatments. However, some fish may have escaped from the seawater net-pens. For purposes of analysis, inventory discrepancies were assigned as mortalities that occurred the month following transfer to the experiment. There were significant differences ($P < 0.01$) in the percentage of fish remaining in the experiment, with the treatments ranked as freshwater tanks > seawater tanks > seawater net-pens treatments ($P < 0.05$).

Analysis of variance (ANOVA) between treatments indicated significant difference ($P < 0.01$) in the percentage of fish remaining in freshwater tank, seawater tank, and seawater net-pen replicates at the end of December 1994. Bacterial kidney disease appears to have caused most of the mortality in the seawater net-pen treatment. However, for some mortalities in the treatments, our pathology laboratory could not confirm a specific cause of death. Results from a Tukey's multiple comparison test indicated that survival in the treatments ranked as follows: freshwater tanks > seawater tanks > seawater net-pens treatments ($P < 0.05$).

Growth differences were noted between the treatments. Size of fish averaged about 0.377 kg in the freshwater tank, 0.267 kg in the seawater tank, and 0.294 kg in the seawater net-pen replicates at the last quarterly measuring period (July 1994). ANOVA indicated that, although there were no significant differences ($P > 0.05$) in average fish weight between the three treatments at the start of the experiment, there were significant differences ($P < 0.05$) between average weights of fish in the three treatments by the last quarterly measuring period. Fish reared in fresh water were about 46% larger than fish reared in seawater tanks and 28% larger than those reared in seawater net-pens. Results from a Tukey's multiple comparison test indicated that average fish weight in the treatments ranked as follows: freshwater tanks > seawater tanks = seawater net-pens ($P < 0.05$).

These growth differences were somewhat similar to results of our rearing study for 1990-brood Lake Wenatchee sockeye salmon. Overall fish size in each treatment was smaller, however, for the 1991-brood than for the 1990-brood after the same amount of culture time. This was probably due to the fact that the 1991-brood were placed on a restricted diet for the first half of 1994 to prevent overcrowding in seawater tanks while awaiting completion of the new saltwater rearing facility, which was to contain larger rearing vessels. Once the new facility was available in July, the seawater tank replicates were transferred in, and normal growth-oriented feeding regimes were resumed.

The 1991-brood Lake Wenatchee sockeye salmon in this experiment were fed a medicated diet containing 0.45% erythromycin at 2% of body weight/day for approximately 28 days in May, September, and December 1993, and erythromycin was fed at 1.25% of body weight/day in February, April, June, and October 1994 as a prophylactic for BKD. Similar treatments were also administered in February and May, 1995.

It is encouraging to note that survival of 1991-brood Lake Wenatchee sockeye salmon reared in freshwater and seawater tank treatments during the 19 months from the beginning of the experiment in 1993 through the end of December 1994 was much higher than for 1990-brood Lake Wenatchee sockeye salmon during the equivalent rearing period. The 1991-brood Lake Wenatchee sockeye salmon in these experiments had a much lower incidence of BKD during fry-to-smolt rearing than did the 1990-brood. As expected, the better presmolt health status of the 1991-brood appears to have translated to higher survival to spawning in our experiments**.**

In contrast, the 1991-brood seawater net-pen replicates reared in natural (untreated) seawater had higher monthly losses than replicates in the other two treatments. These losses were primarily from BKD that was probably transmitted horizontally from other salmonid populations in the net-pen complex. However, these replicates also suffered heavy mortality (18%) in September due to an unidentified vibrio-like (*Vibrio spp.*) bacterium. It is apparent from these experiments that of the three rearing treatments, seawater net-pens are the least conducive to growth and survival.

Spawning 1994

Early maturation (as age-3 fish) occurred in the freshwater tank and seawater tank replicates in 1994. A total of 199 fish (about 14% of each of the two treatments) matured as 3-year-old jacks (191 fish) and jills (8 fish). No matings were made due to the small number of available females. There were no mature fish in the seawater net-pen replicates. It is interesting that a similar percentage (14.8%) of 3-year-old 1990-brood Lake Wenatchee sockeye salmon matured in the freshwater replicates in 1993, but that sex ratios in these fish were approximately equal (Flagg and McAuley 1994). It is also interesting that the 1990-brood Lake Wenatchee sockeye salmon produced no 3-year-old spawners in either of the seawater treatments in 1993 (Flagg and McAuley 1994).

The lack of significant numbers of female spawners (compared to male spawners) in the 1991-brood is most likely the result of their smaller size (< 0.6 kg) compared with the 1990-brood females (> 0.9 kg). The reasons for early maturation of fish in the seawater tank replicates in the 1991-brood, but not in the 1990-brood, are unknown since the size of fish in each treatment was approximately equal.

Spawning 1995

As described in Flagg et al. (1996), the majority of the 1991-brood population matured as 4-year-old fish in the fall of 1995. As indicated above, survival of fish in the experimental groups from 1.5 years of age (at the start of the experiment in 1993) to prespawning in fall 1995 averaged about 88% in the freshwater tanks, 61% in the seawater tanks, and 22% in the seawater net-pens. A total of 96% of surviving fish in freshwater replicates, 81% of those in filtered seawater replicates, and 20% of fish surviving in the seawater net-pen replicates were spawned between 27 September and 20 October 1995. The low number of spawners from the seawater net-pen replicates appears to reflect river otter (*Lutra canadensis*) predation coincident with prespawning sorting of fish.

Because natural anadromous sockeye return to freshwater to spawn, fish in both seawater treatments were sorted according to reproductive state (mature vs. immature), and maturing adults were transferred to freshwater at BBC 2 months prior to spawning. Fish in the freshwater treatment group were also sorted for maturity. At the time of spawning, fecundity and egg size were determined, and gamete quality was monitored by evaluating fertilization rates. The quality of the gametes was further evaluated by monitoring survival to the eyed egg stage.

Female 1991-brood sockeye salmon spawners from the freshwater tank replicates averaged 47.5 cm and 1.31 kg, while male spawners averaged 49.1 cm and 1.58 kg. Fecundity averaged 2,135 eggs/female (1,630 eggs/kg of female weight) for the 1991-brood Lake Wenatchee sockeye salmon spawned from the freshwater rearing treatment in our experiments in 1995. Eyed-egg survival for this treatment averaged 67.2%.

Female 1991-brood spawners from the seawater tank replicates averaged 42.4 cm and 0.96 kg, while male spawners averaged 47.1 cm and 1.32 kg. Fecundity averaged 1,675 eggs/female (1,745 eggs/kg of female weight) with eyed-egg survival averaging 51.7% for the seawater tank replicates. Average length and weight for female spawners from the seawater net-pen treatment were 40.2 cm and 0.74 kg, while male spawners averaged 45.2 cm and 1.12 kg. Fecundity averaged 1,590 eggs/female (2,148 eggs/kg of body weight), with eyed-egg survival averaging 43.2% for this group.

The 4-year-old 1991-brood Lake Wenatchee sockeye salmon spawners from all three rearing treatments were below expected size thresholds for Columbia River sockeye salmon (see size discussion under rearing, growth, and survival section above). ANOVA indicated significance difference ($P < 0.002$) in both male and female spawner length and weight between the rearing treatments. Tukey's multiple comparison test indicated that average male and female spawner size (length and weight) in the treatments ranked as follows: freshwater tanks > seawater tanks > seawater net-pens ($P \leq 0.10$).

The 43-67% average eyed-egg survival rate for 4-year-old spawners in this study was lower than the 70 to 90% often documented in hatchery-spawned wild sockeye salmon (Mullan 1986). ANOVA also indicated significance differences ($P < 0.001$) in fecundities of female spawners between rearing treatments. Results from Tukey's multiple comparison test indicated that average female spawner fecundity in the treatments ranked as follows: freshwater tanks > seawater tanks = seawater net-pens ($P < 0.02$). However, ANOVA indicated no significant difference ($P > 0.10$) in eyed egg survival (viability) of female spawners from the three treatments.

1.3-- Conclusions

Captive broodstock technology for rearing of sockeye salmon appears to be sufficiently advanced to allow carefully planned programs to proceed. In general, survivals of captive broodstocks of sockeye salmon to adulthood of 30%+ can be anticipated if the fish are cultured in water sources low in pathogens. However, survival will be lower for groups of sockeye salmon in surface water situations (e.g., marine net pens). Viability of eggs from sockeye salmon from captive broodstocks will probably average 40-70%. The size and age at maturity for sockeye salmon captive broodstock will typically be less than wild fish except where constant temperature, high growth profile culture techniques are used. The above information generally agrees with the limited information available on captive broodstock culture of other Pacific salmon (cf. Schiewe et al. 1997).

Data from studies using 1990- and 1991-brood Lake Wenatchee sockeye salmon suggest a ranking priority of 1) circular tanks supplied with pathogen-free fresh water, 2) circular tanks supplied with pumped, filtered, and UV treated seawater, and 3) seawater net-pens for rearing sockeye salmon. Full-term freshwater rearing appears to remain a priority option for valuable captive broodstocks (e.g., Redfish Lake sockeye salmon). However, the data was encouraging regarding the use of environmentally-controlled seawater for broodstock rearing. This strategy was subsequently employed for a portion of the Redfish Lake sockeye salmon.

II. Status Of Redfish Lake Sockeye Salmon Broodstocks

NMFS captive broodstock efforts for Redfish Lake sockeye salmon from 1991 to September 2000 (Table 1) have included protective rearing of:

1) first, second, and third generation progeny of the one female and three male wild origin sockeye salmon that returned to the lake in 1991 (1987 wild spawning lineage),
2) first, second, and third generation progeny of the two female and six male wild origin sockeye salmon that returned to Redfish Lake in 1993 (1989 wild spawning lineage),
3) progeny of outmigrating wild origin sockeye salmon captured by IDFG from Redfish Lake Creek in 1991 and spawned in 1993 (1989 wild spawning lineage),
4) progeny of residual wild origin sockeye salmon captured in Redfish Lake by IDFG and spawned in 1993 (1989 wild spawning lineage),
5) first and second generation progeny of the one wild origin female that returned in 1994 (1990 wild spawning lineage),
6) first and second generation progeny of the one female wild origin sockeye salmon that returned to Redfish Lake in 1996 (1992 wild spawning lineage), and
7) first generation progeny of the single female and three of the six male captive broodstock origin sockeye salmon that returned to the Stanley Basin in 1999 (1989 wild spawning lineage).

Single wild males returned in 1992 and 1998. No fish returned in 1995 and1997.

Mating strategies for Redfish Lake sockeye salmon broodstock have been structured to maintain genetic diversity. These strategies have included random pairing, pairing in as many different combinations as possible, avoidance of pairing between siblings, fertilization between different year-classes, and fertilization with cryo-preserved sperm from other generations as suggested by Hard et al. (1992).

Genetic consequences of captive broodstock programs are beyond the scope of this report (see Hard et al. 1992 for review). However, Hard et al. (1992) cautioned that artificially amplifying only a portion of a population through propagation may reduce effective population size (N_e) by dramatically increasing only a fraction of the available genotypes in the parent population. For Redfish Lake sockeye salmon captive broodstocks, many of the potential adverse consequences of broodstock selection were avoided by capturing all returning adults and a large fraction (up to 25%)

of the migrating juveniles. Nevertheless, it should be recognized that such heavy mining of a native population can only be justified in the face of otherwise certain extinction.

Almost all broodstocks maintained by NMFS were obtained as eggs (Table 1). NMFS is maintaining first, second, and third generation captive broodstocks. For most broodstocks, two separate populations divided between IDFG hatcheries and NMFS facilities were established for each group to reduce the risk of catastrophic loss of these valuable gene pools. NMFS and IDFG also were involved in a cooperative project with the Oregon Department of Fish and Wildlife (ODFW) for rearing of progeny of 1991- and 1993-brood to smolt for release in areas of Stanley Basin (ID).

2.1-- 1991 Captive Broodstock Lineage

First Generation Rearing and Spawning

In August 1991, three male and one female adult sockeye salmon were captured during their upstream migration at a weir on Redfish Lake Creek, about 2 km below Redfish Lake. The maturing adults were moved to the IDFG Sawtooth Hatchery near Stanley, Idaho, about 8 km from Redfish Lake, and spawned in late October (Flagg 1993, Johnson 1993). These fish were probably the result of a natural spawning event in Redfish Lake in 1987 (Table 1). Eggs from the 1991 spawning of adult returns were divided between NMFS and IDFG and captive broodstock reared under ESA Permit 795 (Flagg and McAuley 1994).

As described in Flagg and McAuley (1994, 1995) and Flagg et al. (1996), NMFS received a total of 991 eggs from IDFG (Table 1), of which 978 eggs (98.7%) hatched in January 1992. For the first 18 months after hatch, these fish were reared at the NMFS NWFSC in Seattle. During this period, the fish were diagnosed with a clinical infection of *Renibacterium salmoninarum*, the causative agent of BKD. In spring 1993, the fish were transferred to the (then) newly constructed protected species rearing facility at BBC. During rearing at the NWFSC and BBC, the fish were treated with erythromycin to control BKD. Nevertheless, mortality due to BKD continued during rearing, resulting in a cumulative loss of 87% of the initial population (Table 1).

A total of 56 female and 70 male 1991-brood survived and were spawned in October 1994 at 3 years of age (Table 1). We believe the early maturity of these fish was due to fast growth in captive culture. Female spawners averaged 43.6 cm and 1.23 kg, while male spawners averaged 45.7 cm and 1.44 kg (Flagg and McAuley 1995, Flagg et al. 1996). Fecundity averaged 1,644 eggs/female (about 1,337 eggs/kg of female weight) for the 1991-brood females spawned in 1994. Egg viability for these fish was about 60%, resulting in about 48,000 eyed eggs (Flagg et al. 1996). Because BKD was noted as a major cause of mortality during fish rearing, all spawners were surveyed for presence of BKD. IDFG established protocol that only eggs from parent fish testing below a BKD enzyme-linked immunosorbent assay (ELISA) optical density (OD) of < 0.2 in 1994 could be returned directly to Idaho for use in recovery efforts for Redfish Lake sockeye salmon (Flagg et al. 1996).

In December 1994, approximately 23,000 eyed eggs from parents with ODs < 0.2 from NMFS's spawning in 1994 of 1991-brood Redfish Lake sockeye salmon were shipped to Idaho (Flagg and McAuley 1994, 1995, Flagg et al. 1996). The eggs were transferred from NMFS to IDFG under ESA Permit 795. These eggs were incorporated into IDFG rearing groups and outplanted into the Redfish Lake area in summer 1995 under ESA Permit 795 (Flagg et al. 1996, Kline and Lamansky 1997).

1991-Brood Progeny, Smolt Rearing

NMFS retained approximately 25,000 (1994-brood) eyed eggs from parents with ELISA ODs > 0.2 from spawning of 1991-brood Redfish Lake sockeye salmon in fall 1994 (Flagg and McAuley 1995, Flagg et al. 1996). These eggs were incubated and hatched at BBC and the fry transferred in April 1995 to ODFW for rearing in three groups segregated by BKD ELISA OD level at Bonneville Hatchery near Cascade Locks, Oregon (Flagg and McAuley 1995, Flagg et al. 1996). The eggs were transferred from NMFS to ODFW under ESA Permit 795 and WDFW Fish Transfer Permit 2194-4-95. Survival of the fish from hatch to transfer was over 99%. IDFG and NMFS Environmental and Technical Services Division (ETSD), Portland (OR), aided NMFS in arranging details of this fish rearing cooperative with ODFW. Costs associated with rearing this group of fish at the ODFW Bonneville Hatchery were covered by ETSD through Mitchell Act funding.

These 1994-brood juveniles were reared at the ODFW Bonneville Hatchery under IDFG's ESA Permit 795 in three groups segregated by BKD ELISA OD level. Group 1 had 3,362 fish from parents with OD levels 0.2-0.4, Group 2 had 9,561 fish from parents with OD levels 0.4-1.0, and Group 3 had 10,529 fish from parents with OD levels greater than 1.0. The fish were reared using standard fish culture practices and approved therapeutics. Fish were fed a commercial ration (e.g., Biodiet). Mortalities were examined by an ODFW fish pathologist to determine cause of death (Flagg and McAuley 1996, 1997).

All fish from the NMFS captive broodstocks for 1994-brood from captive-reared 1991-brood spawners held at the ODFW Bonneville Hatchery were tagged with coded wire tags (CWT) and right ventral (RV) and adipose fin clipped by ODFW in fall 1995 (Flagg and McAuley 1996). CWTs have been shown to be safe for use in juvenile salmonids. CWTs were injected into the nose cartilage of the fish following procedures described by Jefferts et al. (1963). The coded wire tag code for Group 1 was 071060, 071059 for Group 2, and 071058 for Group 3. The CWTs will remain with the fish throughout the entire lifecycle.

The fish were reared to smoltification at 1.5 years of age (spring 1996). Survival from transfer through April 1996 was about 96% for Group 1, 98% for Group 2, and 92% for Group 3 (Flagg and McAuley 1997). Groups 1 and 2 remained healthy during rearing. However, a clinical outbreak of BKD was observed in Group 3 in November 1995. This disease problem was quickly brought under control with medication (Aquamycin). Fish health sampling of 260 fish/group (60 fish in August 1995, 100 fish in January 1996, and 100 fish in April 1996) by ODFW pathologists indicated that Groups 1 and 2 met IDFG criteria of ELISA OD ≤ 0.2 and were certified for transfer to Idaho (K. Johnson, pers. commun., 1996). Fish health sampling of 260 fish/group (60 fish in August 1995, 100 fish in January 1996, and 100 fish in April 1996) by ODFW pathologists indicated that Group 3 did not meet IDFG criteria of ELISA OD ≤ 0.2 and they were not certified for transfer to Idaho (K. Johnson, pers. commun., 1996). All three groups were certified negative by ODFW pathologists for other important culturable viral and bacterial pathogens.

In spring 1996, about 1,000 fish per Groups 1 and 2 were PIT tagged by NMFS (Prentice et al. 1990a, b). On 2 May 1996, 2,960 fish from Group 1 and 9,142 fish from Group 2 (12,102 fish total) were transported to Idaho by ODFW and released in Redfish Lake Creek (Flagg and McAuley 1997, Kline and Lamansky 1997). The fish averaged about 55 g at release. This release was permitted under ESA Permit 795 and IDFG authorization letters issued 25 April 1996. Adults from this release were expected to begin returning to Redfish Lake in 1998. However, no fish returned in 1998 or 1999.

In early May 1996, about 9,500 fish from Group 3 were released from the ODFW Bonneville Hatchery into the lower Columbia River under Permit 1005 (Flagg and McAuley 1997). Although this group did not meet ELISA certification standards for return to Idaho, the fish were healthy at release. This release was permitted under ESA Permit 795. Adults from this release were expected to begin returning to the ODFW Bonneville Hatchery in May-June1998 at age 4. The adult salmon trap at the Bonneville Hatchery was operating during the June-August period the adult sockeye salmon were expected to return. However, no fish were captured. The adult trap was also operated during June-August 1999, and again no fish were captured.

F2 Captive Broodstock Rearing

The Proposed Recovery Plan for Snake River Salmon (Chapter V, Section 4.1.a.) calls for protecting genetic resources in captive broodstocks by retaining a small number of progeny (i.e., enough to produce 50 spawning pairs) from each brood year as "safety-net" broodstock to ensure the continued survival of the species (Schmitten et al. 1995). These safety-net groups can be a lifesaver for individual year classes if initial outplants fail. In addition, safety-net groups can help increase genetic diversity of captive broodstocks by allowing directed cross-generational breeding.

On 2 May 1996, an additional 305 smolts from Group 1 were transferred from the Bonneville Hatchery to seawater at the NMFS Manchester facility for rearing to maturity as a second generation safety-net captive broodstock for this important (1987 wild spawning lineage) genetic group (Table 1). This transfer was permitted under ESA Permit 795, WDFW Permit 2395-4-96, and ODFW authorization letter issued 29 April 1996.

Survival of these fish to spawn as 3- and 4-year olds was 70% and 63%, respectively (Table 1). BKD was documented from some mortalities. A total of 43 fish (7 females and 36 males) matured and were spawned as age-3 fish in fall 1997. Female spawners averaged 40.1 cm and 0.81 kg, while male spawners averaged 43.5 cm and 1.12 kg (Table 2). Fecundity averaged 1,541 eggs/female (1,902 eggs/kg of female weight) for the 1994-brood females spawned in 1997. Egg viability for these fish was 74.4%, resulting in 6,880 eyed eggs (Table 3). An additional 137 fish (55 females and 82 males) matured and spawned as age-4 fish in the fall of 1998. Female spawners averaged 49.8 cm and 1.61 kg, while male spawners averaged 51.1 cm and 1.88 kg (Table 2). Fecundity averaged 2,043 eggs/female (1,269 eggs/kg of female weight) for the 1994-brood females spawned in 1998 (Table 3). Egg viability for these fish was 54.7%, resulting in 47,156 eyed eggs (Table 3).

F3 Captive Broodstock Rearing

In 1998, green eggs from the 1994-brood (descendents of the IDFG's 1991-brood wild spawner group) reared to maturity in seawater, were fertilized with milt from the lone returning 1998-brood wild male to create a third generation safety-net captive brood. A total of 127 eyed eggs from this safety-net were placed into incubation at BBC for rearing to maturity (Table 1). Survival through August 2000 was 87% (Table 1). An additional 127 eyed eggs were transferred to IDFG with subsequent rearing to maturity. We expect most of these fish to spawn between fall 2001 and fall 2002. Spawn from these fish will be returned to Idaho for use in recovery efforts for Snake River sockeye salmon.

2.2-- 1993 Captive Broodstock Lineage

NMFS captive broodstocks for 1993-brood lineage Redfish Lake sockeye salmon include fish from three sources: 1) progeny of the two female and six male sockeye salmon that returned to

Redfish Lake in 1993, 2) progeny of outmigrating sockeye salmon captured by IDFG from Redfish Lake Creek in 1991 and spawned in 1993, and 3) progeny of residual sockeye salmon captured in Redfish Lake by IDFG and spawned in 1993 (Table 1). The wild spawning lineages for these fish were probably fish spawning in Redfish Lake in 1989. Eggs for initiation of these captive broodstocks were transferred from IDFG to NMFS under ESA Permit 795 and WDFW Fish Transfer Permit 1685-11-93 (Flagg and McAuley 1995, Flagg et al. 1996).

Groups of 1993-brood fish were reared either full-term to maturity in freshwater tanks at BBC or reared to yearling smolt in freshwater at BBC and transferred to Manchester for rearing to maturity in tanks supplied with filtered and UV-treated seawater. Combined survival for 3.8 years of rearing from hatch in 1994 through fall 1997 was 72.3%. Mature fish were returned to BBC for final maturation and spawning. A total of 608 female and 797 male fish matured from these groups (Table 4). An overview of 2-, 3-, and 4-year-old spawning production follows:

2-Year-Old Spawners, 1995-- A small number of 1993-brood lineage spawners (n = 31, 2.2%) matured as jacks in fall 1995 (Table 4). The SBSTOC decided against using these fish for spawning because no other broodstocks matured at BBC in 1995 and similar spawners were available at the IDFG Eagle Hatchery for use with their captive broodstocks.

3-Year-Old Spawners, 1996-- A majority (n = 1,217, 86.6%) of the 1993-brood lineage spawners matured as 3-year-old fish in fall 1996 (Table 4). In mid-late August 1996, maturing fish from seawater rearing groups were moved to freshwater at BBC for final maturation. The combination of freshwater and seawater rearing of the 1993-brood groups provided opportunity for evaluating alternative rearing strategies. Fish from residual-based broodstocks were not included in spawner analysis because only one female spawned in fall 1996 (Tables 1 and 4).

Combined survival for the 2.8 years of rearing from hatch in 1994 through fall 1996 was 77.6%. Survival among freshwater-reared fish was higher (87.8%) than among those reared in seawater (79.9%) (Table 5). In September 1996, 80 prespawning adults from NMFS groups of 1993-brood (40 female and 40 male fish, with an estimated viable egg deposition of 30,800 eggs) were released in Redfish Lake as part of a volitional spawning population (Table 4). This release of NMFS reared 1993-brood Redfish Lake sockeye complemented 40 fish released from the IDFG Eagle Hatchery (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., September 1996), for a total of 60 adult females and 60 adult male fish released to Redfish Lake in 1996. Subsequent natural spawning, indicated by the presence of redds and spawned-out carcasses, was documented for these fish (P. Kline, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., November 1996; Tom Flagg, NMFS, Pers. observation, November 1996).

In October-November 1996, 489 3-year-old adult females from NMFS groups were spawned in captivity and produced about 660,000 green eggs (Table 6). Average (combined group) eyed-egg viability was 57.6%, resulting in about 380,500 viable eggs (Table 6). There was little appreciable difference in spawn timing between anadromous return-based and outmigrant-based captive broodstocks. Rearing environment did not appear to affect egg viability. T-tests (on data arcsine transformed for normality) indicated that there was no significant difference ($P > 0.05$) between eyed egg viability of freshwater and seawater reared groups for either outmigrant-based (66.1% vs. 68.7%) or anadromous return-based (53.7% vs. 55.9%) captive broodstocks (Table 6). However, parental lineage did have an affect on eyed egg viability. T-tests on pooled data indicated a significant difference ($P < 0.001$) in eyed egg viability between anadromous return-based (55.3%) and outmigrant-based (67.4%) captive broodstocks (Table 6).

Time of spawning also affected eyed egg viability in 1996. During the spawn weeks of mid October to early November, average eyed egg viability ranged from about 70-85% for the outmigrant-based and 63-70% for the anadromous return-based captive broodstocks. However, for the spawn weeks of mid-to-late November, average eyed egg viability ranged from about 16-43% for the outmigrant-based and 2-54% for the anadromous return-based captive broodstocks.

Reasons for the difference in eyed egg viability between anadromous return-based and outmigrant-based captive broodstocks in 1996 are unclear. Fish were reared similarly and fed the same diet, so it is unlikely that the egg viability differences were related to husbandry or nutrition. Fish were checked for ripeness at approximately weekly intervals throughout the spawning period and fish were spawned when eggs or milt could be expressed. As noted above, eyed egg viability was considerably higher for fish spawned in mid October to early November, which corresponds to the historical peak spawning for Redfish Lake sockeye salmon, compared to fish spawned later in the season. It is possible that for captive reared sockeye salmon, complete spawning cues may not be available to the fish, delaying egg release beyond the optimal spawning period. Thus, the SBSTOC recommended that groups of captively reared fish delaying spawning beyond late October be implanted with gonadotropin-releasing hormone analog (GnRHa) (Swanson 1995) to accelerate spawning and potentially increase egg viability. These procedures were employed in subsequent spawnings (in 1997 and beyond).

Spawners were tested for BKD at the U.S. Fish and Wildlife Service Olympia Fish Health Center in Olympia, Washington. In addition, spawners were tested for viral pathogens at the Northwest Indian Fisheries Commission Fish Health Laboratory, Olympia, Washington. All groups of spawners were certified as healthy and egg lots were certified for transfer to Idaho. In November 1996, 107,371 eyed eggs were transported to Idaho, and placed by NMFS and IDFG personnel into 21 in-lake incubation boxes which were distributed in Redfish Lake (Table 7). In

December 1996, 28,202 eyed eggs were transported to the IDFG Eagle Hatchery and 144,262 eyed eggs were transported to the Sawtooth Hatchery for final incubation and rearing for juvenile release to aid recovery of ESA-listed endangered Snake River Sockeye salmon in Stanley Basin lakes (e.g., Redfish, Pettit, and Alturas).

In December 1996 and January 1997, a total of 80,061 eyed eggs and swimup fry were transported to the ODFW Bonneville Fish Hatchery for rearing to smolt for release into Stanley Basin habitats. An additional 18,300 eyed eggs were transferred to the Sawtooth Hatchery in January 1997, for a total eyed-egg transfer of 162,539 (Table 7). NMFS retained 500 eyed eggs from progeny of the two female and six male sockeye salmon that returned to Redfish Lake in 1993 as a second generation safety net captive broodstock (Table 1). Transfers of fish and eggs were permitted under ESA Permits 795 and 1005, IDFG authorization letter issued 2 August 1996, IDFG Permit HQ-35-96, IDFG authorization letters issued 27 November 1996 and 12 December 1996, and ODFW authorization letter issued 18 December 1996.

Two hundred fifty nine fish remained in culture and were expected to mature at 4 years of age in fall 1997 (Table 1). Additionally, in December 1996, IDFG transferred 151 1993-brood from wild spawners to NMFS to alleviate a fish rearing space overload at their Eagle Hatchery (Table 1). These fish were transferred from Idaho under ESA Permit 795, ODFW authorization letter issued 6 December 1996, and WDFW Permit 2493-12-96.

4-Year-Old Spawners, 1997-- The remainder (n = 157; 11.2%) of the 1993-brood lineage spawners matured as 4-year-old fish in fall 1997 (Table 4). In mid-late August 1997, maturing fish from seawater rearing groups were moved to freshwater at BBC for final maturation.

Combined survival for the 3.8 years of rearing from hatch in 1994 through fall 1997 was 72.3%. In September 1997, 4 prespawning adult female fish from NMFS 1993-brood residual group (2 freshwater-reared and 2 seawater-reared fish, with an estimated egg deposition of 4,000 eggs) were released into Redfish Lake as part of a volitional spawning population (Table 4). This release of NMFS reared 1993-brood Redfish Lake sockeye complemented a release of 36 (18 female and 18 male) NMFS reared 1994-brood sockeye (see section 1.3), and 40 (20 female and 20 male) 1994-brood from the IDFG Eagle Hatchery (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., September 1997), for a total of 42 adult females and 38 adult male fish released to Redfish Lake in 1997. Subsequent natural spawning, indicated by the presence of redds and spawned-out carcasses, was documented for these fish (P. Kline, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., November 1997)

In October-November 1997, 75 4-year-old adult females from NMFS groups were spawned in captivity and produced about 176,000 green eggs (Table 8). Average (combined group) eyed-egg viability was 31.8%, resulting in about 56,000 viable eggs (Table 8). In addition, 16 4-year-old adult females and 77 males (Table 1) from the IDFG 1993-brood reared at BBC were spawned. Overall survival for the 11 months of rearing at BBC was 62%, producing only 3,800 viable eggs.

Spawners were tested for BKD at the U.S. Fish and Wildlife Service Olympia Fish Health Center in Olympia, Washington. In addition, spawners were tested for viral pathogens at the Northwest Indian Fisheries Commission Fish Health Laboratory, Olympia, Washington. All groups of spawners were certified as healthy and egg lots were certified for transfer to Idaho. In November 1997, eyed eggs were transported to Idaho, and placed by NMFS and IDFG personnel into nine in-lake incubation boxes which were distributed in Redfish Lake (n = 35,061) and Alturas Lake (n = 7,381) (Table 9). In December 1997, a total of 9,824 eyed eggs were transported to the Sawtooth Hatchery for final incubation and rearing for juvenile release, to aid recovery of ESA-listed endangered Snake River Sockeye salmon in Stanley Basin lakes (e.g., Redfish, Pettit, and Alturas).

Specific culture histories for 1993-brood groups are described below.

1993-Brood from Wild Anadromous Returns

First generation rearing and spawning-- In 1993, eight adult sockeye salmon (two females and six males) returned to Redfish Lake. These fish were captured at the weir on Redfish Lake Creek during their upstream migration in August. These fish were probably the result of a natural spawning event in Redfish Lake in 1989 (Table 1). These fish were held by IDFG at the Sawtooth Hatchery and spawned in late October 1993 (Johnson and Pravecek 1995). A full-factorial mating design resulted in six half-sib groups from each female. NMFS and IDFG each retained a portion of these eggs for captive brood. NMFS received 1,180 eggs from 11 of the 12 possible half-sib groups from these spawnings (Table 1). Almost all of these eggs were viable (Flagg and McAuley 1995, 1996, Johnson and Pravecek 1995, Flagg et al. 1996). These eggs were transferred from IDFG to NMFS under ESA Permit 795 and WDFW Fish Transfer Permit 1685-11-93.

The eggs were incubated and juveniles reared at BBC. As described in Flagg and McAuley (1995) and Flagg et al. (1996), in January 1995, juveniles were individually marked with PIT tags and pooled in lots of approximately 250 fish each to 4.1-m diameter tanks at BBC. At smoltification in spring 1995, a total of 188 of these fish were transferred to 4.1-m tanks supplied with filtered and UV-treated seawater at Manchester for rearing to maturity prior to transfer to freshwater at BBC for spawning. Another 939 fish were retained at BBC for full-term rearing to maturity in freshwater.

Overall survival was about 83% during the 35 months of rearing, from hatching in late December 1993 through fall 1996 (Table 1). Survival was 95.6% from hatch to smolt age after 16 months of rearing. Survival during the next 19 months for fish reared full-term from smolt age to maturity in freshwater was 87.9% (84.0% overall survival) and 86.7% (82.9% overall survival) in seawater (Table 5). A total of about 98% of the surviving fish reared in freshwater (n = 812) and about 42% of the fish reared in seawater (n = 63) matured in fall 1996 (Tables 4 and 5). Higher growth rate in constant temperature well water was a probable cause of the higher 3-year-old maturation rate for these freshwater vs. seawater reared fish.

In September 1996, 34 prespawning adult fish from the group reared in freshwater (17 females and 17 males) and 12 prespawning adult fish from the group reared in seawater (6 females and 6 males) were released in Redfish Lake as part of a volitional spawning population (Table 4). All remaining mature females (n = 341) and about 50% of the maturing males (n = 242) were spawned at BBC in October-November 1996 (Table 4). Female spawners from full term freshwater rearing at BBC averaged 45.2 cm and 1.18 kg, while male spawners averaged 45.6 cm and 1.31 kg (Table 10). Fecundity averaged 1,420 eggs/female (about 1,202 eggs/kg of female weight) for the 1993-brood females spawned in 1996 (Table 6). Egg viability for these fish was about 53.7%, resulting in 244,801 eyed eggs (Table 6). Female spawners reared from smolt-to-adult in the filtered and UV-treated seawater system at Manchester averaged 45.7 cm and 1.22 kg, while male spawners averaged 42.1 cm and 1.07 kg (Table 10). Fecundity averaged 1,173 eggs/female (about 961 eggs/kg of female weight) for the 1993-brood females spawned in 1996 (Table 6). Egg viability for these fish was about 55.9%, resulting in 10,491 eyed eggs (Table 6).

A total of 104 1993-brood from wild spawners reared by NMFS survived but did not mature in fall 1996 (Table 1). NMFS maintained 24 of these fish at BBC in freshwater and 80 fish in the seawater system at Manchester. These fish averaged about 1.6 kg each. In addition, in December 1996, IDFG transferred 151 additional 1993-brood from wild spawners to NMFS (131 fish to BBC and 20 fish to Manchester) to alleviate a fish rearing space problem at their Eagle Hatchery (Table 1). By the end of December 1996, 125 fish from the IDFG transfer remained at BBC. However, only six fish survived the transfer to seawater at Manchester.

Overall survival of 1993 brood from hatch to spawning at 4 years of age was 81.2% (Table 5). Survival was 95.6% from hatch to smolt age after 16 months of rearing. Survival for the next 31 months for fish reared full-term from smolt age to maturity in freshwater was 87.3%, compared to 71.3% for fish reared from smolt to adult in seawater (Table 5). Female spawners from full term freshwater rearing at BBC (n = 2) averaged 52.9 cm and 1.84 kg, while male spawners (n = 4) averaged 57.7 cm and 2.81 kg (Table 11). Fecundity averaged 1,893 eggs/female (about 1,029 eggs/kg of female weight) for the 1993-brood females spawned in 1997 (Table 8). Egg viability for these fish was 7.7%, resulting in 292 eyed eggs (Table 8). Female spawners reared from smolt-to-adult in the filtered and UV-treated seawater system at Manchester (n = 24) averaged 58.4 cm and 2.75 kg, while male spawners (n = 41) averaged 60.9 cm and 3.28 kg (Table 11). Fecundity averaged 2,848 eggs/female (about 1,036 eggs/kg of female weight) for the 1993-brood females spawned in 1997 (Table 8). Egg viability for these fish was about 40.3%, resulting in 26,401 eyed eggs (Table 8).

Survival of the IDFG 1993-brood reared for 11 months at BBC, from transfer to spawning in fall 1997 was adequate (> 60%) (Table 1). However, gamete quality was severely compromised (14% viability). These spawnings produced a total of about 3,800 eggs that were incorporated into recovery efforts for the stock in Idaho under ESA Permit 795 (Flagg and McAuley 1997; Kline and Lamansky 1997; P. Kline, IDFG, unpubl. data).

First generation egg transfers-- In November 1996, a total of 44,652 eyed eggs from these 1993-brood from wild spawner female groups were transported to Idaho and placed into in-lake incubation boxes in Redfish Lake (Table 7). In December 1996, an additional 6,334 eyed eggs from these groups were transported to the IDFG Eagle Hatchery and 135,535 eyed eggs were transported to the Sawtooth Hatchery for final incubation and rearing for juvenile release. In December 1996, another 51,859 eyed eggs were transported to the ODFW Bonneville Hatchery for rearing to smolt for release into Stanley Basin habitats. An additional 10,244 eyed eggs were transported to the Sawtooth Hatchery and 4,281 fry were transported to the ODFW Bonneville Hatchery in early 1997 (Table 7).

In November 1997, a total of 17,272 eyed eggs from these 1993-brood from wild spawner female groups were transported to Idaho and placed into in-lake incubation boxes in Redfish and Alturas Lakes (Table 9). In December 1997, an additional 6,576 eyed eggs from these groups were transported to the Sawtooth Hatchery for final incubation and rearing for juvenile release.

Second generation rearing and spawning-- An additional 500 eyed eggs from the 1993-brood from the wild spawner group reared full-term to maturity in freshwater were retained at BBC for rearing to maturity as a second generation safety-net captive broodstock for this important (1993 anadromous return from 1989 wild spawning lineage) genetic group (Table 1). In early March 1997, 398 fry from this group were ponded together into a single 1.8 m tank at BBC. In late December 1997, they were transferred to two 4.1 m tanks. Survival after 13 months in culture was 61%. Most mortalities occurred between hatching and first feeding. In May 1998, 91 of these second generation 1996-brood were transferred to seawater at Manchester, at an average weight of 98 g. The remaining 211 were retained in freshwater at BBC. Combined survival for both fresh and seawater reared fish through December 1998 was 54% (Table 1**).** Combined survival for both fresh and seawater reared fish through August 2000 was 34% (Table 1). Combined survival was

80.5% from hatch to smolt age after 16 months of rearing. Survival for the next 17 months for fish reared full-term from smolt age to maturity in freshwater was 61.1%, compared to 69.2% for fish reared from smolt to adult in seawater (Table 12). Female spawners from full term freshwater rearing at BBC (n = 78) averaged 49.4 cm and 1.6 kg, while male spawners (n = 35) averaged 50.0 cm and 1.9 kg (Table 13). Fecundity averaged 1,919 eggs/female (about 1,199 eggs/kg of female weight) for the 1996-brood females spawned in 1999 (Table 14). Egg viability for these fish was 27.0%, resulting in 37,291 eyed eggs (Table 14). Female spawners reared from smolt-to-adult in the filtered and UV-treated seawater system at Manchester (n = 34) averaged 43.6 cm and 0.9 kg, while male spawners (n = 16) averaged 45.4 cm and 1.2 kg (Table 13). Fecundity averaged 1,239 eggs/female (about 1,377 eggs/kg of female weight) for the 1996-brood females spawned in 1999 (Table 14). Egg viability for these fish was about 43.2%, resulting in 17,113 eyed eggs (Table 14). Spawn from these fish was returned to Idaho for use in recovery efforts.

In November and December 1999, approximately 34,411 eyed eggs from parents with ODs < 0.2 from NMFS's spawning in 1999 of 1996-brood Redfish Lake sockeye salmon were shipped to Idaho (Table 15). In addition, 12,749 eyed eggs from parents with ODs > 0.2 were shipped to ODFW Bonneville Fish Hatchery (Table 15).

A total of 22 1996-brood fish that did not mature in 1999 were maintained in freshwater at BBC and seawater at Manchester. Unfortunately, all the remaining fish reared in freshwater had succumbed to BKD by January 2000. Survival for seawater reared fish from smolt to age-4 adult through August 2000 was 67%. These fish were transferred to freshwater at BBC in August for final maturation and are expected to mature and spawn in fall 2000.

1993-Brood from Wild Residual Spawners

First generation rearing and spawning

Members of the NMFS Biological Review Team theorized that residual fish helped maintain the Redfish Lake sockeye salmon population during historic population lows (Waples et al. 1991a). In fall 1993, eight male and two female residual sockeye salmon were captured at the sockeye salmon spawning beach in Redfish Lake (Johnson and Pravecek 1995). These maturing adult fish were moved to the Sawtooth Hatchery and spawned in early November 1993 by IDFG. This spawning resulted in about 240 eyed eggs that were divided approximately equally between IDFG and NMFS (Flagg and McAuley 1995, 1996, Johnson and Pravecek 1995, Flagg et al. 1996).

As described by Flagg and McAuley (1995, 1996) and Flagg et al. (1996), the NMFS portion of the eggs from the 1993-brood residual spawners were incubated and juveniles reared at

BBC. Unfortunately, eggs and fry from female A were not normal and 85% died before ponding. The remaining 15% died soon after ponding. A similar situation occurred with eggs and fry from female A at the IDFG Eagle Creek Hatchery. However, 51 fish from female B were successfully ponded at BBC. Groups of fish were PIT tagged, combined, and moved to 4.1-m tanks at BBC in early 1995. At smolting in May 1995, 18 fish were transferred to the NMFS Manchester Research Station for rearing to maturity in tanks supplied with filtered and UV-treated seawater. Another 19 fish were retained at BBC for rearing to maturity in freshwater.

Overall survival was about 40% during the 34 months of rearing from hatching in early 1994 through fall 1996 for these groups of fish (Table 1). Combined survival was 63.8% from hatch to smolt age after 15 months of rearing. Survival for the next 19 months for fish reared full-term from smolt age to maturity in freshwater was 52.6% (33.6% overall survival), and 72.2% (46.1% overall survival) in seawater (Table 5). A total of 80% of the surviving fish reared in freshwater (n = 7) and about 69% of the fish reared in seawater (n = 7) matured in fall 1996 (Tables 4 and 5).

There were no female spawners from the full term freshwater rearing at BBC (Table 4). However, some male fish matured from this rearing treatment, these fish averaged 42.7 cm and 1.15 kg (Table 10). One female was spawned from the smolt-to-adult rearing treatment in the filtered and UV-treated seawater system at Manchester. This fish was 37.5 cm long and weighed 0.77 kg (Table 10). Fecundity was 925 eggs/female (about 1,201 eggs/kg of female weight) for the 1993-brood females spawned in 1996 (Table 6). Egg viability for the fish was about 96.0%, resulting in 889 eyed eggs (Table 6). Several adult males also matured and one fish was spawned from this treatment. These fish averaged 42.3 cm and 1.24 kg (Table 10).

A total of six 1993-brood from residual spawners survived but did not mature in fall 1996 (Table 1). NMFS maintained two of these fish at BBC in freshwater and four fish in the seawater system at Manchester.

Overall survival of 1993 brood from hatch to spawning at 4 years of age was 38% (Table 1). Combined survival was 63.8% from hatch to smolt age after 16 months of rearing. Survival for the next 31 months for fish reared full-term from smolt age to maturity in freshwater was 52.6%, compared to 66.6% for fish reared from smolt to adult in seawater (Table 5). No female or male adult fish reared full-term in freshwater were spawned in fall 1997. There were also no seawater reared females spawned. Only one seawater reared male spawned, at 53.0 cm and 1.93 kg. A total of four prespawning adults, two freshwater reared females and two seawater reared females were released in September 1997 into Redfish Lake as part of a volitional spawning population (Table 4).

First generation egg transfers

In November 1996, 889 eyed eggs from these 1993-brood from residual spawner groups were transported to Idaho and placed into in-lake incubation boxes in Redfish Lake (Table 6).

1993-Brood from Captive-Reared Spawners Collected as Juvenile Outmigrants

First generation rearing and spawning

As described in Flagg and McAuley (1995, 1996), Johnson and Pravecek (1995), and Flagg et al. (1996), from 1991-1993, IDFG maintained captive broodstocks of sockeye salmon captured as outmigrants from Redfish Lake in spring 1991. These fish were probably the same year-class(es) as the two female and six male sockeye salmon that returned to Redfish Lake in 1993. A total of 16 females from this group were spawned in October 1993. Although males from this group appeared to be maturing, only a few produced milt. Therefore, IDFG combined the majority of eggs from each female with milt from either one of the six anadromous males that returned in 1993 or with precocious males from broodstock of the one female and three male sockeye salmon that returned to Redfish Lake in 1991. Most of the progeny from the 1993 spawning of IDFG’s outmigrant-to-adult broodstock were used in recovery programs at Redfish Lake in 1994 and 1995 (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., May 1995). As a precaution, it seemed reasonable that a safety-net captive brood be established to protect against loss if outplants initially failed. [Note: Less than 700 fish outmigrated from the lake in spring 1995 from stockings of about 14,000 fish in 1994 (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., August 1995). Therefore, establishment of this safety-net captive broodstock appears to have been a life saver for this 1993-brood outmigrant-to-adult Redfish Lake sockeye salmon captive broodstock genetic group.]

Second generation rearing and spawning

NMFS hatched a total of 701 1993-brood eggs from the spawning of outmigrant-to-adult Redfish Lake sockeye salmon captive broodstock to initiate a safety-net captive broodstock for this group (Flagg and McAuley 1995, 1996, Flagg et al . 1996). The eggs were incubated and juveniles reared at BBC. Groups were PIT tagged, combined, and moved to 4.1-m tanks at BBC in early 1995. At smolting in May 1995, 419 fish were transferred to the NMFS Manchester Marine Experimental Station for rearing to maturity in 4.1-m tanks supplied with filtered and UV-treated seawater. Another 178 fish were retained at BBC for rearing to maturity in freshwater.

Overall survival was about 70% during the 35 months of rearing from hatching in late December 1993 through fall 1996 for these groups of fish (Table 1). Combined survival was 85.7% from hatch to smolt age after 16 months of rearing. Survival for the next 19 months for fish reared full-term from smolt age to maturity in freshwater was 91.1% (78.1% overall survival), and 77.2% (66.2% overall survival) in seawater (Table 5). About 91% of the surviving fish reared in freshwater (n = 145) and about 60% of the fish reared in seawater (n = 183) matured in fall 1996 (Tables 4, and 5). Higher growth rate in constant temperature well water is a probable cause of the higher 3-year-old maturation rate for these freshwater vs. seawater reared fish.

In September 1996, six prespawning adults from the group reared in freshwater (three females and three males) and 28 from the group reared in seawater (14 females and 14 males) were released in Redfish Lake as part of a volitional spawning population (Table 4). All remaining mature females (n = 147) and about 65% of the maturing males (n = 96) were spawned at BBC in October-November 1996 (Table 10). Female spawners from full term freshwater rearing at BBC averaged 45.8 cm and 1.24 kg,, while male spawners averaged 45.9 cm and 1.36 kg (Table 10). Fecundity averaged 1,392 eggs/female (about 1,122 eggs/kg of female weight) for the 1993-brood females spawned in 1996 (Table 6). Egg viability for these fish was about 66.1%, resulting in 66,257 eyed eggs (Table 6). Female spawners reared from smolt-to-adult in the filtered and UV-treated seawater system at Manchester averaged 42.4 cm and 1.01 kg, while male spawners averaged 42.5 cm and 1.09 kg (Table 10). Fecundity averaged 1,264 eggs/female (about 1,251 eggs/kg of female weight) for the 1993-brood females spawned in 1996 (Table 6). Egg viability for these fish was about 68.7%, resulting in 58,137 eyed eggs (Table 6).

A total of 149 1993-brood from captive reared spawners survived but did not mature in 1996 (Table 1). NMFS maintained 44 of these fish at BBC in freshwater and 105 in the seawater system at Manchester. These fish averaged about 1.5 kg each. Overall survival of 1993 brood from hatch to spawning at 4 years of age was 61% (Table 1). Combined survival was 85.7% from hatch to smolt age after 16 months of rearing; survival for the next 31 months for fish reared full-term from smolt age to maturity in freshwater was 87.8%, compared to 63.4% for fish reared from smolt to adult in seawater (Table 5). Female spawners from full term freshwater rearing at BBC (n = 7) averaged 55.6 cm and 2.22 kg, while male spawners (n = 2) averaged 55.7 cm and 2.16 kg (Table 11). Fecundity averaged 2,203 eggs/female (about 992 eggs/kg of female weight) for the 1993-brood females spawned in 1997 (Table 8). Egg viability for these fish was 45.9%, resulting in 5,058 eyed eggs (Table 8). Female spawners reared from smolt-to-adult in the filtered and UV-treated seawater system at Manchester (n = 42) averaged 57.8 cm and 2.73 kg, while male spawners (n = 21) averaged 60.4 cm and 3.66 kg (Table 11). Fecundity averaged 2,661 eggs/female (about 975 eggs/kg of female weight) for the 1993-brood females spawned in 1997 (Table 8). Egg viability for these fish was about 25.4%, resulting in 24,295 eyed eggs (Table 8). Spawn from these fish were returned to Idaho for use in recovery efforts.

Second generation egg transfers

In November 1996, 61,830 eyed eggs from these 1993-brood from captive reared spawner groups were transported to Idaho and placed into in-lake incubation boxes in Redfish Lake (Table

7). In December 1996, an additional 21,868 eyed eggs from these groups were transported to the IDFG Eagle Hatchery and 8,727 eyed eggs were transported to the Sawtooth Hatchery for final incubation and rearing for juvenile release to aid recovery of ESA-listed endangered Snake River Sockeye salmon in Stanley Basin lakes. In December 1996, another 22,251 eyed eggs were transported to the ODFW Bonneville Hatchery for rearing to smolt for release into Stanley Basin habitats (Table 7). An additional 8,033 eyed eggs were transported to the Sawtooth Hatchery and 1,400 to the Bonneville Hatchery in early 1997 (Table 7).

In November 1997, 25,170 eyed eggs from these 1993-brood from captive reared spawner groups were transported to Idaho and placed into in-lake incubation boxes in Redfish and Alturas Lakes (Table 9). In December 1997, an additional 3,248 eyed eggs from these groups were transported to the Sawtooth Hatchery for final incubation and rearing for juvenile release in Stanley Basin lakes (e.g., Redfish, Pettit, and Alturas Lakes).

1993-Brood Progeny, Smolt Rearing

1996-brood, ODFW smolt rearing--NMFS retained approximately 80,000 eyed eggs from the spawning of 1993-brood Redfish Lake sockeye salmon captive broodstock in fall 1996 (Flagg and McAuley 1997). About 57,000 of the eggs were from spawning of 1993-brood from wild spawners and 23,000 of the eggs were from 1993-brood from captive-reared spawners (see above). These eggs were initially incubated at BBC and subsequently transferred in December 1996 to ODFW for rearing at the Bonneville Hatchery near Cascade Locks, Oregon (Flagg and McAuley 1997, 1998). The eggs were transferred from NMFS to ODFW under ESA Permit 1005 and ODFW authorization letter issued 18 December 1996. All eggs were from parents with OD levels > 0.4. Fish rearing for these groups was conducted under Permit 1005.

The fish were reared using standard fish culture practices and approved therapeutics. Fish were fed a commercial ration (e.g., Biodiet). Survival was high (> 85%) for all groups during rearing. Mortalities were examined by an ODFW fish pathologist to determine cause of death. All groups were certified negative by ODFW pathologists for important culturable viral and bacterial pathogens (R. Holt, ODFW, pers. commun., December 1997, and April 1998).

All fish from the NMFS captive broodstocks for 1996-brood held at the ODFW Bonneville Hatchery were tagged with coded wire tags (CWT) and left ventral (LV) and adipose fin clipped by ODFW in January 1998. The fish were tagged in two release groups, Redfish Lake Creek (Group 1, n = about 28,500) and the Salmon River (Group 2, n = about 40,500). The coded wire tag code for Group 1 was 092445 and 092444 for Group 2. Above totals include 1,000 PIT-tagged fish per group, tagged by NMFS (following the methods of Prentice et al. 1990a, b).

Releases of fish occurred on 28 April and 4 May 1998 as a cooperative effort between NMFS, IDFG, and ODFW (Flagg et al. 1999). These fish were transferred and released under

ESA Permit 1148 and IDFG Transfer Permit HQ-98-15. Adults from these releases were expected to begin returning to Redfish Lake in 2000 as 2-ocean age fish. However, seven adults (one female and six males) returned in 1999 (see below), a year earlier than expected, as 1-ocean age fish (Kline 1999).

1999 and 2000 Adult Returns

In 1999, seven adult sockeye salmon (one female and six males) returned to the Stanley Basin (P. Kline, IDFG, unpubl. information). These fish were progeny of 1996 spawners that were reared to smolt at the ODFW Bonneville Hatchery and subsequently released below Redfish Lake in 1998 (see above). This represented the first return of program hatchery sockeye to the Stanley Basin. The wild spawning lineage for this 1999 adult return was probably fish spawning in Redfish Lake in 1989. The fish were captured at the Sawtooth Fish Hatchery weir during upstream migration and held at the Sawtooth Hatchery. Three of the wild-returning males were released into Redfish Lake on September 15 to spawn volitionally. The remaining three males, and the single female, were moved to the IDFG Eagle Fish Hatchery, and spawned on 1 October 1999 (Kline 1999). The eggs were divided into four sub lots, with three sub lots fertilized with different captive reared males from the IDFG Redfish Lake sockeye broodstocks, and the fourth sub lot fertilized with the combined milt from the three wild returning sockeye males. In November 1999, 198 eggs (Table 1) from two of the 1999-brood sub lots that were fertilized with different captive reared males (66 eggs per group), and the sub lot fertilized with the combined milt of the three wild returning males (66 eggs) were transferred from IDFG to NMFS under ESA Permit 1120 and WDFW Fish Transfer Permit 3108-11-99. Survival from transfer through August 2000 has been lower than expected (52%) (Table 1), due to a 15% loss prior to hatch, and a 36% unexplained mortality in the first month post ponding. We expect most of these fish to spawn between fall 2002 and fall 2003. Eggs from this program will be returned to Idaho for use in recovery efforts for Snake River sockeye salmon.

In 2000, a total of 243 age-4 fish, 189 of which were from smolts reared at Bonneville Hatchery and released into Redfish Lake Creek and the Salmon River, returned to the Stanley Basin (0.27% smolt-to-adult return). A total of 92 of these fish were caught at the Redfish Lake Creek trap and another 97 were caught at the Sawtooth Hatchery weir. A total of 200 of the 243 returning fish (164 of which were reared at Bonneville Hatchery) were released into Stanley Basin lakes in early September for volitional spawning. A total of 43 fish are being held at the IDFG Eagle Fish Hatchery for spawning into the captive brood program.

2.3-- 1994 Captive Broodstock Lineage

First generation rearing and spawning

In 1994, one adult sockeye salmon female returned to Redfish Lake. This fish was captured at the weir on Redfish Lake Creek during upstream migration in August, moved to the IDFG Eagle Hatchery, and spawned in early October by IDFG. The eggs were divided into four groups and each group was fertilized with a captive-reared male from the IDFG 1991-brood of Redfish Lake sockeye salmon. The wild spawning lineage for 1994 adult return was probably fish spawning in Redfish Lake in 1990. In December 1994, 461 eggs from the 1994 brood Redfish Lake sockeye salmon (approximately 120 eggs from each group) were transferred from IDFG to NMFS under ESA Permit 795 and WDFW Fish Transfer Permit 2066-12-94. Almost all of these eggs were viable (Flagg and McAuley 1995, 1996, Flagg et al. 1996).

Eggs from these four matings were successfully incubated at BBC. In February 1995, 434 fry were ponded as discrete half-sib groups in 1.8-m tanks at BBC. Almost all fry in one tank were lost due to a clogged inlet screen, resulting in reduced oxygen level and suffocation of about 100 fish. Groups of fish were PIT tagged, combined, and moved into two 4.1-m tanks at BBC in early 1996. Overall survival was about 50% during the 35 months of rearing from hatching in late December 1994 through spawning in fall 1997 (Table 1). About 90% of surviving fish (n = 224) matured in fall 1997.

In September 1997, 36 prespawning adult fish (18 females and 18 males) were released in Redfish Lake as part of a volitional spawning population (Table 16). All remaining mature females (n = 65) and mature males (n = 123) were spawned in October-November 1997 (Table 16). Female spawners averaged 48.9 cm and 1.52 kg, while male spawners averaged 50.3 cm and 1.87 kg (Table 2). Fecundity averaged 1,715 eggs/female (1,128 eggs/kg of female weight) for the 1994-brood females spawned in 1997 (Table 3). Egg viability for these fish was 73.6%, resulting in 80,869 eyed eggs (Table 3).

A total of 24 1994-brood survived but did not mature in 1997. Unfortunately, all 24 fish were lost in December 1997 due probably to inadequate neutralization and flushing of the rearing tank after disinfecting with chlorine.

In fall 1997, IDFG transferred 304 immature adults to NMFS to alleviate a fish crowding situation at their Eagle Hatchery (Table 1). These fish were transferred under ESA Permit 795 and WDFW Transfer Permit 2671-11-97. BKD was documented in mortalities during the rearing period at BBC. Survival of these fish from transfer to spawning in fall 1998 was 39% (Table 1).

However, only 13 females matured; producing only 15 viable eyed eggs. Similar, poor gamete contribution was observed for 1993-brood prespawning groups transferred in 1996 (see Section 1.2). The probable cause is inability of fish reared at the IDFG Eagle Hatchery to achieve a second year maturation opportunity (most cohorts had spawned the previous year at Eagle Hatchery). This husbandry strategy was henceforth abandoned.

First generation egg transfers

In November 1997, a total of 56,469 eyed eggs from these 1994-brood from wild spawner females were transferred to Idaho and placed into 12 in-lake incubation boxes in Redfish and Alturas Lakes (Table 17). In December 1997, an additional 23,954 eyed eggs were transported to the Sawtooth Hatchery for final incubation and rearing for juvenile release to aid recovery of ESA-listed endangered Snake River Sockeye salmon in Stanley Basin lakes (Table 17).

Second generation rearing

In 1997, 296 eyed eggs from the 1994-brood of the IDFG wild spawner group reared full-term to maturity in freshwater and spawned in 1997 were transferred to BBC for rearing to maturity as a second generation safety-net captive broodstock for this important 1990 wild spawning lineage genetic group (Table 1). These eggs were transferred under ESA Permit 795, and WDFW Transfer Permit 2679-11-97. Survival of these fish through August 2000 has been about 72%. In October 1999, 76 males matured as age-2 spawners. The average weight of these males was 0.8 kg and the average length was 38.8 cm (Table 18). Milt from these males was used to fertilize eggs from 1) second generation females from the wild returning 1993-brood and 2) first generation females from the single wild returning 1996-brood female. We expect the remainder of these fish to spawn between fall 2000 and fall 2001. Spawn from these fish will be returned to Idaho for use in recovery efforts for Snake River sockeye salmon.

Adult Release Program

In April 1999, the SBSTOC adopted a plan to supplement the Redfish Lake sockeye captive brood program with an annual adult release program. This program would encompass rearing additional fish (beyond the number required for the captive brood program) to maturity in NMFS fresh and seawater facilities, and releasing the adults into Stanley Basin lakes for volitional spawning.

In May 1999, 310 smolts (Table 1) from the BY97 production group reared at Sawtooth Hatchery were transferred to the Manchester Research Station for grow-out to pre-spawning adult. Survival through August 2000 has been 78%. In September 2000, 61 maturing fish were transferred to Stanley Basin lakes for volitional spawning. The remainder of the population is expected to mature in fall 2001.

2.4-- 1996 Captive Broodstock Lineage

First generation rearing and spawning

In 1996, one adult sockeye salmon female returned to Redfish Lake. This fish was captured at the weir on Redfish Lake Creek during upstream migration, moved to the IDFG Eagle Hatchery, and spawned in late September by IDFG. The female's eggs were divided into four groups and each group was fertilized with a captive-reared male from IDFG's Redfish Lake sockeye salmon broodstocks. The wild spawning lineage for the 1996 adult return was probably fish spawning in Redfish Lake in 1992. In November 1996, 412 eggs (Table 1) from the 1996-brood Redfish Lake sockeye salmon (approximately 103 eggs from each group) were transferred from IDFG to NMFS under ESA Permit 1005 and WDFW Fish Transfer Permit 2483-11-96. Almost all of these eggs were viable.

Eggs were incubated and juveniles reared at BBC. Groups of fish were PIT tagged, combined and moved into two 4.1-m tanks at BBC in late 1997. In May 1998, 74 of these 1996-brood were transferred to seawater at Manchester, at an average weight of 131 g. The remaining 171 were retained in freshwater at BBC. Survival for both the fresh and seawater reared fish through December 1998 was 51%. Most mortalities were attributed to abnormally high levels of opticalplasia, resulting in blindness and a high rate of attrition at ponding. These developmental deformities were also noted as an elevated cause of mortality in the IDFG captive broodstock for this group (K. Johnson, IDFG, unpubl. data). An unusually high number (24%) of the freshwater reared population matured as 2-year-olds in fall 1998. A total of 39 fish (1 female and 38 of the available 57 males) were spawned in October-November 1998 (Table 19). The single female spawner (0.6% of the captive population) had a length of 33.3 cm, and a weight of 0.51 kg, while male spawners averaged 34.6 cm, and 0.53 kg (Table 20). Fecundity was 997 eggs (1,955 eggs/kg of female weight) for this 1996-brood female (Table 14). Egg viability was 53.4%, resulting in 553 eyed eggs (Table 14). The IDFG-held population also produced mature 2-year-old females, but at an even higher rate, 8.5% vs. 0.6% for NMFS (Kline and Heindel 1999). This marked the first occurrence of mature 2-year-old females in the Redfish Lake sockeye captive brood program.

A total of 152 1996-brood that did not mature in 1998 (Table 1) were maintained in freshwater at BBC (n = 100) and in seawater at Manchester (n = 52). Combined survival for both fresh and seawater reared fish through August 2000 was 28% (Table 1). Combined survival was 60% from hatch to smolt age after 16 months of rearing. Survival for the next 17 months for fish reared full-term from smolt age to maturity in freshwater was 50.3%, compared to 83.8% for fish reared from smolt to adult in seawater (Table 12). Female spawners from full term freshwater rearing at BBC (n = 23) averaged 49.6 cm and 1.6 kg, while male spawners (n = 4) averaged 44.0 cm and 1.2 kg (Table 13). Fecundity averaged 1,724 eggs/female (about 1,078 eggs/kg of female weight) for the 1996-brood females spawned in 1999 (Table 14). Egg viability for these fish was 35.3%, resulting in 14,003 eyed eggs (Table 14). Female spawners reared from smolt-to-adult in the filtered and UV-treated seawater system at Manchester (n = 13) averaged 43.4 cm and 0.9 kg, while male spawners (n = 5) averaged 44.4 cm and 1.2 kg (Table 13). Fecundity averaged 1,233 eggs/female (about 1,370 eggs/kg of female weight) for the 1996-brood females spawned in 1999 (Table 14). Egg viability for these fish was about 53.9%, resulting in 7,311 eyed eggs (Table 14).

In November and December 1999, approximately 13,162 eyed eggs from parents with ODs < 0.2 from NMFS's spawning in 1999 of 1996-brood Redfish Lake sockeye salmon were shipped to Sawtooth Hatchery for final incubation and rearing for juvenile release (Table 15). In addition, approximately 5,012 eyed eggs from parents with ODs > 0.2 were shipped to ODFW Bonneville Fish Hatchery for rearing to smolt for release into Stanley Basin habitats (Table 15).

A total of 41 1996-brood that did not mature in 1999 were maintained in freshwater at BBC (n = 21) and in seawater at Manchester (n = 20). Unfortunately, all the remaining fish at BBC succumbed to BKD by February 2000 (survival = 38%). Survival for seawater reared fish from smolt to age-4 adult through August 2000 has been 75%. These fish were transferred to freshwater at BBC in August for final maturation and are expected to mature and spawn in fall 2000.

Second generation rearing

In 1998, green eggs from the 1996-brood of the IDFG wild spawner group reared to maturity in freshwater were fertilized with milt from the lone returning 1998-brood wild male to create a second generation safety-net captive brood. A total of 55 eyed eggs from this safety-net were transferred to BBC for rearing to maturity (Table 1). These eggs were transferred under ESA Permit 1120 and WDFW Transfer Permit 2905-11-98. Survival through August 2000 has been 53% (Table 1). We expect these fish to spawn between fall 2001 and fall 2002.

In 1999, green eggs from the 1996-brood of the IDFG wild spawner group reared to maturity in freshwater were fertilized with milt from various lineages of the IDFG captive brood program to create a second generation captive brood. A total of 396 eyed eggs for this program were transferred to BBC for rearing to maturity in the captive broodstock program (Table 1). These eggs were transferred under ESA permit 1120, and WDFW Transfer Permit 3108-11-99. Survival through August 2000 has been 71% (Table 1). We expect most of these fish to spawn between fall 2002 and fall 2003.

Adult Release Program

In fall 1998, green eggs and milt from two sub-families of the 1996-brood of the IDFG wild spawner group were used to create a BY98 adult release group. A total of 401 eyed eggs were committed to this program. These offspring were reared to smolt stage in freshwater, then transferred to seawater at Manchester in May 2000 for grow-out to pre-spawning adult. Survival through August 2000 has been 89% (Table 1). About 30% of the population was projected to mature and spawn volitionally in fall 2001, with the remainder spawning in fall 2002. However, due to the genetic consequences of early (precocial) age-2 maturation originating from the maternal lineage (single wild female that returned in 1996), 46% of these fish are maturing in fall 2000. Similar results are being seen in IDFG reared groups with the same maternal lineage.

In February 2000, 325 swim-up fry from the 1996-brood of the IDFG wild spawner group reared to maturity in freshwater and 75 swim-up fry from the IDFG BY99 sub lots were combined and transferred from IDFG to NMFS to create a BY99 adult release group (Table 1). Survival through August 2000 has been 97% (Table 1). Most of these fish are expected to mature between fall 2002 and fall 2003.

2.5-- Conclusions

Because of the low replacement rate and critically low population size of Redfish Lake sockeye salmon, captive broodstocks appear to offer the only hope to maintain this species while habitat improvements are underway. Current natural survival of Redfish Lake sockeye salmon is at best a few tenths of one percent. Survival for the nine groups of Redfish Lake sockeye salmon cultured through complete egg-to-adult cycles has ranged 13-85% and averaged 50%. Thus, the population amplification potential is significant.

Current captive broodstock culture technologies are producing adults within the expected 1 - 2 kg range for Redfish Lake sockeye salmon. However, egg viabilities are below expectations for wild counterparts; 30-70% range vs. 90%+ for wild fish. Both freshwater and UV-treated seawater culture appear to produce fish with similar survival, size, and maturation attributes. Thus, culture in either medium appears suitable for these captive broodstocks. During the program, over 742,000 eggs, 90,000 smolts and 180 prespawning adults have been returned to Idaho for use in recovery efforts.

It is virtually certain that without the boost provided by these captive broodstock projects, Redfish Lake sockeye salmon would soon be extinct. However, captive broodstocks should be viewed as a short-term measure to aid in recovery of the gene pool, and not as a substitute for recovering naturally spawning fish to the ecosystem. Effective recovery of the species requires relaxation of barriers to survival to produce natural long-term increases in population size. Once these barriers are relaxed, the relatively stable egg supply assured through captive broodstock projects should help guarantee the success of recovery efforts for Redfish Lake sockeye salmon.

August 1999 and 2000 marked a milestone in the use of captive broodstock technology to help restore the region's ESA-listed salmon stocks. The first adult returns to the Stanley Basin from the captive broodstock program began with 7 fish in 1999 and increased to about 250 fish in 2000.

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TABLES AND FIGURES

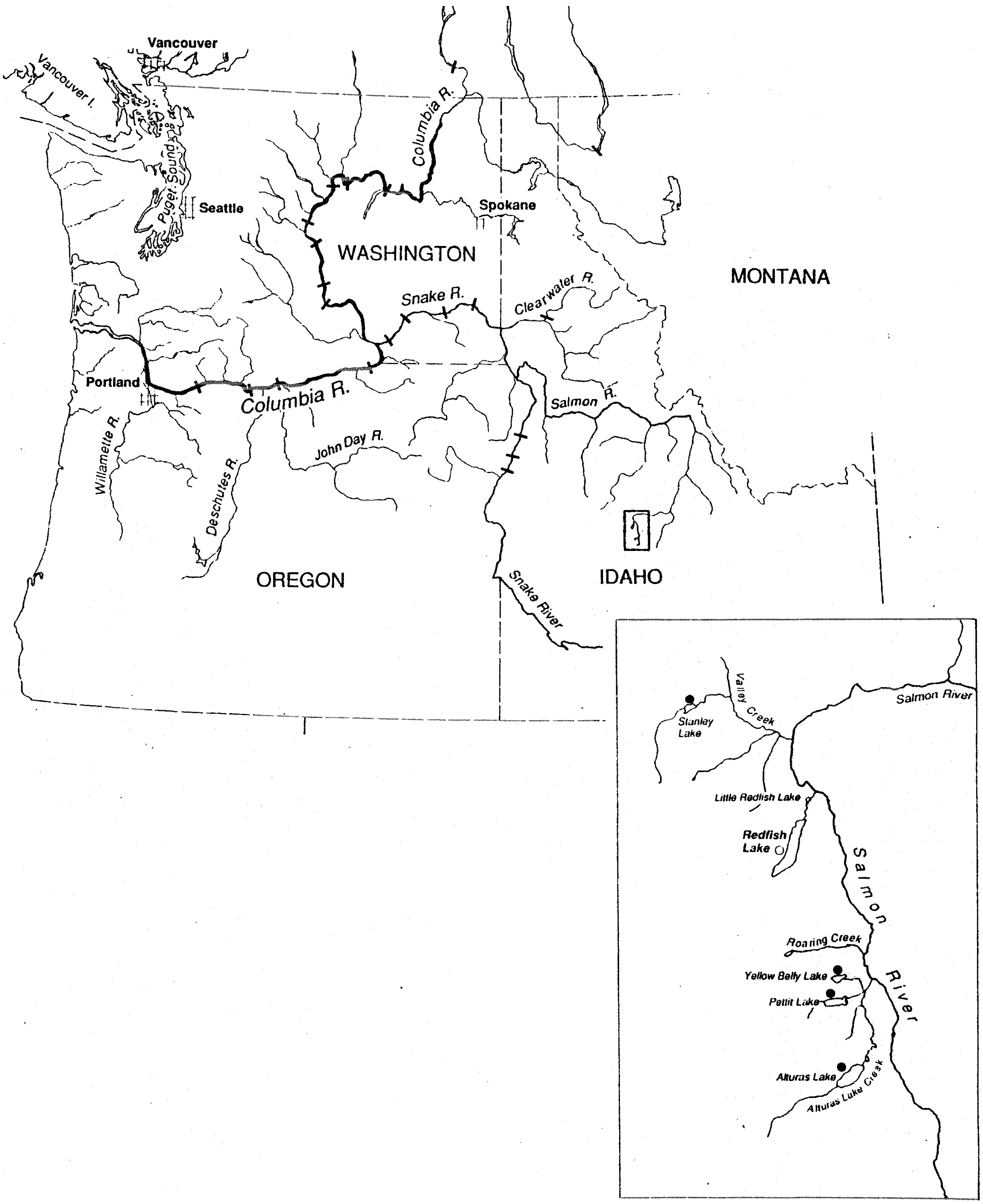

Figure 1. Map showing location of Redfish Lake. Sockeye salmon returning to Redfish Lake travel a greater distance from the sea (almost 1,450 km) and spawn at a higher elevation (almost 2,000 m) than any other sockeye salmon population.

Table 1. Status of Redfish Lake sockeye salmon captive broodstocks maintained by NMFS through August 2000.

Broodstock source	Wild spawning lineage[a]	Initial inventory	Source	Months in culture	Average survival (%) [b]	Number of mature females	Number of mature males[c]	Inventory number
Wild adult returns[d]								
Fall 1991	1987	991	eggs	35	13	56	70	0
Fall 1993	1989	1180	eggs	35	83	364	523	104
				48	81	26	45	0
Fall 1994	1990	461	eggs	35	50	65	149	0
Fall 1996	1992	412	eggs	25	51	1	58	152
				35	30	36	9	18
				43	28			13
Wild adult residuals[d]								
Fall 1993	1989	58	eggs	34	40	1	47	6
				46	38	4	1	0
Captive reared adults (F2)[e]								
Fall 1993	1989[f]	701	eggs	35	70	164	180	149
				48	61	51	33	0
Fall 1994	1987[g]	305	smolts	35	70	7	36	170
				48	63	55	82	0
Fall 1996	1989[h]	500	eggs	25	54	0	4	266
				35	35	112	51	5
				43	34			4
Fall 1997	1990[i]	296	eggs	25	85	0	76	176
				33	72			136
Fall 1997	1990[j]	310	smolts	16	78			242
Fall 1998	1992[k]	55	eggs	21	53			29
Fall 1998	1992[l]	401	eggs	21	89			358
Fall 1999	1992[k]	396	eggs	9	71			281
Fall 1999	1992[k],1989	400	fry	8	97			386
Captive reared adults (F3)[m]								
Fall 1998	1987[n]	127	eggs	21	87			111
IDFG age-3 fish transfer[o]								
Fall 1993	1989	151	age-3	13	62	16	77	0
Fall 1994	1990	304	age-3	12	39	13	31	0
Anadromous returns from captive broodstocks[p]								
Fall 1999	1989	198	eggs	9	52			102

[a] Scale and otolith analysis indicates that most adults captured for broodstock were 4 years old at maturity (P. Kline, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., December 1996). Wild spawning lineage year is age class back calculation to presumed most recent natural wild spawning event year for broodstock.

[b] Captive broodstocks are being held as multiple discrete lots in multiple rearing tanks supplied with either fresh (well) water or filtered and UV-treated seawater. Survival percentage is approximate overall average.

[c] Some male fish matured as jacks in fall 1995, 1996, 1998 and 1999.

[d] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[e] Second generation captive broodstocks.
[f] Fish are progeny of wild juveniles captured outmigrating from Redfish Lake in 1991, reared, and spawned by IDFG.
[g] Fish are progeny of 1991-brood reared to maturity at NMFS facilities.
[h] Fish are progeny of 1993-brood reared to maturity at NMFS facilities.
[i] Fish are progeny of 1994-brood reared to maturity at IDFG facilities.
[j] Fish are progeny of 1994-brood reared to maturity at NMFS and IDFG facilities for release as adults into Stanley Basin Lakes.
[k] Fish are progeny of 1996-brood reared to maturity at IDFG facilities.
[l] Fish are progeny of 1996-brood reared to maturity at NMFS facilities for release as adults into Stanley Basin Lakes.
[m] Third generation captive broodstocks.
[n] Fish are second generation progeny of 1991-brood reared to maturity at NMFS facilities.
[o] Age-3 fish transferred by IDFG to NMFS to alleviate a fish rearing space overload at the IDFG Eagle Hatchery.
[p] Fish are ocean return adults from fish released from 1993-brood captive broodstock spawned in 1996.

Table 2. Weight, length, and number of age-3 and age-4 1994 brood Redfish Lake sockeye salmon spawned at NMFS facilities, 1997 and 1998.

Broodstock source	Female		Male[a]	
	Freshwater[b]	Seawater	Freshwater	Seawater
Wild adult returns (age-3)[c]				
Number of fish spawned	65	--	74	--
Length (cm)	48.9	--	50.3	--
Weight (kg)	1.52	--	1.87	--
Captive reared adults (age-3)[c]				
Number of fish spawned	--	7	--	36
Length (cm)	--	40.1	--	43.5
Weight (kg)	--	0.81	--	1.12
Captive reared adults (age-4)[d]				
Number of fish spawned	--	55	--	82
Length (cm)	--	49.8	--	51.1
Weight (kg)	--	1.61	--	1.88
Combined data				
Number of fish spawned	65	62	74	118

[a] Some male fish matured but were not spawned. Male length and weight data from subsample n = 123 for progeny of the wild adult return group reared from smolt to adult in freshwater. All males in the captive-reared group (n=118), reared in seawater, matured, but were not spawned.

[b] Freshwater = yearling smolt-age to adult rearing in fresh well water at BBC; seawater = yearling smolt-age to adult rearing in pumped, filtered, and UV-treated seawater at Manchester. Note: wild adult return offspring were reared from egg to smolt in fresh well water at BBC, captive-reared adult offspring were reared from fry to smolt age in fresh well water at Bonneville Hatchery.

[c] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[d] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by NMFS.

Table 3. Fecundity and egg viability for 1994 brood Redfish Lake sockeye salmon reared to age-3 and age-4 at NMFS facilities, 1997 and 1998[a].

Broodstock source	Females spawned	Fecundity (eggs/fish)	Green eggs (n)	Eyed eggs (n)	Viability (% to eye)
Wild adult returns[b]					
Freshwater age-3[c]	65	1,715	109,771	80,869	73.6
Captive reared adults[d]					
Seawater age-3	7	1,541	9,244	6,880	74.4
Seawater age-4	55	2,043	86,231	47,156	54.7
Combined data					
Total	127		205,246	134,905	65.7

[a] Data from fish spawned in captivity. In addition, 18 adult female fish from the wild adult returns were released in Redfish Lake and produced approximately 30,000 green eggs.

[b] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[c] FW = yearling smolt-age to adult rearing in fresh well water at BBC; SW = yearling smolt-age to adult rearing in pumped, filtered, and UV-treated seawater at Manchester. Note: wild adult return offspring were reared from egg to smolt age in fresh well water at BBC. Captive-reared adult offspring were reared from fry to smolt on fresh well water at Bonneville Hatchery.

[d] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by NMFS.

Table 4. Maturation records for 1993 brood Redfish Lake sockeye salmon reared at NMFS facilities, 1995-1997.

Broodstock source	Female[a]		Male[b]		Total
	Freshwater[c]	Seawater	Freshwater	Seawater	
Wild adult returns[d]					
Age-2 precocious (1995)	0	0	6	6	12
Age-3 adults (1996) released to Redfish Lake	17	6	17	6	46
Age-3 adults (1996) matured in captivity	323	18	455	33	829
Age-4 adults (1997) matured in captivity	2	24	4	41	71
Wild adult residuals[d]					
Age-2 precocious (1995)	0	0	1	2	3
Age-3 adults (1996) released to Redfish Lake	0	0	0	0	0
Age-3 adults (1996) matured in captivity	0	1	7	6	14
Age-4 adults (1997) released to Redfish Lake	2	2	0	0	4
Age-4 adults (1997) matured in captivity	0	0	0	1	1
Captive reared adults[e]					
Age-2 precocious (1995)	0	0	4	12	16
Age-3 adults (1996) released to Redfish Lake	3	14	3	14	34
Age-3 adults (1996) matured in captivity	73	74	66	81	294
Age-4 adults (1997) matured in captivity	7	42	2	30	81
Combined data[f]					
Total age-2 (1995)	0	0	11	20	31
Total age-3 (1996)	416	113	548	140	1,217
Total age-4 (1997)	11	68	6	72	157

[a] All females that survived to maturity in captivity were spawned.

[b] All male fish that matured as age-2 jacks in 1995 and 35-70% of groups of males that matured as age-3 fish in 1996, and age-4 fish in 1997 were excess to spawning needs.

[c] All fish were reared from egg to smolt age in fresh well water at BBC. Yearling smolt-age fish were then reared to age-3 and age-4 adult in either fresh well water at BBC or in pumped, filtered, and UV-treated seawater at Manchester.

[d] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[e] Second generation captive broodstocks. Fish are progeny of wild juveniles captured, reared, and spawned by IDFG.

[f] Combined data from all rearing groups.

Table 5. Survival and percent maturation for 1993 brood Redfish Lake sockeye salmon reared to age-3 and age-4 at NMFS facilities, 1996 and 1997.

	Survival (%)					Maturation (%)	
Broodstock source	Hatch to smolt	Smolt to age 3	Smolt to age 4	Hatch to age 3	Hatch to age 4	Age 3	Age 4
Wild adult returns[a]							
Freshwater[b]	95.6	87.9	87.3	84.2	81.2	98.0	100.0
Seawater		86.7	71.3			42.0	100.0
Wild adult residuals[a]							
Freshwater	63.8	52.6	52.6	39.7	38.0	80.0	100.0
Seawater		72.2	66.6			69.0	100.0
Captive-reared adults[c]							
Freshwater	85.7	91.1	87.8	69.8	60.7	91.0	100.0
Seawater		77.2	63.4			60.0	100.0
Combined[d]							
Freshwater	91.0	87.8	86.8	77.6	72.3	97.0	
Seawater		79.9	65.9			55.0	

[a] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[b] All fish were reared from egg to smolt age in fresh well water at BBC. Yearling smolt-age fish were then reared to age-3 and age-4 adult in either fresh well water at BBC or in pumped, filtered, and UV-treated seawater at Manchester.

[c] Second generation captive broodstocks. Fish are progeny of wild juveniles captured, reared, and spawned by IDFG.

[d] Combined data from all rearing groups.

Table 6. Fecundity and egg viability for 1993 brood Redfish Lake sockeye salmon reared to age-3 at NMFS facilities, 1996[a].

Broodstock source	Females spawned	Fecundity (eggs/fish)	Green eggs (n)	Eyed eggs (n)	Viability (% to eye)
Wild adult returns[c]					
Freshwater[b]	323	1,420	455,733	244,801	53.7
Seawater	18	1,173	18,766	10,491	55.9
Wild adult residuals[c]					
Freshwater	0				
Seawater	1	925	925	889	96.0
Captive reared adults[d]					
Freshwater	73	1,392	100,222	66,257	66.1
Seawater	74	1,264	84,670	58,137	68.7
Combined data					
Total	489		660,316	380,575	57.6

[a] Data from fish spawned in captivity. In addition, 40 adult female fish were released in Redfish Lake and produced approximately 39,000 eyed eggs.

[b] FW = yearling smolt-age to adult rearing in fresh well water at BBC; SW = yearling smolt-age to adult rearing in pumped, filtered, and UV-treated seawater at Manchester. Note: all fish were reared from egg to smolt age in fresh well water at BBC.

[c] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[d] Second generation captive broodstocks. Fish are progeny of wild juveniles captured, reared, and spawned by IDFG.

[e] Approximately 1,900 (0.5%) died after eyeing; resulting in about 379,000 eggs available for transfer.

Table 7. Egg and fry distribution data for 1993 brood Redfish Lake sockeye salmon spawned at age-3 at NMFS facilities, 1996.

Broodstock source	Redfish Lake[a]	Eagle Hatchery[b]	Sawtooth Hatchery[b]	Bonneville Hatchery[c]	Total
Wild adult returns[d]					
Age 3	44,652	6,334	145,779[e]	56,140[f]	253,405[g]
Wild adult residuals[d]					
Age 3	889	0	0	0	889
Captive reared adults[h]					
Age 3	61,830	21,868	16,760[i]	23,921[j]	124,379
Combined data					
Total age-3	107,371	28,202	162,539	80,061	378,673

[a] Eyed eggs placed by NMFS and IDFG personnel into 21 in-lake incubation boxes (at about 5,000 eggs/box) in Redfish Lake in November 1996.

[b] Eyed eggs transferred to IDFG for rearing to juvenile stage for release into Stanley Basin habitats (e.g., Redfish, Pettit, and Alturas Lakes) in 1997.

[c] Transfer to ODFW for rearing to yearling smolt age for release into Stanley Basin Habitats (e.g., Redfish Lake Creek and the upper Salmon River) in spring 1998.

[d] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[e] Includes 10,244 eyed eggs transferred in January 1997.

[f] Includes 4,281 fry transferred in January 1997.

[g] Total includes 500 eyed eggs retained at BBC for second generation rearing.

[h] Second generation captive broodstocks. Fish are progeny of wild juveniles captured, reared, and spawned by IDFG.

[i] Includes 8,033 eyed eggs transferred in January 1997.

[j] Includes 1,400 eyed eggs transferred in January 1997.

Table 8. Fecundity and egg viability for 1993 brood Redfish Lake sockeye salmon reared to age- 4 at NMFS facilities, 1997[a].

Broodstock source	Females spawned	Fecundity (eggs/fish)	Green eggs (n)	Eyed eggs (n)	Viability (% to eye)
Wild adult returns[c]					
Freshwater[b]	2	1,893	3,785	292	7.7
Seawater	24	2,848	65,501	26,401	40.3
Wild adult residuals[c]					
Freshwater	0				
Seawater	0				
Captive reared adults[d]					
Freshwater	7	2,203	11,017	5,058	45.9
Seawater	42	2,661	95,806	24,295	25.4
Combined data					
Total	75		176,109	56,046	31.8

[a] Data from fish spawned in captivity. In addition, 4 adult female fish were released in Redfish Lake and produced approximately 4,000 green eggs.

[b] Freshwater = yearling smolt-age to adult rearing in fresh well water at BBC; seawater = yearling smolt-age to adult rearing in pumped, filtered, and UV-treated seawater at Manchester. Note: all fish were reared from egg to smolt age in fresh well water at BBC.

[c] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[d] Second generation captive broodstocks. Fish are progeny of wild juveniles captured, reared, and spawned by IDFG.

Table 9. Egg and fry distribution data for 1993 brood Redfish Lake sockeye salmon spawned at age-4 at NMFS facilities, 1997.

Broodstock source	Redfish Lake[a]	Alturus Lake[a]	Sawtooth Hatchery[b]	Total
Wild adult returns[c]				
Age 4	13,093	4,179	6,576	23,848
Wild adult residuals[c]				
Age 4	0	0	0	0
Captive reared adults[d]				
Age 4	21,968	3,202	3,248	28,418
Combined data				
Total age-4	35,061	7,381	9,824	52,266

[a] Eyed eggs placed by IDFG personnel into 9 in-lake incubation boxes (at about 5,000 eggs/box) in Redfish and Alturas Lakes in November 1997.

[b] Eyed eggs transferred to IDFG for rearing to juvenile stage for release into Stanley Basin habitats (e.g., Redfish, Pettit, and Alturas Lakes) in 1998.

[c] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[d] Second generation captive broodstocks. Fish are progeny of wild juveniles captured, reared, and spawned by IDFG.

Table 10. Weight, length, and number of age-3 1993 brood Redfish Lake sockeye salmon spawned at NMFS facilities, 1996.

Broodstock source	Female		Male[a]	
	Freshwater[b]	Seawater	Freshwater	Seawater
Wild adult returns[c]				
Number of fish spawned	323	18	225	17
Length (cm)	45.2	45.7	45.6	42.1
Weight (kg)	1.18	1.22	1.31	1.07
Wild adult residuals[c]				
Number of fish spawned	0	1	5	1
Length (cm)		37.5	42.7	42.3
Weight (kg)		0.77	1.15	1.24
Captive reared adults[d]				
Number of fish spawned	73	74	59	37
Length (cm)	45.8	42.4	45.9	42.5
Weight (kg)	1.24	1.01	1.36	1.09
Combined data[f]				
Number of fish spawned	396	93	289	55

[a] Some male fish matured but were not spawned. Male length and weight data from subsample n = 415 for progeny of wild adult returns reared from smolt to adult in freshwater and n = 31 for fish reared in seawater (see below); n = 7 for progeny of wild adult residuals reared from smolt to adult in freshwater and n = 6 for fish reared in seawater; and n = 65 for progeny of captive reared adult fish reared from smolt to adult in freshwater and n = 37 for fish reared in seawater.

[b] FW = yearling smolt-age to adult rearing in fresh well water at BBC; SW = yearling smolt-age to adult rearing in pumped, filtered, and UV-treated seawater at Manchester. Note: all fish were reared from egg to smolt age in fresh well water at BBC.

[c] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[d] Second generation captive broodstocks. Fish are progeny of wild juveniles captured, reared, and spawned by IDFG.

Table 11. Weight, length, and number of age-4 1993 brood Redfish Lake sockeye salmon spawned at NMFS facilities, 1997.

Broodstock source	Female		Male[a]	
	Freshwater[b]	Seawater	Freshwater	Seawater
Wild adult returns[c]				
Number of fish spawned	2	24	4	41
Length (cm)	52.9	58.4	57.7	60.9
Weight (kg)	1.84	2.75	2.81	3.28
Wild adult residuals[c]				
Number of fish spawned	0	0	0	1
Length (cm)				53.0
Weight (kg)				1.93
Captive reared adults[d]				
Number of fish spawned	7	42	2	21
Length (cm)	55.6	57.8	55.7	60.4
Weight (kg)	2.22	2.73	2.16	3.66
Combined data				
Number of fish spawned	9	66	6	63

[a] Some male fish matured but were not spawned. Male length and weight data from subsample n = 30 for progeny of captive reared adult fish reared from smolt to adult in seawater.

[b] FW = yearling smolt-age to adult rearing in fresh well water at BBC; SW = yearling smolt-age to adult rearing in pumped, filtered, and UV-treated seawater at Manchester. Note: all fish were reared from egg to smolt age in fresh well water at BBC.

[c] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[d] Second generation captive broodstocks. Fish are progeny of wild juveniles captured, reared, and spawned by IDFG.

Table 12. Survival and percent maturation for 1996-brood Redfish Lake sockeye salmon reared to age-3 at NMFS facilities, 1999.

	Survival (%)		Maturation(%)
Broodstock source	Hatch to smolt	Smolt to age 3	Age 3
Wild adult returns[a]			
Freshwater[b]	59.5	50.3	57.4
Seawater		83.3	40.9
Captive-reared adults[c]			
Freshwater	80.5	61.1	87.6
Seawater		69.2	87.7
Combined[d]			
Freshwater	60.0	56.3	79.5
Seawater		75.8	67.3

[a] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[b] All fish were reared from egg to smolt age in fresh well water at BBC. Yearling smolt-age fish were then reared to age-3 adult in either fresh well water at BBC or in pumped, filtered, and UV-treated seawater at Manchester.

[c] Fish are second generation progeny of 1993-brood reared to maturity at NMFS facilities.

[d] Combined data from all rearing groups.

Table 13. Weight, length, and number of age-3 1996 brood Redfish Lake sockeye salmon spawned at NMFS facilities, 1999.

Broodstock source	Female		Male	
	Freshwater[a]	Seawater	Freshwater	Seawater
Wild adult returns[b]				
Number of fish spawned	23	13	4	5
Length (cm)	49.6	43.4	44.0	44.4
Weight (kg)	1.6	0.9	1.2	1.2
Captive reared adults[c]				
Number of fish spawned	78	34	35	16
Length (cm)	49.4	43.6	50.0	45.4
Weight (kg)	1.6	0.9	1.9	1.2
Combined data				
Number of fish spawned	101	47	39	21

[a] Egg to adult fish were reared in freshwater.

[b] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[c] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by NMFS.

Table 14. Fecundity and egg viability for 1996 brood Redfish Lake sockeye salmon reared to ages-2 and 3 at NMFS facilities, 1998 and 1999[a].

Broodstock source	Females spawned	Fecundity (eggs/fish)	Green eggs (n)	Eyed eggs (n)	Viability (% to eye)
Wild adult returns[b]					
Freshwater age-2[c]	1	997	997	533	53.4
Freshwater age-3	23	1,724	39,647	14,003	35.3
Seawater age-3	11	1,233	13,564	7,311	53.9
Captive reared adults[d]					
Freshwater age-3	73	1,919	138,153	37,291	27.0
Seawater age-3	32	1,239	39,652	17,113	43.2
Combined data					
Total	140	---	232,013	76,271	32.9

[a] Data from fish spawned in captivity.

[b] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[c] FW = yearling smolt-age to adult rearing in fresh well water at BBC; SW = yearling smolt-age to adult rearing in pumped, filtered, and UV-treated seawater at Manchester. Progeny of captive-reared and wild adult returns were reared from egg to smolt age in fresh well water at BBC.

[d] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by NMFS.

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Table 15. Egg and fry distribution data for 1996 brood Redfish Lake sockeye salmon spawned at age-2 and 3 at NMFS facilities, 1998 and 1999.

Broodstock source	Redfish Lake	Alturus Lake	Sawtooth Hatchery[a]	Bonneville Hatchery[b]	Big Beef Creek Hatchery	Total
Wild adult returns[c]						
Age 2[d]	0	0	0	0	401	401
Age 3	0	0	13,162	5,012	0	18,174
Captive reared adults[e]						
Age 3	0	0	34,411	12,749	0	47,160
Combined data						
Total	0	0	47,573	17,761	0	65,735

[a] Eyed eggs transferred to IDFG for rearing to juvenile stage for release into Stanley Basin habitats (e.g., Redfish, Pettit, and Alturas Lakes) in 2000.

[b] Eyed eggs transferred to ODFW for rearing to smolt stage for release into the Salmon River in 2001.

[c] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[d] Progeny of single spawning female retained at Big Beef Creek Hatchery for adult production program.

[c] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by NMFS.

Table 16. Maturation records for 1994 brood Redfish Lake sockeye salmon reared at NMFS facilities, 1995-1998.

Broodstock source	Female[a]		Male[b]		Total
	Freshwater[c]	Seawater	Freshwater	Seawater	
Wild adult returns[d]					
Age-2 precocious (1996)	0	---	6	---	6
Age-3 adults (1997) released to Redfish Lake	18	---	18	---	36
Age-3 adults (1997) matured in captivity	65	---	123	---	188
Captive reared adults[e]					
Age-2 precocious (1996)	---	0	---	0	0
Age-3 adults (1997) matured in captivity	---	7	---	36	42
Age-4 adults (1998) matured in captivity	---	55	---	82	137
Combined data[f]					
Total age-2 (1996)	0	0	6	0	6
Total age-3 (1997)	83	7	141	36	267
Total age-4 (1998)		55		82	137

[a] All females that survived to maturity in captivity were spawned.

[b] All male fish that matured as age-2 jacks in 1996 and 48% of males that matured as age-3 fish in 1997 were excess to spawning needs. All males in the captive reared adult group exceeded number needed for spawning.

[c] Wild adult return offspring were reared from egg to adult in fresh well water at BBC. Captive-reared adult offspring were reared from fry to smolt in fresh well water at Bonneville Fish Hatchery and from smolt to adult in pumped, filtered, and UV-treated seawater at Manchester.

[d] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[e] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by NMFS

Table 17. Egg and fry distribution data for 1994 brood Redfish Lake sockeye salmon spawned at ages-3 and 4 at NMFS facilities, 1997 and 1998.

Broodstock source	Redfish Lake[a]	Alturus Lake[a]	Sawtooth Hatchery[b]	Total
Wild adult returns[c]				
Age 3	43,461	13,008	23,954	80,603
Captive reared adults[d]				
Age 3	4,064	0	2,787	6,851
Age 4	0	0	46,898	46,898
Combined data				
Total	47,705	13,008	73,639	134,352

[a] Eyed eggs placed by IDFG personnel into 12 in-lake incubation boxes (at about 5,000 eggs/box) in Redfish and Alturas Lakes in November 1997.

[b] Eyed eggs transferred to IDFG for rearing to juvenile stage for release into Stanley Basin habitats (e.g., Redfish, Pettit, and Alturas Lakes) in 1998 and 1999. Note: 127 eggs were transferred to Eagle Hatchery for rearing as a safety net group in fall 1998.

[c] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[d] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by NMFS.

Table18. Weight, length, and number of age-2 1997 brood Redfish Lake sockeye salmon spawned at NMFS facilities, 1999.

Broodstock source	Freshwater[a]	
	Females	Males
Captive reared adults[b]		
Number of fish spawned	0	76
Length (cm)	---	38.8
Weight (kg)	---	0.80
Combined data		
Number of fish spawned	0	76

[a] Egg to adult fish were reared in freshwater.

[b] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by IDFG.

Table 19. Maturation records for 1996 brood Redfish Lake sockeye salmon reared at NMFS facilities, 1998-1999.

Broodstock source	Female[a]		Male[b]		Total
	Freshwater[c]	Seawater	Freshwater	Seawater	
Wild adult returns[d]					
Age-2 precocious (1998)	1	0	41	17	59
Age-3 adults (1999)	23	13	4	5	45
Captive reared adults[e]					
Age-2 precocious (1998)	0	0	0	4	4
Age-3 adults (1999)	78	34	35	16	163
Combined data					
Total age-2 (1998)	1	0	41	17	63
Total age-3 (1999)	101	47	39	21	208

[a] All females that survived to maturity in captivity were spawned.

[b] A total of 93% of all male fish that matured as age-2 jacks in freshwater in 1998 were spawned. None of the age-2 jacks that matured in seawater in 1998 were spawned.

[c] A total of 70% of the wild adult return offspring and 70% of the captive-reared adult offspring are being reared from egg to adult in fresh well water at BBC, with the remaining 30% being reared from smolt to adult in pumped, filtered, and UV-treated seawater at Manchester.

[d] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.

[e] Second generation captive broodstocks. Fish are progeny of first generation captive broodstocks reared and spawned by NMFS.

Table 20. Weight, length, and number of age-2 1996 brood Redfish Lake sockeye salmon spawned at NMFS facilities, 1998.

Broodstock source	Female		Male	
	Freshwater[a]	Seawater	Freshwater	Seawater
Wild adult returns[b]				
Number of fish spawned	1	0	38	0
Length (cm)	33.3		34.6	
Weight (kg)	0.51		0.53	
Combined data				
Number of fish spawned	1	0	38	0

[a] Egg to adult fish were reared in freshwater.

[b] First generation captive broodstocks. Fish are progeny of wild adults captured and spawned by IDFG.