Redfish Lake Sockeye Salmon Captive Broodstock Rearing and Research

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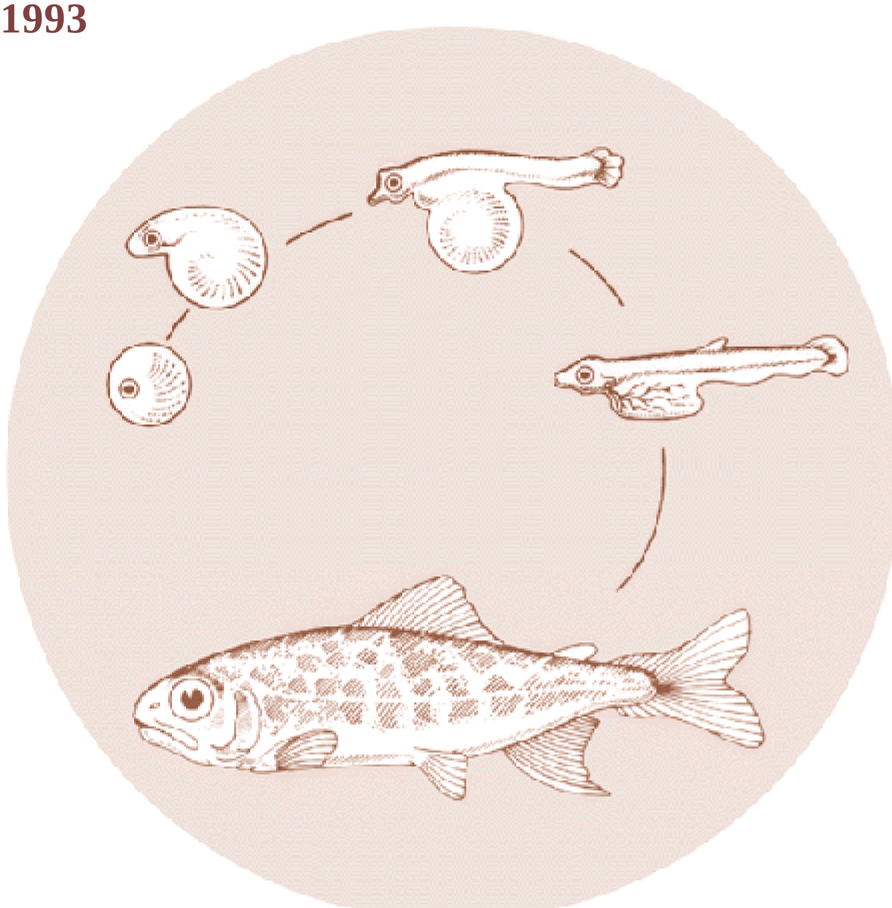

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REDFISH LAKE SOCKEYE SALMON CAPTIVE BROODSTOCK REARING AND RESEARCH, 1993

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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. These efforts focus on protecting 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. NMFS is currently maintaining four separate Redfish Lake sockeye salmon captive broodstocks: 574 1991-brood from wild spawners (59% survival during 26 months of rearing); 1,181 1993-brood from wild spawners (100% survival during 3 months of rearing); 750 1993-brood from captive-reared spawners (100% survival during 2 months of rearing); and 133 1993-brood from residual spawners (100% survival during 1 month of rearing). All Redfish Lake sockeye salmon captive broodstocks are being reared full-term to maturity in fresh (well) water, because it appears this medium will ensure higher survival than seawater. Spawn from these captive broodstocks will be returned to Idaho to aid recovery efforts for the species.

We are also conducting experiments using non-endangered 1990- and 1991-brood Lake Wenatchee (Washington) sockeye salmon **to compare the effects on** survival and reproduction of rearing yearling (smolt size) fish to maturity in fresh water and

seawater. Survival of 1990-brood Lake Wenatchee sockeye salmon during 19 months of rearing averaged about 30% for replicates held in conventional seawater net-pens, 39% for replicates in circular tanks supplied with pumped, filtered, and ultravioiet (UV) light-sterilized seawater, and 37% for replicates in circular tanks supplied with fresh (well) water. Survival of 1991-brood Lake Wenatchee sockeye salmon during 7 months of rearing averaged about 76% in the seawater net-pen replicates, 93% in the seawater tank replicates, and almost 100% in the freshwater tank replicates. For both brood-years, fish reared in fresh water were larger than those reared in seawater. About 15% of the 1990-brood reared in fresh water matured (as age-3 jacks and jills) in fall 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 (about 1,560 eggs/kg of female weight). However, egg viability only averaged about 36%.

Preliminary studies comparing seawater adaptability of 1991-brood Lake Wenatchee sockeye salmon from resident freshwater and seawater parents suggest that full-term freshwater rearing of captive broodstocks does not compromise seawater adaptability of offspring. Survival of smolts of "freshwater-parentage" was 79% compared to 83% for smolts of "seawater-parentage" after 4 months in seawater.

Currently, the data from our captive rearing experiments suggests a ranking priority of 1) circular tanks supplied with pathogen-free fresh water; 2) circular tanks supplied with pumped, filtered, and W-sterilized seawater; and 3) seawater net-pens for rearing sockeye salmon to maturity. Even though full-term freshwater rearing appears the correct choice for valuable captive broodstocks (e.g., Redfish Lake sockeye salmon), the data are also encouraging regarding culture to maturity in environmentally-controlled seawater. However, these experiments will need to continue for several years before they are concluded and complete information is available regarding overall survival, gamete quality, and offspring fitness from captive broodstocks.

CONTENTS

INTRODUCTION

In December 1991, the National Marine Fisheries Service (NMFS) listed Snake River sockeye salmon ***(Oncorhynchus nerka)*** as endangered under the U.S. Endangered Species' Act (ESA) (Waples et al. 1991). The NMFS is developing a recovery plan for Snake River salmon (SRSRP 1993). The goal of this plan will be to rebuild listed Snake River sockeye salmon within its historic range in order to delist the species.

Snake River sockeye salmon are a prime example of a species on the threshold of extinction. The last known remnants of this stock return to Redfish Lake, Idaho (Fig. 1). Only a few sockeye salmon adults (zero to eight per year) have returned to Redfish Lake in each of the last 6 years. On the basis of these critically low population numbers, NMFS, in cooperation with the Idaho Department of Fish and Game (IDFG), the Bonneville Power Administration (BPA), and others, recently implemented a captive broodstock project as an emergency measure to save Redfish Lake sockeye salmon (Flagg 1993, Johnson 1993). The Redfish Lake project is intended to be a stop-gap measure until migration habitat improvements can be implemented to increase survival. These interim recovery efforts are being coordinated through the Stanley Basin Sockeye Technical Oversight Committee (SBSTOC); membership on the committee includes representatives from NMFS,

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[1] The 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 (1991).

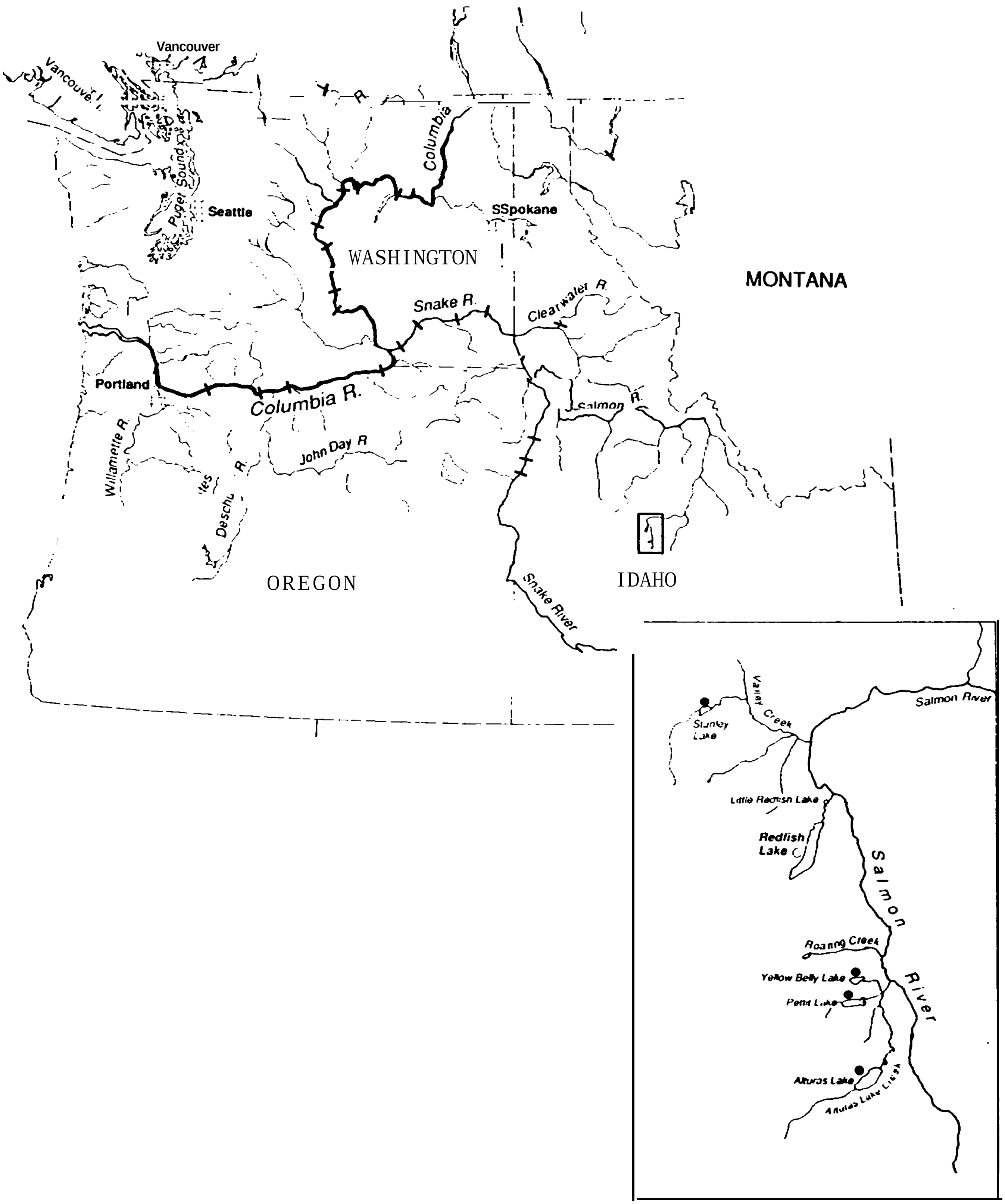

Figure 1.--Map showing location of Redfish Lake. Sockeye salmon returning to Redfish Lake travel a greater distance from the sea (almost 1,450 km) and spawn at a higher elevation (almost 2,000 m) than any other sockeye salmon population.

IDFG, BPA, the Shoshone-Bannock Tribe, and other state and federal agencies and private groups involved in sockeye salmon restoration in Idaho.

The NMFS Northwest Fisheries Science Center entered into a cooperative project with BPA (Project 92-40, Contract DE-AI79-92BP41841) for involvement in the Redfish Lake captive broodstock project from March 1992 through November 1997. The current report addresses NMFS research from October 1992 through December 1993 on the Redfish Lake sockeye salmon captive broodstock and summarizes results since the beginning of the study in October 1991. Our efforts from October 1992 through December 1993 focused on 1) incubation and rearing of 1991- and 1993-brood Redfish Lake sockeye salmon and 2) research on techniques to refine captive broodstock methods. Robin Waples and/or Thomas Flagg represented NMFS at monthly SBSTOC meetings and visited IDFG fish culture and fish trapping operations for Redfish Lake sockeye salmon. In addition, Thomas Flagg was senior author of a paper, "Redfish Lake sockeye salmon captive broodstock programs," published in 1994 in the proceedings of the 1993 Alaska Department of Fish and Game Sockeye Salmon Culture Workshop (Flagg et al. 1994, Appendix A).

REDFISH LAKE SOCKEYE SALMON CAPTIVE BROODSTOCK CULTURE

Captive propagation is an important component of species restoration world wide. 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). These techniques have won acceptance in endangered species restoration (Gipps 1991, Johnson and Jensen 1991, Olney et al. 1994). 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. Offspring from captive broodstocks are released to supplement wild populations. The relatively high fecundity of Pacific salmon, coupled with potentially high survival in protective culture, allows 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 assure that genetic Integrity and adaptability to native habitats are preserved. Importantly, the relatively stable egg supply provided through a catpive broodstock program should help ensure supplementaation efforts for depleted stocks such as Redfish Lake sockeye salmon.

All three known forms of 0. ***nerka*** occur in Redfish Lake. 1) The anadromous form usually spends 1 to 2 year-s in its nursery lake before migrating to sea as a smolt, and remains at sea for an additional 2 to 4 years before returning to the natal area to spawn (Bjornn et al. 1968, Foerster 1968, Groot and Margolis 1991). The two other 0. ***nerka*** forms remain in fresh water to mature and reproduce. 2) Residual sockeye salmon are progeny of anadromous fish and produce mostly anadromous offspring (Ricker 1938, Foerster 1968, Groot and Margolis 1991). It was theorized that residual 0. ***nerka*** helped maintain the Redfish Lake sockeye salmon population during historic population lows (Waples et al. 1991). 3) 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, Groot and Margolis 1991). Residual sockeye salmon in Redfish Lake were included in the anadromous gene pool for ESA protection, while kokanee were excluded.

Since both anadromous and residual forms of sockeye salmon inhabit Redfish Lake along with kokanee, mechanisms were needed to differentiate them from kokanee in developing broodstocks. Spatial and temporal spawning separation occur between anadromous sockeye salmon and kokanee in Redfish Lake. The anadromous and residual sockeye salmon are shoal spawners that reproduce in the lake in late October, whereas kokanee spawn in a tributary to the lake in late August and early September. Also, skin and flesh may be more red at spawning in kokanee than in residuals (Waples 1992). This is because kokanee, which have adapted to a carotenoid-poor forage environment, appear to be more efficient than sockeye salmon at storing carotenoid. In addition, recent investigations have indicated that anadromous and residual sockeye salmon can be genetically differentiated from kokanee by protein electrophoresis (R. Waples, NMFS. Pers. commun., December 1993) and DNA analysis (Brannon et al. 1992). Recent information also suggests that since anadromous fish spend time in seawater, an environment rich in strontium, it is possible to distinguish the progeny of anadromous and non-anadromous parents based on the elevated strontium/calcium (Sr/Ca) ratio in the primordial core of their otoliths (Kalish 1990, Reiman et al. 1994, IDFG[2]). All of the criteria described above were employed to differentiate kokanee from anadromous sockeye salmon in developing broodstocks.

The exact status of the Snake River sockeye salmon population was unknown at the time of ESA listing. No fish returned during 1990, the year of the ESA biological review, and there were suggestions that the population was functionally extinct (Waples et al. 1991). However, it was determined that there is no provision in the ESA for declaring a species extinct until the last individual perishes. Since redds (nests) were observed in Redfish Lake in 1988 and 1989, and assuming 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. 1991). Subsequent collections of outmigrating juveniles and returns of anadromous adult sockeye salmon to Redfish Lake in 1991, 1992,

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[2] Idaho Department of Fish and Game. Boise, ID 83707. Unpublished data.

and 1993 put to rest any uncertainties regarding the persistence of this population.

Between 1991 and 1993, captive broodstocks were initiated for Redfish Lake sockeye saimon. One of the primary obligations when maintaining an endangered species in protective culture is ensuring the highest possible survival. Full-term culture in pathogen-free fresh water has generally resulted in higher survival to spawning and higher percentages of viable gametes than culture in seawater for Pacific salmon (McAuley 1983; Harrell et al. 1984a,b, 1985, 1987; Peterschmidt 1991; C. Wood, Canada Department of Fish and Oceans, Pacific Biological Station, Nanaimo, B.C., Canada. Pers. commun. October 1991; C. Mahnken and T. Flagg, NMFS, unpublished data). Therefore, full-term freshwater rearing in pathogen-free water was chosen for these captive broodstocks.

Two separate captive populations have been established to reduce the risk of catastrophic loss of these valuable gene pools. Most broodstocks obtained as eggs have been divided between IDFG hatcheries and NMFS facilities (Table 1). Because of health risks and regulations associated with interstate transfer of live fish, IDFG is maintaining all broodstocks obtained as juveniles (Flagg 1993, Johnson 1993). IDFG captive broodstocks are cultured at the IDFG Eagle Hatchery near Boise, Idaho in 13OC well water (Johnson 1993). NMFS is rearing fish in 10°C well water at a NMFS facility at the University of

Washington's Big Beef Creek (BBC) Research Station near Seabeck, Washington.

NMFS is providing 7-day-a-week staffing for protective culture of Redfish Lake sockeye salmon with constant electronic security and facilities monitoring. The fish are reared using standard fish culture practices and approved therapeutics (for an overview of standard methods see Leitritz and Lewis 1976). Fish are fed a commercial ration (e.g., Biodiet[3]). 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 has been deemed infeasible, and the fish are not routinely handled during rearing. This precludes documentation of parameters such as growth except as an endpoint measurement. Therefore, survival and primary causes of death are the only data reported for these fish in this report.

The NMFS captive broodstocks are from eggs from the following sources: 1) wild adults returning to Redfish Lake, 2) wild adult residuals captured in the lake, and 3) captive broodstocks reared and spawned in captivity. Our captive broodstocks include eggs from adults that returned to Redfish Lake in 1991 and 1993; in 1992, only a single male returned to

[3] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table l.--Status of Redfish Lake sockeye salmon captive broodstocks through December 1993.[a]

Broodstock source	Agency	Initial stage	Number	Months in culture	Average survival[b] (%)
Wild juvenile outmigrants					
spring 1991	IDFG	juveniles	559	32	39
spring 1992	IDFG	juveniles	79	20	88
spring 1993	IDFG	juveniles	48	8	48
Captive-reared adults					
fall 1993	NMFS	eggs	750	2	100
fall 1993	IDFG	eggs	450	2	100
Wild adult residuals					
fall 1992	IDFG	eggs	35	12	100
fall 1993	IDFG	eggs	120	1	100
fall 1993	NMFS	eggs	133	1	100
Wild adult returns"					
fall 1991	NMFS	eggs	991	26	59
fall 1991	IDFG	eggs	998	26	93
fall 1993	NMFS	eggs	1,181	3	100
fall 1993	IDFG	eggs	1,000	3	100

a Information on Idaho Department of Fish and Game captive broodstocks from Keith Johnson, IDFG, 1800 Trout Rd., Eagle, ID 83616. Pers. commun. December 1993.

b Captive broodstocks are being held as multiple discrete lots in multiple rearing containers. Survival percentage is approximate overall average.

c In fall 1991, one female and three male adult sockeye salmon returned to Redfish Lake and were captured and spawned; in fall 1992, one male returned, was captured, and its milt cryo-preserved; in fall 1993, two females and six males returned and were captured and spawned.

the lake. We believe broodstocks sourced from returning adult spawners are the most valuable for captive rearing since we are confident they are part of the anadromous sockeye salmon gene pool from Redfish Lake.

Redfish Lake sockeye salmon will be reared to maturity at NMFS laboratories. Spawn will be returned to Idaho for use in recovery programs for Snake River sockeye salmon. All spawners will be analyzed for common bacterial and viral pathogens, e.g., bacterial kidney disease (BKD), infectious hematopoietic necrosis virus, etc. NMFS will obtain appropriate permits for interstate transport of eggs, fish, and progeny.

1991 Brood

In August 1991, three male and one female adult sockeye salmon were captured at a weir on Redfish Lake Creek about a mile below Redfish Lake during their upstream migration. The maturing adults were moved to IDFG's Sawtooth Hatchery near Stanley, Idaho (about 5 miles from Redfish Lake) and spawned in late October by IDFG (Flagg 1993, Johnson 1993). Five egg lots were created from the spawning of the single female and three male sockeye salmon (Table 2). The female spawned volitionally with an unknown combination of the males on gravel placed in the holding tank. This spawning resulted in deposition of about one half of the female's eggs (about 1,000 eggs). The female was then removed from the tank and the remaining eggs strip-spawned. Portions of these eggs were fertilized with milt from each of the three

Table 2.--Inventory record of adult Redfish Lake sockeye salmon spawned at Sawtooth Fish Hatchery (Idaho), 1991.

Mating cross[a]	Total eggs	Dead eggs	Fertility (%)	Eggs transferred NMFS	IDFG
1.	220	0	100.0	110	110
2.	240	5	97.9	117	118
3.	235	8	97.6	109	118
4.	185	16	91.3	84	89
5.	1,297	170	86.9	560	563
Total	2,177	199		980[b]	998
Average			90.9		

[a] Mating crosses: males A, B, and C were individually spawned with a portion of the female's eggs (groups l-3); a pool of sperm from males A, B, and C was used to fertilize a portion of the eggs (group 4); and the female spawned volitionally with an unknown combination of males A, B, and C (group 5).

[b] Subsequent counts indicated that 991 eggs were transferred to NMFS.

males, while another portion was fertiiized with pooled milt from all three males.

On 3 December 1991, one-half the progeny of these fish were transferred to NMFS for rearing to maturity. IDFG was issued Washington State Department of Fisheries and Wildlife (WDFW) Fish Transfer Permit 1275-11-91 to move these fish from Idaho to Seattle. The remaining 1991-brood progeny are in the custody of IDFG at the Eagle Fish Health Laboratory near Boise, Idaho (Johnson 1993).

Although the hatchery in Seattle was ideal for the early rearing of Redfish Lake sockeye salmon, it lacked adequate space to rear fish beyond smolt size. Therefore, in spring 1993, NMFS's portion of the 1991-brcod Redfish Lake sockeye salmon was transferred to a newly constructed NMFS endangered species rearing facility at BBC. Both NMFS hatcheries conform to isolation and quarantine standards and are supplied with pathogen-free water.

Progeny from all five groups of 1991-brcod Redfish Lake sockeye salmon were incubated as separate groups (Flagg 1993). The eggs accumulated a total of about 365 ("Cl temperature units at the Sawtooth Hatchery prior to transfer to NMFS. Egg counts at the Sawtooth Hatchery had indicated that a total of 980 eggs were transferred to NMFS (Table 2). Subsequent counts indicate the actual number transferred was 991 eggs. These egg lots hatched on 4 and 5 January 1992 at about 654 ('C) temperature units. A total of 13 blank and/or dead eggs were removed from the egg lots during incubation; 978 eggs (98.7%) were hatched. Inventory information for the 1991-brood Redfish Lake sockeye salmon is detailed in Appendix B.

The 1991-brood Redfish Lake sockeye salmon were ponded at the Seattle hatchery on 13 February 1992 at about 965 (OC) temperature units. Progeny from the five mating crosses of 1991-brood Redfish Lake sockeye salmon were maintained as separate groups until late May 1993. At swim-up, fry were moved from the incubators to 1.2-m diameter tanks. Initial fish density in tanks was under 2 kg/m3 (0.1 lbs/ft^3); densities were maintained below 8 kg/m^3 (0.5 lbs/ft^3) during rearing at the Seattle hatchery (from February 1992 to May 1993).

In May 1992, background levels of Renibacterium salmoninarum the causative agent of BKD, were noted in some mortalities during routine assays for BKD by fluorescent antibody technique (FAT). Salmonids are susceptible to this bacteria at all life stages in both freshwater and marine environments (Banner et al. 1986). The disease may be passed horizontally (fish-to-fish) or vertically from infected parents to offspring. The Snake River Basin (including Redfish Lake and surrounding watersheds in the upper Salmon River) is considered a positive area for BKD, with both sockeye salmon and chinook salmon (0. tshawytscha) often testing positive for the disease (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., December 1993). Nevertheless, the one female and three male parents of the 1991 brood had tested negative for BKD by both FAT and the more sensitive enzyme-linked immunosorbent assay (Johnson 1993). It is unknown whether the tests provided a false negative, since only a small sample of tissue from each adult spawner was tested, or if there was another source of infection.

The survival of the fish from hatch in January to May 1992 was over 96% (Appendix B); since background levels of BKD were low, the few mortalities at that time were attributed to normal attrition rather than infectious disease. Nevertheless, the 1991-brood sockeye salmon groups were fed a medicated diet containing 0.45% erythromycin at 2 of body weight/day for about 2 weeks during late May to early June 1992 (Fig. 2). Erythromycin is a macrolide antibiotic and is considered the drug-of-choice for treating BKD (Austin 1985). However, erythromycin is bacteriostatic rather than bacteriolytic. Therefore, while erythromycin may arrest progression of BKD, it is not considered a cure for fish with the disease. It is believed that the primary benefit of erythromycin treatment is aiding healthy fish in the population to avoid contracting BKD during an epizootic. This drug was administered under Food and Drug Administration Investigational New Animal Drug (INAD) 4333. Mortality rates of the 1991-brood remained low after the initial drug therapy (Appendix B and Fig. 2).

In mid January 1993, all 919 remaining 1991-brood Redfish Lake sockeye salmon were PIT-tagged for individual identification. The PIT tag has been shown to be both safe for use in juvenile salmonids and reliable in operation (Prentice

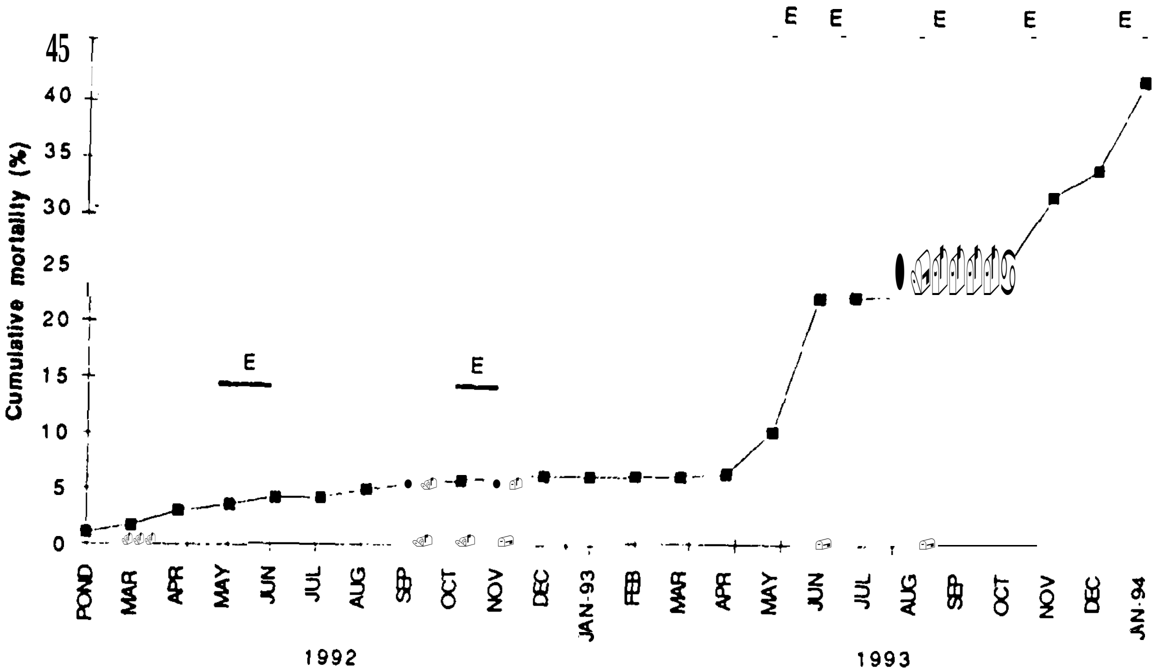

Figure 2.--Cumulative percent mortality durinq rearing for the 1991-brood sockeye salmon, 1991-1993. Areas under E indicate periods of oral administration of erythromycin incorporated in feed.

et al. 1990a,b). There was no mortality in any of the five half-sib groups during the month after FIT tagging (Appendix B and Fig. 3).

Survival rates of the groups remained high during the first 14 months of rearing at the Seattle hatchery (from January 1992 to April 1993); ranging from 86.8 to 94.9% in the 5 groups and averaging almost 94% (Appendix B). All fish appeared healthy. Nevertheless, in April 1993 (during the 15th month of rearing), fish in all 5 groups experienced an outbreak of BKD. At the time of this BKD episode, the fish were yearlings and presumably undergoing smoltification in preparation for their normal life-stage transition to seawater.

During smoltification, the fish's body chemistry changes to allow the fish to successfully transition from the hype-osmotic (freshwater) environment to the hyper-osmotic (seawater) environment. The onset and degree of smoltification is controlled by combinations of photoperiod, water temperature, and endogenous factors (Folmar and Dickhoff 1980). The physiological changes that take place during smoltification result in a transitory decrease in immunocompetence (Maule et al. 1987). Normally, anadromous salmonid smolts migrate to seawater, body chemistry is adapted for maintaining osmotic balance, and immunocompetence returns to presmoltification levei. When anadromous juveniles do not reach, or are not allowed to reach, seawater, the juvenile's body chemistry re-adjusts for life in a

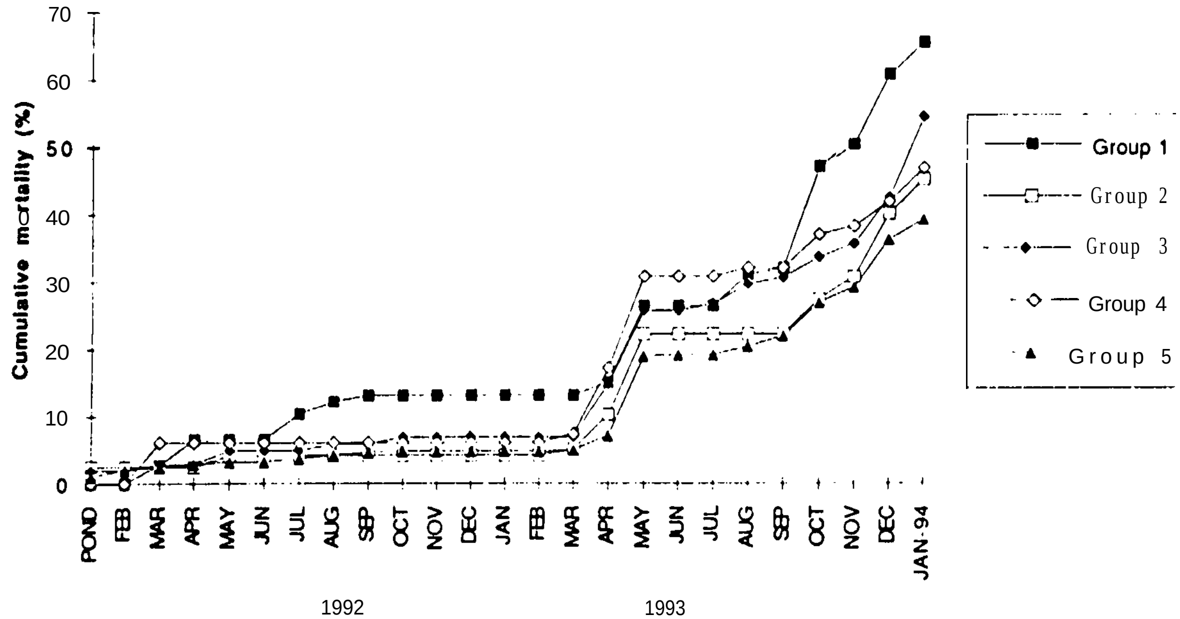

Figure 3.--Cumulative percent mortality during rearing for each half-sib group of 1991-brood Redfish Lake sockeye salmon, 1991-1993.

hypo-osmotic medium, and immunocompetence also returns to presmoltification level.

The 1991-brood Redfish Lake sockeye salmon juveniles at the Seattle hatchery were held in ambient temperature water under natural photoperiod. Therefore, fish at the Seattle hatchery should have had a strong springtime smolt response. Since documentation of biochemical smoltification responses requires lethal sampling, the exact degree of smoltification was impossible to document for these endangered species. However, non-endangered Lake Wenatchee sockeye salmon held at the Seattle hatchery have shown strong smoltification responses and migratory tendencies (Flagg et al. 1991; W. Dickhoff and T. Flagg, NMFS, unpublished data). It is probable that the general decrease in immunocompetence during the spring smoltification period precipitated and/or amplified the BKD outbreak.

It should be emphasized, however, that although there is risk of smoltification-related stress for fish forcibly retained in fresh water after smolting, given the status of current seawater rearing technology and the documented poor survival of other groups of sockeye salmon in seawater, transfer to seawater would likely have presented the greater jeopardy. In cooperation with BPA, NMFS is investigating the reliability of processed seawater in increasing potential survival of salmonid captive broodstocks held in seawater (preliminary results of these studies are described elsewhere in this report). Furthermore, all future freshwater juvenile rearing will be conducted at BBC.

The constant 10°C water temperature at BBC has been noted to decrease both smoltification intensity and overall seawater tolerance in other salmonids, e.g., Atlantic salmon (Salmo salar) (T. Flagg, W. Dickhoff, and C. Mahnken, NMFS, unpublished data). This should increase the potential survival of captive broodstocks held full-term in fresh water.

At the first signs of the BKD outbreak in April 1993, the 1991-brood Redfish Lake sockeye salmon groups were again given a medicated diet containing 0.45% erythromycin at 2% of body weight/day. This treatment was continued throughout May; by late May the mortalities had subsided (Fig. 2). On 29 May to 1 June 1993, with the concurrence of the SBSTOC, the fish were transferred from the Seattle hatchery to BBC (about a 2-hour trip). It was agreed that the benefits of increased rearing space at BBC greatly outweighed any risk of moving the fish. The fish were transferred under WDFW Fish Transfer Permit 1504-12-92 at low density (less than 8 kg/m^3) in NMFS tanks and trucks. The fish were transferred in three individual trips with 200 to 300 fish/trip. A second truck with a tank containing water but no fish followed each load in case of an unexpected emergency. Although this truck was not needed, it was considered a reasonable precaution.

The NMFS hatchery at BBC was designed as a protective rearing facility for salmonid captive broodstocks. The facility was remodelled from a hatchery at the site and now includes a newly constructed 425-m^2 building. At present, the protected rearing area contains six 3.9-m diameter circular tanks; however, over two-dozen more 1.2- to 2.6-m diameter tanks are being added. A separate hatchery room accommodates down-well incubators (Novotny et al. 1985) for isolated egg incubation. Whereas water at the Seattle hatchery required processing through a series of dechlorinators and chillers to ensure quality, the BBC hatchery is supplied with over 450 gpm of 10°C artesian well water, thereby greatly reducing risk of mechanical failure. Water flow, fire, and intruder alarms are monitored through a security system linked to pagers and home and office telephones. Effluent from the hatchery is depurated through a settling basin and ultraviolet (UV) sterilization system.

A total of 763 of 1991-brood Redfish Lake sockeye were moved to BBC; this represented 78% survival from hatch In January 1992 (Appendix B). The half-sib families were combined to five 3.9-m tanks at BBC on the basis of prior BKD history at the Seattle hatchery (e.g., fish from tanks with no BKD history were held together, fish from tanks with moderate BKD history were held together, etc.), with between 54 to 317 fish/tank (Table 3). Dividing portions of each half-sib group into several ranks reduced risk of loss of an entire half-sib family. Beginning fish density in the tanks at BBC were established at under 2.0 kg/m^3. Fish density in the tanks will be maintained at under 8 kg/m^3 during most of the culture period; however, fish density may range to 25 kg/m' (1.5 lbs/ft^3) at maturity.

Table 3.--Inventory record of pooled groups[a,b] of 1991-brood Redfish Lake sockeye salmon spawned at NMFS BBC endangered species rearing facility, 1993.

Date	Tank number,[c,d,e,f,g] 2	3	4	5	6
	Survival (%)				
1 Jun	100.0	100.0	100.0	100.0	100.0
30 Jun	99.7	100.0	100.0	100.0	100.0
31 Jul	99.7	100.0	100.0	100.0	99.3
31 Aug	96.8	98.4	100.0	97.6	97.9
30 Sep	95.3	96.8	100.0	96.0	96.5
31 Oct	86.4	91.9	100.0	85.7	86.7
30 Nov	83.3	88.6	100.0	82.5	82.5
31 Dec	70.0	80.5	100.0	74.6	72.0

[a] Fish pooled to 3.9-m diameter fiberglass tanks. Tanks contained combinations of the five half-sib mating crosses from the 1991 spawning based on prior BKD history at the Seattle hatchery.

[b] Mating crosses: males A, B, and C were individually spawned with a portion of the female's eggs (groups 1-3); a pool of sperm from males A, B, and C was used to fertilize a portion of the eggs (group 4); and the female spawned volitionally with an unknown combination of males A, B, and C (group 5).

[c] Tank 2 initially contained 38 fish from group 1, 30 fish from group 4, and 249 fish from group 5 (total n = 317) from rearing lots judged as having moderate prior BKD incidence.

[d] Tank 3 contained 51 fish from group 2, 26 fish from group 4, and 46 fish from group 5 (total n = 123) from rearing lots judged as having medium prior BKD incidence.

[e] Tank 4 contained 54 fish from group 5 from a rearing lot having no prior BKD incidence.

[f] Tank 5 contained 40 fish from group 1, 40 fish from group 3, and 46 fish from group 5 (total n = 126) from rearing lots judged as having low prior BKD incidence.

[g] Tank 6 contained 40 fish from group 2, 35 fish from group 3, and 68 fish from group 5 (total n = 143) from rearing lots judged as having medium prior BKD incidence.

The PIT tags that were implanted in the fish in January 1993 allowed for continued tracking of individual half-sib family performance (Appendix B and Fig. 3). The fish were fed a medicated diet containing 0.45% erythromycin at 2% of body weight/day for approximately 2 weeks after transfer to BBC (Fig. 2). The SBSTOC with concurrence of NMFS, recommended that 28-day prophylactic treatments with erythromycin be continued on an every-other-month basis (e.g., August, October, December, etc.) through at least fall 1993. In winter 1994, the SBSTOC will evaluate the success of the medicated treatments and recommend either continuation or modification of the medication regime.

There was minimal mortality for about 60 days post transfer to BBC (Figs. 2-3). However, in August 1993, increasing mortality from BKD was documented. At the end of December 1993, there **was** a total of 574 1991-brood Redfish Lake sockeye at BBC; survival in the five half-sib groups averaged about 59% from hatch and ranged from 38.7 to 63.7% in the five groups (Table 1 and Appendix B). One 3.9-m tank at BBC remained BKD free (Table 3). We expect most of these fish to spawn between fall 1995 and 1996.

1993 Broods

1993 Brood from Adult Returns to Redfish Lake

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. The maturing adults were moved to the Sawtooth Hatchery and spawned in early October by IDFG. A full-factorial mating design resulted in six half-sib groups from each female. NMFS received 1,181 eggs from 11 of the 12 possible half-sib groups from these spawnings, while IDFG retained a total of 945 eggs from **11** of the 12 possible half-sib groups (Tables **1** and 4). Because of low fertility from male 2, resulting in a low number of viable eggs, all of mating 2A (i.e., male 2 crossed with a portion of female A's eggs) were retained by IDFG and all of mating 2B were transferred to NMFS (Table 4).

On 30 November 1993, NMFS's portion of the 1993-brood Redfish Lake sockeye salmon eggs were transported by BPA plane from Idaho to Washington. The eggs had accumulated a total of about 450 temperature units at the Sawtooth Hatchery prior to transfer to NMFS. IDFG received WDFW Fish Transfer Permit **1685-11-93** for this transfer of eggs to NMFS. All eggs were transferred safely and are being incubated at the NMFS endangered species rearing facility at BBC.

Fish culture and security strategies will be similar to those outlined for rearing of 1991-brood juvenile Redfish Lake sockeye salmon at BBC. NMFS's portion of each half-sib group is being maintained separately in isolation incubators. We anticipate fish from these eggs will be ponded in early February 1994. Half-sib groups will be maintained separately in 1.8-m diameter tanks until they are large enough to PIT tag (probably summer 1994). Groups may eventually be combined to 3.9-m tanks

Table 4.--Number of 1993-brood Redfish Lake sockeye salmon eggs from anadromous parents transferred to NMFS[a] and retained by IDFG[b] for captive broodstock from each individual female/male mating from the two female and six male sockeye salmon that returned to Redfish Lake in 1993.

	Male					
Female	1	2	3	4	5	6
	Number of eggs					
A- NMFS	114	0	114	114	62	114
IDFG	92	45	92	92	63	92
B- NMFS	114	117	114	114	102	102
IDFG	92	0	92	92	101	92

a NMFS total = 1,181 eggs.

b IDFG total = 945 eggs.

for rearing to maturity. We expect most of these fish to spawn between fall 1997 and 1998.

IDFG also retained approximately 1,200 eggs from these spawnings for production rearing. IDFG has applied for a NMFS permit to release these fish in Redfish Lake as underyearlings in 1994 (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun. December 1993).

1993-Brood "Safety-Net'*

IDFG has maintained captive broodstocks of sockeye salmon captured as outmigrants from Redfish Lake since spring 1991 (Johnson 1993). About 15% of these matured in October 1993 (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., December 1993). These fish were reared at the IDFG Eagle Hatchery and moved by IDFG to the Sawtooth Hatchery prior to spawning. 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. Both protein electrophoretic and DNA information suggested that fish captured as outmigrants were from the anadromous gene pool (R. Waples, NMFS. Pers. commun., December 1993). A total of 16 females from this group were spawned. Although males from this group appeared to be maturing, only a few produced milt. Therefore, IDFG combined the majority of each female's eggs with either one of the six anadromous males that returned in 1993 or with precocious males from their captive broodstock from one female and three male sockeye salmon that returned to Redfish Lake in 1991 (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun. December 1993)

Most of the progeny from the 1993 spawning of IDFG's outmigrant-to-adult broodstock will be used in recovery programs at Redfish Lake (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun. December 1993). However, it seemed reasonable that a "safety-net" captive brood be established to protect against loss if outplants initially fail. Therefore, NMFS requested a total of 765 eggs from 22 of the 45 individual egg lots from the spawnings of the IDFG 1991 outmigrant-to-adult Redfish Lake sockeye salmon captive broodstock for the beginnings of a "safety-net" captive broodstock program, with about 35 eggs being drawn from each of the 22 lots (Table 5). Only eggs from the first 14 spawning females were retained for this captive broodstock (the 15th female had nonviable eggs and the 16th female's eggs were not yet eyed). Egg lots.were chosen to maximize male and female contribution to the "safety-net" captive broodstocks and to ensure that portions of as many matings as possible are in either NMFS's or IDFG's captive broodstock. IDFG retained 470 eggs drawn as groups of 20 to 25 eggs from 28 of the 45 individual egg lots from these spawnings for their "safety-net" captive broodstock (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun. December 1993).

On 30 November 1993, NMFS's portion of these eggs were transported on the BPA plane from Idaho to Washington along with the groups of eggs from anadromous parents (described earlier).

Table 5.--Individual matings of 1993-brood Redfish Lake sockeye salmon from IDFG captive reared females that eggs weredrawn from for transfer to NMFS in 1993.

Female/male cross[b]	Number of eggs	Female/male cross[a]	Number of eggs
1 x 1&2[b]	35	9x2	35
2x5	35	9x5	35
2x2	35	10 x 6	35
3x3	35	10 x 7	35
4x5	35	11 x 3	35
5x1	35	12 x 1	35
6x4	35	12 x 4	35
6x6	35	13 x 1	35
7x3	35	13 x 6	35
8x6	35	14 x 9	30
8x2	35	14 x 8	35
TOTAL			765

a Males 1 through 6 are the six anadromous male sockeye salmon that returned to Redfish Lake in 1993; male 7 is a precocious fish from IDFG's captive broodstock for progeny of the one female and three males that returned to Redfish Lake in 1991; males 8 and 9 are adult spawners from IDFG's captive broodstock for outmigrants captured exiting the lake in 1991.

b Pooled milt from males 1 and 2.

The eggs had accumulated a total of about 400 to 500 °C) temperature units at the Sawtooth Hatchery prior to transfer to NMFS (individual females were spawned between the first and third weeks of October, therefore cumulative temperature units varied). IDFG received WDFW Fish Transfer Permit 1687-11-93 fcr this transfer of eggs to NMFS. All eggs were transferred safely and are being incubated at BBC. Incubation and culture strategies will be similar to those outlined for 1993-brood juvenile Redfish Lake sockeye salmon at BBC. We anticipate fish from these eggs will be ponded in early February 1994. This ' safety-net" captive broodstock will be combined in grcups of about 200 fish each at ponding.

If space limitations at BBC become a concern, or if results from captive broodstock research with Lake Wenatchee sockeye salmon reared in seawater tanks remain positive, NMFS may consider transferring some yearling smolts from this 1993-brood "safety-net" group to seawater at the NMFS Manchester Marine Experimental Station near Manchester, Washington. Otherwise, fish will be held to maturity in fresh water. We expect most of these fish to spawn between fall 1997 and fall 1998.

IDFG also retained approximately 9,000 eggs from these spawnings for production rearing (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun. December 1993). IDFG has applied for a NMFS permit to release these fish in Redfish Lake as underyearlings in 1994.

1993-Brood Residuals

Members of the NMFS Bioiogical Review Team theorized that residuals helped maintain the Redfish Lake sockeye salmon population during historic population lows (Waples et al. 1991). In fall 1993, eight male and two female residuals were captured at the sockeye salmon spawning beach in Redfish Lake. These maturing adult fish were moved to the Sawtooth Hatchery and spawned in early November by IDFG (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun. December 1993). This spawning resulted in about 240 eyed eggs that were divided approximately equally between IDFG and NMFS (Table 1).

On 21 December 1993, NMFS's portion of the 1993-brood residual eggs (133 eggs) was transported by commercial airline from Idaho to Washington. The eggs had accumulated a total of 400 (°C) temperature units at the Sawtooth Hatchery prior to transfer to NMFS. IDFG received WDFW Fish Transfer Permit 1686-11-93 for this transfer of eggs to NMFS. All eggs were transferred safely and are being incubated at the NMFS endangered species rearing facility at BBC. Fish will be held to maturity in fresh water. We expect most of these fish to spawn between fall 1997 and fall 1998.

CAPTIVE BROODSTOCK RESEARCH USING NON-ENDANGERED LAKE WENATCHEE SOCKEYE SALMON

Exacting fish culture methods must be developed to ensure that offspring of captive broodstock have the same genetic, physiological, and behavioral make-up as their wild grandparents. It would seem prudent for captive culture to mirror the natural life-cycle of the fish. Whenever this is not possible, potential effects to the broodstock and their offspring must be determined. Although full-term freshwater rearing may enhance survival, and seems the correct choice for Redfish Lake sockeye salmon captive broodstock, there are numerous unanswered questions regarding the role of seawater residence in overall fitness. In the long run, it may be advantageous to develop effective seawater captive broodstock culture systems rather than alter fish life-cycles through full-term freshwater rearing.

We feel many husbandry problems in seawater may be 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 predation from marine mammals and birds, natural catastrophes, and escape. However, land-based facilities with pumped seawater and environmental control (e.g., filtration, flow, and aeration) may provide the quality environment necessary for protective culture of salmonids in seawater.

We are now comparing sockeye salmon reared with and without a period in seawater. These studies are being conducted with Lake Wenatchee (Washington) sockeye salmon so as not to jeopardize the Redfish Lake sockeye salmon gene pool. This research will allow various sockeye salmon culture strategies to be evaluated prior to implementation with the Redfish Lake fish.

Comparison of Freshwater and Seawater Rearing for Lake Wenatchee Sockeye Salmon Broodstock

In late spring 1992, we began tests to compare fish reared to maturity in fresh water with fish reared in conventional seawater net-pens and in land-based seawater tanks (Flagg 1993). Temporary pumped and filtered seawater facilities were constructed for the seawater portion of these experiments at our Manchester field station. NMFS is finishing construction of a permanent land-based seawater laboratory for captive broodstock research at Manchester; this will be available in 1994. The freshwater experiments are being conducted at BBC.

Both 1990- and 1991-brood Lake Wenatchee sockeye salmon are being reared and evaluated in these experiments. Fish culture strategies are similar to those outlined for Redfish Lake juvenile-to-adult rearing. Evaluation focuses on comparison of fish growth, health, survival, and reproductive success.

1990 Brood

About 3,000 1990-brood Lake Wenatchee (yearling) sockeye salmon were donated to this study from the BPA-NMFS Cle Elum Lake study (Project 86-45). Experimental groups were established for the 1990-brood in mid May 1992. Three replicates of about 300 fish each were set up in 1) circular tanks supplied with pathogen-free fresh water at BBC; 2) circular tanks supplied with pumped, filtered, and W-sterilized seawater at Manchester; and 3) seawater net-pens at Manchester. 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).

Inventory discrepancies were noted in all groups during rearing. The inventory discrepancies averaged about 17% in the seawater net-pen replicates, 7% in the seawater tanks, and 5% in the freshwater tanks. 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 experiment (the period of maximum mortality for all groups). 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 19 months of rearing from the beginning of the experiment in May 1992 through December 1993 averaged about 30% in the seawater net-pen replicates, 39% in the seawater tanks, and 37% in the freshwater tanks (Appendix C and Fig. 4). Even though survival differences appeared sizable, analysis of variance (ANOVA) indicated no significant differences ($P > 0.05$) in the percentage of fish remaining in freshwater, seawater, and seawater net-pen replicates at the end of December 1993.

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 to BKD thereafter. Most mortalities in the freshwater tank replicates 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. 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) (Fig. 4). Thereafter, most mortality was attributed to normal attrition. This is similar to BKD related mortality experienced by one IDFG Redfish Lake sockeye salmon captive broodstock (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun. December 1993). This suggests that, under proper husbandry situations, segments of cultured sockeye salm populations may be able to withstand BKD infections and survive.

Growth differences were noted between the treatments. Size of fish averaged 995 g in the freshwater tank, 697 g in the

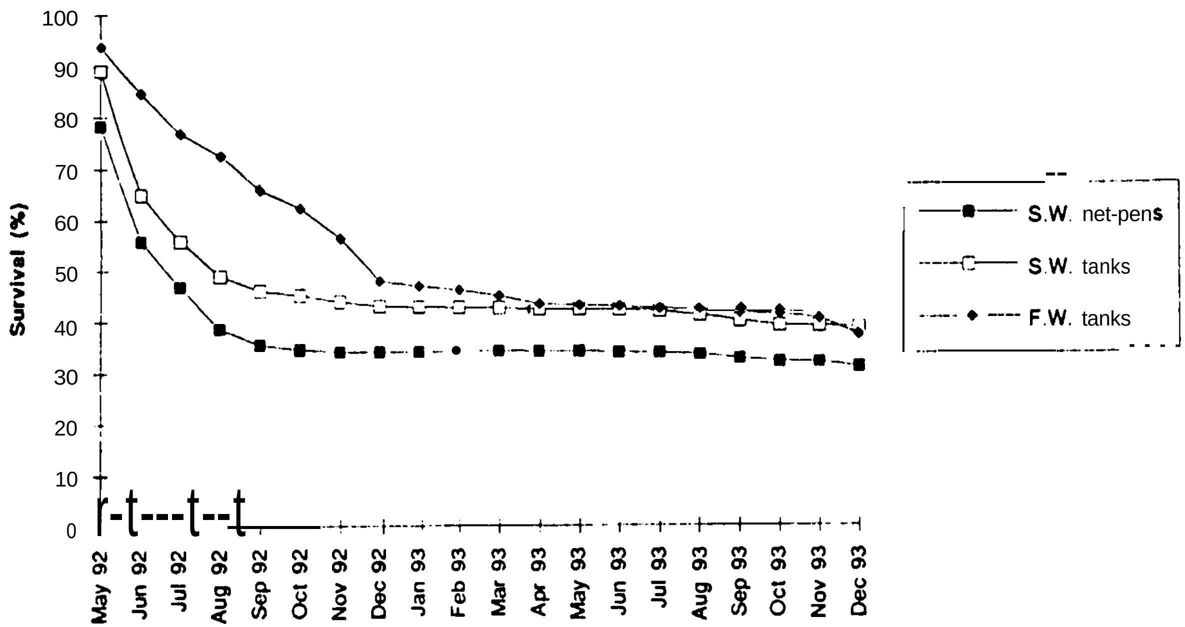

Figure 4.--Survival during rearing for 1990-brood *Lake Wenatchee sockeye salmon, 1992-1993.*

seawater tank, and 509 g in the seawater net-pen replicates at the last quarterly measuring period (November 1993) during the reporting period (Appendix C and Fig. 5). ANOVA indicated significant differences ($P < 0.01$) between average weights of fish in the three treatments. Tukey's multiple comparison test indicated that average fish weight in the treatments ranked freshwater tanks > seawater tanks > seawater net-pens ($P < 0.01$).

The cause of these growth differences is unclear. Fish in the treatments received approximately the same ration proportion (on a size-adjusted basis). 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.

Cumulative temperature units during rearing varied by about 8%: 5,953°C for the freshwater treatment and 6,439°C for the saltwater treatments from the beginning of the experiment in May 1992 through the end of December 1993. Although, theoretically, the additional temperature units should have favored growth in the seawater treatments, growth was greatest in the freshwater treatment. The fish reared in fresh water were about 43% larger than fish reared in the seawater tanks and almost 95% larger than those reared in the seawater net-pens. Stress related to combinations of seawater osmoregulatory problems and disease may

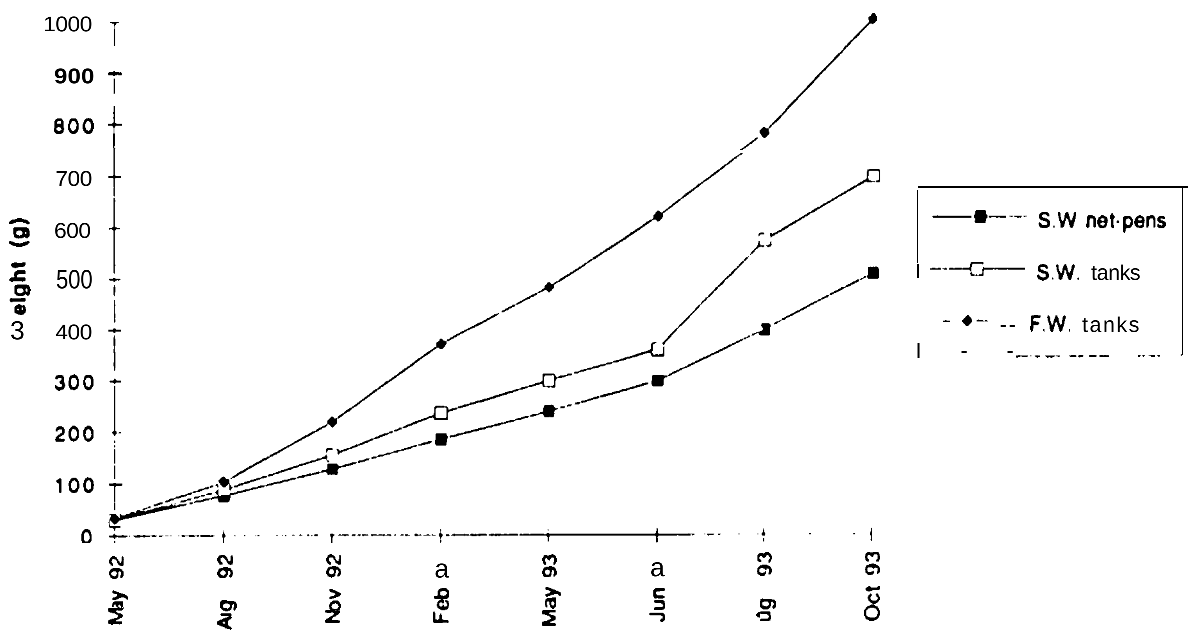

figure 5.--Growth during rearing for 1990-brood *Lake* Wenatchee *sockeye* salmon, 1992-1993.

have suppressed growth in seawater treatments compared to the treatment of constant 10°C fresh (well) water.

The 1990-brood were expected to mature as 4-year-old fish in fall 1994. However, approximately 15% of fish in the freshwater replicates (30 females and 24 males) matured (as jacks and jills) at 3 years of age in late October 1993 (Table 6). No fish matured in the seawater treatments in 1993. Fast growth and large size can trigger early maturity in sockeye salmon (C. Wood, Canada Department of Fish and Oceans, Pacific Biological Station, Nanaimo, B.C., Canada. Pers. commun. October 1991). We believe the early maturity of some fish in the freshwater treatment was due to their larger size.

In 1994, we plan to sequentially sample fish from all three treatments for growth and reproduction to help determine factors influencing maturation of captive broodstocks. Sexual maturation of fish reared in the three treatments will be monitored by non-destructive methods. Plasma hormone levels that are elevated only during sexual maturation (sex steroids and pituitary gonadotropins) will be measured at monthly intervals in 3- and 4-year-old fish. The plasma hormone levels will be used as an index of the number of fish in a given group that will spawn that year and to determine the sex of the maturing fish. At the time of spawning, fecundity and egg size will be determined and gamete quality will be monitored by evaluating fertilization rate. The quality of the offspring will be evaluated by monitoring survival to the time of hatching. During the month preceding spawning,

Table 6.--Length and weight information for mature 1990-brood Lake Wenatchee sockeye salmon held full-term in fresh water, 1993.

Replicate number	Fish number	Male Length (cm)	Male Weight (kg)	Female Length (cm)	Female Weight (kg)
1	1	40.6	0.76	41.7	0.88
	2	41.4	0.87	41.6	0.93
	3	42.2	0.98	39.6	0.75
	4	32.6	0.56	42.0	0.86
	5	43.7	1.14	40.3	0.71
	6	42.0	0.91	40.0	0.71
	7	---	---	42.7	0.96
	8	---	---	40.7	0.85
	9	---	---	41.9	0.99
	10	---	---	43.0	0.92
	11	---	---	42.0	0.97
	12	---	---	43.0	0.96
	13	---	---	39.4	0.72
Average		40.4	0.87	41.4	0.86
SD		3.6	0.18	1.2	0.10
2	1	40.4	0.75	40.6	0.85
	2	41.0	0.95	42.2	0.91
	3	43.2	1.02	38.3	0.72
	4	37.5	0.73	41.8	0.90
	5	44.6	1.17	42.7	0.98
	6	40.3	0.84	43.9	0.99
	7	43.4	1.04	39.8	0.78
	8	42.1	0.92	41.5	0.87
	9	40.6	0.84	42.0	0.98
	10	---	---	40.2	0.79
Average		41.5	0.92	41.4	0.88
SD		2.0	0.14	1.4	0.09

Table 6.--Continued.

Replicate number	Fish number	Male Length (cm)	Male Weight (kg)	Female Length (cm)	Female Weight (kg)
3	1	45.1	1.21	40.0	0.81
	2	45.8	1.33	43.6	0.92
	3	45.0	1.26	40.5	0.80
	4	43.8	1.07	43.8	0.11
	5	42.8	0.98	45.1	0.10
	6	44.6	1.15	39.7	0.76
	7	43.5	1.08	41.9	0.88
	8	44.1	1.15	---	
	9	47.4	1.53	---	---
Average		44.7	1.12	42.1	0.90
SD		1.3	0.15	1.9	0.12
Combined[a]					
Average		42.7	1.01	41.5	0.87
SD		1.3	0.22	1.6	0.10
Overall average[b]					
Length	41.9 cm				
SD	2.3				
Weight	0.94 kg				
SD	0.18				

[a] Pooled replicates.

[b] Total pooled male and female.

experiments will also be conducted on artificial induction of ovulation and spermiation using implants containing gonadotropin-releasing hormone analogue (GnRHa).

Female 1990-brood sockeye salmon spawned from the freshwater tank replicates averaged 41.5 cm and 0.87 kg (Table 6). ANOVA indicated no significant difference ($P > 0.05$) in female length or weight between fish spawned from the freshwater replicates. Male 1990-brood sockeye salmon spawned from the freshwater tank replicates averaged 42.7 cm and 1.01 kg (Table 6). ANOVA indicated significant difference ($P < 0.01$) in male length and weight between the freshwater replicates. Tukey's multiple comparison test indicated that average male length and weight (Table 6) was greater ($P < 0.03$) for fish spawned from replicate 3 than replicates 1 and 2. The reason for differences in male length and weight between the replicates is unclear. However, this size difference may be related to chance, since fish in all three replicates received approximately the same ration and since spawning females in the freshwater replicates showed no significant size differences.

Fecundity averaged 1,359 eggs/female (about 1,560 eggs/kg of female weight) for the 1990-brood Lake Wenatchee sockeye salmon spawned from the freshwater rearing treatment in our experiments in 1993 (Table 7). Columbia River Basin female sockeye salmon normally mature as 4- and 5-year-old fish, at about 50 cm and 1.7 kg, with fecundities averaging about 2,600 eggs per female (about 1,500 eggs/kg of female weight) (Mullan 1986, Flagg et al.

Table 7.--Individual matings and egg survivals for mature 1990-brood Lake Wenatchee sockeye salmon held full-term in fresh water, 1993.

Replicate	Matins cross Female number	 Male[a] number	Fecundity	Eyed-egg survival (%)
1	1-1	1-1,2	1,480	65.3
	1-2	1-1,2	1,464	44.8
	1-3	1-1,2	1,161	14.3
	1-4	1-1,2	1,283	24.2
	1-5	1-3,4,5	1,129	0.0
	1-6	1-3,4,5	1,260	39.1
	1-7	1-3,4,5	1,396	91.2
	1-8	1-3,4,5	1,312	58.9
	1-9	1-3,4,5	1,530	55.0
	1-10	1-3,4,5	1,261	54.8
	1-11	1-1,2	1,159	58.8
	1-12	1-1,2	1,112	16.4
	1-13	1-1,2	1,309	78.8
Average			1,297	46.3
SD			133	25.6
2	2-1	2-2,3	1,394	1.4
	2-2	2-2,3	2,021	0.0
	2-3	2-4,5,6	1,009	0.0
	2-4	2-4,5,6	1,382	44.7
	2-5	2-4,5,6	1,378	51.5
	2-6	2-7,8,9	1,418	0.0
	2-7	2-7,8,9	1,592	0.0
	2-8	2-7,8,9	1,527	53.1
	2-9	2-2,3	1,479	54.3
	2-10	2-4,5,6	1,078	96.6
Average			1,428	21.5
SD			264	24.3

Table 7.--Continued.

Replicate	Mating cross Female number	Male[a] number	Fecundity	Eyed-egg survival (%)
3	3-1	3-1,2	1,428	42.9
	3-2	3-1,2	1,196	0.0
	3-3	3-3,4	1,258	0.0
	3-4	3-3,4	1,789	41.0
	3-5	3-5,6	1,560	20.8
	3-6	3-5,6	1,247	93.7
	3-7	3-7,8,9	1,151	63.8
Average			1,413	37.5
SD			209	31.6
Combined[b]				
Average			1,359	35.9
SD			215	29.3

a Eggs fertilized with pooled lots of milt from two or three males.

b Pooled replicates.

1991). In addition, positive fecundity/size relationships are common for sockeye salmon (Groot and Margolis 1991). Therefore, lower absolute fecundity is to be expected in smaller early maturing fish (e.g., the age-3 sockeye in our experiments). Even though the age-3 maturing fish in this experiment were smaller than normal age-4 and age-5 maturing fish, fecundity was within the expected range for sockeye salmon. ANOVA indicated no significant difference ($P > 0.05$) in fecundity of females spawned from the three freshwater replicates. There was a significant correlation ($P < 0.01$) between female weight and fecundity in the freshwater treatment (Table 6 and Fig. 6). Eyed-egg survival from 1990-brood Lake Wenatchee sockeye salmon from the freshwater rearing treatment in 1993 averaged only about 36% (Table 7). ANOVA indicated no significant difference ($P > 0.05$) in eyed-egg survival in the three freshwater rearing replicates (Table 7). In addition, there was no correlation ($P > 0.05$) between female weight and egg survival in the freshwater treatment (Table 7 and Fig. 7). The eyed-egg survival rate in this study is much lower than the 70 to 90% often seen from wild sockeye salmon (Mullan 1986, Flagg et al. 1991). However, the rate is similar to the 30% eyed-egg survival documented for IDFG Redfish Lake sockeye salmon captive broodstock spawned in 1993 (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun. December 1993)

We are unsure of causes of these low egg-viability rates from captive-reared fish. However, spawning techniques were ruled out: these were the same as techniques successfully used in

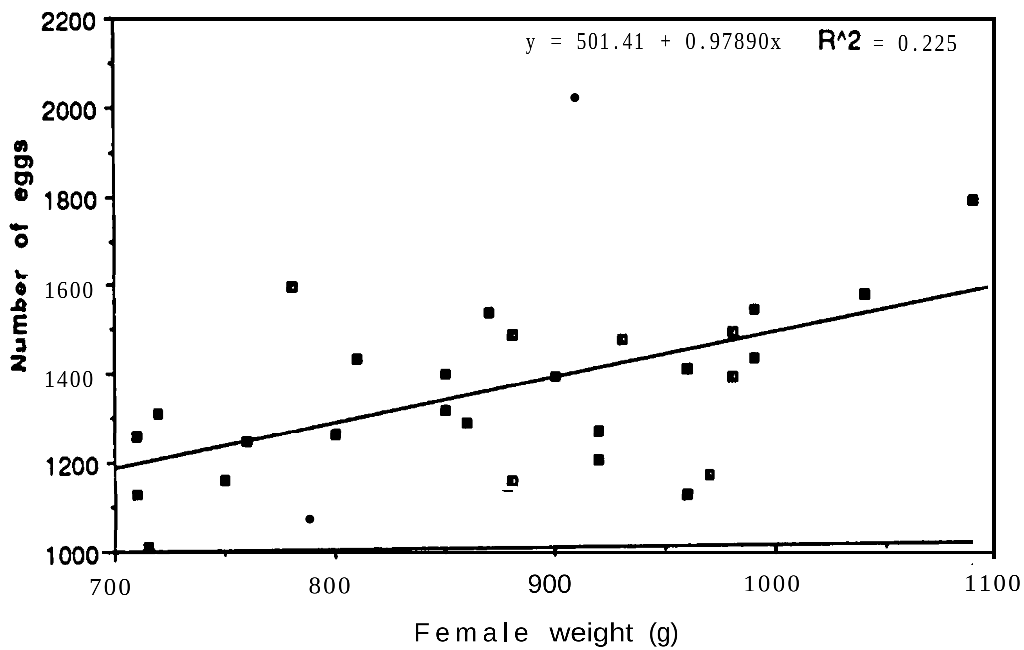

Figure 6.--Correlation between female weight and number of eggs for 1990-brood Lake Wenatchee sockeye salmon spawned in 1993.

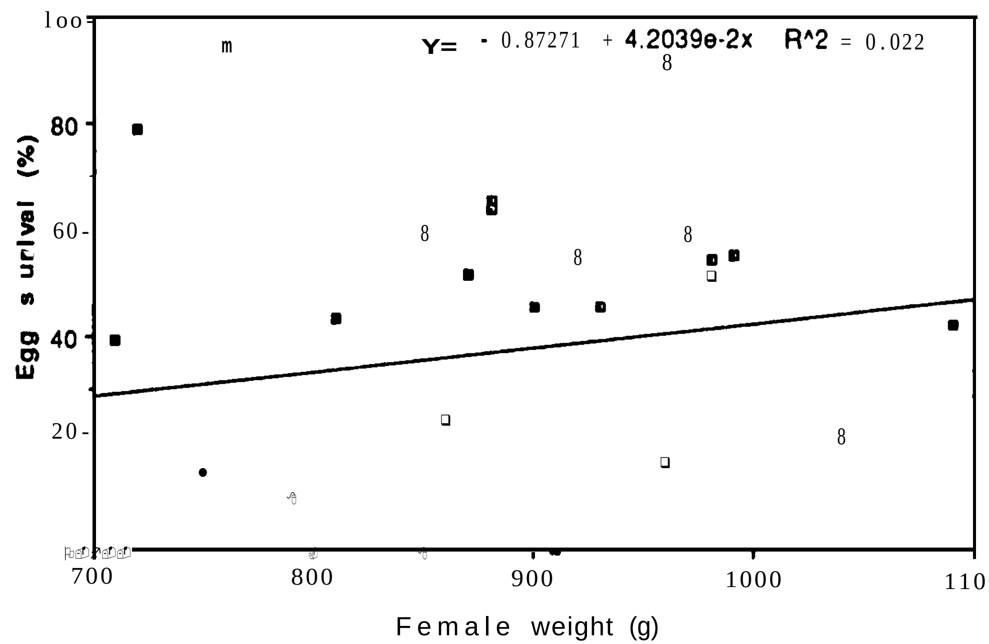

Figure 7.--Correlation between female weight and egg survival for 1990-brood Lake Wenatchee sockeye salmon spawned in 1993.

other NMFS and IDFG programs. High eyed-egg survival has been reported for other Pacific salmon (Oncorhynchus spp.) and Atlantic salmon captive broodstocks (McAuley 1983; Harrell et al. 1984a,b, 1985, 1987; Peterschmidt 1991; C. Mahnken and T. Flagg, NMFS, unpublished data). Consequently, we believe it is not the act of culture, per se, that is reducing egg survival. Nevertheless, low fertilization rates will hamper recovery efforts using captive broodstocks. Therefore, in cooperation with IDFG, we are beginning to investigate a number of factors to increase spawning success, including development of species-specific broodstock diets (sockeye salmon are planktivorous whereas commercial brood diets are formulated for piscivorous fish) and implementation of environmental and hormonal manipulation of reproduction.

Experimental rearing of the 1990-brood Lake Wenatchee sockeye salmon in the three rearing treatments will continue until fish reach normal age-4 maturity in fall 1994.

1991 Brood

About 3,000 1991-brood Lake Wenatchee (yearling) sockeye salmon were donated to this study from the BPA-NMFS Cle Elum Lake study (Project 86-45). Experimental groups were established for the 1991-brood in mid May 1993. Three replicates of about 300 fish each were set up in 1) circular tanks supplied with pathogen-free fresh water; 2) seawater net-pens at Manchester; and 3) circular tanks supplied with pumped, filtered, and UV sterilized seawater at Manchester. Freshwater replicates were held at the Seattle hatchery until early November 1993 and transferred to BBC for rearing to maturity. All fish were injected with bivalent vibrio vaccine (0.15 cc/fish) and erythromycin (50 mg/kg of body weight) prior to transfer.

Inventory records for experimental groups of 1991-brood Lake Wenatchee sockeye salmon during the 7 months of rearing from the beginning of the experiment in 1993 through the end of December 1993 indicate survival averaged about 76% in the seawater net-pen replicates, 93 in the seawater tanks, and almost 100% in the freshwater tanks (Appendix D and Fig. 8). 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%). 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 of dead or moribund fish during the months just after transfer to the experiment. 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.

Analysis of variance (ANOVA) indicated a significant difference ($P < 0.01$) in the percentage of fish remaining in freshwater, seawater, and seawater net-pen replicates at the end of December 1993. Tukey's multiple comparison test indicated that survival in the seawater net-pens was significantly other NMFS and IDFG programs. High eyed-egg survival has been reported for other Pacific salmon (*Oncorhynchus* spp.) and Atlantic salmon captive broodstocks (McAuley 1983; Harrell et al. 1984a,b, 1985, 1987; Peterschmidt 1991; C. Mahnken and T. Flagg, NMFS, unpublished data). Consequently, we believe it is not the act of culture, per se, that is reducing egg survival. Nevertheless, low fertilization rates will hamper recovery efforts using captive broodstocks. Therefore, in cooperation with IDFG, we are beginning to investigate a number of factors to increase spawning success, including development of species-specific broodstock diets (sockeye salmon are planktivorous whereas commercial brood diets are formulated for piscivorous fish) and implementation of environmental and hormonal manipulation of reproduction.

Experimental rearing of the 1990-brood Lake Wenatchee sockeye salmon in the three rearing treatments will continue until fish reach normal age-4 maturity in fall 1994.

1991 Brood

About 3,000 1991-brood Lake Wenatchee (yearling) sockeye salmon were donated to this study from the BPA-NMFS Cle Elum Lake study (Project 86-45). Experimental groups were established for the 1991-brood in mid May 1993. Three replicates of about 300 fish each were set up in 1) circular tanks supplied with pathogen-free fresh water; 2) seawater net-pens at Manchester; and 3) circular tanks supplied with pumped, filtered, and UV sterilized seawater at Manchester. Freshwater replicates were held at the Seattle hatchery until early November I993 and transferred to BBC for rearing to maturity. All fish were injected with bivalent vibrio vaccine (0.15 cc/fish) and erythromycin (50 mg/kg of body weight) prior to transfer.

Inventory records for experimental groups of 1991-brood Lake Wenatchee sockeye salmon during the 7 months of rearing from the beginning of the experiment in 1993 through the end of December 1993 indicate survival averaged about 76 in the seawater net-pen replicates, 93 in the seawater tanks, and almost 100% in the freshwater tanks (Appendix D and Fig. 8). 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%). 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 of dead or moribund fish during the months just after transfer to the experiment. 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.

Analysis of variance (ANOVA) indicated a significant difference ($P < 0.01$) in the percentage of fish remaining in freshwater, seawater, and seawater net-pen replicates at the end of December 1993. Tukey's multiple comparison test indicated that survival in the seawater net-pens was significantly

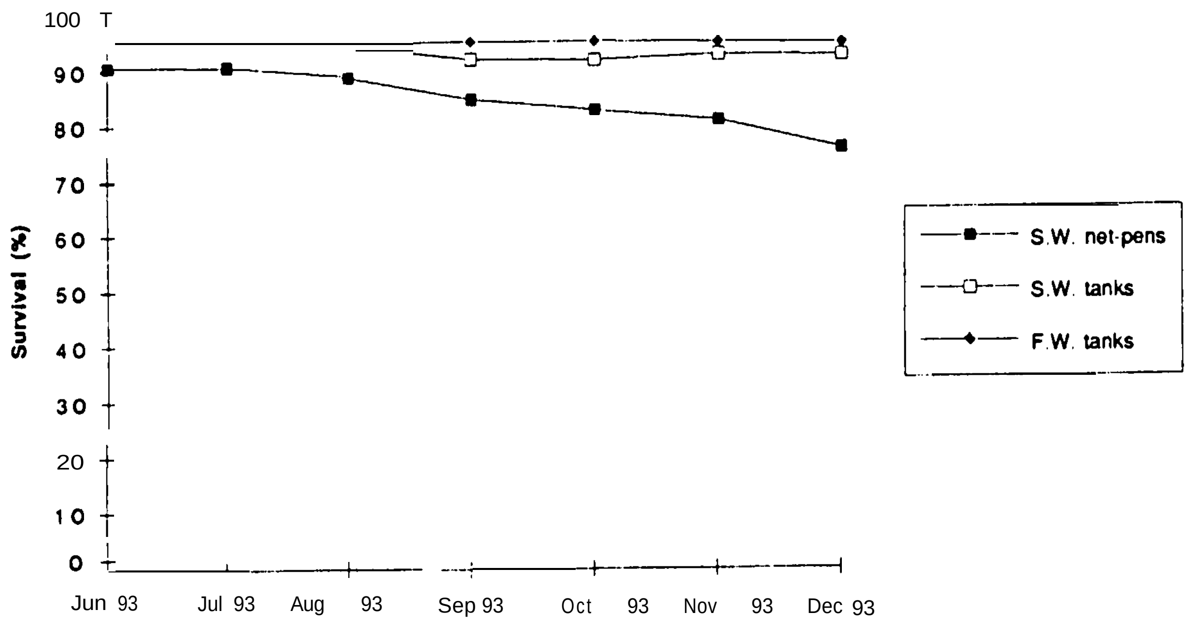

Figure 8.--Survival during rearing for 1991-brood Lake Wenatchee sockeye salmon, 1993.

($P < 0.01$) lower than survival in the freshwater and seawater tank treatments. BKD appears to have caused some of the mortality in the seawater net-pen treatment. However, for most mortalities in the treatments, diagnosis could not confirm a specific cause of death.

Growth differences were noted between the treatments. Size of fish averaged about 112 g in the freshwater tank, 116 g in the seawater tank, and 95 g in the seawater net-pen replicates at the last quarterly measuring period (November) during the reporting period (Appendix D and Fig. 9). 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 ($P < 0.01$) between average weights of fish in the three treatments at the end of December 1993. Tukey's multiple comparison test indicated that average weight of fish reared in the seawater net-pen treatment was significantly ($P < 0.01$) lower than fish reared in the other two treatments (e.g., freshwater and seawater tanks)

These results are similar to results of our rearing study for 1990-brood Lake Wenatchee sockeye salmon (described above). The reasons for these differences in growth and survival remain unclear. However, it is apparent that seawater net-pens are the least conducive to survival and growth in these experiments.

It is encouraging to note that mortality for experimental groups of 1991-brood Lake Wenatchee sockeye salmon during the 7 months of rearing from the beginning of the experiment in 1993

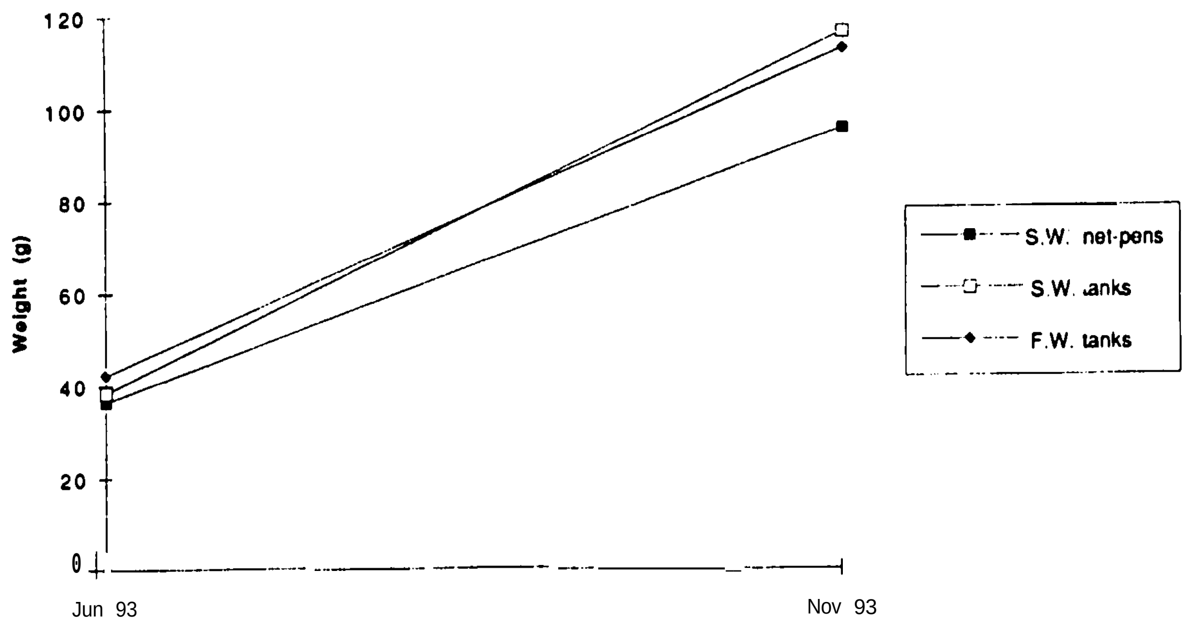

Figure 9.--Growth during rearing for 1991-brood Lake Wenatchec sockeye salmon, 1992-1993.

through the end of December 1993 is much lower than for the 1990-brood Lake Wenatchee sockeye salmon during the equivalent rearing period (Appendices C and D and Figs. 4 and 8). The 1991-brood Lake Wenatchee sockeye salmon in these experiments had a much lower incidence of BKD during fry-to-smolt rearing compared to the 1990-brood. As expected, the better presmolt health status of the 1991-brood appears to have translated to higher survival in our experiments. 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 as a prophylactic for BKD. Experimental rearing of the 1991-brood Lake Wenatchee sockeye salmon in the three rearing treatments will continue until the fish mature in fall 1994 to fall 1996.

Evaluation of Parental Seawater Exposure vs. Full-Time Freshwater Residence on Performance of Offspring

In early 1993, we began an experiment to compare performance of progeny of sockeye salmon held full-term to maturity in fresh water and progeny of sockeye salmon parents with a period of seawater residence. This experiment helps determine if seawater adaptability of progeny is compromised by the one generation break in the normal seawater life-phase of sockeye salmon that results from captive broodstocks being reared full-term to maturity in freshwater. This experiment focused on survival of yearling smolt-size and smolt-age juveniles from "freshwater-parentage" and "seawater-parentage" during the first 4 months after transfer to seawater net-pens at Manchester.

One 1987-brood Lake Wenatchee female was held full-term to maturity in fresh water and spawned in 1991 at the Seattle hatchery as part of BPA Project 86-45. This female was 340 mm fork length and contained 959 eggs. The eggs were fertilized with milt from males held full-term to maturity in fresh water. Progeny from these fish were ponded in early February 1992; survival to hatch (viability) was 65.7%. It was impossible to determine if the low egg-viability was the result of full-term freshwater culture or other influences. Survival of this 1991 freshwater-cultured brood from hatch in early January 1992 to spring 1993 was about 90%.

Wild anadromous adult Lake Wenatchee stock sockeye salmon were taken from the Wenatchee River Basin in 1991, spawned, and juveniles reared at the Seattle hatchery as part of BPA Project 86-45. Survival of these fish was about 80% during rearing. About 400 juveniles from each group (e.g., "freshwater-parentage" and "seawater-parentage") were donated to our captive broodstock study from BPA Project 86-45. These fish were held in an outside rearing area at the Seattle hatchery under ambient photoperiod during spring 1993.

In May 1993, two replicates of 1991-brood "freshwater-parentage and 1991-broo "seawater-parentage" juveniles were transferred to seawater net-pens at Manchester (Appendix E). Culture strategies were similar to those outlined for 1990-brood

Lake Wenatchee sockeye salmon seawater net-pen rearing. The limited number of juveniles available for this study precluded lethal sampling of parameters (e.g., plasma electrolytes) to measure immediate seawater tolerance. Therefore, survival was the only quantity documented in this study. Survival of the fish during the seawater phase of the experiment from May through September 1993 averaged about 83% for the 1991 "freshwater-parentage" replicates and 79% for the 1991 "seawater-parentage" replicates (Appendix E and Fig. 10). A T-test indicated that there was no significant difference ($P > 0.05$) in survival for the two treatments.

Results of this experiment suggest that full-term freshwater rearing of sockeye salmon captive broodstocks may not compromise seawater adaptability of offspring. However, it should be cautioned that these data are somewhat inconclusive due to the fact that the progeny of only one female held full-term to maturity in fresh water were available for testing. In the future, numerous progeny from Lake Wenatchee sockeye salmon reared to maturity in fresh water and seawater in our captive broodstock experiments should be available. Evaluation of seawater performance of these fish should better determine the effects on progeny of full-term freshwater rearing of parents.

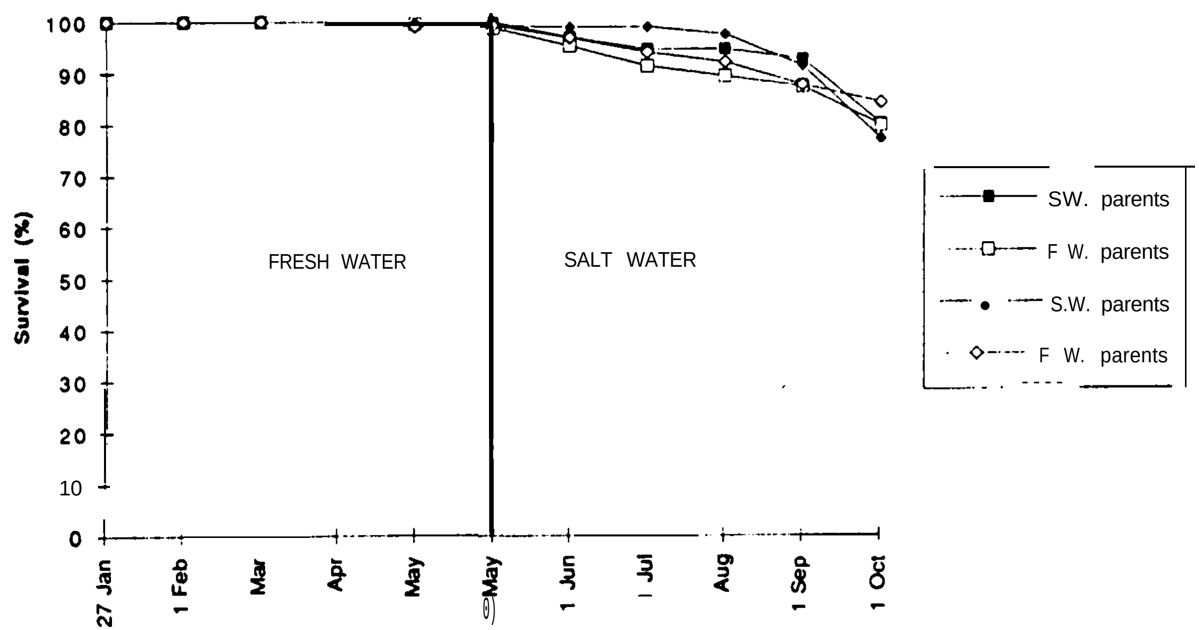

Figure 10.- Survival during rearing for individual replicates of 1991-brood Lake Wenatchee sockeye salmon from freshwater and seawater percentage, 1993.

CONCLUSIONS

1) Endangered Redfish Lake sockeye salmon captive broodstocks.

Because of the low replacement rate and the critically low population size of Redfish Lake sockeye salmon, captive broodstocks appear to offer the only hope to maintain the species while habitat improvements are underway. 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 the captive broodstock projects should help guarantee the success of recovery efforts for Redfish Lake sockeye salmon. It is virtually certain that without the boost provided by these captive broodstock projects, Redfish Lake sockeye salmon would soon be extinct.

2) Captive broodstock experiments using non-endangered Lake Wenatchee. sockeye salmon.

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 sterilized seawater; and 3) seawater net-pens for rearing sockeye salmon. In addition, our studies suggest that full-term freshwater rearing of sockeye salmon captive broodstocks should not compromise seawater adaptability of offspring. Even though full-term freshwater rearing appears to be the correct choice for valuable captive broodstocks (e.g., Redfish Lake sockeye salmon), the data are also encouraging regarding the use of environmentally-controlled seawater for broodstock rearing. However, these experiments need to be continued for several years before complete information is available regarding overall survival, gamete quality, and offspring fitness from captive broodstocks.

This research will aid in refining captive broodstock technology for application to the recovery of threatened and endangered species of salmonids. Perhaps most importantly, vital research using Lake Wenatchee sockeye salmon will allow selected fish culture strategies to be evaluated prior to implementation with Redfish Lake stock, thus providing maximum safeguards for the maintenance of this valuable gene pool.

ACKNOWLEDGMENTS

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Appendix A

REDFISH LAKE SOCKEYE SALMON
CAPTIVE BROODSTOCK PROGRAMS

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INTRODUCTION

In December 1991, the National Marine Fisheries Service (NMFS) listed Snake River sockeye salmon (Oncorhynchus nerka) as endangered under the U.S. Endangered Species Act (ESA). This action was the result of a petition presented to NMFS by the Shoshone-Bannock Tribe of Idaho. The petition requested NMFS to consider the status of these fish under the ESA. Subsequently, NMFS conducted a formal Biological Status Review for these fish. After considering the precipitous decline of this population, from a healthy status in the 1950s to few fish returning in the late 1980s, as well as the ecological significance and biological integrity of the species, the NMFS Biological Review team concluded in favor of listing (Waples et al. 1991).

NMFS is developing a formal Recovery Plan for Snake River sockeye salmon. In cooperation with the Idaho Department of Fish and Game (IDYG), the Bonneville Power Administration (BPA), and others, NMFS has begun interim recovery measures for anadromous Snake River sockeye salmon. These efforts focus on protecting 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. Because of the critically low population size of Redfish Lake sockeye salmon, interim recovery measures are centered around a series of captive broodstocks to maintain the species while habitat improvements are underway (Flagg 1993, Johnson 1993).

There are several known forms of 0. nerka. The anadromous sockeye salmon usually spends 1 to 2 years in its nursery lake before migrating to sea as a smolt. Anadromous sockeye salmon remain at sea for 2 to 3 years before returning to the natal area to spawn (Foerster 1968, Groot and Margolis 1991). Two other 0. nerka forms remain in fresh water to mature and reproduce. Residual sockeye salmon are progeny of anadromous fish and produce mostly anadromous offspring (Ricker 1938, Foerster 1968, Groot and Margoiis 1991). 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, Groot and Margolis 1991). Residual sockeye salmon in Redfish Lake were included in the anadromous gene pool for ESA protection, while kokanee were excluded.

Since both anadromous and residual forms of sockeye salmon inhabit Redfish Lake along with kokanee, a continuing challenge has been to differentiate them from the kokanee in developing broodstocks. Fortunately, there are a number of mechanisms to help differentiate sockeye salmon from kokanee. First, there is both spatial and temporal separation of the two 0. nerka forms in Redfish Lake. The anadromous and residual forms are beach spawners that spawn in the lake in late October, whereas the kokanee spawn in a tributary to the lake in early September. Also, kokanee skin and flesh may be more red at spawning than sockeye salmon maintained on the same diet (Waples 1992). This is because kokanee, which live in a carotenoid-poor environment, appear to be more efficient than sockeye salmon at utilizing carotenoid in the diet. In addition, recent investigations have indicated that anadromous and residual sockeye salmon can be differentiated from kokanee by both protein electrophoresis[1] and DNA analysis (Brannon et al. 1992). Recent information also suggests that since anadromous fish spend time in seawater, an environment rich in strontium, it is possible to distinguish the progeny of anadromous parents based on the elevated strontium/calcium ratio in the primordial core of their otoliths (Kalish 1990). All of the criteria described above are being used in helping differentiate kokanee from anadromous sockeye salmon.

This paper describes the current status of Redfish Lake sockeye salmon captive broodstock recovery programs.

STATUS OF CAPTIVE BROODSTOCKS

Between 1991 and 1993, a number of captive broodstocks have been initiated to preserve the Redfish Lake sockeye salmon. Sources for these broodstocks include: 1) juveniles captured during their outmigration from Redfish Lake; 2) adults captured returning to Redfish Lake; and 3) mature residuals captured in the lake. Most past attempts to rear sockeye salmon to maturity in seawater have ended in failure due to high mortality from

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[1] Robin Waples. National Marine Fisheries Service. Northwest Fisheries Science Center. Seattle, Washington. Pers. commun. October 1993.

disease and poor gamete quality of captive-reared spawners[2,3]. However, culture in pathogen-free fresh water has generally resulted in higher survival to spawning and higher percentages of viable gametes[2,3]. One of our primary obligations when maintaining an endangered species in protective culture is ensuring the highest possible survival. Therefore, full-term freshwater rearing was chosen for these endangered species captive broodstocks.

In most cases, fish in the captive broodstocks will be grown to maturity, spawned, and their progeny released into Redfish Lake. Enhancement strategies include growing the juveniles in a hatchery or in net-pens in Redfish Lake for presmolt release to the lake in the fall. These juveniles would overwinter in the lake and outmigrate naturally as yearling smolts the next spring. Other juveniles may be reared in the hatchery for release into Redfish Lake as yearling smolts in the spring. In addition, a few maturing adults from Idaho captive broodstocks may be released in the fall to spawn naturally in Redfish Lake.

Outmigrant-based captive broodstocks

Juvenile *O. nerka* were captured by IDFG in a smolt trap as they exited Redfish Lake during the spring in 1991, 1992, and

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[2] Chris Wood. Department of Fish and Oceans. Pacific Biological Station. Nanaimo, B.C., Canada. Pers. commun. 1991.

[3] William Waknitz. NMFS, Manchester Marine Experimental Station. Manchester, Washington. Pers. commun. 1991.

1993. Presumably, these fish are progeny of the single pair of anadromous adults observed in the lake in 1989 mixed with residuals and resident kokanee.

In spring 1991, 0. nerka outmigrants were collected in the smolt trap and moved to the IDFG Eagle Hatchery near Boise, Idaho. It is estimated that another 4,000 outmigrants passed downstream in 1991. About 50% of the 759 outmigrants captured in 1991 have survived 2.5 years, from the time of capture to fall 1993. Some mortality during rearing was attributable to bacterial kidney disease (BKD) and aeromonad infection. Although these were mostly yearling fish at capture (1989 brood), and were expected to mature in 1993 as Age-4 fish, very few (about 15%) appear to be maturing in 1993. Only twenty-four maturing adults (12 males and 12 females) from this broodstock were released into Redfish Lake in late August to spawn naturally. These fish were sonic tagged and are being tracked to identify their spawning locations. It is projected that another 15 to 20 females will spawn in captivity this year, resulting in 30,000 to 40,000 eggs. Over 250 immature fish will be held at Eagle Hatchery to be spawned during the next 2 years.

In spring 1992, 79 0. nerka outmigrants were collected in the smolt trap and moved to the IDFG Eagle Hatchery. It is estimated that another 1,200 fish outmigrated in 1992. Survival of these fish during the 1.5 years from capture to fall 1993 has been about 88%. We expect most of these fish to spawn between fall 1994 and 1996.

In spring 1993, 35 *O. nerka* outmigrants were collected in the smolt trap and moved to the IDFG Eagle Hatchery. It is estimated that another 600 fish outmigrated in 1993. Survival of these fish during the 6 months from capture to fall 1993 has been almost 100%, and most of these fish should spawn between fall 1995 and 1997.

We are most interested in breeding the portion of these captive broodstock populations that originated from anadromous parents. A combination of factors described above (e.g., age and time of maturity, Sr/Ca ratios, skin and flesh color, genetics, etc.) will be used to help separate sockeye salmon from kokanee. Only gametes from fish of confirmed anadromous parentage will be used in recovery programs.

Residual captive broodstocks

Members of the NMFS Biological Status Review team theorized that residuals helped maintain the Redfish Lake sockeye salmon population during historic population lows (Waples et al. 1991). In fall 1992, a number of residuals were observed spawning on the Sockeye Salmon Spawning Beach in Redfish Lake and some of them were captured. Thirty-five eggs were recovered from a "spawned-out" female and were fertilized with milt from a residual male that was also captured. Survival of these fish during the year, from capture to fall 1993, has been almost 100%. We anticipate that most of these fish will spawn between fall 1996 and 1998.

IDFG is undertaking efforts to capture more residuals in fall 1993. To date, eight male and two female residuals have been captured. These fish will be spawned in November 1993.

Anadromous captive broodstocks

The most valuable of the captive broodstocks are derived from adult sockeye salmon returning to Redfish Lake. We are confident that these fish are part of the anadromous sockeye salmon gene pool from Redfish Lake. Progeny of returning adult sockeye salmon have the highest likelihood (of the available broodstocks) of aiding the recovery of the species in Redfish Lake.

In 1991, three males and one female adult sockeye salmon returned to Redfish Lake and were captured and held by IDFG. The female spawned volitionally with an unknown combination of males, on gravel placed in the holding tank. This spawning resulted in deposition of about one-half of the female's eggs (about 1,000 eggs). The female was then removed from the tank and the remaining eggs strip spawned. About four-fifths of the stripped eggs were separated into three lots to be fertilized with milt from individual males. The remainder were fertilized with pooled milt from all three males. Two geographically separate captive-brood populations were established from these egg lots in order to reduce the risk of catastrophic loss due to mechanical failure, human error, or disease.

Approximately one-half the progeny of adults that returned to Redfish Lake in 1991 were transferred to NMFS Northwest

Fisheries Science Center in Seattle, Washington. Survival of these fish has been about 72% during 1.75 years of rearing (from hatch in January 1992 to fall 1993), with most mortalities due to BKD. The remaining 1991-brood Redfish Lake sockeye salmon are in the custody of IDFG and are being held at Eagle Hatchery. Survival of the fish at IDFG has been over 90% during 1.75 years of rearing. We anticipate that most of these fish (at both NMFS and IDFG) will mature during the fall of 1995 and 1996 as normal Age-4 and Age-5 fish.

In fall 1992, a single male sockeye salmon returned to Redfish Lake, and its milt was cryopreserved for mating with future generations.

In fall 1993, two female and six male sockeye salmon returned to Redfish Lake. These fish were held by IDFG at the Sawtooth Hatchery and strip spawned in October 1993, producing over 6,000 eggs. A full-factorial mating design resulted in six half-sib groups from each female. In addition, a portion of each female's eggs were crossed with cryopreserved milt from the single male sockeye salmon that returned to Redfish Lake in 1992. It is anticipated that NMFS and IDFG will subdivide each of these 14 mating crosses for captive-broodstock rearing.

DISCUSSION

The use of captive-broodstock technology holds promise as a means of accelerating recovery of depleted stocks. One of the current barriers to restoration of many depleted stocks of salmonids in the Columbia River Basin and elsewhere is the availability of suitable numbers of juveniles for supplementation. The relatively high fecundity of Pacific salmon, coupled with potentially high survival in protective culture, allows captive broodstocks to produce large numbers of juveniles in a single generation. We believe that maintenance of each year-class of broodstock in captivity for only a single generation or a limited number of generations should help assure that genetic integrity and adaptability to native habitats are preserved.

Captive broodstocks should be viewed as a short-term measure to aid in recovery, never as a substitute for returning naturally spawning fish to the ecosystem. The first juvenile sockeye salmon from our captive broodstocks will be released into Redfish Lake in 1994. Other research is underway in Redfish Lake to determine the carrying capacity and the feasibility of lake fertilization as enhancement strategy (Spaulding 1993).

The relatively stable egg supply provided by the captive broodstock program should help guarantee the success of recovery efforts for Redfish Lake sockeye salmon. It is a virtual certainty that, given the critically low population size, without the captive broodstock programs, Redfish Lake sockeye salmon would soon be extinct.

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APPENDIX B

Appendix B --Monthly inventory records for 1991-brood Redfish Lake sockeye salmon at NMFS, 1991-1993.

A. Number of fish

	1991				1992					
Group[a]	Eggs received (7 Dec)	Blank/ dead eggs	Fish Hatched (4-5 Jan)	Jan mort	Fish ponded (13 Feb)	Feb mort	Fish 1 Mar	Mar mort	Fish 1 Apr	Apr mort
1.	106	0	106	0	106	0	106	4	102	4
2.	119	2	117	3	114	0	114	0	114	0
3.	103	2	101	2	99	0	99	1	98	0
4.	83	2	81	0	81	0	81	5	76	0
5.	580	7	573	6	567	6	561	3	558	2
Total	991	13	978	11	967	6	961	13	948	6

1992

Group[a]	Fish 1 May	May mort	Fish 1 Jun	Jun mort	Fish 1 Jul	Jul mort	Fish 1 Aug	Aug mort	Fish 1 Sep	Sep mort
1.	98	0	98	0	98	4	94	1	93	1
2.	114	2	112	0	112	0	112	0	112	0
3.	98	2	96	0	96	0	96	1	95	0
4.	76	0	76	0	76	0	76	0	76	0
5.	556	2	554	0	554	3	551	3	548	2
Total	942	6	936	0	936	7	929	5	924	3

Appendix B.--Continued.

A. Number of fish (continued)

Group[a]	Fish 1 Oct	Oct mort	Fish 1 Nov	Nov mort	Fish 1 Dec	Dec Mort	Fish 1 Jan	Jan mort	Fish 1 Feb	Feb mort
	1992						1993			
1.	92	0	92	0	92	0	92	0	92	0
2.	112	0	112	0	112	0	112	0	112	0
3.	94	1	94	0	94	0	94	0	94 76	0
4.	76	0	76	0	76	0	76	0	545	0
5.	546	1	545	0	545	0	545	0		0
Total	921	2	919	0	919	0	919	0	919	0

Group[a]	Fish 1 Mar	Mar mort	Fish 1 Apr	Apr mort	Fish 1 May	May mort	Fish 1 Jun[b]	Jun mort	Fish 1 Jul	Jul mort
					1993					
1.	92	0	92	2	90	12	78	0	78	0
2.	112	1	111	6	105	14	91	0	91	0
3.	94	1	94	8	86	11	75	0	75	1
4.	76	1	75	8	67	11	56	0	56	0
5.	545	1	544	12	532	68	464	1	463	0
6.[c]								0		0
Total	919	3	916	36	880	116	764	1	763	1

Appendix B.--Continued.

A. Number of fish (continued)

Group[a]	Fish 1 Aug	Aug mort	Fish 1 Sep	Sep mort	Fish 1 Oct	Oct mort	Fish 1 Nov	Nov mort	Fish 1 Dec	Dec mort
	1993									
1.	78	5	73	1	72	16	56	4	52	11
2.	91	0	91	0	91	6	85	4	81	11
3.	74	3	71	0	70	3	67	2	65	7
4.	56	1	55		55	4	51	1	50	3
5.	463	7	456	19	447	28	419	13	406	41
6.[c]						3		0		4
Total	762	16	746	11	735	60	675	24	651	77

Group[a]	Fish 31 Dec
	1993
1.	41
2.	70
3.	58
4.	47
5.	365
6.[c]	
Total	574

Appendix B.--Continued.

B. Survival from hatch (%)

	Group[a]					
	1	2	3	4	5	Cumulative
			1992			
Feb 13 (pond)	100.0	97.4	98.0	100.0	99.0	98.9
Mar 1	100.0	97.4	98.0	100.0	97.9	98.3
Apr 1	96.3	97.4	97.0	93.8	97.4	96.9
May 1	92.5	97.4	97.0	93.8	97.0	96.3
Jun 1	92.5	95.7	95.0	93.8	96.7	95.7
Jul 1	92.5	95.7	95.0	93.8	96.7	95.7
Aug 1	88.8	95.7	95.0	93.8	96.2	95.0
Sep 1	87.7	95.7	94.1	93.8	95.6	94.5
Oct 1	86.8	95.7	94.1	93.8	95.3	94.2
Nov 1	86.8	95.7	93.1	93.8	95.1	94.0
Dec 1	86.8	95.7	93.1	93.8	95.1	94.0
			1993			
Jan 1	86.8	95.7	93.1	93.8	95.1	94.0
Feb 1	86.8	95.7	93.1	93.8	95.1	94.0
Mar 1	86.8	95.7	93.1	93.8	95.1	94.0
Apr 1	86.8	94.9	93.1	92.6	94.9	93.7
May 1	84.9	89.7	85.1	82.7	92.8	90.0
Jun 1	73.6	77.8	74.3	69.1	81.0	78.1
Jul 1	73.6	77.8	74.3	69.1	80.8	78.0
Aug 1	73.6	77.8	73.3	69.1	80.8	77.9
Sep 1	68.9	77.8	70.3	67.9	79.6	76.3
Oct 1	67.9	77.8	69.3	67.9	78.0	75.2
Nov 1	52.8	72.6	66.3	63.0	73.1	69.0

Appendix B.--Continued.

B. Survival from hatch (%) (continued)

	Group[a]					
	1	2	3	4	5	Cumulative
Dec 1	49.1	69.2	64.4	61.7	70.9	66.9
Dec 31	38.7	59.8	57.4	58.0	63.7	58.7

C. Weight (g)

	Date						
Group[a]	(pond) 2/13/92	4/22/92	6/2/92	6/29/92	7/29/92	8/27/92	9/30/92
1.	0.12	1.09	3.0	6.6	9.0	14.1	19.8
2.	0.12	1.13	3.4	6.1	9.4	13.1	19.2
3.	0.13	1.28	3.8	7.1	10.7	16.7	23.9
4.	0.12	1.35	3.8	7.3	10.8	17.0	23.9
5.	0.11	1.00	2.7	5.3	8.2	12.4	17.1
Average	0.12	1.17	3.4	6.5	9.6	14.7	20.8
SD	0.01	0.14	0.5	0.8	1.1	2.1	3.1

Appendix B.--Continued.

C. Weight (g) (continued)

Group[a]	Date 10/30/93	12/31/93	1/28/93	9/1/93[d]	10/1/93[d]	12/31/93[d]
1.	22.6	38.7	40.2	150	200	350
2.	23.0	39.4	42.8	150	200	350
3.	29.0	43.2	47.0	150	200	350
4.	28.6	47.3	47.1	150	200	350
5.	20.2	33.9	37.2	150	200	350
Average	24.7	40.5	42.9	150	200	350
SD	3.9	5.0	4.3	---	---	---

[a] Males A, B, and C were individually spawned with a portion of the females eggs (groups 1-3) a pool of sperm from males A, B, and C was used to fertilize a portion of the eggs (group 4); and the female spawned volitionally with an unknown combination of males A, B, and C (group 5).

[b] Fish transferred to BBC.

[c] Group 6 includes fish mortalities that have rejected (lost) PIT tags, making identification of mating cross impossible.

[d] Estimated weight. Because of health concerns, and with concurrence of NMPS and the SBSTOC, fish populations are not currently being weighed or measured. Therefore, no standard deviations are given.

APPENDIX C

Appendix C.--Monthly inventory records for 1990-brood Lake Wenatchee sockeye salmon at NMFS, 1992-1993.

A. Number of fish

Treatment/ replicate	Starting n	May mort	Fish 1 Jun	Jun mort	Fish 1 Jul	Jul mort	Fish 1 Aug	Aug mort	Fish 1 Sep	Sep mort
					1992					
Freshwater Tanks[a]										
1.	301	5	296	23	273	28	245	15	230	18
2.	291	15	276	31	245	24	221	12	209	22
3.	289	35	254	26	228	17	211	12	199	20
Total	881	55	826	80	746	69	677	39	638	60
Seawater Tanks[a]										
1.	260	29	231	63	168	21	147	12	135	9
2.		28	232	68	164	23	141	23	118	7
3.	260	29	233	58	175	27	148	18	130	7
Total	782	86	696	189	507	71	436	53	383	23
Seawater Net-pens[a]										
1.	252	58	194	55	139	21	118	14	104	4
2.	258	55	203	55	148	25	123	26	97	8
3.	265	55	210	65	145	23	122	24	98	12
Total	775	168	607	175	432	69	363	64	299	24

Appendix C.--Continued.

A. Number of fish (continued)

Treatment/ replicate	1992 Fish 1 Oct	1992 Oct mort	1992 Fish 1 Nov	1992 Nov mort	1992 Fish 1 Dec	1992 Dec mort	1993 Fish 1 Jan	1993 Jan mort	1993 Fish 1 Feb	1993 Feb mort
Freshwater Tanks[a]										
1.	212	15	197	24	173	32	141	3	138	1
2.	187	7	180	15	165	18	147	4	143	4
3.	179	9	170	13	157	24	133	1	132	2
Total	578	31	547	52	495	74	421	8	413	7
Seawater Tanks[a]										
1.	126	4	122	4	118	2	116	1	115	1
2.	111	0	111	3	108	4	104	0	104	0
3.	123	3	120	3	117	1	116	0	116	0
Total	360	7	353	10	343	7	336	1	335	1
Seawater Net-pens[a]										
1.	100	4	96	2	94	0	94	0	94	0
2.	89	2	87	2	85	0	85	0	85	0
3.	86	1	85	0	85	0	85	0	85	0
Total	275	7	268	4	264	0	264	0	264	0

Appendix C.--Continued.

A. Number of fish (continued)

Treatment/ replicate	Fish 1 Mar	Mar mort	Fish 1 Apr	Apr mort	Fish 1 May	May mort	Fish 1 Jun	Jun mort	Fish 1 Jul	Jul mort
					1993					
Freshwater **Tanks**[a]										
1.	137	1	136	2	134	0	134	1	133	1
2.	139	4	135	6	129	1	128	0	128	1
3.	130	5	125	6	119	2	117	0	117	2
Total	406	10	396	14	382	3	379	1	378	4
Seawater **Tanks**[a]										
1.	114	1	113	0	113	0	113	0	113	1
2.	104	0	104	2	102	0	102	1	101	1
3.	116	0	116	0	116	0	116	0	116	0
Total	334	1	333	2	331	0	331	1	330	2
Seawater **Net-pens**[a]										
1.	94	0	94	0	94	0	94	0	94	0
2.	85	0	85	0	85	0	85	0	85	0
3.	85	0	85	1	84	0	84	1	83	1
Total	264	0	264	1	263	0	263	1	262	1

Appendix C.--Continued.

A. Number of fish (continued)

Treatment/ replicate	Fish 1 Aug	Aug mort	Fish 1 Sep	Sep mort	Fish 1 Oct	Oct mort	Fish 1 Nov	Nov mort	Fish 1 Dec	Dec mort	Fish 31 Dec
					1993						
Freshwater Tanks[a]											
1.	132	1	131	2	129	0	129	1	128	1	127
2.	127	1	126	2	124	0	124	3	121	10	111
3.	115	0	115	3	112	2	110	4	106	16	90
Total	374	2	372	7	365	2	363[b]	8	355	27	328
Seawater Tanks[a]											
1.	112	3	109	3	106	4	102	0	102	1	101
2.	100	2	98	5	93		90	1	89	1	88
3.	116	2	114	1	113	4	113	0	113	0	113
Total	328	7	321	9	312	7	305	1	304	2	302
Seawater Net-pens=											
1.	94	1	93	4	89	2	87	1	86	3	83
2.	85	1	84	1	83	3	80	0	80	2	78
3.	82	1	81	1	80	0	80	0	80	2	78
Total	261	3	258	6	252	5	247	1	246	7	239

Appendix C.--Continued.

B. Survival

Treatment/ replicate	Starting n	Survival (%) 1992: 1 Jun	1 Jul	1 Aug	1 Sep	1 Oct	1 Nov	1 Dec	1993: 1 Jan
Freshwater Tanks[a]									
1.	301	98.3	90.7	81.4	76.4	70.4	65.4	57.5	46.8
2.	291	94.8	84.2	75.9	71.8	64.3	61.9	56.7	50.5
3.	289	87.9	78.9	73.0	68.9	61.9	58.8	54.3	46.0
Average		93.7	84.6	76.8	77.1	65.5	62.0	56.2	47.8
SD		5.3	5.9	4.3	3.8	4.4	3.3	1.7	2.4
Seawater Tanks[a]									
1.	260	88.8	64.6	56.5	51.9	48.5	46.9	45.4	44.6
2.	260	89.2	63.1	54.2	45.4	42.7	42.7	41.5	40.0
3.	262	88.9	66.8	56.5	49.6	46.9	45.8	44.7	44.3
Average		89.0	64.8	55.7	49.0	46.0	45.1	43.9	42.9
SD		0.2	1.9	1.3	3.3	3.0	2.2	2.1	2.6
Seawater Net-pens[a]									
1.	252	77.0	55.2	46.8	41.3	39.7	38.1	37.3	37.3
2.	258	78.7	57.4	47.7	37.6	34.5	33.7	32.9	32.9
3.	265	79.2	54.7	46.0	37.0	32.5	32.1	32.1	32.1
Average		78.3	55.8	46.8	38.6	35.6	34.6	34.1	34.1
SD		1.2	1.4	0.9	2.3	3.7	3.1	2.8	2.8

Appendix C.--Continued.

B. Survival (continued)

Treatment/ replicate	Survival (%) 1993								
	1 Feb	1 Mar	1 Apr	1 May	1 Jun	1 Jul	1 Aug	1 Sep	1 Ott
Freshwater Tanks[a]									
1.	45.8	45.5	45.2	44.5	44.5	44.2	43.9	43.9	43.2
2.	49.1	47.8	46.4	44.3	44.0	44.0	43.6	43.3	42.6
3.	45.7	45.0	43.3	41.2	40.5	40.5	39.8	39.4	38.4
Average	46.7	46.1	44.9	43.3	43.0	42.9	42.4	42.2	41.4
SD	1.9	1.5	1.6	1.9	2.2	2.1	2.3	2.4	2.6
Seawater Tanks[a]									
1.	44.2	43.8	43.5	43.5	43.5	43.5	43.1	41.9	40.8
2.	40.0	40.0	40.0	39.2	39.2	38.8	38.5	37.7	35.8
3.	44.3	44.3	44.2	44.3	44.3	44.3	44.3	43.5	43.1
Average	42.8	42.7	42.6	42.3	42.3	42.2	41.9	41.0	39.9
SD	2.5	2.4	2.3	2.7	2.7	3.0	3.1	3.0	3.7
Seawater Net-pens[a]									
1.	37.3	37.3	37.3	37.3	37.3	37.3	37.3	36.9	35.3
2.	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.6	32.2
3.	32.1	32.1	32.1	31.7	31.7	31.3	30.9	30.6	30.2
Average	34.1	34.1	34.1	34.0	34.0	33.8	33.7	33.4	32.6
SD	2.8	2.8	2.8	2.9	2.9	3.1	3.3	3.2	2.6

Appendix C.--Continued.

B. Survival (continued)

Survival (%)

1993

Treatment/ replicate	1 Nov	1 Dec	31 Dec
Freshwater Tanks[a]			
1.	43.2	42.9	42.5
2.	42.6	41.6	38.1
3.	37.7	36.3	30.8
Average	41.2	40.3	37.1
SD	3.0	3.5	5.9
Seawater Tanks[a]			
1.	39.2	39.2	38.8
2.	34.6	34.2	33.8
3.	43.1	43.1	43.1
Average	38.9	38.8	38.6
SD	4.3	4.5	4.7

Treatment/ replicate	1 Nov	1 Dec	31 Dec
Seawater Net-pens=			
1.	34.4	34.1	32.9
2.	31.0	31.0	30.2
3.	30.2	30.2	29.4
Average	31.9	31.8	30.8
SD	2.2	2.1	1.8

Appendix C.--Continued.

C. Weight[c]	Average weight (kg)						
Treatment/			1992			1993	
replicate	Starting	1 Sep	1 Dec	1 Mar	1 Jun	1 Sep	1 Nov
Freshwater Tanks[a]							
1.	0.033	0.102	0.215	0.360	0.476	0.755	0.952
2.	0.034	0.104	0.212	0.360	0.460	0.749	0.983
3.	0.033	0.106	0.233	0.395	0.511	0.821	1.051
Average	0.033	0.104	0.220	0.372	0.482	0.775	0.995
SD	0.001	0.002	0.012	0.021	0.026	0.034	0.051
Seawater Tanks[a]							
1.	0.031	0.087	0.152	0.234	0.384	0.568	0.706
2.	0.031	0.091	0.166	0.231	0.358	0.572	0.756
3.	0.030	0.088	0.150	0.247	0.339	0.583	0.629
Average	0.031	0.089	0.156	0.237	0.360	0.575	0.697
SD	0.001	0.021	0.089	0.085	0.023	0.008	0.064
Seawater Net-pens[a]							
1.	0.030	0.075	0.132	0.194	0.304	0.399	0.510
2.	0.032	0.079	0.130	0.193	0.284	0.370	0.493
3.	0.030	0.077	0.123	0.172	0.310	0.426	0.523
Average	0.031	0.077	0.129	0.187	0.299	0.398	0.509
SD	0.001	0.002	0.005	0.012	0.014	0.028	0.015

Appendix C.-- Continued.

[a] Freshwater replicates established at BBC on 18 May 1992; seawater replicates established at Manchester Marine Experimental Laboratory on 26 May 1992.

[b] Includes 30 female and 24 male fish spawned in late October.

[c] Quarterly subsample.

APPENDIX D

Appendix D.--Monthly inventory records for 1991-brood Lake Wenatchee sockeye salmon at NMFS, 1993.

A. Number of fish

Treatment/ replicate	Starting n	1993 Jun mort	Fish 1 Jul	Jul mort	Fish 1 Aug	Aug mort	Fish 1 Sep	Sep mort	Fish 1 Oct	Oct mort
Freshwater Tanks[a]										
1.	323	0	323	0	323	0	323	0	323	0
2.	323	0	323	0	323	0	323	0	323	0
3.	323	0	323	0	323		323	0	323	0
Total	969	0	969	0	969	0	969	0	969	0
Seawater Tanks[a]										
1.	314	13	301	1	300	2	298	5	293	0
2.	314	15	299	0	299	0	298	5	293	2
3.	314	17	297	1	298		298	14	284	0
Total	942	45	897	2	895	3	892	24	868	2
Seawater Net-pens[a]										
1.		43	273	1	272	5	267	10	257	6
2.	326	28	298	0	298	7	294	8	286	4
3.	326	20	306	0	306		299	21	278	9
Total	968	91	877	1	876	16	860	39	821	19

Appendix D.--Continued.

A. Number of fish (continued)

Treatment/ replicate	Fish 1 Nov	Nov mort	Fish 1 Dec	Dec mort	Fish 1 Jan
			1993		
Freshwater Tanks[a]					
1.	323	1	322	0	322
2.	323	0	323	1	322
3.	323	1	322	1	321
Total	969	2	967	2	965
Seawater Tanks[a]					
1.	293	1	292	1	291
2.	291	0	291	0	291
3.	284	-[b]	---[b]	-[b]	---[b]
Total	868	1	583	1	582
Seawater Net-pens[a]					
1.	251	3	248	16	232
2.	282	5	277	10	267
3.	269	9	260	22	238
Total	802	17	785	48	737

Appendix D.--Continued.

B. Survival

Treatment/ replicate	Starting n	Survival (%)						
		1993						1994
		1 Jul	1 Aug	1 Sep	1 Oct	1 Nov	1 Dec	1 Jan
Freshwater Tanks[a]								
1.	323	100.0	100.0	100.0	100.0	100.0	99.7	99.7
2.	323	100.0	100.0	100.0	100.0	100.0	100.0	99.7
3.	323	100.0	100.0	100.0	100.0	100.0	99.7	99.4
Average		100.0	100.0	100.0	100.0	100.0	99.8	99.6
SD		0.0	0.0	0.0	0.0	0.0	0.1	0.1
Seawater Tanks[a]								
1.	314	95.9	95.5	94.9	93.3	93.3	93.0	92.7
2.	314	95.2	95.2	94.9	93.3	92.7	92.7	92.7
3.	314	94.6	94.3	94.3	89.8	89.0	----[b]	----[b]
Average		95.2	95.0	94.7	92.1	91.9	92.9	92.7
SD		0.5	0.5	0.3	1.6	1.5	0.1	0.0
Seawater Net-pens[a]								
1.	316	86.4	86.1	84.5	81.3	79.4	78.5	73.4
2.	326	91.4	91.4	90.2	87.7	86.5	85.0	81.9
3.	326	93.9	93.9	91.1	85.3	87.5	79.8	73.0
Average		90.6	90.5	88.8	84.8	82.8	81.1	76.1
SD		3.1	3.3	3.1	2.6	3.6	2.8	4.1

Appendix D.--Continued.

C. **Weight**[c]

Treatment/ replicate	Average weight (g)	
	Starting	1 Nov
Freshwater **Tanks**[a]		
1.	38.0	109.4
2.	44.6	113.6
3.	44.7	113.0
Average	42.3	112.0
SD	3.7	2.3
Seawater **Tanks**[a]		
1.	38.2	111.8
2.	38.5	114.7
3.	38.5	120.3
Average	38.4	115.6
SD	0.2	4.3
Seawater **Net-pens**[a]		
1.	35.3	92.5
2.	37.4	92.6
3.	36.6	99.1
Average	36.4	94.7
SD	1.1	3.8

Appendix D.--Continued.

[a] Freshwater replicates established at BBC on 3 Nov, 1993; seawater replicates established at Manchester Marine Experimental Laboratory on 2 Jun,1993.

[b] Replicate lost in November 1993 due to mechanical failure on inflow line.

[c] Quarterly subsample.

APPENDIX E

Appendix E. --Monthly inventory records for 1991-brood Lake Wenatchee Wild vs. Captive sockeye
salmon at NMFS, 1993.

A. Number of fish

Treatment/ replicate	Starting n	May mort	Fish 1 Jun	Jun mort	Fish 1 Jul	Jul mort	Fish 1 Aug	Aug mort	Fish 1 Sep	Sep mort	Fish 1 Oct
						1993					
Wild Cross[a]											
1.	206	6	200	5	195	0	195	4	191	26	165
2.	196	1	195	0	195	3	192	12	180	28	162
Total	402	7	395	5	390	3	387	16	371	54	327
Captive Cross[a]											
1.	196	7	189	8	181	4	177	4	173	15	158
2.	202	5	197	6	191	4	187	9	178	7	171
Total	398	12	386	14	372	8	364	13	351	22	329

Appendix E.--Continued.

B. Survival (%)

Treatment/ replicate	Starting n	1993 1 Jun	1 Jul	1 Aug	1 Sep	1 Oct
Wild Cross[a]						
1.	206	97.1	94.7	94.7	92.7	80.1
2.	196	99.5	99.5	98.0	91.8	77.6
Average		98.3	97.1	96.4	92.3	78.9
SD		1.2	2.4	1.7	0.5	1.3
Captive Cross[a]						
1.	196	96.4	92.3	90.3	88.3	80.6
2.	202	97.5	94.6	92.6	88.1	84.7
Average		97.0	93.5	91.5	88.2	82.7
SD		0.6	1.2	1.2	0.1	2.1

Appendix E.--Continued.

C. **Weight**[b]

Treatment/ replicate	Average Weight (g) Starting	Average Weight (g) 1 Aug
Wild **Cross**[a]		
1.	38.2	74.2
2.	40.5	70.0
Average	39.4	72.1
SD	1.6	3.0
Captive **Cross**[a]		
1.	45.1	68.3
2.	48.9	70.8
Average	47.0	69.6
SD	2.7	1.8

[a] Wild and captive crosses established at Manchester Marine Experimental Laboratory on May 19, 1993.

[b] Quarterly subsample.