Redfish Lake Sockeye Salmon Captive Broodstock Rearing and Research

Annual Report
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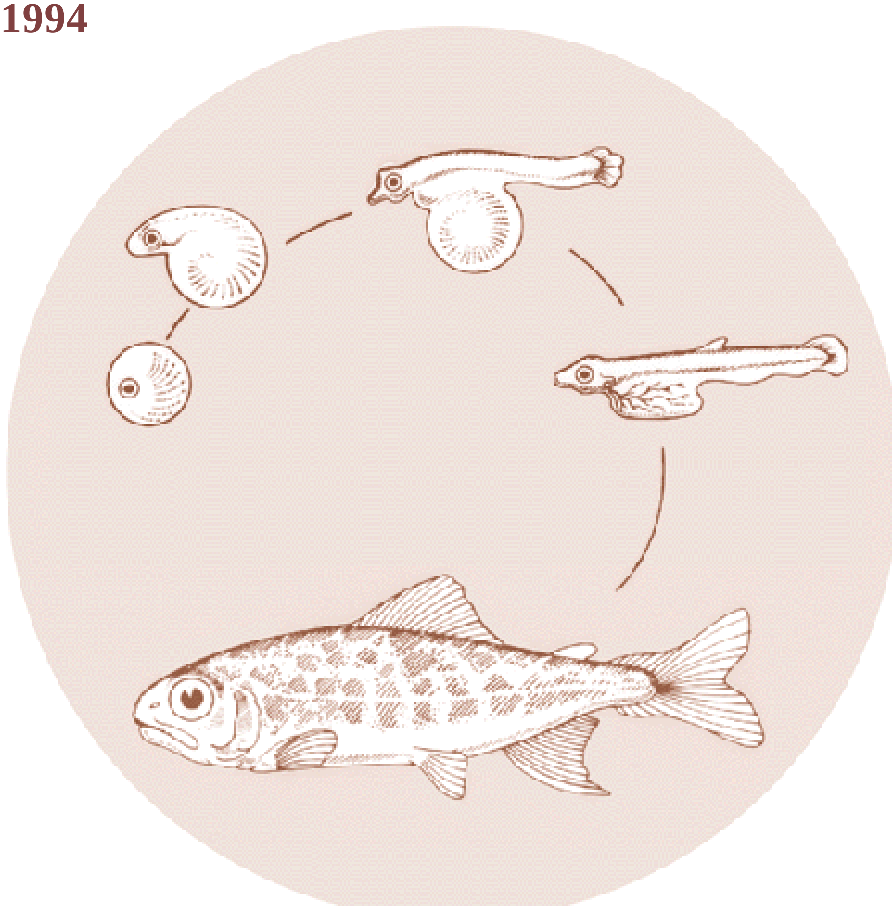

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REDFISH LAKE SOCKEYE SALMON CAPTIVE BROODSTOCK REARING AND RESEARCH, 1994

ANNUAL REPORT

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EXECUTIVE SUMMARY

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

The captive broodstocks discussed in this report were intended to protect the last known remnants of this stock: sockeye salmon that rerun to Redfish Lake in the Sawtooth Basin of Idaho at the headwaters of the Salmon River. This report addresses NMFS research from January to December 1994 on the Redfish Lake sockeye salmon captive broodstock program and summarizes results since the beginning of the study in 1991. Spawn from NMFS Redfish Lake sockeye salmon captive broodstocks is being returned to Idaho to aid recovery efforts for the species.

NMFS is currently maintaining five separate Redfish Lake sockeye salmon captive broodstocks: 1) 39 1991-brood from wild spawners about 17% survival, including fall 1994 spawners (see below), during 38 months of rearing and spawing). 2) 1.136 1993-brood from wild spawners (96% survival during 15 months of rearing). 3) 604 1993-brood from captive-reared spawners (86% survival during 14 months of rearing). 4) 39 1993-brood from residual spawners (67% survival during 13 months of rearing). 5) 447 1994-brood from a single wild spawning female (97% survival during 3 months of incubation). All Redfish Lake sockeye salmon captive broodsrocks at NMFS are currently being reared in fresh well water.

The 1991-brood Redfish Lake sockeye salmon in the NMFS captive broodstock program were expected to mature as I-year-old fish in fall 1995. However, approximately 77% of the fish (56 females and 70 males) matured at 3 years of age in late October 1994. We believe the early maturity of these fish was due to fast growth in captive culture. Female 1991-brood Redfish Lake sockeye salmon spawners averaged 43.6 cm and 1.23 kg, while male spawners averaged 45.7 cm and 1.14 kg. Fecundity averaged 1,644 eggs/female (about 1,337 eggs/kg of female weight) for the 1991-brood females spawned in 1994.

All 1991-brood spawners were surveyed for presence of bacterial kidney disease (BKD) by enzyme-linked immunosorbent assay (ELISA) by U.S. Fish and Wildlife Service personnel at the Olympia Fish Health Center in Olympia, Washington. There was no correlation ($P > 0.05$) between female spawner ELISA optical density (OD) level and fecundity. In addition, there was no correlation ($P > 0.05$) between male ELISA OD level and eyed-egg survival (viability). However. there was a weak but significant ($P < 0.05$) negative correlation between female ELISA OD level and eyed-egg survival.

Eyed-egg survival from these 1991-brood spawners averaged about 60’%, resulting in over 50.000 eyed eggs. IDFG had established protocol that eggs From any parent tested for BKD and having an ELISA OD less than 0.2 could be returned directly to Idaho for use in recovery efforts for Redfish Lake sockeye salmon. Therefore, in December 1994, approximately 23,000 eyed eggs from parents with ELISA ODs < 0.2 were shipped to Idaho via priority air cargo. These eggs were incorporated into IDFG rearing groups for outplanting into the Redfish Lake area in summer 1995. NMFS retained approximately 27,000 eyed eggs from parents with ODs greater than 0.2. NMFS currently plans to rear these fish to smolt stage and, if they are healthy, return them to Idaho for use in recovery efforts for Redfish Lake sockeye salmon.

In future years, additional Redfish Lake sockeye salmon broodstock being reared by NMFS will mature, and additional eggs will be supplied to Idaho for use in ESA recovery efforts for Snake River sockeye salmon.

We are also conducting experiments using non-endangered 1990- and 199 l-brood Lake Wenarchee (Washington) sockeye salmon to compare the effects on survival and reproduction between yearling (smolt size) fish reared to maturity in fresh water and seawater. These studies are being conducted to allow optimal fish culture strategies to be identified prior to implementation with Redfish Lake stock.

Survival of 1990-brood Lake Wenatchee sockeye salmon reared for 28 months prior to spawning at the end of August 1994 averaged as follows: about 32% for replicates held in circular tanks supplied with fresh well water. 35% for replicates in circular tanks supplied with pumped filtered, and ultraviolet (UV) light-sterilized seawater, and 263 for replicates held in conventional seawater net-pens. There were no significant differences (P > 0.05) in survival percentages between fish remaining in the freshwater tank, seawater tank. and seawater net-pen treatments.

In fall 1993, about 15% of the 1990-brood Lake Wenatchee sockeye salmon reared in fresh water matured at age-3. Male spawners averaged 12.7 cm and 1.01 kg, and female spawners averaged 41.5 cm and 0.57 kg. Fecundity averaged 1,359 eggs/female and egg viability averaged about 36%. No fish from either seawater treatment matured in 1993.

In fall 199-t. 79% of the 1990-brood Lake Wenatchee sockeye salmon reared in freshwater treatment tanks and 70% of the same brood reared in seawater tanks matured as 4-year-olds. In contrast, only 83 of the 1990-brood fish reared in seawater net-pens treatment matured in the same time frame.

Female 1990-brood Lake Wenatchee sockeye salmon from the freshwater tanks averaged 54.4 cm and 2.24 kg. while male spawners averaged 56.5 cm and 2.51 kg. Fecundity averaged 2.477 eggs/female, with egg viability averaging 19.6% for fish reared to maturity in freshwater. Female 1990-brood from the seawater tanks averaged 50.3 cm and 1.56 kg, while male spawners averaged 5 1 .O cm and 1.69 kg. Fecundity for these fish averaged I.899 eggs/female, with egg viability averaging 42.4% Average length and weight for the female spawners from the seawater net-pens was 43.0 cm and 0.99 kg, while males spawners averaged 44.6 cm and 1.17 kg. Fecundity averaged 1,783 eggs/female (1.801 eggs/kg of body weight). with egg viability averaging 15.8% for this group. There were significance differences (P < 0.001) in fecundities between treatments, with fecundity ranked as freshwater tanks > seawater tanks = seawater net-pens (P < 0.02). However, there were no significant differences (P > 0.10) in eyed-egg survival (viability) of female spawners between the three treatments.

Survival of 1991-brood Lake Wenatchee sockeye salmon during 19 months of rearing averaged about 93% in the freshwater tank replicates, 71% in the seawater tank replicates, and 27% in the seawater net-pen replicates. There were significant differences (P < 0.01) between experimental treatments in percentages of fish remaining by the end of December 1994, with the survival ranked as freshwater tanks > seawater tanks > seawater net-pens trestmenrs (P < 0.05).

For both brood-years, fish reared in fresh water were significantly (P < 0.05) larger than those reared in seawater. The average prespawning weight of 1990-brood Lake Wenatchee sockeye salmon reared in fresh water was about 44% greater than that of fish reared in the seawater tanks and 52% greater than that of fish reared in the seawater net-pens. The 1991-brood Lake Wenatchee sockeye salmon reared in fresh water were about 46% larger than fish reared in the seawater tanks and 28% larger than those reared in the seawater net-pens.

Currently, the data from our captive rearing experimenrs suggests 3 ranking priority for rearing sockeye salmon to maturity of 1) circular tanks supplied with pathogen-free fresh water; 2) circular tanks supplied with pumped. filtered, and UV-sterilized seawater: 3nd 3) seawater net-pens. Even though full-term freshwater rearing appears the correct choice for valuable captive broodstocks (e.g., Redfish Lake sockeye salmon), the data is also encounging regarding culture to maturity in environmentally controlled seawater, and it appears reasonable to consider this strategy for a portion of the Redfish Lake sockeye salmon.

CONTENTS

INTRODUCTION

In December 1991, the Sational Marine Fisheries Service (NMFS) listed Snake River sockeye salmon (*Oncorhynchus nerka*) as endangered under the U.S. Endangered Species Act[1] (ESA j (Waples et al. 199 1). Snake River sockeye salmon are a prime example of a species on the threshoid of extinction. The last known remnants of this stock return to Redfish Lake, Idaho (Fig. 1). The NMFS is developing a recovery plan for Snake River salmon (SRSRP 1993), and the goal of this plan will be to rebuild listed Snake River sockeye salmon within its historic range in order to delist the species.

Captive broodstock programs are emerging as an important component of restoration efforts for ESA-listed salmon populations. Captive broodsrock programs are a form of artificial propagation. However, they differ from standard hatchery techniques in one important respect: fish are cultured in captivity for the entire life cycle. The high fecundity of Pacific salmon, coupled with their potentially high survival in protective culture. affords an opportunity for captive broodstocks to produce large numbers of juveniles in a single generation for supplementation of natural populations. In concert with efforts to correct causes of decline in stocks at risk of extinction, this technology holds promise as a means of accelerating stock recovery by rapidly increasing the abundance of fish available for restocking suitable habitat.

Only a few sockeye salmon adults (0 to 8 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, implemented a captive broodstock project as an emergency measure to save Redfish Lake sockeye salmon (Flagg 1993, Johnson 1993. Flagg and McAuley

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[1] Use of the term "species'* in the context of ESX can refer to taxonomic species, subspecies, and distinct population segments. The definition of what constitutes a species under the ESX ia addressed by Waples (199 1).

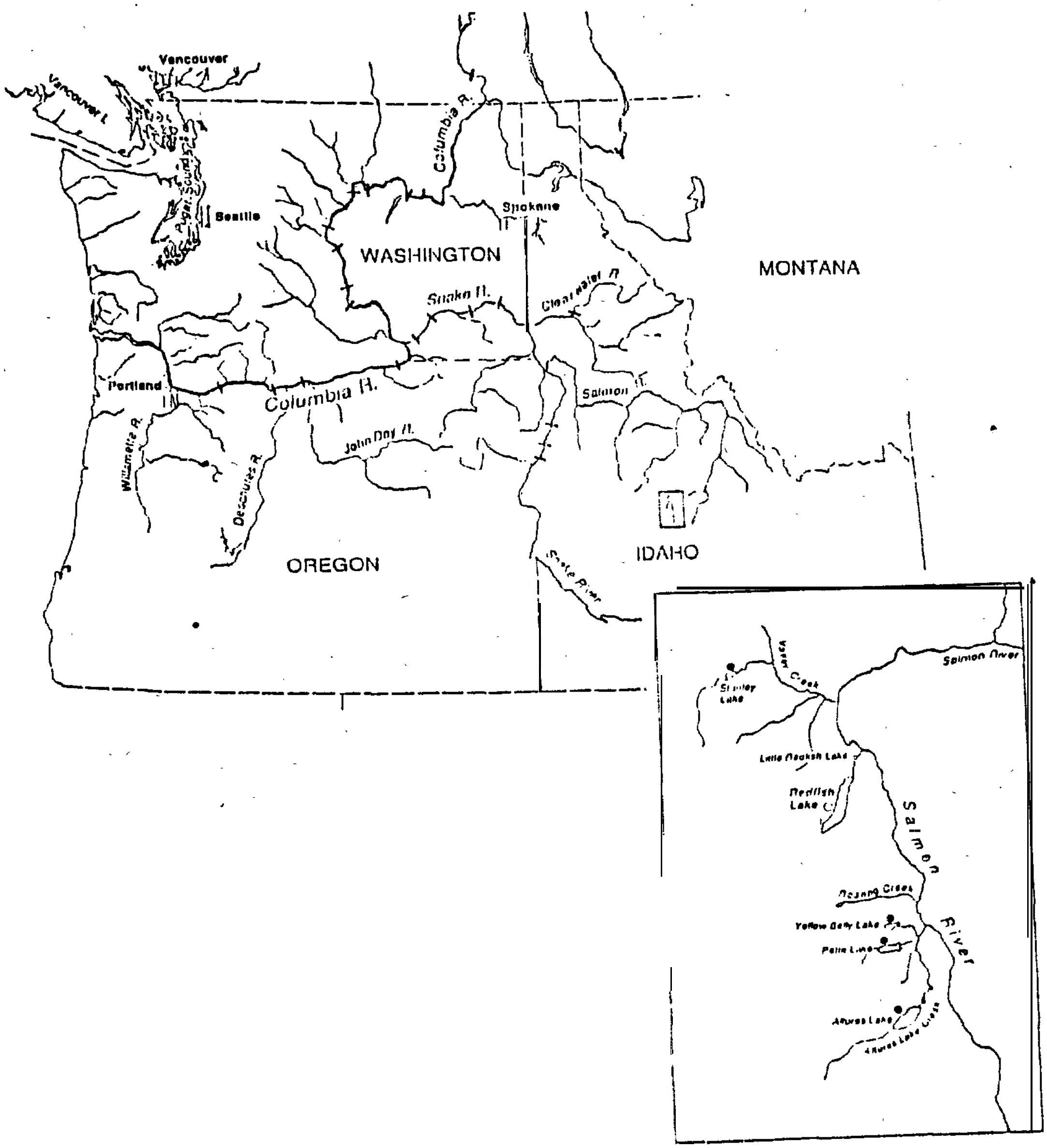

Figure 1. Map showing location of Redfish Lake. Sockeye salmon **returning to** Redfish Lake **travel** a **greater distance from the sea (almost 1,450 km) and spawn at a higher elevation (almost 2,000** m) **than any other sockeye salmon population.**

1994). The Redfish Lake project is intended as a stop-gap measure until migration and rearing 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, IDFG, BPA, the Shoshone-Bannock Tribe, other state and federal agencies, and private groups interested 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 1998. This report focuses on NMFS research on the Redfish Lake sockeye salmon captive broodstock from January through December 1994 and summarizes results since the beginning of the study in October 1991. Our efforts from January through December 199-I focused on 1) rearing and spawning of 1991-brood, rearing of 1993-broods, and incubation of 1994-brood Redfish Lake sockeye salmon, and 2) research on techniques to refine captive broodstock methods. Robin Waples or Thomas Flagg represented NMFS at monthly SBSTOC meetings and visited IDFG fish culture and fish trapping operations for Redfish Lake sockeye salmon.

REDFISH LAKE SOCKEYE SALMON CAPTIVE BROODSTOCK CULTURE

Captive propagation of animals to maximize their survival and reproductive potential has won acceptance in endangered species restoration (Gipps 1991, Johnson and Jensen 1991, DeBlieu 1993, Olney et al. 1994). Currently, over 105 species of mammals, 40 species of birds, 12 species of reptiles, 29 species of fish, and 14 species of invertebrates are being maintained or enhanced through forms of captive breeding (CBSG 1991). The captive broodstock concept for salmon differs from that used in conventional hatcheries in that fish of wild origin are maintained in captivity throughout their life. 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 captive broodstock program should help ensure supplementation efforts for depleted stocks such as Redtish Lake sockeye salmon.

The exact status of the Snake River sockeye salmon population was unknown at the time of ESA listing. Consnuction of impassable hydroelectric and irrigation dams on the Snake River system in the 1950s and i96Os had markedly reduced the geographic distribution of Snake River sockeye salmon to a single watershed in the Stanly Basin at the headwaters of the Salmon River in Idaho (Fig. 1 j. In addition. barriers :o upstream migration were installed in the 1950s at three of the four remaining salmon-producing lakes in the Stanley Basin. and the lakes were poisoned. These alterations were made to promote Tout (*Oncorhynchus* spp.) fisheries, but they further limited the range of Snake River sockeye salmon to a single lake--Redfish Lake (Fig lj. Eight major hydroelectric dams on the Colcmbia River System currently interfere with the almost 1.450-km migration to and from the ocean i'or Rcdfish Lake sockeye salmon (Fig. 1).

So sockeye salmon returned :o the Stanly Basin during 1990. :he year of the ESA-mandated biological review. However because redds (nests) were observed in Redfish Lake in 1988 and 1989. indicating that juveniles could still be in the lake or at Sea, the NMFS Biological Review Team decided that the Snake River sockeye salmon population could still exist (Waples et al. 1991 j. Subsequent collections ofoutmigrating juveniles and returns of anadromous adult sockeye salmon to Redfish Lake in 1991, 1992. 1991. and 1994 confirmed the persistence of this population.

All three known forms of 0. *nerka* occur in Redfish Lake.

1) The anadromous form usually spends 1 to 2 years in its nursery lake before migrating to sea as a smolt during the spring and remains at sea for an additional 2 to 1 years before returning to the natal area to spawn (Bjornn et al. 1968, Foerster 1968. Burgner 1991 j.

2) Residual sockeye salmon are progeny of anadromous fish that remain in fresh water to mature and reproduce: they produce mostly anadromous offspring (Ricker 1938. Foester 1968. Burgner 1991). It was theorized that residual sockeye salmon helped maintain the Redfish Lake sockeye salmon population during historic population lows (Waples et al. 1991).

3j The more distinct kokanee form appears to have diverged from anadromous stock in recent geological time and is fully adapted to fresh water Foester 1965. Burgner 199 1 j. Xnadromous and residual sockeye salmon in Redfish Lake were included together in the anadromous gene pool for ESX protection. while kokanee was excluded.

Since both anadromous and residuai forms of sockeye salmon inhabit Redfish Lake along with kokanee, mechanisms were needed to differentiate them from kokanee in developing broodstocks. Sockeye salmon and kokanee occupy overlapping habitats in lake environments (Foerster 1965. Burgner 1991 j. However. spatial and temporal spawning separation occur between anadromous sockeye salmon forms and kokanee in Redfish Lake. The anadromous and residual forms 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 (Spaulding 1993, Teuscher et al. 1994). Also, skin and flesh may be more red at spawning in kokanee than in residuals. because kokanee, which have adapted to a carotenoid-poor forage environment, appear to be mor2 efficient than sockeye salmon at storing carotenoid (Waples 1992).

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 2t al. 1992, 1994). Recent information also suggests that since ansdromous fish spend time in seawater. an environment rich in strontium, it is possible to distinguish the progency of anadromous and nonanadromous parents based on the elevated strontium/calcium (Sr/Ca) ratio in the primordial core of the progeny's otoliths (Kalish 1990, Reiman et al. 1993, Kline 1994). All of :he criteria described above were employed to differentiate kokanee from the anadromous sockeye salmon gene pool in developing broodstocks.

Between 199 1 and 1994, captive broodstocks *for* Redfish Lake sockeye salmon were initiated from the following sources: 1) wild juveniles captured at 3 weir during their outmigration from Redfish Lake, 2) eggs taken from wild returning adults captured at 3 weir just below Redfish Lake, 3) eggs from wild adult residuals captured in nets in the lake and 4) second-generation eggs from captive broodstocks reared and spaw ned in captivity Mating strategies for Rsdfish Lake sockeye salmon broodstock were structured to maintain genetic diversity. These strategies included random pairing, pairing in as many different combinations 3s possible. avoidance of pairing between siblings. fertilization between different year-classes, and fertilization with cryo-preserved sperm from other generations 3s suggested by Hard et al. (1992).

Genetic consequences of captive broodstock programs are beyond the scope of this report (see Hard et 31. 1992 for review). However, we feel that :t is important to point out that Hard et 31. (1992; cautioned that artificially amplifying only a portion of a population through propagation may reduce effective population size (N_e) by dramatically increasing only a fraction of the available genotypes in the parent population. For our Redfish Lake sockeye salmon program, many of the potential adverse consequences of broodstock selection were avoided by capturing all returning adults and 3 large fraction (up to 25%) of the migrating juveniles. Nevertheless, it should be recognized that such heavy mining of 3 native population can only be justified in the face of otherwise certain extinction.

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. 1983, 1985, 1987; Peterschmidt 1991; C. Mahnken and T. Flagg, NMFS, unpublished data: C. Wood, Canada Department of Fish and Oceans, Pacific Biological Station, Pers. Commun., October 1991). Therefore, full-term freshwater rearing in pathogen-free water was chosen for these endangered captive broodstocks.

Two separate captive populations of Redfish Lake sockeye salmon 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. 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, Flagg and McAuley 1994). IDFG captive broodstocks are cultured at the IDFG Eagle Hatchery near Boise. Idaho in 13°C 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 (Flagg 1993. Flagg and McAuley 1993).

The NMFS captive broodstocks eggs are 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 (Table 1). Our captive broodstocks focus on eggs from adults that returned to Redfish Lake in 1991, 1993 and 1993; in 1992 only a single male returned to 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.

NMFS is providing daily 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

Table 1. Status of Redfish Lake sockeye salmon captive broodstocks maintained by NMFS through December 1994.

Broodstock source	Hatch number	Months in culture	Average survival[a] (%)	Final inventory number
Captive-reared adults				
fall 1993	701	13	86	604
Wild adult residuals				
fall 1993	58	13	67	39
Wild adult returns[b]				
fall 1991	975	38	17[c]	39[d]
fall 1993	1,180	15	96	1.136
fall 1994	461	3	97	447

[a] Captive broodstocks are being held as multiple discrete lots in multiple rearing containers. Survival percentage is approximate overall avenge.

[b] 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 cry-preserved; in fall 1993, two females and six males returned and were captured and spawned; in fall 1994, one female returned and was spawned with captive-reared males.

[c] Includes 56 female and 70 male spawners in fall 1994 and 39 bright fish alive at the end of December 1994.

[d] Number of nonmature fish remaining.

Lewis 1976). Fish are fed a commercial ration (e.g., Biodiet[2]). Mortalities are examined by a fish pathologist to determine cause of death. Specimens not vital to analysis or restoration are incinerated or buried. Because Redfish Lake sockeye salmon 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 (Table 1) and primary causes of death are the only quantities described in this report.

Rsdfish Lake sockeye salmon are being reared to maturity at NMFS laboratories. Progeny from these captive broodstocks is intended for incorporation into Idaho's recovery programs for Snake River sockeye salmon. All spawners are analyzed for common bacterial and viral pathogens such as bacterial kidney disease (BKD) and infectious hematopoietic necrosis virus (IHNV). 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 during their upstream migration at a weir on Redfish Lake Creek, about a mile below Redfish Lake. The maturing adults were moved to the IDFG Sawtooth Hatchery near Stanley, Idaho (about 8 km from Redfish Lake) and spawned in late October 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 were strip-spawned. Portions of these eggs were fertilized with milt from each of the three males, while another portion was fertilized with pooled milt from all three males.

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

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

Mating cross[a]	Total eggs	Dead eggs	Fertility (%)	Eggs transferred NMFS	Eggs transferred 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, snd 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.

On 3 December 1991, one-half the progeny of these fish were transferred to NMFS for rearing to maturity (Flagg 1993, Flagg and McAuley 1994). IDFG was issued Washington State Department of Fisheries and Wildlife (WDFW) Fish Transfer Permit 1275-l l-91 to move these fish from Idaho to Seattle. The remaining 1991-brood progeny are in the custody of IDFG at the Eagle Fish Hatchery (Johnson 1993).

The 1991-brood were reared at the NMFS facility in Seattle for the next 18 months, until June 1993. During this period the entire population (919 fish) was PIT tagged, following the methods of Prentice et al. (1990), for future individual identification. Survival was excellent (90%) until April 1993, when mortality began to elevate. Postmortem examination revealed high levels of *Renibacterium salmoninarum*, the causative agent of BKD, to be the cause of the increased mortality. Subsequent treatment with 0.45% erythromycin, administered in the diet at 2% of body weight per day for 35 days, brought the epizootic under control. Losses during this disease outbreak totaled 12% of the population (Flagg and McAuley 1994).

Although the NMFS hatchery in Seattle was ideal for the early rearing of the Redfish Lake sockeye salmon, it lacked adequate space to rear fish beyond smolt size. Therefore, the remainder of the population (764 fish) was transferred to BBC between May 29 and June 1, 1993 (Appendix A). Survival of these fish from hatch in January 1992 until transfer to BBC was 78%. The half-sib families were combined in five 4.1 -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 and 317 fish/tank (Table 3). Dividing portions of each half-sib group into several tanks reduced risk of loss of an entire half-sib family. Beginning fish density in the tanks at BBC was established at under 2.0 kg/m^3 (Flagg and McAuley 1994). Fish density in the tanks was maintained at under 8 kg/m^3 during most of the culture period; however, fish density had approached 16 kg/m^3 (1 .O lbs/ft^3) by the time of maturity.

Table 3. Inventory record of pooled groups[a,b] of 199 l-brood Redfish Lake sockeye salmon reared at NMFS BBC endangered species rearing facility, 1993-1994.

Date	Tank number[c,d,e,f,g]				
	2	3	4	5	6
	Survival (%)				
1 Jun 93	100.0	100.0	100.0	100.0	100.0
30 Jun 93	99.7	100.0	100.0	100.0	100.0
31 Jul 93	99.7	100.0	100.0	100.0	99.3
31 Aug 93	96.8	98.4	100.0	97.6	97.9
30 sep 93	95.3	96.8	100.0	96.0	96.5
31 Oct 93	86.1	91.9	100.0	85.7	86.7
30 Nov 93	83.3	88.6	100.0	82.5	82.5
31 Dec 93	70.0	80.5	100.0	74.6	72.0
31 Jan94	63.7	77.2	100.0	59.5	70.6
28 Feb 94	56.5	70.7	100.0	4i.6	67.8
31 Mar94	53.3	57.7	100.0	43.6	63.6
30 Apr 94	17.6	45.5	100.0	40.0	63.6
3 1 May 94	44.3	39.0	100.0	38.0	58.7
30 Jun 93	39.1	32.5	100.0	33.3	56.6
31 Jul 94	32.5	29.2	100.0	31.0	52.4
31 Aug 94	25.9	23.5	98.1	26.2	45.5
30 Sep 94	19.2	17.8	96.3	23.0	39.9

Table 3. Continued.

[a] Fish pooled to 4. l-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 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).

[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 3. and 16 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 1.10 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 6X 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 A and Fig. 2). There was minimal mortality for about 60 days post transfer to BBC (Fig. 2). However, beginning in August 1993, and continuing through September 1994, mortality from BKD increased. 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. Twenty-eight-day prophylactic treatments with erythromycin were fed on an every-other-month basis (e.g., August, October, December, etc.) through June 1994 (Fig. 3).

The 1991 brood were expected to spawn as 4-year-olds in fall 1995. However, beginning in August 1994, the majority of the population began to rake on secondary sexual characteristics indicative of maturation. Therefore, oral medication was halted in favor of injection. Fish in the five half-sib groups were sorted as mature vs. immature and injected with erythromy cin (50 mg/kg of body weight) on a monthly basis until spawning in October 190-t.

By the onset of final maturation at the beginning of October 1994. there was a total of 222 1991-brood Redfish Lake sockeye salmon at BBC; survival in the five half-sib groups averaged about 23% from hatch and ranged from 13.2 to 30.5% (Appendix A). One 4. l-m tank at BBC remained BKD-free until August 1994,2 months prior to spawn (Table 3).

A total of 165 fish (17% of the starting population) surived to spawing About 76% of the surviving population (56 females and 70 males) spawned in fall 1994 as 3-year-old fish. Spawning commenced October 13, peaked Sovember 2-9 (55% of the fish spawned during this period), and ended Sovember 23. We believe the early maturity of these fish was due to fast growth in captive culture.

Female 1991-brood Redfish Lake sockeye salmon spawners at BBC averaged 43.6 cm and 1.23 kg, while male spawners averaged 45.7 cm and l.U kg. Fecundity averaged 1.6-U eggs/female (about 1,337 eggs/kg of female weight) (Table 4). Redfish Lake and other Columbia River sockeye salmon normally mature as 4- and j-year-old fish. with adult size ranging from

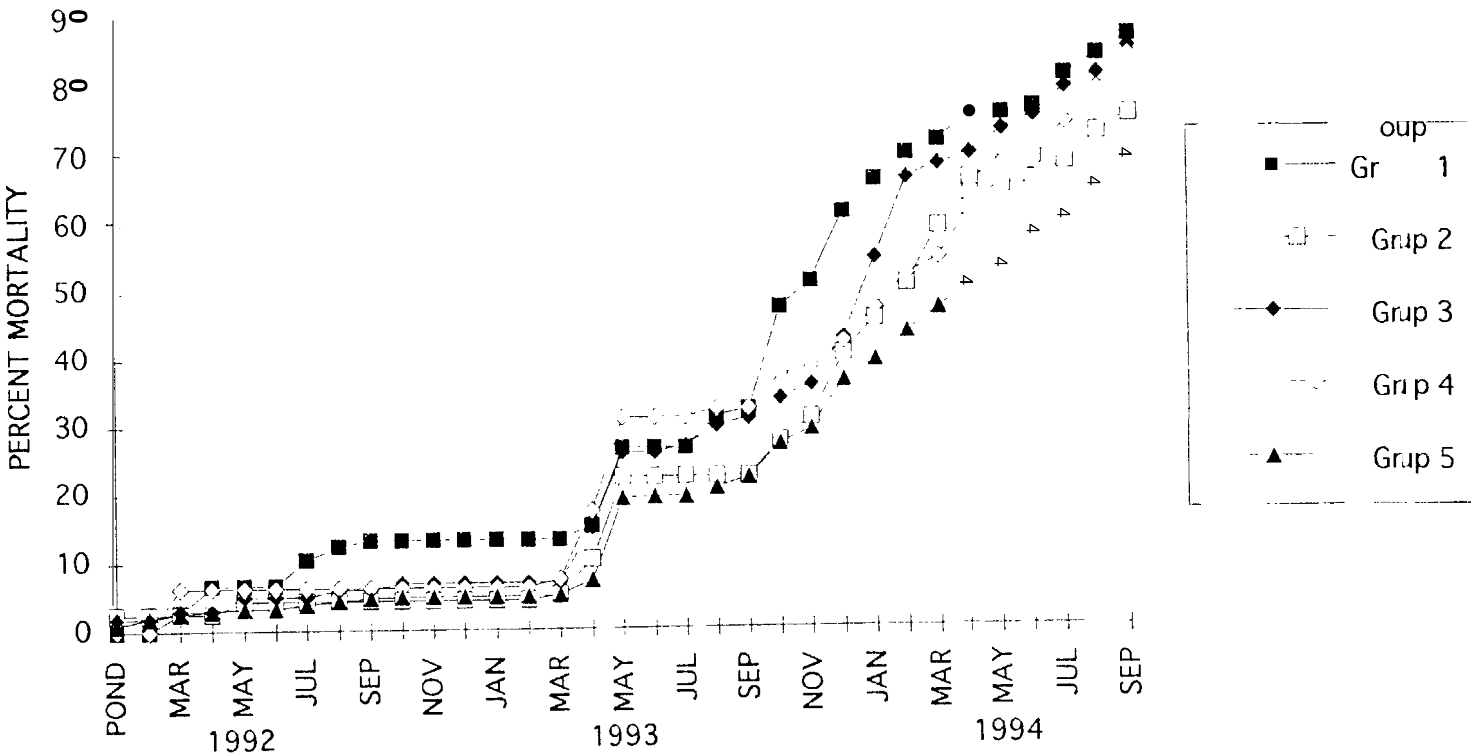

Figure 2. Cumulative percent mortality during rearing at NMFS for each ha f-sib group of 1991-brood Redfish Lake sockeye salmon. 1992-1994.

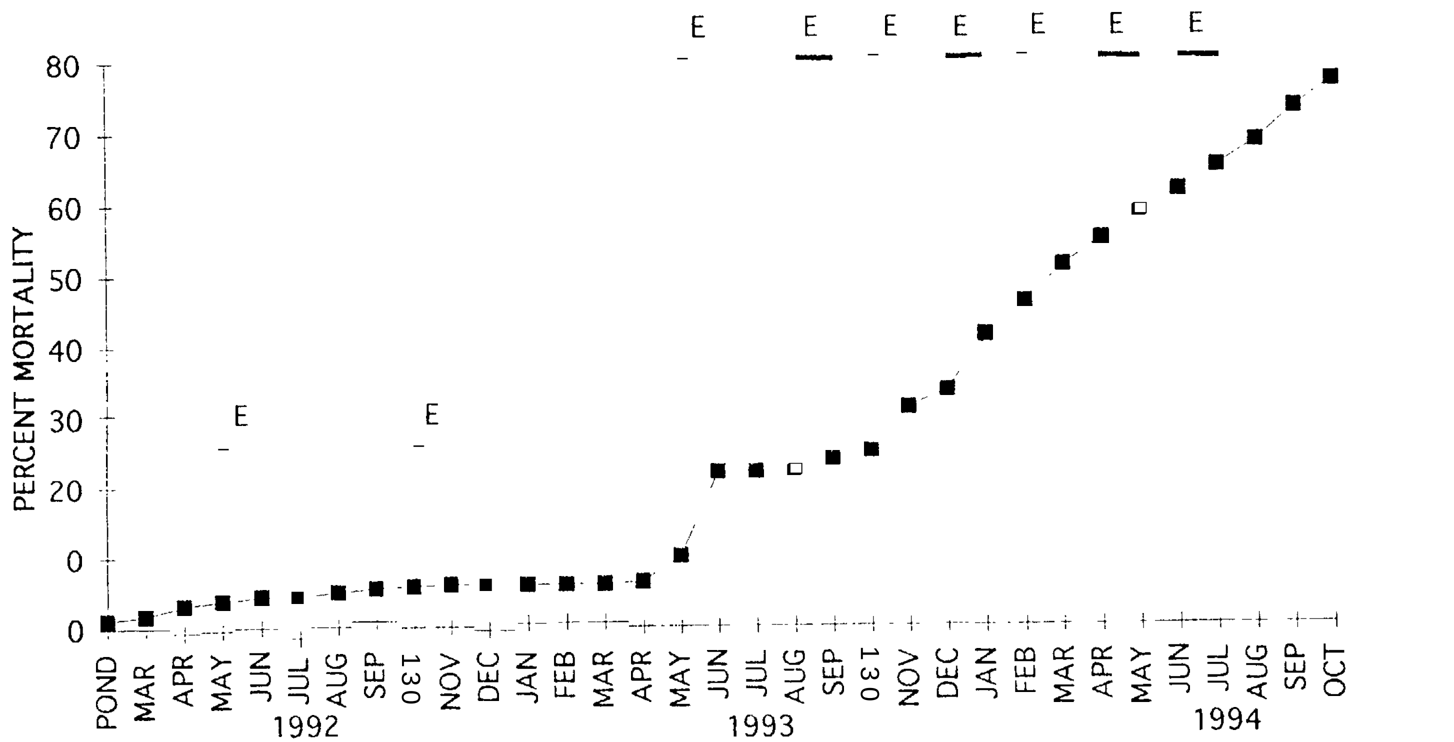

Figure 3 Cumulative percent mortality during rearing at NMFS for 1991-brood Redfish Lake sockeye salmon, 1992-1994. Areas under E indicate periods of medication with erythromycin

Table 4. Results from spawning of 1991-brood Redfish Lake sockeye salmon at NMFS, 1994.

Female Number	Spawn date	Total egg weight (g)	Dead eggs (n)	Live eggs (n)	Individual egg weight (g)	Fecundity	Eyed egg survival (%)
F1	13-Oct	229.0	111	1,751	0.126	1,862	94.0
F2	13-Oct	185.0	892	610	0.138	1,502	40.6
F3	13-Oct	307.0	959	1,533	0.128	2,492	61.5
F4	13-Oct	222.0	1,584	386	0.117	1,970	19.6
F5	20-Oct	152.0	263	1,479	0.090	1,742	84.9
F6	20-Oct	190.0	1,630	10	0.100	1,640	0.6
F7	28-Oct	181.0	199	1,138	0.136	1.337	85.1
F8	28-Oct	150.0	439	757	0.128	1,196	63.3
F9	28-Oct	162.0	166	1,141	0.128	1.307	87.3
F10	28-Oct	153.0	830	472	nd	1,302	36.3
F11[a]	28-Oct	32.0	180	61	nd	241	25.3
F12	28-Oct	158.0	1,456	62	0.115	1.518	4.1
F13	28-Oct	207.0	443	1,172	0.125	1,615	72.6
F14	28-Oct	189.0	1,492	0	0.000	1,492	0.0
F15	28-h	237.0	1,564	513	0.131	2,077	24.7
F16	28-Oct	211.0	256	1,682	0.110	1,938	86.8
F17	28-Oct	135.0	213	1.126	0.100	1.339	84.1
F18	28-Oct	208.0	1,028	717	0.116	1,745	41.1
F19	28-W	228.0	1,304	885	0.119	2.189	40.4
F20	28-Oct	236.0	407	1,658	0.120	3.065	80.3
F21	28-Oct	211.0	564	1,213	0.122	1.777	68.3
F22	28-Oct	154.0	403	1,057	0.120	1,160	72.4
F23	2-Nov	175.8	392	1,240	0.108	1,632	76.0
F24	2-Nov	200.8	316	1,428	0.116	1,744	81.9
F25	2-Nov	160.5	204	1,325	0.106	1.529	86.7
F26	2-Nov	206.3	185	1,578	0.118	1.763	89.5
F27	2-Nov	153.1	411	822	0.120	1.233	66.7
F28	2-Nov	200.6	86	1,818	0.106	1,901	95.5
F29	2-Nov	306.2	2,080	154	0.147	2.234	6.9
F30	2-Nov	322.6	1,315	1,023	0.128	2,338	43.8
F31	2-Nov	169.7	182	1,071	0.140	1,253	85.5
F32	2-Nov	176.0	329	1,329	0.112	1,658	80.2
F33	2-Nov	143.3	878	504	0.110	1,382	36.5
F34	2-Nov	303.0	255	[illegible]	0.12-t	2,178	89.7
F35	2-Nov	180.0	274	1,035	0.146	1,309	79.1
F36	2-Nov	189.0	174	1,254	0.138	1,428	87.8
F37	2-Nov	145.0	736	856	0.082	1.592	53.8

Table 4. Continued.

Female Number	Spawn date	Total egg weight (g)	Dead eggs (n)	Live eggs (n)	Individual egg weight (g)	Fecundity	Eyed egg survival (%)
F38[a]	2-Nov	54.0	234	496	0.080	730	68.0
F39	2-Nov	109.0	646	643	0.090	1,289	49.9
F40	2-Nov	223.0	754	1,237	0.112	1,991	62.1
F41	9-Nov	257.0	103	2.083	0.118	2,187	95.2
F42	9-Nov	289.0	1,443	857	0.125	2,300	37.3
F43	9-Nov	251.9	613	1,392	0.128	2,005	69.4
F44	9-Nov	256.0	411	1,522	0.136	1,933	78.7
F45	9-Nov	136.9	450	804	0.124	1,254	64.1
F46	9-sov	229.0	473	1.229	0.140	1.702	72.2
F47	9-Nov	172.3	704	979	0.108	1,683	58.2
F48	9-Nov	282.5	1,770	407	0.163	2,177	18.7
F49	9-Nov	179.0	143	1,292	0.126	1.435	90.0
F50	9-Nov	155.0	303	995	0.122	1.298	76.7
F51	9-Nov	172.0	1,382	169	0.085	1,551	10.9
F52	9-Nov	178.0	443	1,188	0.113	1,631	72.8
F53	9-Nov	164.8	847	768	0.110	1,615	47.6
F54	16-Nov	190.0	26-l	1,156	0.138	1,120	81.4
F55	16-Nov	135.1	82	1,118	0.114	1,200	93.2
F56	23-Nov	123.0	1,367	29	0.093	1,396	2.1
Total live eggs				55,446			
Avenge					0.117	1,644	60.4
Eggs shipped to Idaho[b]				23.294			
Eggs retained by NMFS[c]				30,838			

[a] Female's eggs were partially unripe.

[b] Eggs incorporated into IDFG rearing groups for outplanting into the Redfish Lake area in summer 1995.

[c] NMFS currently plans to rear these fish to smolt stage and, if they are healthy, return them to Idaho for use in recovery efforts for Redfish Lake sockeye salmon.

1968, Mullan 1986, Flagg et al. 1991). Positive fecundity/size relationships are common for sockeye salmon (Burgner 1991, Flagg and McAuley 1994). Therefore, lower absolute fecundity is to be expected in smaller early maturing fish such as the age-3 Redfish Lake sockeye salmon.

All spawners were surveyed for presence of *Renibacreriwn salmoninarum* using enzyme-linked immunosorbent assay (ELISA) for BKD by U.S. Fish and Wildlife Service personnel at the Olympia Fish Health Center in Olympia, Washington. There was no correlation ($P > 0.05$) between female spawner ELISA optical density (OD) level and fecundity (Fig. 4). In addition, there was no correlation ($P > 0.05$) between male ELISA OD level and eyed-egg survival (Fig. 5). However, there was 3 weak significant ($P < 0.05$) negative correlation between female ELISA OD level and eyed-egg survival (Fig. 6).

Eyed-egg survival (egg viabilitv) from 1991-brood Redfish Lake sockeye salmon spawned at BBC in 1994 averaged about 60%, resulting in over 55,000 eyed eggs (Table 4). According to IDFG established protocol, eggs from any parent with an ELISX OD less than 0.2 could be returned directly to Idaho for use in recover) efforts for Redfish Lake sockeye salmon. In December 1994, approximately 23,000 eyed eggs from 1991-brood parents with ODs less than 0.2 were shipped to Idaho via priority sir cargo. These eggs were incorporated into IDFG rearing groups for outplanting into the Redfish Lake area in summer 1995 (K. Johnson, IDFG, 1800 Trout Road. Eagle, ID 83616. Pers. commun., December 1994). NMFS retained approximately 30,000 eyed eggs from parents with ELISX ODs greater than 0.2. NMFS currently plans to rear these fish to smolt stage and. if they are healthy. return them to Idaho for use in recovery effons for Redfish Lake sockeye salmon.

Thirty nine 1991-brood Redfish Lake sockeye salmon did not spawn at BBC in 1994. These fish are currently being maintained in 3 4. l-m diameter circular tank at BBC and are expected to spawn in fall 1995.

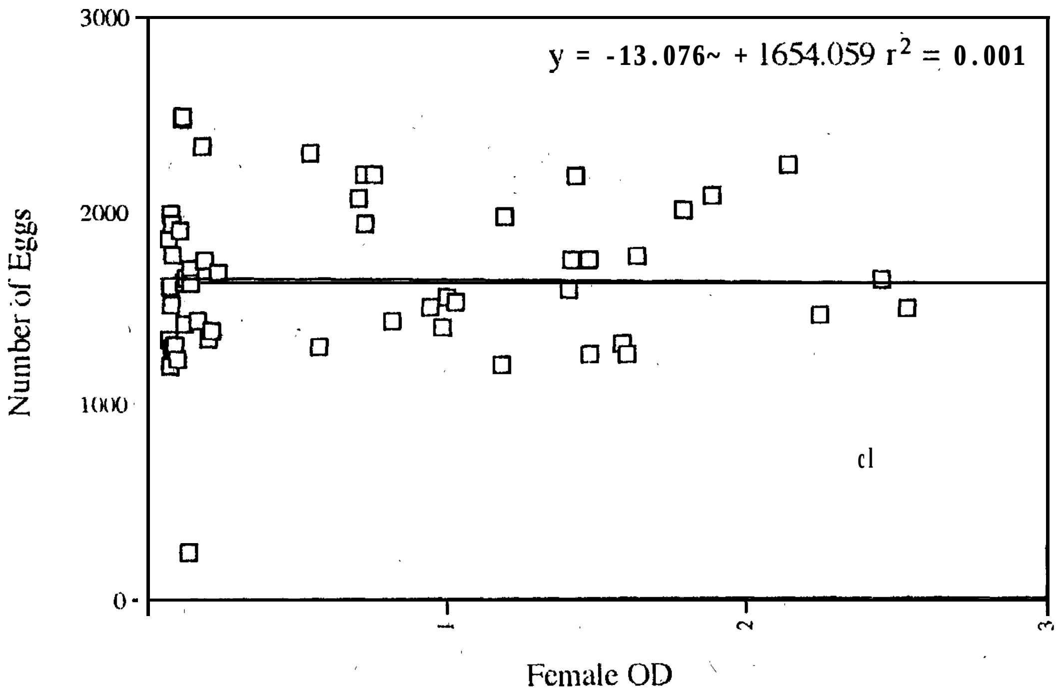

Figure 4. Correlation between female ELISA OD level for presence of *Renibacterium salmoninarum*, the causative agent of HKD, and number of eggs for 1991-brood Redfish Lake sockeye salmon spawned in 1994.

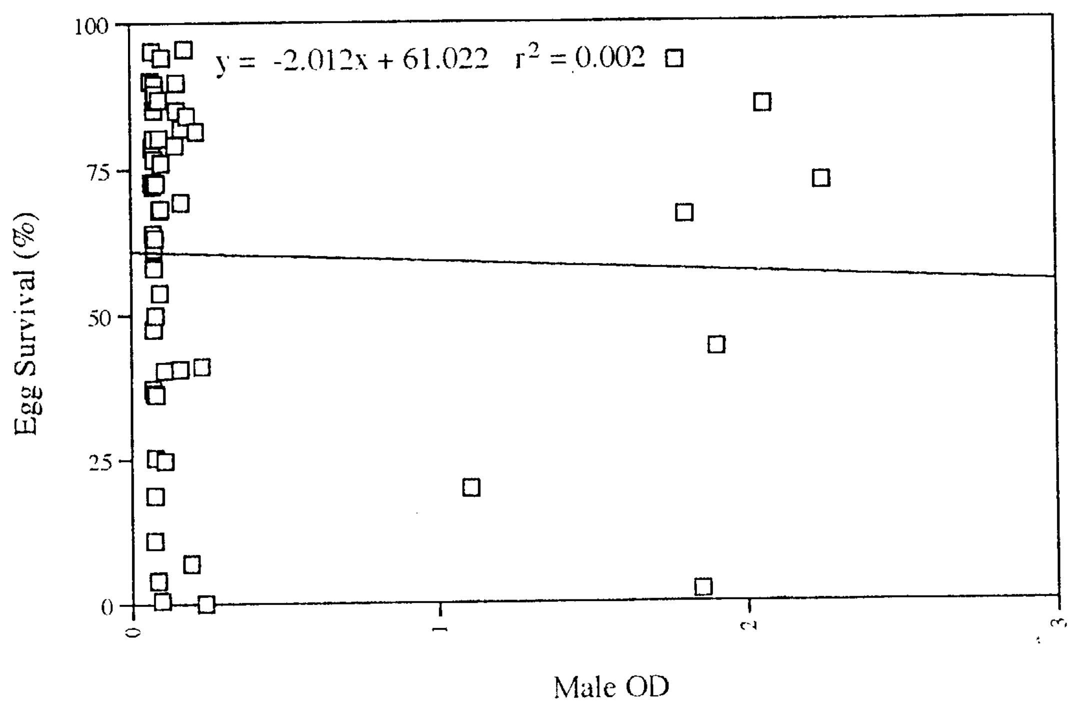

Figure 5. Correlation between male ELISA OD level for presence of Renibacterium salmoninarum, the causative agent of BKD, and egg survival for 1991-brood Redfish Lake sockeye salmon spawned in 1994.

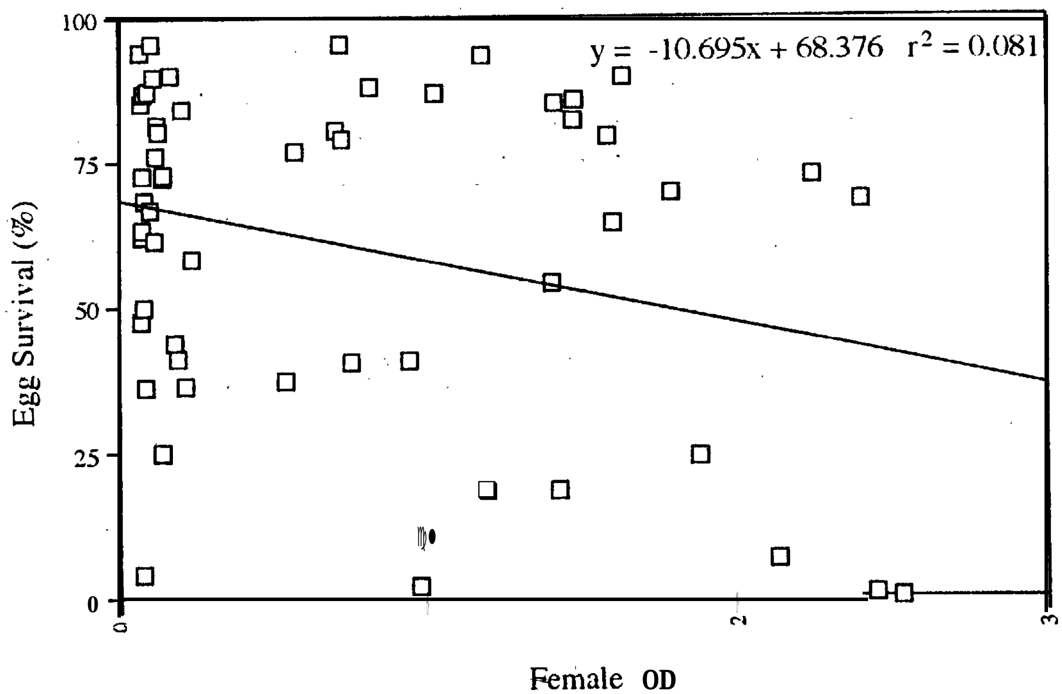

Figure 6. **Correlation between female ELISA OD level for presence of <u>Renibacterium salmoninarum</u>, the causative agent of BKD, and egg survival for 1991-brood Redfish Lake sockeye salmon spawned in 1994.**

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. They 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. However, low fertility from Male 2 resulted in 3 low number of viable eggs in Mating 2A and 2B. Therefore, eggs from Mating 2X (Male 2 milt crossed with 3 portion of Female A's eggs) were retained by IDFG and eggs from Mating 2B (Male 2 milt crossed with a portion of Female B's eggs) were transferred to NMFS (Table 5). NMFS received 1,18 1 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 for captive broodstock rearing (Table 5) and approximately 1,200 eggs for production rearing (Flagg and McAuley 1994).

On 30 November 1993, NMFS's portion of the 1993-brood Redfish Lake sockeye salmon eggs was transported by BPA plane from Idaho to Washington. The eggs had accumulated a total of about 450 (°C) temperature units at the Sawtooth Hatchery prior to transfer to NMFS. IDFG received WDFW Fish Transfer Permit 1685-l l-93 for this transfer of eggs to NMFS. All eggs were transferred safely and successfully incubated 3s half-sib lots in isolation incubators at the NMFS endangered species rearing facility at BBC.

Fish culture and security strategies for the rearing of 1991-brood juvenile Redfish Lake sockeye salmon at BBC were similar to those described above and by Flagg and McAuley (1994). On 25 January 1994, 1,155 fry were ponded into 11 1.8-m tanks. Survival of these fish from hatch to the end of December 1994 averaged 96% (Appendix B and Fig. 7). Even though survival for these groups was high during this period, BKD was documented in a few mortalities from approximately one-half of the rearing groups. All groups of 1993-brood progeny of anadromous

Table 5. 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

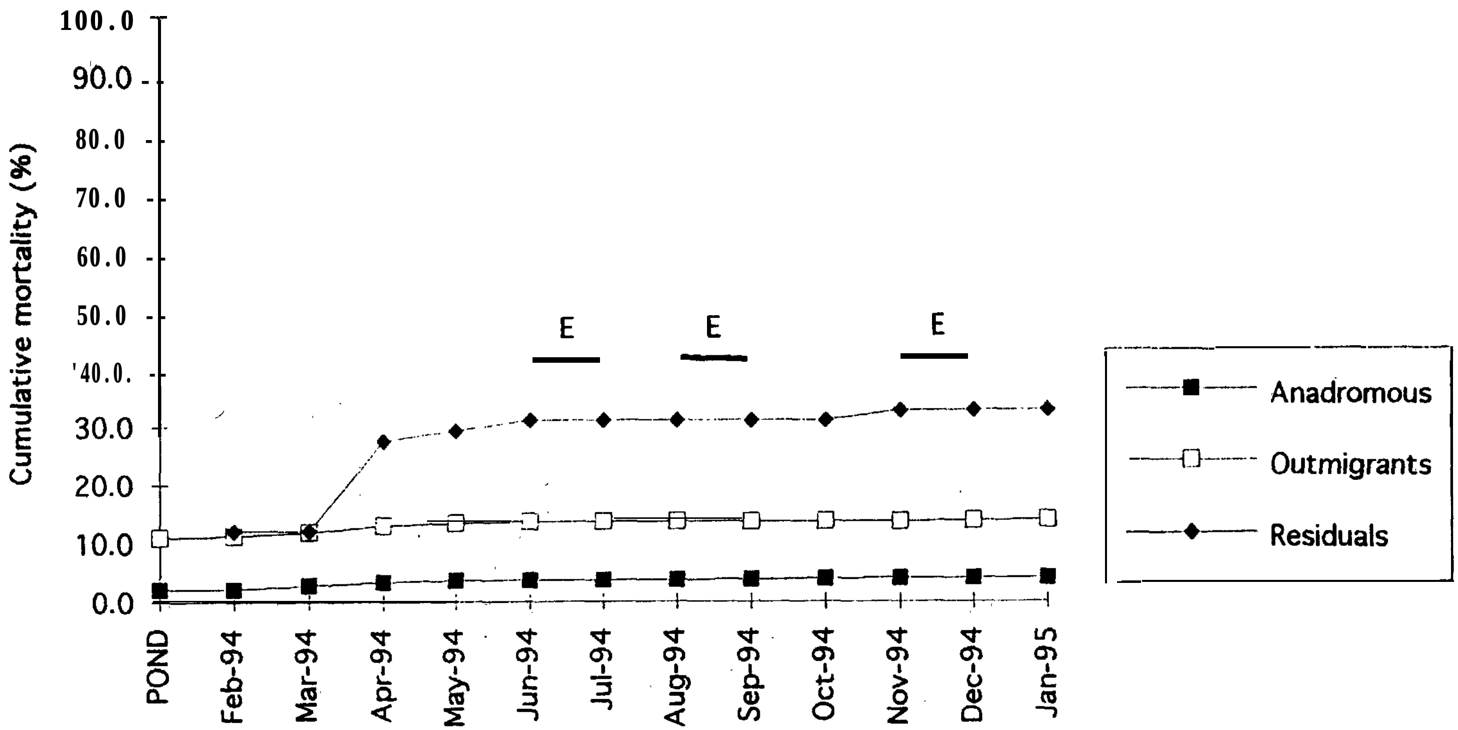

Figure 7. Cumulative percent mortality during rearing for 1993-brood Redfish Lake sockeye salmon, 1994. Areas under E indicate periods of medication with erythromycin.

parents were fed a medicated diet containing 0.45% erythromycin at 2% of body weight/day for about 4 weeks during June, August, and November 1994 (Fig. 7). Prophylactic erythromycin feeding treatments will continue to be administered on an intermittent basis during fry-to-adult rearing.

At the end of December 1994, NMFS had 1,136 1993-brood Redfish Lake sockeye salmon from anadromous parents at BBC (Appendix B and Table 1). These fish average about 40 g each. Groups will be PIT tagged and combined in 4.1 -m tanks in early 1995 for rearing to maturity. Approximately 15% of these fish will be transferred to seawater in May 1995 for rearing to maturity at the NMFS Manchester Marine Experimental Station near Manchester, Washington. The remainder will continue to be reared in fresh water at BBC. We expect most of these fish to spawn between fall 1996 and 1998.

1993-Brood "Safety-Net"

IDFG has maintained captive broodstocks of sockeye salmon captured as outmigrants from Redfish Lake since spring 1991 (Johnson 1993), and about 15% of these fish matured in October 1993 (K. Johnson, IDFG. 1800 Trout Road, Eagle. ID 33616. 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 milt from either one of the six anadromous males that returned in 1993 or with precocious males from broodstock of the one female and three male sockeye salmon that returned to Redfish Lake in 1991 (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. However, as an extra precaution, 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 the spawning of outmigrant-to-adult Redfish Lake sockeye salmon captive broodstock to initiate this "safety-net" captive broodstock (Flagg and McAuley 1994).

On 30 November 1993, NMFS's portion of these eggs were transported on a BPA plane from Idaho to Washington along with the groups of eggs from anadromous parents (described earlier). 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 for this transfer of eggs to NMFS. All eggs were transferred safely and were successfully incubated at BBC. Fish culture strategies were similar to those previously described for 1991-brood juvenile Redfish Lake sockeye salmon at BBC.

The 1993-brood "safety-net" captive broodstock was ponded in late January 1994 at BBC. Groups of about 150 fish each are being maintained separately in 1.8-m diameter tanks. Survival of these fish from hatch to the end of December 1994 has averaged 86% (Appendix B. Fig. 7. and Table 1). Even though survival for these groups has been high. BKD has been documented in a few mortalities from approximately 40% of the rearing groups. All 1993-brood "safety-net" groups were fed a medicated diet containing 0.45% erythromycin at 2% of body weight/day for about 4 weeks during June. August. and November 1994 (Fig. 7). Prophylactic erythromycin feeding treatments will continue on an intermittent basis during fry-to-adult rearing.

At the end of December 1994. NMFS had 604 1993-brood Redfish Lake sockeye salmon at BBC for the "safety-net" (Appendix B and Table 1). These fish average about 35 g each. Groups will be PIT tagged and combined in 4.1-m tanks in early 1995 for rearing to maturity.

Approximately 70% of these fish will be transferred to seawater at Manchester in May 1995 for rearing to maturity. The remainder will continue to be reared in fresh water at BBC. We expect most of these fish to spawn between fall 1996 and 1998.

1993-Brood Residuals

Members of the NMFS Biological 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 (Flagg and McAuley 1993).

On 21 December 1993, NMFS's portion of the 1993-brood residual eggs (125 eggs) was transported by commercial airline from Idaho to Washington. The eggs (57 from female A and 68 from female B) had accumulated a total of 400 (°C) temperature units at the Sawtooth Hatchery prior to transfer to NMFS. IDFG received WDFW Fish Transfer Permit 1686-1 l-93 for this transfer of eggs to NMFS. All eggs were transferred safely and incubated at the NMFS endangered species rearing facility at BBC.

Unfortunately, eggs and fry from female A were not normal: 85% died before ponding and the remaining 15% died soon after ponding. A similar situation occurred with eggs and fry from female A at the IDFG Eagle Creek Hatchery, (K. Johnson, IDFG, 1800 Trout Road, Eagle, ID 83616. Pers. commun., April 1994). However, 51 fish from female B were successfully ponded into a 1.8-m diameter tank at BBC in mid-February 1991. Survival of this group of fish from hatch to the end of December 1994 was 67% (Appendix B, Fig. 7, and Table 1). BKD has not been documented in these fish; nevertheless, the remaining group of 1993-brood residuals was fed a medicated diet containing 0.45% erythromycin at 2% of body weight/day for about 4 weeks during June, August, and November 1994 (Fig. 7). Prophylactic erythromycin feeding treatments will continue to be administered on an intermittent basis during fry-to-adult rearing.

At the end of December 1994, NMFS had 39 1993-brood residual Redfish Lake sockeye salmon at BBC (Table 1). These fish average about 30 g each. This group will be PIT tagged and returned to the 1.8-m tanks in early 1995, and held until large enough for transfer to a 4.1-m tank for rearing to maturity. We expect most of these fish to spawn between fall 1996 and fall 1998.

1991 Brood

In 1994, one adult sockeye salmon female returned to Redfish Lake. This fish was captured at the weir on Redfish Lake Creek during upstream migration in August, and it was moved to the IDFG Eagle Hatchery and spawned in early October by IDFG. The female's eggs were divided into four groups and each group was fertilized with a captive-reared male from IDFG's 199 l-brood of Redfish Lake sockeye salmon. NMFS requested approximately 120 eggs from each of these mating crosses for captive rearing at BBC.

On 13 December 1994, 461 eggs from the 1994-brood Redfish Lake sockeye salmon spawned by IDFG were transported by commercial airline from Idaho to Washington (Table 1). IDFG received WDFW Fish Transfer Permit 2066-12-9-I 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. Survival of this group of fish from hatch to the end of December 1994 was 97% (Table 1). At the end of December 1994, NMFS had 447 199-I-brood Redfish Lake sockeye salmon at BBC (Table 1). We expect most of these fish to spawn in fall 1997 and fall 1999.

CAPTIVE BROODSTOCK RESEARCH USING NON-ENDANGERED LAKE WENATCHEE SOCKEYE SALMON

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. Exacting fish culture methods must be developed to ensure that offspring of captive broodstock have the same genetic, physiological, and behavioral makeup 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. 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 escape. natural catastrophes, and predation from marine mammals and birds. However, land-based facilities with pumped seawater and environmental controls (e.g., filtration, flow, and aeration) may provide the quality environment necessary for protective culture of salmonids in seawater.

In 1992, we initiated studies to compare sockeye salmon reared with and without a period in seawater (Flagg 1993). These studies are being conducted with two year-classes of Lake Wenatchee (Washington) sockeye salmon so as not to jeopardize the endangered Redfish Lake sockeye salmon gene pool. Evaluation focuses on comparison of fish growth, health, survival, and reproductive success. Fish culture strategies are similar to those outlined for Redfish Lake juvenile-to-adult rearing. This research will allow various sockeye salmon culture strategies to be evaluated prior to implementation with the Redfish Lake fish.

The freshwater portion of these experiments are being conducted at NMFS BBC hatchery (these facilities were described previously). The seawater portion of these experiments are being conducted at NMFS Manchester Marine Field Station. where experiment groups are reared in either conventional seawater net-pens or in fiberglass circular tanks supplied with filtered and sterilized seawater (Flagg 1993, Flagg and McAuley 1994).

We recently completed construction of a permanent land-based seawater laboratory for captive broodstock research at Manchester. both Lake Wenatchee captive broodstocks were moved into the facility in July 1994. The marine lab is supplied with over 3.100 L/min (550 gpm) of raw seawater, which is pumped from the end of the pier at Manchester to the land-based marine laboratory through a 700-m-long, 15-cm-diameter polyethylene pipe line. Water is pumped via a 20-hp centrifugal pump. and the system is fitted with another 20-hp pump and a 7.5hp pump as back-up in case of primary pump failure. An emergency generator is automatically activated in the event of a power failure.

About one-half of the seawater supplied to the laboratory is processed before use in fish culture. The filtering consists of six sand filters containing number 20-grade sand; this filters out all organic and inorganic material more than 20 microns in diameter. Water exiting the sand filters immediately enters a second set of four cartridge filters holding 28 filter elements, which are capable of filtering out all material more than 5 microns in diameter. The water then passes through ultraviolet (UV) light-sterilizers to inactivate remaining organic material.

Flow and pressure sensors monitor flow through the seawater filtration/sterilization system. The water is then passed through 12-cm-long by 254-cm-wide packed column degassers which are located at each pool to strip out any excess niuogen and to boost dissolved oxygen levels. An alarm system monitors the pumps and electrical supply and is tied into an automatic dialer system, which is programmed to notify personnel in the event of a problem. Any interruption in pump operation or power supply triggers the alarm and activates an emergency oxygen supply to all rearing containers.

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 each of the following environments: 1) 3. l-m diameter circular fiberglass tanks supplied with pathogen-free fresh water at BBC; 2) 4.1 -m diameter circular fiberglass tanks supplied with pumped, filtered, and UV-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).

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

Survival for experimental groups of 1990-brood Lake Wenatchee sockeye salmon during the 28 months of rearing from the beginning of the experiment in May 1992 through August 1994 averaged about 32% in the freshwater tanks, 35% in the seawater tanks, and 26% in the seawater net-pen replicates (Appendix C and Figs. 8 and 9). Analysis of variance (ANOVA) indicated no significant differences ($P > 0.05$) in the percentage of fish remaining in freshwater tanks, seawater tanks, and seawater net-pens to prespawning at the end of August 1991.

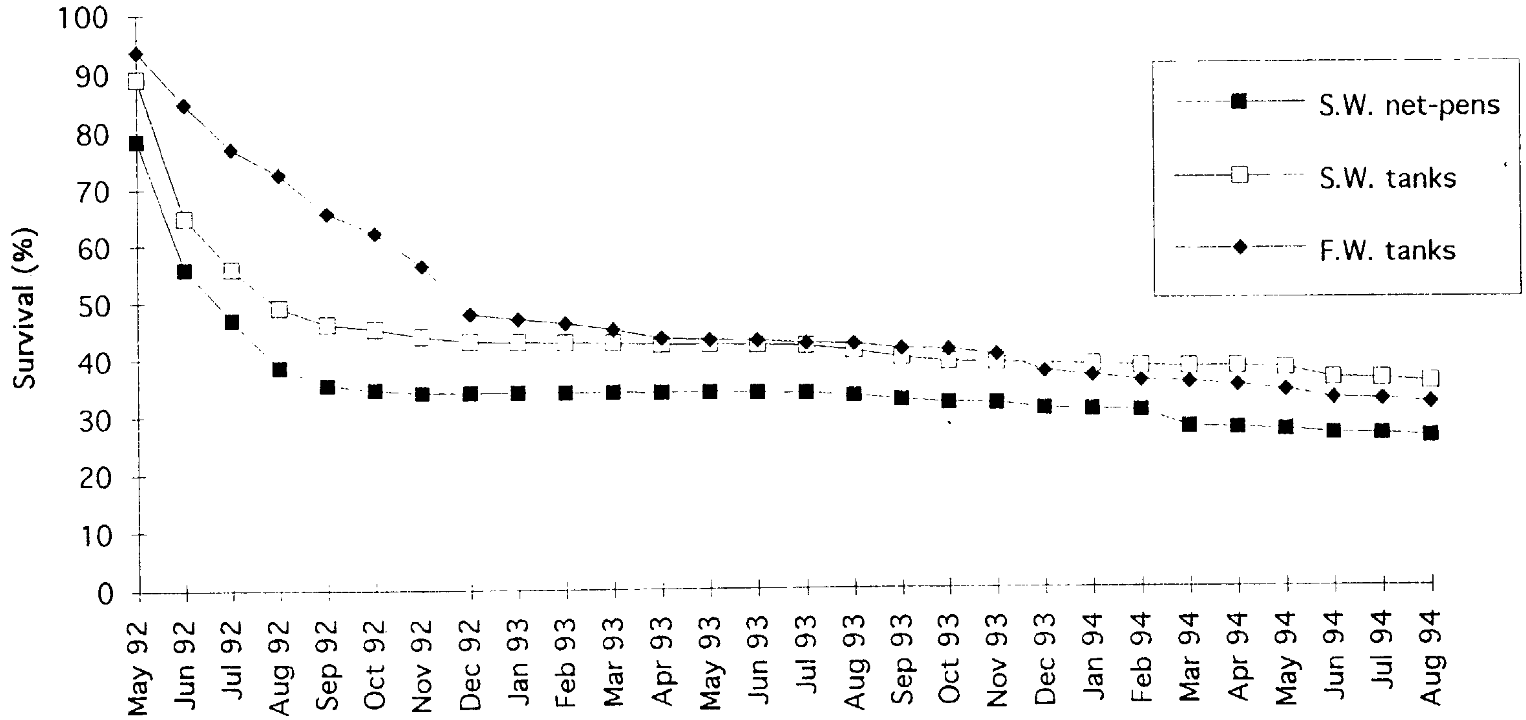

Figure 8. Survival during rearing for 1990-brood Lake Wenatchee sockeye salmon, 1992-1994.

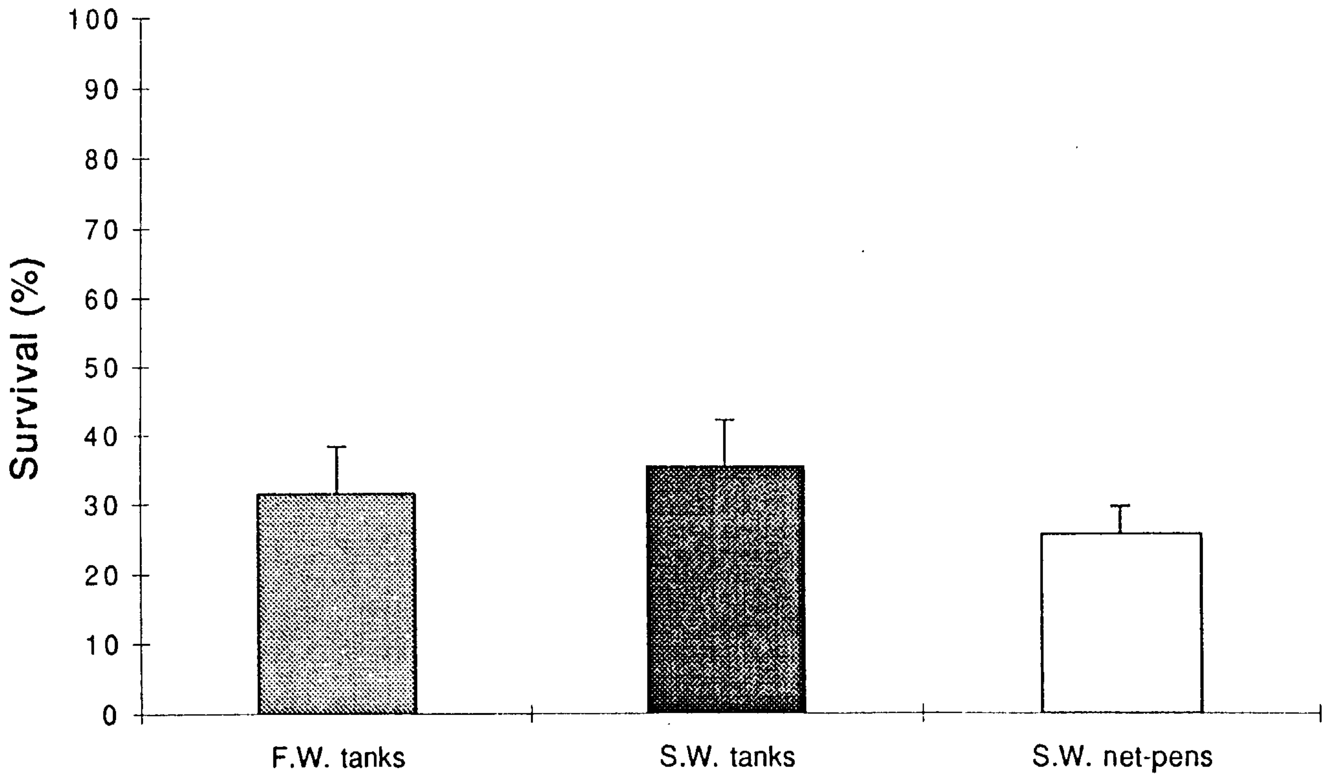

Figure 9. Comparison of survival of 1990-brood Lake Wenatchee sockeye salmon reared in freshwater tanks, seawater tanks, or seawater net-pens to prespawning at the end of August 1994. Bars indicate standard deviation.

Mortalities in the seawater net-pen and seawater tank replicates appeared related to a combination of osmoregulatory distress and BKD during the months just after seawater transfer, and thereafter, mortalities were associated with BKD (Flagg and McAuley 199-t). Most mortalities in the freshwater tank replicates also appeared related to BKD during this same period (Flagg and McAuley 1993). Fish in all treatments were fed a medicated diet containing 0.45% erythromycin at 2% of body weight/day for approximately 28 days in December 1992 and April and December 1993. Erythromycin was fed at 1.2% of body weight/day in February, April. and June 1994. This medication may have helped arrest BKD incidence. Mortality stabilized (at about 60%) after 8 to 12 months of rearing (at about 2 to 2.5 years of age) (Fig. 8).

Growth differences were noted between the treatments. Size of fish averaged 2.26 kg in the freshwater tanks, 1.57 kg in the seawater tanks, and 1.49 kg in the seawater net-pens at the last measuring period prior to spawning (September 199-I) (Appendix C and Figs. 10 and 11). ANOVA indicated significant differences ($P < 0.05$) between average weights of fish in the three treatments. The fish reared in fresh water were about 44% larger than fish reared in the seawater tanks and 52% larger than those reared in the seawater net-pens. Tukey's multiple comparison test indicated that average fish weight in the treatments ranked as follows: freshwater tanks > seawater tanks = seawater net-pens ($P < 0.10$).

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

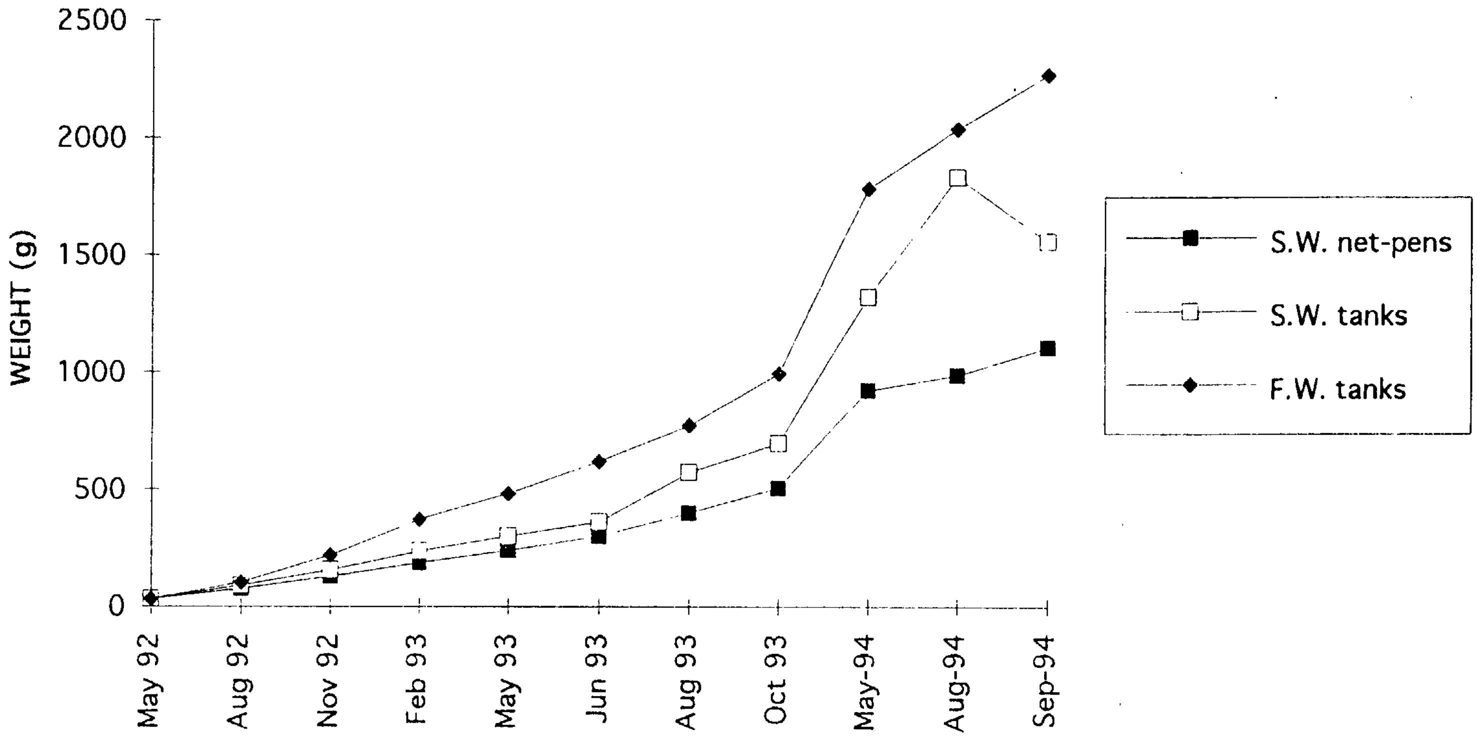

Figure 10. Growth during rearing for 1990-brood Lake Wenatchee sockeye salmon, 1992-1994.

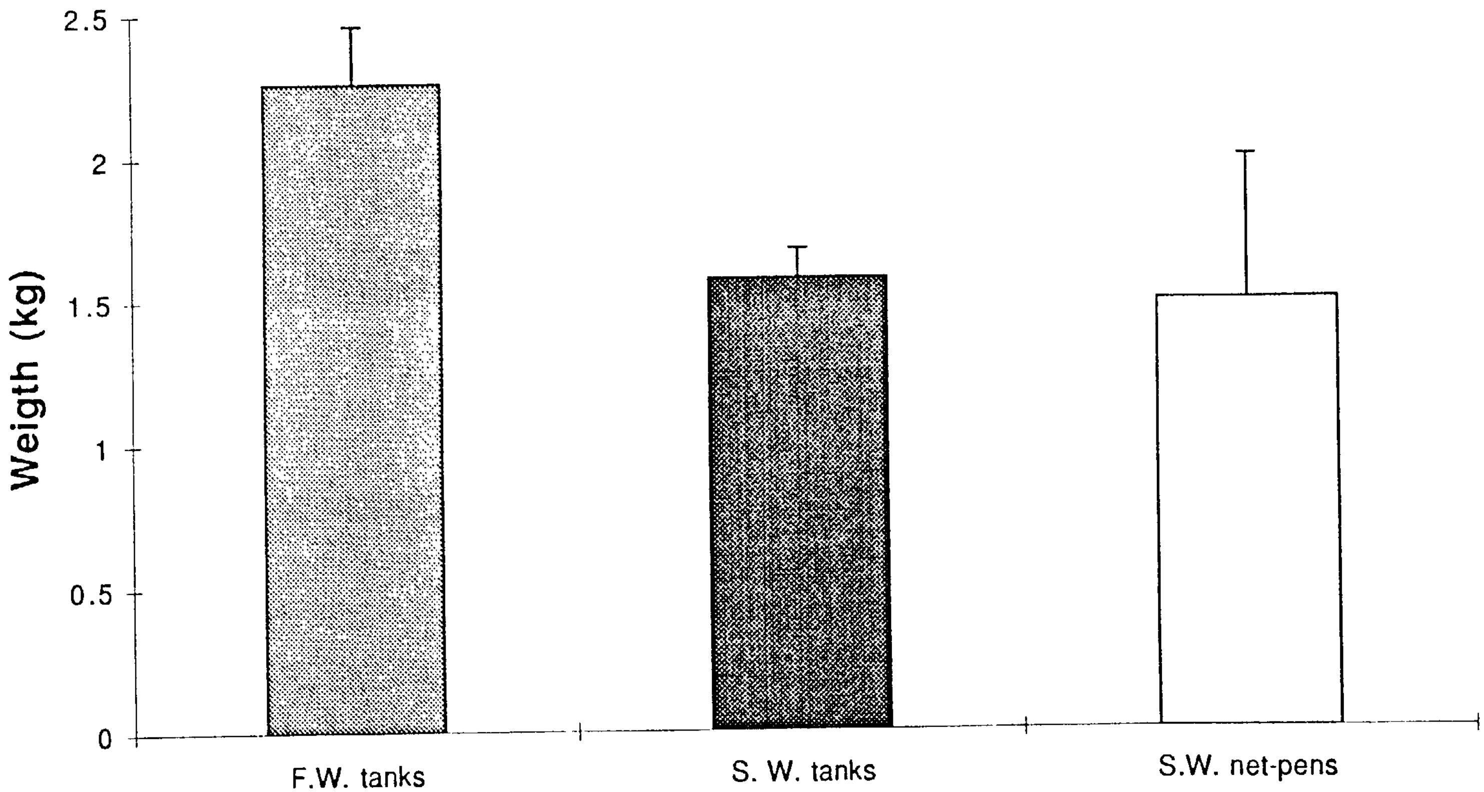

Figure 11. Comparison of weight of 1990-brood Lake Wenatchee sockeye salmon reared in freshwater tanks, seawater tanks, or seawater net-pens to prespawning at the end of August 1994. Bars indicate standard deviation.

Spawning 1993--The faster growth rate of the freshwater replicates resulted in a few fish (15%) maturing at 3 years of age in late October 1993 (Flagg and McAuley 1994). 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%. No fish from either seawater tank or seawater net-pen treatments matured in 1993.

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

Because natural anadromous sockeye return to freshwater to spawn, fish in both seawater treatments were sorted according to reproductive state (mature vs. immature). and maturing adults were transferred to freshwater at BBC 1 month prior to spawning. Fish in the freshwater treatment group were also sorted for maturity. At the time of spawning, fecundity and egg size were determined, and gamete quality was monitored by evaluating fertilization rates The quality of the gametes was further evaluated by monitoring survival to the eyed egg stage.

Female 1990-brood sockeye salmon from the freshwater tank replicates averaged 54.4 cm and 2.24 kg, while male spawners averaged 56.5 cm and 2.5 1 kg (Table 6). Fecundity averaged 2,477 eggs/female (1,106 eggs/kg of female weight) for the 1990-brood Lake Wenatchee sockeye salmon spawned from the freshwater rearing treatment in our experiments in 1994 (Table 7). Eyed-egg survival for this treatment averaged 49.6% (Table 7).

Table 6. Length and weight information for mature 1990-brood Lake Wenatchee sockeye salmon reared in freshwater tanks, 1994.

Replicate number	Female Fish number[a]	Female Length (cm)	Female Weight (kg)	Male Fish number	Male Length (cm)	Male Weight (kg)
1	1	56.9	2.24	A	52.2	1.80
	2	57.2	2.69	B	56.6	2.60
	3	53.3	2.04	C	59.0	3.35
	4	55.6	2.52	D	54.2	2.10
	5	54.9	2.34	E	57.3	2.60
	6	58.0	2.95	F	59.9	3.30
	7	54.4	2.15	G	54.0	1.95
	8	47.7	1.49	H	55.3	2.14
	10	55.6	2.59	1	57.1	2.77
	11	51.6	1.91	2	52.9	1.90
	12	56.0	2.66	3	57.4	2.37
	13	57.1	2.61	4	53.2	2.00
	14	59.5	2.92	5	55.4	2.32
	15	58.4	2.51	6	57.7	2.42
	16	60.3	3.23	7	54.2	2.20
	17	56.6	2.34	8	56.3	2.42
	18	56:0	2.47	9	56.1	2.80
	19	57.8	1.87	10	59.0	2.79
	20	55.8	2.36	11	55.5	2.48
	21	56.2	2.50	12	56.8	2.54
	22	48.6	1.83	13	56.3	2.72
	23	55.3	2.22	14	46.0	1.44 .
	24	56.8	2.56	15	59.0	1.35
	25	52.3	1.88	16	52:0	2.13
	26	55.3	2.35	17	47.5	1.00
	27	54.8	2.19	18	48.3	1.41
	28	55.0	2.08	19	57.1	2.58
	29	53.6	2.16	20	56.5	2.49
	30	55.5	2.41	21	52.7	2.96
	31	53.8	2.30		- -	- -
	32	56.6	2.33			---
	33	53.0	1.78		---	- -
	34	50.5	1.72		---	- -
	35	53.0	2.02	--		- -
	36	55.8	2.15	--		---
	37	47.6	1.74	--	---	---
	38	60.4	3.28	--	---	- -
	39	38.5	0.69	--		---
	40	50.6	1.49	--		- -

Table 6. Continued.

Replicate number	Female Fish number[a]	Female Length (cm)	Female weight (kg)	Male Fish number	Male Length (cm)	Male weight (kg)
	41	52.0	1.81	--	---	---
Average		54.4	2.24		55.0	2.31
SD		4.0	0.49		3.4	0.56
2	1	53.2	2.16	A	60.4	3.10
	2	56.5	2.51	B	57.5	2.55
	3	52.4	1.73	C	56.8	2.48
	4	57.5	2.54	D	57.3	2.79
	5	55.5	2.55	E	59.8	1.72
	6	56.6	2.48	F	55.6	2.25
	7	51.4	2.91	G	59.8	2.89
	8	54.8	2.21	H	57.2	2.77
	10	53.9	2.11	1	57.2	2.82
	11	57.8	2.21	2	60.8	3.18
	12	57.8	2.78	3	56.7	2.47
	13	48.8	1.47	4	54.1	2.33
	14	47.0	1.47	5	60.7	3.38
	15	52.3	1.76	6	55.0	2.46
	16	53.4	2.00	7	60.4	3.12
	17	48.0	1.41	8	57.3	2.67
	18	58.0	1.73	9	52.5	2.23
	19	49.8	1.58	10	53.5	2.15
	20	50.2	1.47	11	54.2	2.26
	21	50.8	1.63	12	59.8	3.10
	22	53.3	1.72	13	50.2	1.87
	23	51.9	1.75	14	55.4	2.05
	24	54.6	2.36	15	58.6	2.52
	--	--	--	16	57.4	2.80
		--	---	17	57.1	2.31
	--	--	---	18	54.4	2.37
	--	---	---	19	59.5	2.71
Average		53.3	2.02		56.9	2.57
SD		3.3	0.46		2.7	0.41

Table 6. Continued.

Replicate number	Female: Fish number[a]	Female: Length (cm)	Female: Weight (kg)	Male: Fish number	Male: Length (cm)	Male: weight (kg)
3	1	60.0	3.15	A	63.4	3.28
	2	53.5	2.37	B	61.0	3.05
	3	53.6	1.95	C	63.0	4.09
	4	55.8	2.32	D	59.4	2.92
	5	49.8	1.62	E	57.2	2.98
	6	59.0	3.01	F	56.5	2.54
	7	55.0	2.09	G	54.6	2.24
	8	59.6	2.86	H	62.0	3.20
	10	54.5	2.16	1	62.2	3.52
	11	58.3	2.87	2	54.8	2.50
	12	57.4	2.47	3	52.8	2.40
	13	54.9	2.37	4	63.1	3.55
	14	54.8	2.08	5	55.0	2.38
	15	52.9	2.24	6	39.3	0.72
	16	55.9	2.29	--	---	---
	17	53.8	2.20	--	- -	- -
	18	57.8	2.54	--	---	---
	19	54.6	2.12	--	---	- -
	20	58.4	2.71	--	---	---
	21	55.2	2.35		---	---
	22	53.2	2.28	--	---	---
	23	51.0	3.27		---	---
	24	52.8	1.88	--	---	---
	25	60.0	3.08	--	---	---
	26	59.8	3.11	--	---	---
	27	54.4	2.28		---	---
Average		55.6	2.45		57.5	2.81
SD		2.8	0.43		6.4	0.80
Combined[b]						
Average		54.5	2.24		56.2	2.51
SD		3.6	0.49		4.0	0.59
Overall average[c]						
Length	55.2 cm					
SD	3.9					
Weight	2.36 kg					
SD	0.55					

Table 6.. Continued.

[a] Female numbering system purposely skipped from number 8 to number 10 to avoid use of number 9.

[b] Pooled replicates.

[c] Total pooled male and female.

Table 7. Individual male/female matings and egg survivals for mature 1990-brood Lake Wenatchee sockeye salmon held full-term in freshwater tanks, 1994.

Replicate	Mating cross: Female number	Mating cross: Male number	Fecundity	Eyed-egg survival (%)
1	1-1	1-A,B,C,D	1,846	21.3
	1-2	1-A,B,C,D	3,208	42.2
	1-3	1-A,B,C,D	2,298	59.4
	1-4	1-A,B,C,D	2,996	51.3
	1-5	1-E,F,G,H	2,563	68.2
	1-6	1-E,F,G,H	3,077	73.2
	1-7	1-E,F,G,H	1,953	36.6
	1-8	1-E,F,G,H	2,248	63.0
	1-12	l-1.218	nd	nd
	1-14	1-1,21	nd	nd
	l-15	1-1,21	2,062	0.1
	1-16	1-1,21	1,112	16.4
	1-17	1-1,21	nd	nd
	1-18	1-1,21	nd	nd
	1-19	1-1,21	nd	nd
	1-20	1-1,21	nd	nd
	1-21	1-1,21	nd	nd
	l-22	1-1,21	nd	nd
	l-23	1-1,21	nd	nd
	1-24	1-1,21	nd	nd
	1-25	1-1,21	1,793	58.9
	l-26	1-1,21	2,647	84.4
	l-27	1-1,21	3,667	2.8
	1-28	1-1,21	2,512	79.6
	l-29	1-1,21	2,347	72.2
	l-30	1-1,21	2,417	34.6
	1-31	1-1,21	2,825	70.4
	l-32	1-1,21	3,263	36.0
	1-33,34	1-1,21	4,517	8.1
	1-35,36	1-1,21	5331	77.0
	1-37,38	1-1,21	5,898	15.5
	l-39	1-1,21	1,340	66.4
	1-41	1-1,21	2,505	10.8
Average			2,474	45.6
SD			572	26.8

Table 7. Continued.

Replicate	Mating cross: Female number	Mating cross: Male number	Fecundity	Eyed-egg survival (%)
2	2-1	2-A,B,C,D	1,342	42.5
	2-2	2-A,B,C,D	2,648	68.0
	2-3	2-A,B,C,D	2,568	71.1
	2-4	2-A,B,C,D	2,658	71.6
	2-5	2-E,F,G,H	3,111	77.1
	2-6	2-E,F,G,H	2,150	72.9
	2-7	2-E,F,G,H	1,372	68.2
	2-8	2-E,F,G,H	2,817	65.9
	2-10	2-1,19[b]	1,385	46.8
	2-11	2-1,19	1,701	90.1
	2-12	2-1,19	3,064	78.9
	2-13	2-1,19	2,632	79.4
	2-14	2-1,19	1,707	73.0
	2-15	2-1,19	1,991	43.5
	2-16	2-1,19	3.136	0.1
	2-17,18	2-1,19	nd	nd
	2-19	2-1,19	nd	nd
	2-21,22	2-1,19	nd	nd
Average			2,285	63.3
SD			637	21.4
3	3-1	3-A,B,C,D	3,387	47.9
	3-2	3-A,B,C,D	2,797	5.7
	3-3	3-A,B,C,D	2,161	65.2
	3-4	3-A,B,C,D	2,465	70.5
	3-5	3-E,F,G,H	2,437	0.1
	3-6	3-E,F,G,H	2,085	18.8
	3-7	3-E,F,G,H	2,058	34.7
	3-8	3-E,F,G,H	2,348	45.1
	3-10	3-1,6[c]	2,155	0.1
	3-11	3-1,6	3.838	44.4
	3-12	3-1,6	3,210	51.2
	3-13	3-1,6	1,790	77.4
	3-15	3-1,6	3,097	84.7
	3-16	3-1,6	3,072	74.7
	3-17	3-1,6	1,821	77.2
	3-18,19	3-1,6	nd	nd
	3-20,21	3-1,6	4,096	68.0
	3-22,23	3-1,6	4,728	53.4

Table 7. Continued.

Replicate	Mating cross Female number	 Male number	Fecundity	Eyed-egg survival (%)
	3-25	3-1,6	3,396	65.1
	3-26.27	3-1,6	6.525	10.6
Average			2,612	47.1
SD			587	27.3
Combined[d]				
Average			2,477	49.6
SD			606	27.2

[a] Females from replicate 1 crossed with random combination of milt fiom males 1 to 21.

[b] Females from replicate 2 crossed with random combination of milt from males 1 to 19.

[a] Females fiom replicate 3 crossed with random combination of milt from males 1 to 6.

[d] Pooled replicates.

Female 1990-brood from the seawater tank replicates averaged 50.3 cm and 1.56 kg, while male spawners averaged 51.0 cm and 1.69 kg (Table 8). Fecundity averaged 1,899 eggs/female (1,217 eggs/kg of female weight) with eyed-egg survival averaging 42.4% for the seawater tank replicates (Table 9).

Average length and weight for female spawners from the seawater net-pen treatment were 43.0 cm and 0.99 kg, while males spawners averaged 44.6 cm and 1.17 kg (Table 10). Fecundity averaged 1,783 eggs/female (1,801 eggs/kg of body weight), with eyed-egg survival averaging 45.8% for this group (Table 11).

Columbia River Basin female sockeye salmon normally mature as 4- and 5-year-old fish? at about 45-60 cm and 2-4 kg (Mullan 1986. Flagg et al. 1991). The 4-year-old 1990-brood Lake Wenatcbee sockeye salmon spawners from the freshwater tank rearing treatment were within the expected size range for Columbia River sockeye salmon. However, spawners from the seawater tank and net-pen rearing treatments were below expected size thresholds (see size discussion under tearing, growth, and. survival section above). ANOVX indicated significance differences ($P < 0.002$) in both male and female spawner length and weight between the rearing treatments. Tukey's multiple comparison test indicated that average male and female spawner size (length and weight) in the treatments ranked as follows:. freshwater tanks > seawater tanks > seawater net-pens ($P \leq 0.10$).

ANOVA also indicated significance differences ($P < 0.001$) in fecundities of female spawners between tearing treatments (Fig. 12). Results from Tukey's multiple comparison test indicated that average female spawner fecundity in the treatments ranked as follows: freshwater tanks > seawater tanks = seawater net-pens (P c 0.02). However, ANOVA indicated no significant difference ($P > 0.10$) in eyed egg survival (viability) of female spawners from the three treatments (Fig. 13).

The 42-50% average eyed-egg survival rate for 4-year-old spawners in this study was lower than the 70 to 90% often seen in wild sockeye salmon (Mullan 1986, Flagg et al. 1991).

Table 8. Length and weight information for mature 1990-brood Lake Wenatchee sockeye salmon reared in seawater tanks, 1994.

Replicate number	Female: Fish number[a]	Female: Length (cm)	Female: Weight (kg)	Male: Fish number	Male: Length (cm)	Male: Weight (kg)
1	1	51.5	1.64	A	53.5	1.76
	2	53.0	1.90	B	55.5	2.01
	3	48.9	1.32	C	52.0	1.72
	4	55.3	2.01	D	43.0	1.20
	5	51.5	1.50	E	54.0	1.74
	6	55.0	1.96	F	52.0	1.66
	7	54.0	1.93	G	51.8	1.84
	8	53.5	1.85	H	46.6	1.24
	10	47.2	1.14	1	52.7	1.61
	11	49.0	1.67	2	52.0	1.71
	12	49.0	1.43	3	54.5	1.93
	13	45.0	1.17	4	44.2	0.98
	14	53.0	1.70	5	45.9	1.25
	15	47.8	1.19	6	42.8	1.22
	16	51.0	1.57	7	52.3	1.75
	17	51.5	1.62	8	50.2	1.50
	18	50.8	1.74	9	50.4	1.48
	19	54.0	1.81	10	48.9	1.41
	20	50.5	1.73	11	49.8	1.46
	21	49.8	1.52	12	46.7	0.76
	22	55.5	1.84	--	--	--
	23	49.9	1.57		--	--
	24	52.0	1.55		--	--
	25	53.5	1.93		--	--
	26	53.4	1.93		--	--
	27	53.5	1.92		--	--
	28	50.5	1.51		--	--
	29	46.0	1.10		--	--
	30	48:o	1.25		--	--
	31	44.1	0.97		--	--
	32	55.0	1.91		--	--
	33	50.9	1.55	--	--	--
	34	52.6	1.71		--	--
	35	53:o	1.71		--	--
	36	47.9	1.37		--	--
	37	55.3	1.79		--	--
	38	51.5	1.80		--	--
	39	44.6	0.96		--	--
	40	57.3	2.16		--	--

Table 8. Continued.

Replicate number	Female Fish number[a]	Female Length (cm)	Female Weight (kg)	Male Fish number	Male Length (cm)	Male weight (kg)
	41	57.7	2.41		—	—
Average		5i.3	1.63		49.9	1.51
SD		3.3	0.32		3.9	0.32
2	1	47.0	1.20	A	57.0	2.10
	2	53.0	1.68	B	46.5	1.36
	3	54.0	2.08	C	47.3	1.22
	4	48.5	1.39	D	46.8	1.23
	5	52.3	1.83	E	44.8	1.18
	6	49.6	1.45	F	55.5	2.33
	7	56.6	2.52	G	54.0	2.09
	8	49.5	1.63	H	50.0	1.62
	10	55.0	2.10	1	48.8	1.42
	11	50.5	1.83	2	55.7	2.47
	12	52.0	1.60	3	55.5	2.35
	13	50.9	1.67	4	56.8	2.56
	14	43.2	0.98	5	52.2	1.53
	15	51.0	1.52	6	51.0	1.83
	16	52.8	1.78	7	55.0	2.08
	17	51.5	1.68	8	48.2	I.41
	18	50.3	1.53	9	56.5	2.36
	19	51.5	1.68	10	53.5	1.80
	--	- -	- -	11	57.0	2.20
			a-	12	55.0	2.19
	--	—	- -	13	50.9	1.71
Average		51.1	1.68		52.3	1.86
SD		3.0	0.34		4.0	0.45
3	1	50.0	1.90	A	46.5	1.12
	2	47.7	1.18	B	53.5	2.05
	3	48.2	1.31	C	49.8	1.68
	4	49.6	1.31	D	57.8	2.48
	5	53.8	2.03	E	44.8	1.18
	6	52.2	1.61	F	55.5	2.33
	7	45.0	1.06	G	54.0	2.09
	8	45.0	1.12	H	50.0	1.62
	10	54.4	1.84	1	55.0	2.08

Table 8. Continued.

Replicate number	Female Fish number[a]	Female Length (cm)	Female Weight (kg)	Male Fish number	Male Length (cm)	Male Weight (kg)
	11	49.8	1.49	2	54.0	1.87
	12	55.0	2.36	3	52.6	1.51
	13	46.0	1.16	4	52:0	1.86
	14	49.5	1.32	5	53.2	2.14
	15	47.0	1.10	6	44.2	1.21
	16	53.0	1.86	7	56.3	2.18
	17	54.5	1.84	8	40:o	0.65
	18	47.0	1.22	9	41.1	0.5 1
	19	48.5	1.42	--	--	--
	20	48.9	1.30	--	--	--
	21	46.2	0.99	--	--	--
	22	46.2	1.26	--	--	--
	23	44.3	0.80	--	--	--
	24	51.0	1.59	--	--	--
	25	50.0	1.51	--	--	--
	26	44.7	1.06	--	--	--
	27	54.8	2.02	--	--	--
	28	52.4	1.80	--	--	--
	29	49.8	1.66	--	--	--
	30	50.8	1.55	--	--	--
	31	51.9	1.71	--	--	--
	32	51.9	1.64	--	--	--
	33	40.4	0.86	--	--	--
	34	46.1	1.03	--	--	--
	35	47.8	1.36	--	--	--
	36	51.2	1.53	--	--	--
	37	52.2	1.63		--	--
	38	32.5	0.31	--	--	--
Average		48.9	1.43		50.6	1.68
SD		4.4	0.40		5.4	0.58
Combined[b]						
Average		50.3	1.56		51.0	1.69
SD		3.9	0.37		4.4	0.47
Overall average[c]						
Length	50.6 cm					
SD	4.1					
weight	1.61 kg					
SD	0.42					

Table 8. Continued.

[a] Female numbering system purposely skipped from number 8 to number **10** to avoid use of **number 9.**

[b] Pooled replicates.

[c] Total pooled male and female.

Table 9. Individual male/female matings and egg survivals for mature! 1990-brood Lake Wenatchee sockeye salmon held full-term in seawater tanks, 1994.

Replicate	Mating cross: Female number	Mating cross: Male number	Fecundity	Eyed-egg survival (%)
1	1-1	1-A,B,C,D	2.327	0.1
	1-2	1-A,B,C,D	2,613	78.4
	l-3	1-A,B,C,D	1,591	55.2
	l-4	1-A,B,C,D	2,561	74.4
	1-5	1-E,F,G,H	2,265	26.2
	1-6	1-E,F,G,H	2294	76.0
	1-7	1 -E,F,G,H	1,826	8.4
	l-8	1-E,F,G,H	2,261	74.3
	l-10 .	1-1,12[a]	1,714	51.1
	1-12	1-1.12	2,002	9.2
	1-13	1-1,12	2,165	54.3
	1-14	1-l.12	2,161	82.2
	l-15	1-1.12	1,887	72.1
	1-16	1-1,12	2,678	31.7
	l-17	l-1.12	1,897	36.4
	1-18	1-1,12	1,905	56.4
	l-19	1-1,12	2,281	0.0
	l-20	1-1,12	2,202	70.0
	1-21	1-1,12	1,817	4.7
	1-22	l-1.12	2,154	36.9
	1-23	1-1,12	1,693	70:o
	l-24	1-1,12	2,757	0.0
	1-25	1-1,12	2,123 .	65.1
	1-26,27 .	1-1,12	5,302	35.5
	l-28	1-1,12	1,589	3.5
	l-29,30,3 1	l-l.12	3,714	8.0
	l-34	1-1,12	2,159	0.4
	1-37	1-1.12	1,409	0.0
	l-38	1-1,12	1;258	4.3
	l-39	1-1,12	628	0.3
	l-40	l-l.12	1.540	1.2
Average			1,964	35.0.
SD			498	30.4

Table 9. Continued.

Replicate	Mating cross Female number	 Male number	Fecundity	Eyed-egg survival (%)
2	2-1	2-A,B,C,D	1,758	74.1
	2-2	2-A,B,C,D	1,318	27.2
	2-3	2-A,B,C,D	1,876	28.9
	2-4	2-A,B,C,D	1,797	53.0
	2-5	2-E,F,G,H	2,063	44.8
	2-6	2-E,F,G,H	1,956	48.2
	2-7	2-E,F,G,H	2,598	58:0
	2-8	2-E,F,G,H	2,005	14.8
	2-10	2-1,13[b]	2,157	68.3
	2-11	2-1,13	2,270	82.2
	2-12	2-1,13	2,801	41.4
	2-13	2-1.13	2,019	78.2
	2-14	2-1,13	1,436	14.8
	2-15	2-1,13	2,143	35.2
	2-16	2-1,13	2,019	0.3
	2-18	2-1,13	2,361	22.5
	2-19	2-1,13	1,197	15.0
Average			1,987	41.6
SD			405	24.1
3	3-1	3-A,B,C,D	1,835	77.4
	3-2	3-A,B,C,D	2,388	83.5
	3-3	3-A,B,C,D	2,347	76.6
	3-4	3-A,B,C,D	1,454	96.2
	3-5	3-E,F,G,H	2,401	65.4
	3-6	3-E,F,G,H	1,934	57.0
	3-7	3-E.F,G,H	2,142	0.0
	3-8	3-E,F,G,H	1,612	69.0
	3-10	3-1,9[a]	2,305	0.1
	3-11	3-1,9	1,856	44.4
	3-12	3-1,9	2,794	51.2
	3-13	3-1,9	2,246	77.4
	3-14	3-1,9	1,429	84.7
	3-15	3-1,9	1,061	74.7
	3-16	3-1,9	2,388	77.2
	3-17	3-1,9	1,899	nd
	3-18	3-1,9	1,667	68.0
	3-19	3-1,9	2,158	53.4
	3-20.23	3-1,9	2,433	65.1

Table 9. Continued.

Replicate	Mating cross: Female number	Mating cross: Male number	Fecundity	Eyed-egg survival (%)
	3-24,25	3-1,9	3,761	10.6
	3-26,27	3-1,9	2,897	44.3
	3-28.29	3-1,9	4,008	63.9
	3-30.3 1	3-1,9	2,528	59.6
	3-32.33	3-1,9	2,091	22.5
	3-37	3-1,9	1,535	0.1
Average			1,780	55.9
SD			466	29.5
Combined[d]				
Average			1,899	42.4
SD			477	28.9

[a] Females crossed with random combination of milt from males 1 to 12.

[b] Females crossed with random combination of milt from males 1 to 13.

[c] Females crossed with random combination of milt from males 1 to 9.

[d] Pooled replicates.

Table 10. Length and weight information for mature 1990-brood Lake Wenatchee sockeye salmon bred in seawater net-pens, 1994.

Replicate number	Female: Fish number	Female: Length (cm)	Female: Weight (kg)	Male: Fish number	Male: Length (cm)	Male: weight (kg)
1	1	47.3	1.27	1	44.4	1.00
2	1	42.2	0.91	1	44.4	1.00
	2	45.3	1.06	--	----	- -
	3	41.9	0.90		---	- -
	4	38.5	0.76	--	- -	- -
	5	48.0	1.39		----	----
Average		43.2	1.00			
SD		3.6	0.24			
3	1	44.9	1.08	1	----	----
	2	41.0	0.89	2	47.0	1.46
	3	38.3	0.66	3	42.4	1.04
Average		41.4	0.88		44.7	1.25
SD		3.3	0.21		3.3	0.30
Combined[a]						
Average		43.0	0.99		44.6	1.17
SD		3.5	0.23		2.3	0.26
Overall average[b]						
Length	43.4 cm					
SD	3.3					
Weight	1.04 kg					
SD	0.24					

[a] Pooled replicates.

[b] Total pooled male and female.

Table 11. Individual male/female matings and egg survivals for mature 1990-brood Lake Wenatchee sockeye salmon held full-term in seawater net-pens, 1994.

Replicate	Mating cross: Female number	Male number	Fecundity	Eyed-egg survival (%)
1	1-1	1-1	2,083	64.0
2	2-1	1-1	1,324	86.9
	2-2	1-1	2,082	42.4
	2-3	1-1	1,873	56.1
	2-4	1-1	1.248	39.5
	2-5	1-1	2,344	39.0
Average			1,774	52.8
SD			426	18.2
3	3-1	3-1	2,299	63.5
	3-2	3-2	1,388	0.9
	3-3	3-3	1,407	20.2
Average			1,698	28.2
S D			425	26.2
Combined[a]				
Average			1,783	45.8
SD			417	24.1

[a] Pooled replicates

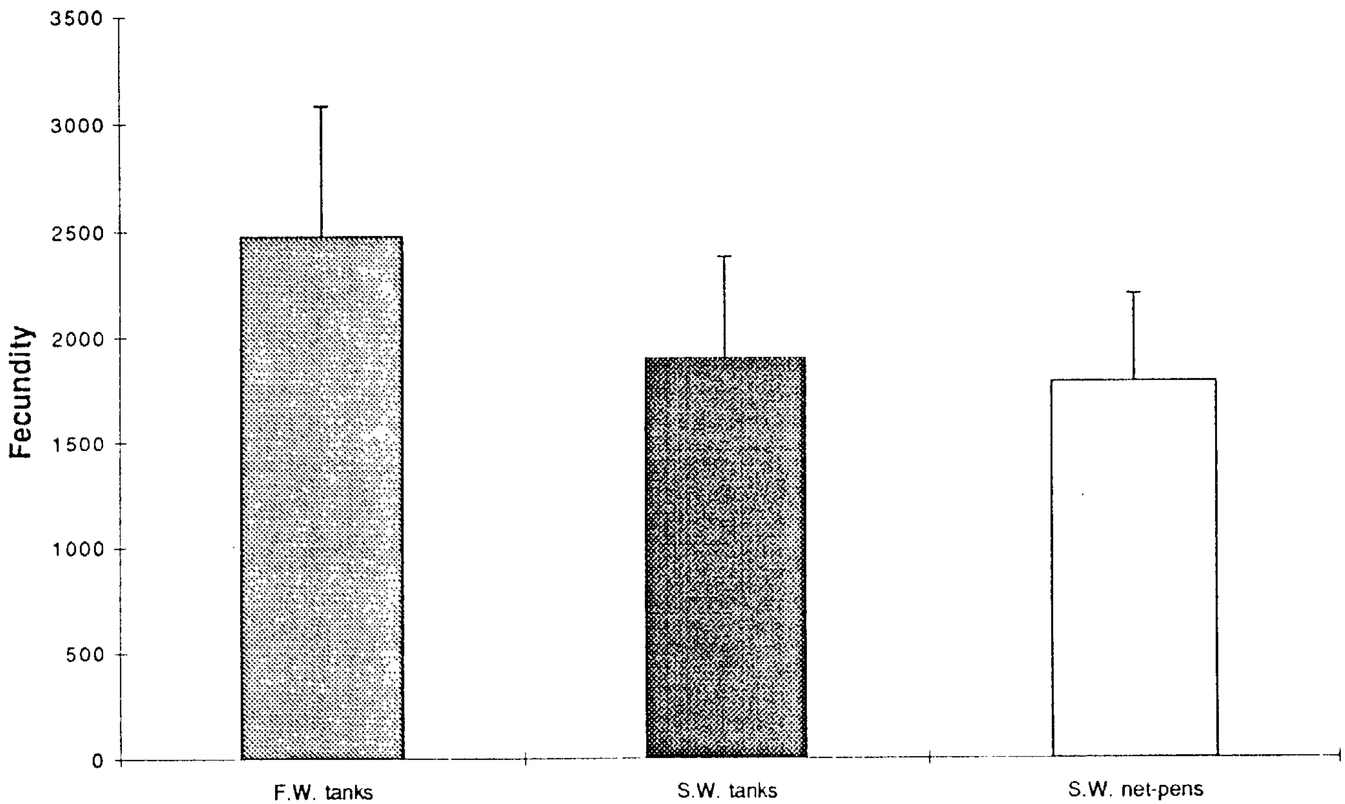

Figure 12. Comparison of fecundity of 1990-brood Lake Wenatchee female sockeye salmon reared in freshwater tanks, seawater tanks, or seawater net-pens. Bars indicate standard deviation.

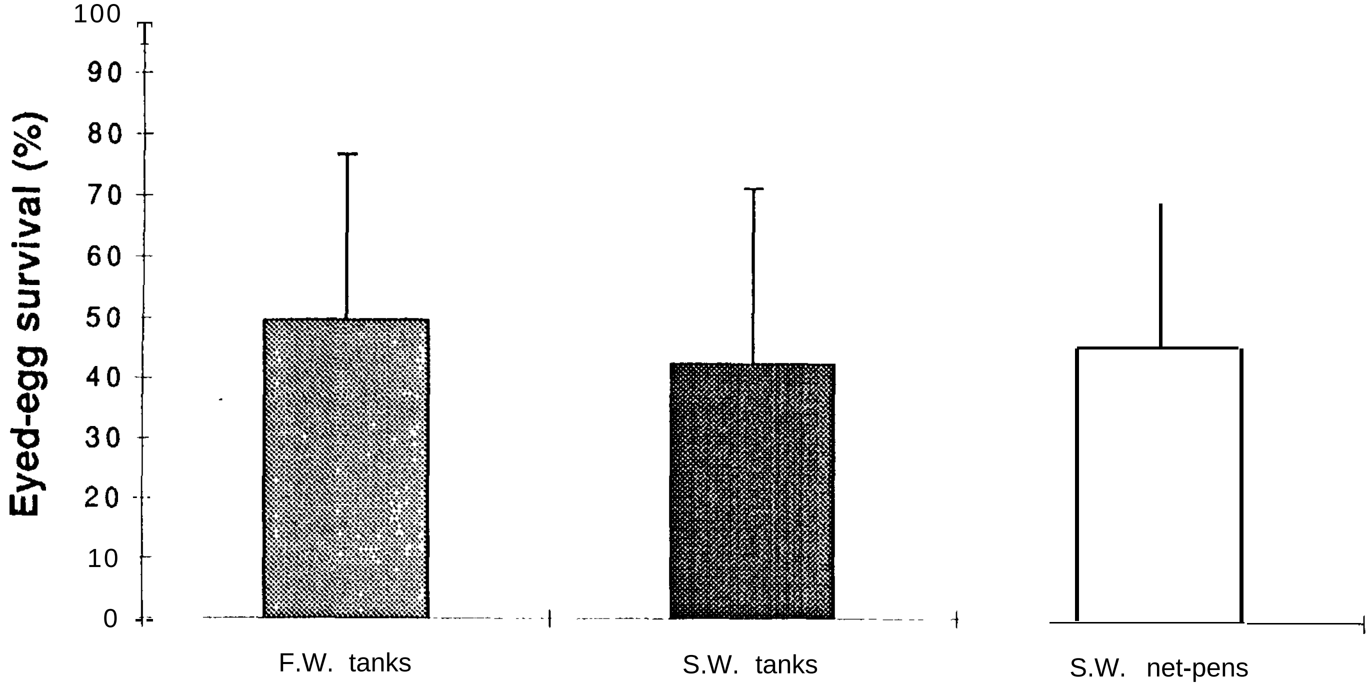

Figure 13 Comparison of eyed egg survival (viability) of spawn from 1990-brood Lake Wenatchee female sockeye salmon reared in freshwater tanks, seawater tanks, or seawater net-pens, 1994. Bars indicate standard deviation.

However, the rate was higher than the 36% eyed-egg survival documented for 1990-brood 3-year-olds spawned in 1993 (Flagg and McAuley 1994).

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 techniques successfully used in standard fish culture programs. High eyed-egg survival has been reported for other Pacific salmon (*Oncorhynchus* spp.) and Atlantic salmon captive broodstocks (McAuley 1983; Harrell et al. 1984, 1985, 1987; Peterschmidt 1991; C. Mahnken and T. Flagg, NMFS, unpubl. data). Consequently, we believe it was not the act of culture, per se, that reduced egg survival. Nevertheless, low fertilization rates will hamper recovery efforts using captive broodstocks. Therefore, under BPA Project 93-56 (Assessment of Captive Broodstock Technology), NMFS and other cooperating investigators (e.g., National Biological Survey, University of Washington) are beginning investigations of factors to potentially increase spawning success, including development of species-specific broodstock diets (sockeye salmon are planktivorous whereas commercial brood diets are formulated for piscivorous fish), refinement of husbandry technology, and implementation of environmental and hormonal manipulation of reproduction.

Experimental rearing of 199%brood Lake Wenatchee sockeye salmon in the three rearing treatments was terminated after spawning 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 three rearing environments: 1) circular tanks supplied with pathogen-free fresh water; 2) circular tanks supplied with pumped, filtered, and UV-sterilized seawater at Manchester, and 3) seawater net-pens at Manchester. Freshwater replicates were held at the Seattle hatchery until early November 1993 and then 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.

Rearing, growth, and survival--Inventory records for experimental groups of 1991-brood Lake Wenatchee sockeye salmon during the 19-month rearing period from experiment inception (May 1993) to the end of December 1994 indicated survival averaged 93% in the freshwater tanks, 71% in the seawater tanks, and 27% in the seawater net-pen replicates (Appendix D and Figs. 14 and 15). A replicate was lost from the seawater tank treatment in November 1993 due to mechanical failure of the inflow line feeding the tank, and a replicate was lost from the seawater net-pen treatment in September 1994 due to river otter predation. In addition, inventory discrepancies were noted in all treatments in August 1993 and were substantially greater in the seawater net-pen treatments (about 6%) compared to the seawater tanks (3%) and freshwater tanks (0%). A subsequent inventory of freshwater replicates in March 1994 revealed a 5% discrepancy, which was most likely due to bird predation, despite bird-netting covers on the tanks. Higher inventory discrepancies for fish in seawater net-pens were also noted for 1990-brood Lake Wenatchee sockeye salmon (described above). These losses were probably due to bird predation on dead or moribund fish during the months just after transfer to the experimental treatments. However, some fish may have escaped from the seawater net-pens. For purposes of analysis, inventory discrepancies were assigned as mortalities that occurred the month following transfer to the experiment.

Analysis of variance (ANOVA) between treatments indicated significant difference ($P < 0.01$) in the percentage of fish remaining in freshwater tank, seawater tank, and seawater net-pen replicates at the end of December 1994 (Fig. 15). Bacterial kidney disease appears to have caused most of the mortality in the seawater net-pen treatment. However, for some mortalities in the treatments, our pathology laboratory could not confii a specific cause of death. Results from a Tukey's multiple comparison test indicated that survival in the treatments ranked as follows: freshwater tanks > seawater tanks > seawater net-pens treatments ($P < 0.05$).

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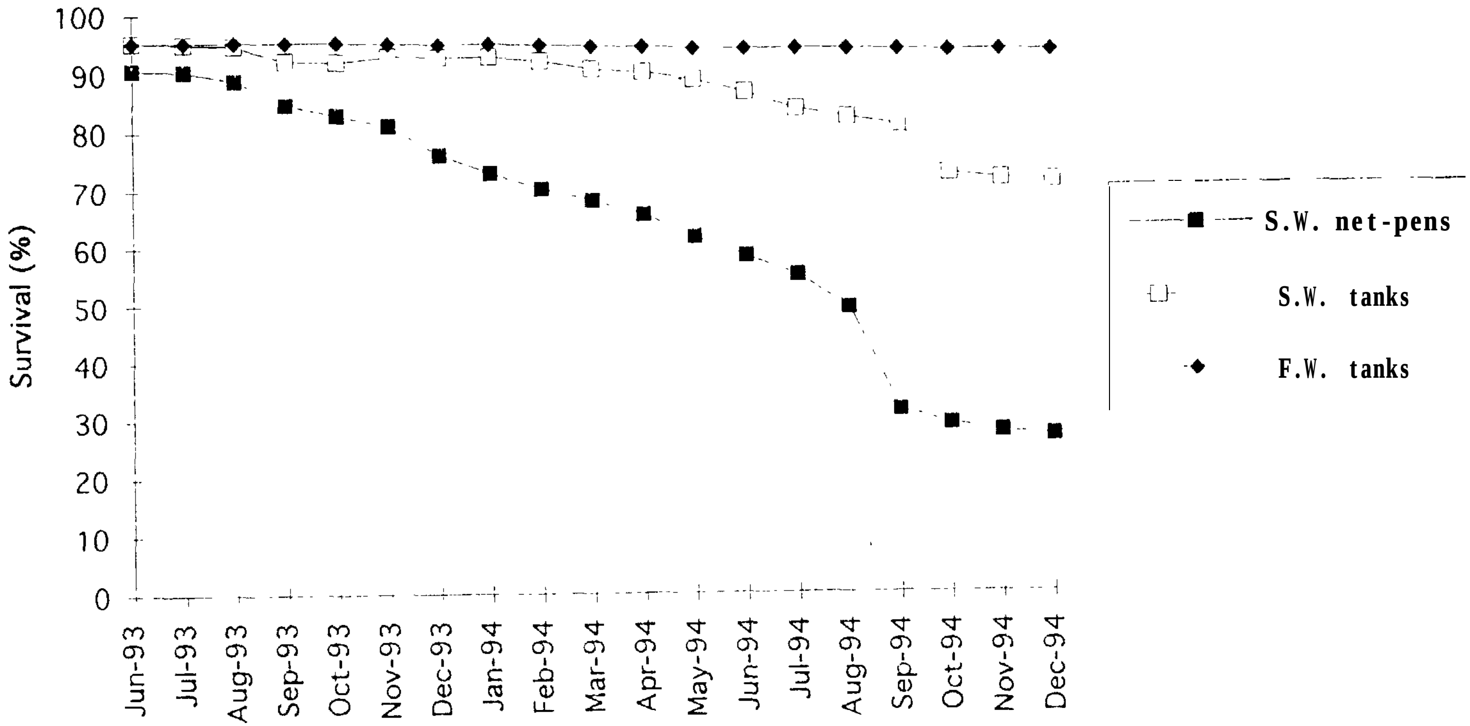


Figure 14. Survival during rearing for 1991-brood **Lake** Wenatchee **sockeye salmon, 1993-1994.**

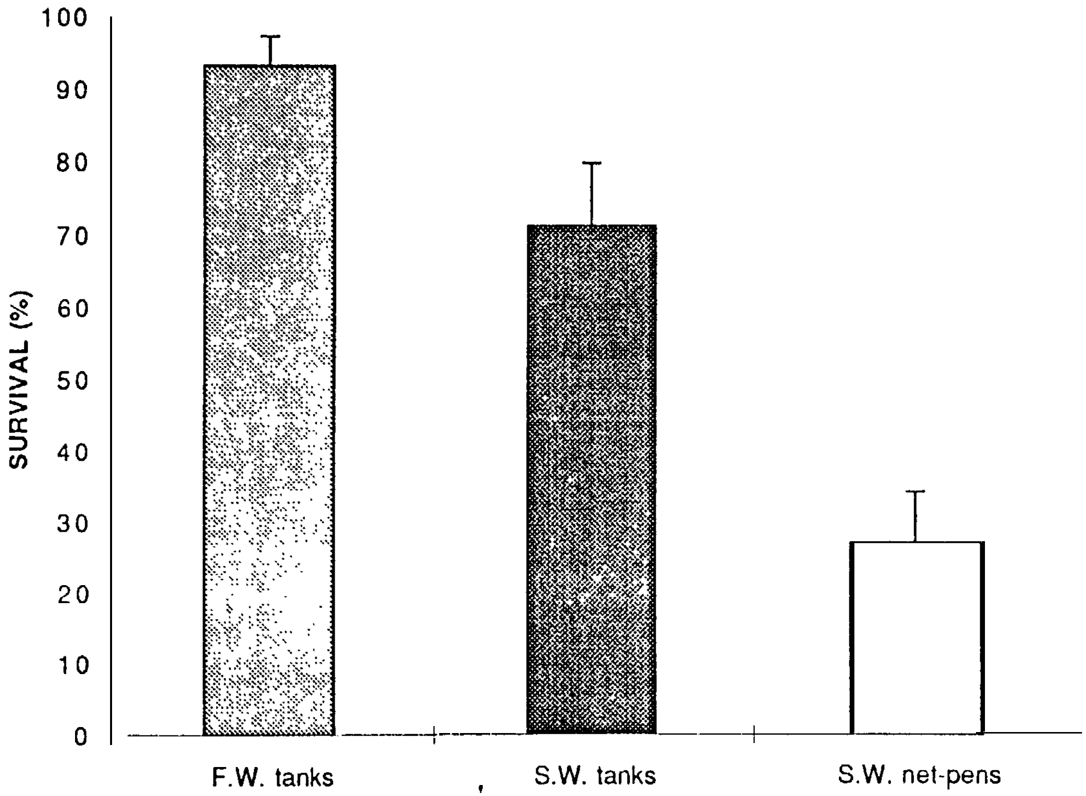


Figure 15. Comparison of survival of 1991-brood Lake Wenatchee sockeye salmon reared in freshwater tanks, seawater tanks, or seawater net-pens, 1994. Bars indicate standard deviation.

Growth differences were noted between the treatments. Size of fish averaged about 0.377 kg in the freshwater tank, 0.267 kg in the seawater tank, and 0.294 kg in the seawater net-pen replicates at the last quarterly measuring period (July 1994) (Figs. 16 and 17). ANOVA indicated that, although there were no significant differences ($P > 0.05$) in average fish weight between the three treatments at the start of the experiment, there were significant differences ($P < 0.05$) between average weights of fish in the three treatments by the last quarterly measuring period. Fish reared in fresh water were about 46% larger than fish reared in seawater tanks and 28% larger than those reared in seawater net-pens. Results from a Tukey's multiple comparison test indicated that average fish weight in the treatments ranked as follows: freshwater tanks > seawater tanks = seawater net-pens ($P < 0.05$).

These growth differences were somewhat similar to results of our rearing study for 1990-brood Lake Wenatchee sockeye salmon (Figs. 10 and 11). Overall fish size in each treatment was smaller, however, for the 1991-brood than for the 1990-brood after the same amount of culture time. This was probably due to the fact that the 1991-brood were placed on a restricted diet for the first half of 1994 to prevent overcrowding in seawater tanks while awaiting completion of the new saltwater rearing facility, which was to contain larger rearing vessels. Once the new facility was available in July, the seawater tank replicates were transferred in, and normal growth-oriented feeding regimes were resumed.

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

It is encouraging to note that survival of 1991-brood Lake Wenatchee sockeye salmon reared in freshwater and seawater tank treatments during the 19 months from the beginning of the experiment in 1993 through the end of December 1994 was much higher than for 1990-brood Lake Wenatchee sockeye salmon during the equivalent rearing period (Appendices C and D and Figs. 8,

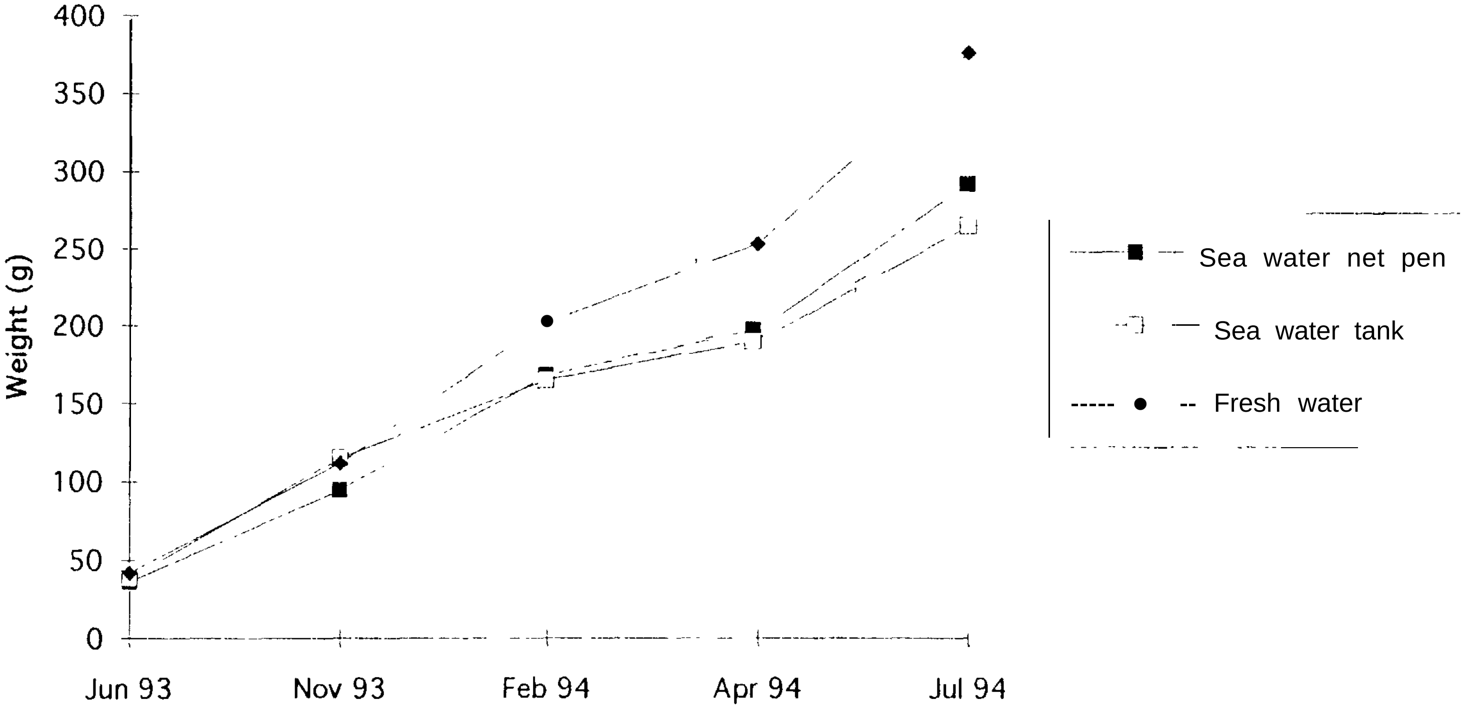
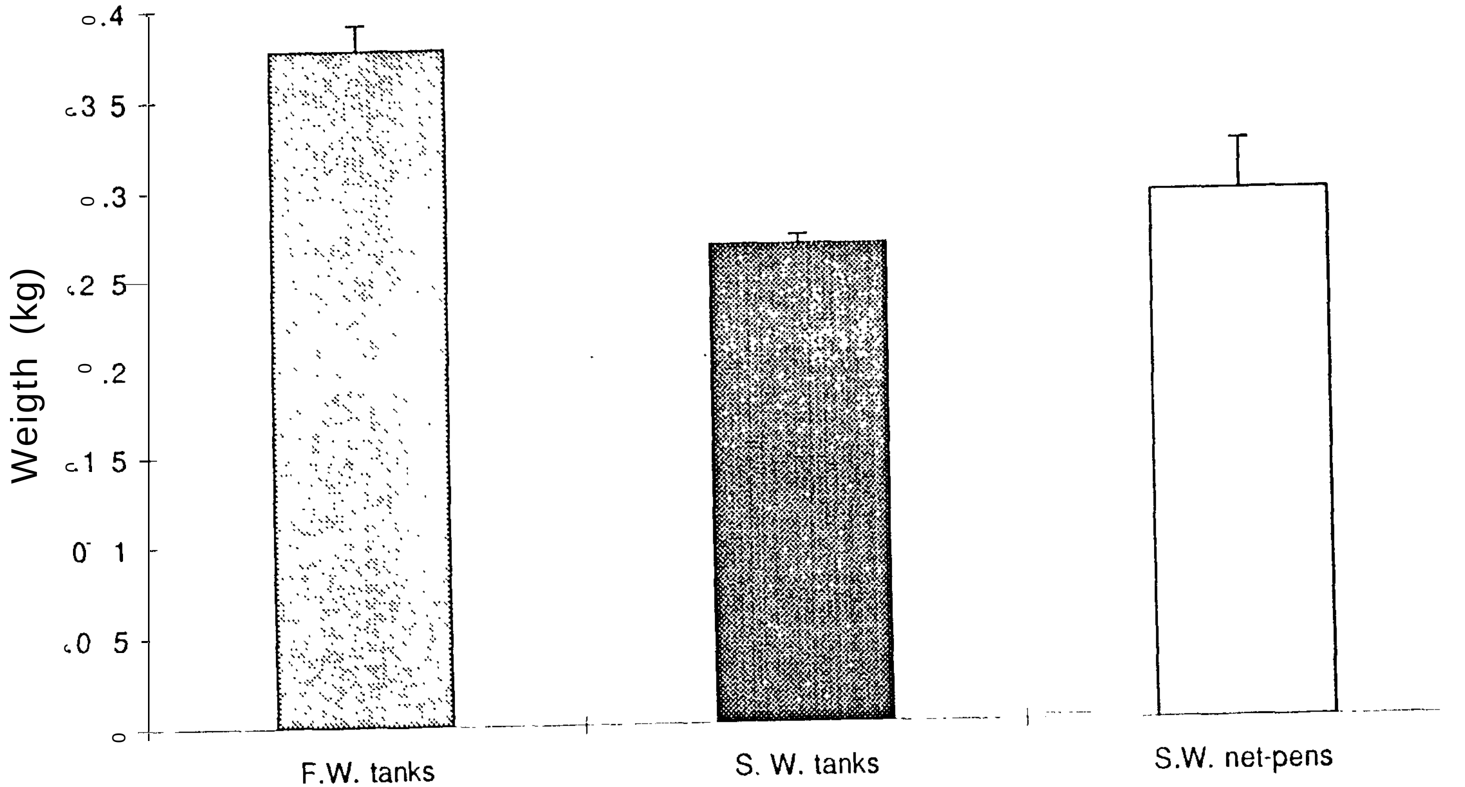


Figure 16. Growth during rearing for 1991-brood Lake Wenatchee sockeye salmon, 1993-1994.



Figre 7 Comparison of weight of 1991-brood Lake Wenatchee sockeye salmon reared in freshwater tanks, seawater tanks, or seawater net-pens, 1994. Bars indicate standard deviation.

9, 14, and 15). The 1991-brood Lake Wenatchee sockeye salmon in these experiments had **a** much lower incidence of BKD during fiy-to-smolt rearing than did the 1990-brood. As expected, the better presmolt health status of the 1991-brood appears to have translated to higher survival to spawning in our experiments (Fig. 18).

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

Spawning 1994--Early maturation (as age-3 fish) occurred in the freshwater tank and seawater tank replicates in 1994. A total of 199 fish (about 14% of each of the two treatments) matured as 3-year-old jacks (19 1 fish) and jills (8 fish). No matings were made due to the small number of available females. There were no mature fish in the seawater net-pen replicates. It is interesting that a similar percentage (14.8%) of 3-year-old 1990-brood Lake Wenatchee sockeye salmon matured in the freshwater replicates in 1993 but that sex ratios in these fish were approximately equal (Flagg and McAuley 1994). It is also interesting that the 1990-brood Lake Wenatchee sockeye salmon produced no 3-year-old spawners in either of the seawater treatments in 1993 (Flagg and McAuley 1994).

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

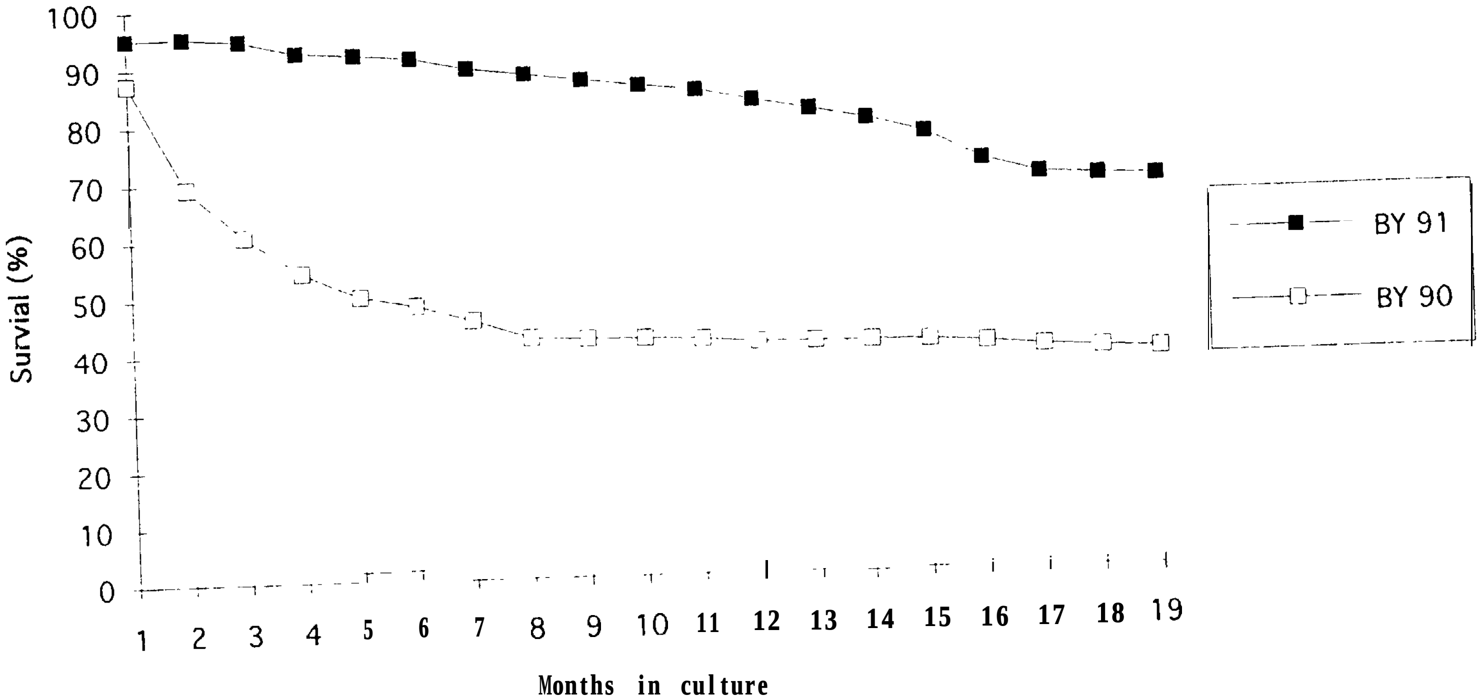


Figure 18. Comparison of survival for combined treatments of 1990- and 1991-brood Lake Wenatchee sockeye salmon reared in freshwater tanks, seawater tanks, or seawater net-pens.

Experimental rearing of 1991-brood Lake Wenatchee sockeye salmon in the three rearing treatments will continue until the fish mature in fall 1995.

CONCLUSIONS

1) Endangered Redfish Lake sockeye salmon captive broodstocks.

Because of the low replacement rate and critically low population size of Redfish Lake sockeye salmon, captive broodstocks appear to offer the only hope to maintain this species while habitat improvements are underway. However, captive broodstocks should be viewed as a short-term measure to aid in recovery of the gene pool, and not as a substitute for recovering naturally spawning fish to the ecosystem. Effective recovery of the species requires relaxation of barriers to survival to produce natural long-term increases in population size. Once these barriers are relaxed, the relatively stable egg supply assured through captive broodstock projects should help guarantee the success of recovery efforts for Redfish Lake sockeye salmon. 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. Full-term freshwater rearing appears to remain a priority option for valuable captive broodstocks (e.g., Redfish Lake sockeye salmon). However, the data are also encouraging regarding the use of environmentally-controlled seawater for broodstock rearing, and it appears reasonable to consider this strategy for a portion of the Redfish Lake sockeye salmon.

ACKNOWLEDGMENTS

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APPENDIX A

Appendix A. Monthly inventory records for 1991-brood Redfish Lake sockeye salmon at NMFS, 1991-1994.

A. Number of fish[a]

Group[b]	1991 Eggs received (7 Dec)	Blank/ dead eggs	Fish Hatched (4-5 Jan)	Jan mort	1992 Fish ponded (13 Feb)	Mar	Apr	May	Jun
1.	106	0	106	0	106	106	102	98	98
2.	119	2	117	3	114	114	114	114	112
3.	103	2	101	2	99	99	98	98	96
4.	83	2	81	0	81	81	76	76	76
5.	580	7	573	6	567	561	558	556	554
Total	991	13	978	11	967	961	948	942	936

Group[b]	1992 Jul	Aug	Sep	Oct	Nov	Dec	1993 Jan	Feb	Mar
1.	98	98	93	92	92	92	92	92	92
2.	112	112	112	112	112	112	112	112	112
3.	96	96	95	94	94	94	94	94	94
	76	76	76	76	76	76	76	76	76
4 5:	554	551	548	546	545	545	545	545	545
Total	936	929	924	921	919	919	919	919	919

Appendix A. Continued.

A. Number of fish[a] (continued)

	1993									1994
Group[b]	Apr	May	Jun[c]	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1.	92	90	78	78	78	73	72	56	52	41
2.	111	105	91	91	91	91	91	85	81	70
3.	94	86	75	75	74	71	70	67	65	58
4.	75	67	56	56	56	55	55	51	50	47
5.	544	532	464	463	463	456	447	419	406	365
6.d								- 3	- 3	-7
Total	916	880	764	763	762	746	735	675	651	574

	1994									
Group[b]	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov-Jan[e]
1.	36	32	30	26	26	25	20	17	14	0
2.	64	58	48	43	41	40	37	31	28	2
3.	46	34	32	31	27	25	21	19	15	0
4.	43	39	37	31	25	25	21	17	12	0
5.	348	324	304	285	269	241	225	198	171	23
6.d	-8	-9	-9	-11	-12	-13	-15	-18	-18	14
Total	529	478	442	405	376	343	309	264	222	39

Appendix A. Continued.

B. Survival from hatch[a] (%)

	Group[b] 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 A. Continued.

B. Survival from hatch[a] (%) (continued)

	Group[b]					
	1	2	3	4	5	Cumulative
Dec 1	49.1	69.2	64.4	61.7	70.9	66.9
			1994			
Jan 1	38.7	59.8	57.4	58.0	63.7	58.7
Feb 1	34.0	54.7	45.5	53.1	60.7	54.1
Mar 1	30.2	49.6	33.7	48.1	56.5	48.9
Apr 1	28.3	41.0	31.7	45.7	53.1	45.2
May 1	24.5	36.8	30.7	38.3	49.7	41.4
Jun 1	24.5	35.0	26.7	30.9	46.9	38.4
Jul 1	23.6	34.2	24.8	30.9	42.1	35.1
Aug 1	18.9	31.6	20.8	25.9	39.3	31.6
Sep 1	16.0	26.5	18.8	21.0	34.6	27.0
Oct 1	13.2	24.8	14.9	16.0	30.5	22.7
Nov-Jan 1[e]	0.0	1.7	0.0	0.0	3.5	4.0

Appendix A. Continued.

C. Weight[a] (g)

	Date						
Group[b]	(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

	Date						
Group[a]	10/30/93	12/31/93	1/28/93	9/1/93[f]	10/1/93[f]	12/31/93[f]	Spawn[e]
1.	22.6	38.7	40.2	150	200	350	1,233
2.	23.0	39.4	42.8	150	200	350	1,262
3.	29.0	43.2	47.0	150	200	350	1,307
4.	28.6	47.3	47.1	150	200	350	1,392
5.	20.2	33.9	37.2	150	200	350	1,341
Average	24.7	40.5	42.9	150	200	350	1,307
SD	3.9	5.0	4.3	---	---	---	56

Appendix A. Continued.

[a] Inventory records are to 1st of each month.

[b] 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).

[c] Fish transferred to BBC.

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

[e] Spawning occurred in October and November 1994.

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

APPENDIX B

Appendix B. Monthly inventory records for 1993-brood Redfish Lake sockeye salmon established from anadromous adult returns, juvenile outmigrants, and residuals, and reared at NMFS, 1993-1994

A. Number of fish

	1993					1994			
Group[a]	Eggs received (Dec)	Blank/ dead eggs	Fish Hatched (20-25 Dec)	Mort Dec/Jan	Fish ponded[b]	Feb	Mar	Apr	May
A.	1,181	1	1,180	25	1,155	1,155	1,147	1,143	1,140
O.	765	64	701	77	624	624	618	610	607
R.	125	42	58	7	51	51	51	42	41
Total	2,071	107	1,939	109	1,830	1,830	1,816	1,795	1,788

	1994							
Group[a]	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
A.	1,140	1,139	1,139	1,138	1,137	1,136	1,136	1,136
O.	606	606	606	606	606	606	605	604
R.	40	40	40	40	40	39	39	39
Total	1,786	1,785	1,785	1,784	1,783	1,781	1,780	1,779

Appendix B. Continued.

B. Survival from hatch (%)

	Group[a]		
	Anadromous	Outmigrants	Residuals
		1994	
Feb 1	97.9	89.0	
Mar 1	97.2	88.2	87.9
Apr 1	96.9	87.0	72.4
May 1	96.6	86.6	70.7
Jun 1	96.6	86.4	69.0
Jul 1	96.5	86.4	69.0
Aug 1	96.5	86.4	69.0
Sep 1	96.4	86.4	69.0
Oct 1	96.4	86.4	69.0
Nov 1	96.3	86.4	67.2
Dec 1	96.3	86.3	67.2
		1995	
Jan 1	96.3	86.2	67.2

Appendix B. Continued.

C. Weight (g)

Group[a]	(pond)[b] Feb 94	3/1/94	4/1/94	5/1/94	6/3/94	7/4/94	8/2/94
	Date						
A.	0.11	0.40	1.13	2.7	5.6	8.2	11.5
0.	0.13	0.43	1.25	3.0	5.8	8.1	10.6
R.	0.10	nd	0.50	1.4	2.9	5.6	8.8
Average	0.11	0.42	0.96	2.4	4.8	7.3	10.3

Group[a]	Date 9/7/94	10/31/94
A.	16.1	25.2
0.	14.1	22.5
R.	12.7	20.0
Average	14.3	22.6

[a] A.- Progeny from Anadromous (wild) adults that returned to Redfish Lake in 1993; O.- Progeny from Outmigrant smolts (spring 1991) held in captivity to maturity and spawned in 1993; R.- Progeny from Residual adults captured in Redfish Lake in 1993.

[b] Ponding dates for each of the three groups varied according to spawn date. A.- January 25, 1994; O.- January 24 and 31, 1994; R.- February 14, 1994.

APPENDIX C

Appendix C. Monthly invetory records for 1990-brood Lake Wenatchee sockeye salmon at NMFS, 1992-1994.

A. Number of fish

Treatment/ replicate	Starting n	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
					1992						1993			
Freshwater tanks[a]														
1.	301	296	273	245	230	212	197	173	141	138	137	136	134	134
2.	291	276	245	221	209	187	180	165	147	143	139	135	129	128
3.	289	254	228	211	199	179	170	157	133	132	130	125	119	117
Total	881	826	746	677	638	578	547	495	421	413	406	396	382	379
Seawater tanks[a]														
1.	260	231	168	147	135	126	122	118	116	115	114	113	113	113
2.	260	232	164	141	118	111	111	108	104	104	104	104	102	102
3.	262	233	175	148	130	123	120	117	116	116	116	116	116	116
Total	782	696	507	436	383	360	353	343	336	335	334	333	331	331
Seawater net-pens[a]														
1.	252	194	139	118	104	100	96	94	94	94	94	94	94	94
2.	258	203	148	123	97	89	87	85	85	85	85	85	85	85
3.	265	210	145	122	98	86	85	85	85	85	85	85	84	84
Total	775	607	432	363	299	275	268	264	264	264	264	264	263	263

Appendix C. Continued.

A. Number of fish (continued)

Treatment/ replicate	1993 Jul	Aug	Sep	Oct	Nov	Dec	1994 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Freshwater tanks[a]															
1.	133	132	131	129	129	128	127	127	126	126	126	121	118	118	116
2.	128	127	126	124	124	121	111	107	103	103	99	97	90	88	88
3.	117	115	115	112	110	106	90	88	84	82	81	80	77	77	74
Total	378	374	372	365	363[b]	355	328	322	313	311	306	298	285	283	278[c]
Seawater tanks[a]															
1.	113	112	109	106	102	102	101	100	99	99	99	98	96	96	96
2.	101	100	98	93	90	89	88	87	86	85	85	83	75	74	72
3.	116	116	114	113	113	113	113	113	113	113	113	113	109	109	107
Total	330	328	321	312	305	304	302	300	298	297	297	294	280	279	275[c]
Seawater net-pens[a]															
1.	94	94	93	89	87	86	83	82	80	79	77	77	75	75	73
2.	85	85	84	83	80	80	78	77	77	57	57	56	56	56	55
3.	83	82	81	80	80	80	78	78	78	77	77	75	72	71	71
Total	262	261	258	252	247	246	239	237	235	213	211	208	203	202	199[c]

Appendix C. Continued.

B. Survival

Treatment/ replicate	Starting n	Survival (%) 1992 Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan 1993	Feb
Freshwater tanks[a]										
1.	301	98.3	90.7	81.4	76.4	70.4	65.4	57.5	46.8	45.8
2.	291	94.8	84.2	75.9	71.8	64.3	61.9	56.7	50.5	49.1
3.	289	87.9	78.9	73.9	68.9	61.9	58.8	54.3	46.0	45.7
Average		93.7	84.6	76.8	77.1	65.5	62.0	56.2	47.8	46.7
SD		5.3	5.9	4.3	3.8	4.4	3.3	1.7	2.4	1.9
Seawater tanks[a]										
1.	260	88.8	64.6	56.5	51.9	48.5	46.9	45.4	44.6	44.2
2.	260	89.2	63.1	54.2	45.4	42.7	42.7	41.5	40.0	40.0
3.	262	88.9	66.8	56.5	49.6	46.9	45.8	44.7	44.3	44.3
Average		89.0	64.8	55.7	49.0	46.0	45.1	43.9	42.9	42.8
SD		0.2	1.9	1.3	3.3	3.0	2.2	2.1	2.6	2.5
Seawater net-pens[a]										
1.	252	77.0	55.2	46.8	41.3	39.7	38.1	37.3	37.3	37.3
2.	258	78.7	57.4	47.7	37.6	34.5	33.7	32.9	32.9	32.9
3.	265	79.7	54.7	46.0	37.0	32.5	32.1	32.1	37.1	32.1
Average		78.3	55.8	46.8	38.6	35.6	34.6	34.1	34.1	34.1
SD		1.2	1.4	0.9	2.3	3.7	3.1	2.8	2.8	2.8

Appendix C. Continued.

B. Survival (continued)

Treatment/ replicate	Survival (%) 1993 Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Freshwater tanks[a]										
1.	45.5	45.2	44.5	44.5	44.2	43.9	43.9	43.2	43.2	42.9
2.	47.8	46.4	44.3	44.0	44.0	43.6	43.3	42.6	42.6	41.6
3.	45.0	43.3	41.2	40.5	40.5	39.8	39.4	38.4	37.7	36.3
Average	46.1	44.9	43.3	43.0	42.9	42.4	42.2	41.4	41.2	40.3
SD	1.5	1.6	1.9	2.2	2.1	2.3	2.4	2.6	3.0	3.5
Seawater tanks[a]										
1.	43.8	43.5	43.5	43.5	43.5	43.1	41.9	40.8	39.2	39.2
2.	40.0	40.0	39.2	39.2	38.8	38.5	37.7	35.8	34.6	34.2
3.	44.3	44.3	44.3	44.3	44.3	44.3	43.5	43.1	43.1	43.1
Average	42.7	42.6	42.3	42.3	42.2	41.9	41.0	39.9	38.9	38.8
SD	2.4	2.3	2.7	2.7	3.0	3.1	3.0	3.7	4.3	4.5
Seawater net-pens[a]										
1.	37.3	37.3	37.3	37.3	37.3	37.3	36.9	35.3	34.4	34.1
2.	32.9	32.9	32.9	32.9	32.9	32.9	32.6	32.2	31.0	31.0
3.	32.1	32.1	31.7	31.7	31.3	30.9	30.6	30.2	30.2	30.2
Average	34.1	34.1	34.0	34.0	33.8	33.7	33.4	32.6	31.9	31.8
SD	2.8	2.8	2.9	2.9	3.1	3.3	3.2	2.6	2.2	2.1

Appendix C. Continued.

B. Survival (continued)

Treatment/ replicate	Survival (%) 1994 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Freshwater tanks[a]									
1.	42.5	42.5	42.2	42.2	42.2	40.5	39.5	39.5	38.9
2.	38.1	36.8	35.4	35.4	34.0	33.3	30.9	30.2	30.2
3.	30.8	30.1	28.7	28.0	27.7	27.3	26.3	26.3	25.3
Average	37.1	36.5	38.8	35.2	34.6	33.7	32.2	32.0	31.5
SD	5.9	6.2	4.8	7.1	7.3	6.6	6.7	6.8	6.9
Seawater tanks[a]									
1.	38.8	38.5	38.1	38.1	38.1	37.7	36.9	36.9	36.9
2.	33.8	33.5	33.1	32.7	32.7	31.9	28.8	28.5	27.7
3.	43.1	43.L	43.1	43.1	43.1	43.1	41.6	41.6	40.8
Average	38.6	38.6	38.1	38.0	38.0	37.6	35.8	35.7	35.1
SD	4.7	4.6	5.0	5.2	5.2	5.6	6.5	6.6	6.7
Seawater net-pens[a]									
1.	32.9	32.5	31.7	31.3	30.6	30.6	29.8	29.8	29.0
2.	30.2	29.8	29.8	22.1	22.1	21.7	21.7	21.7	21.3
3.	79.4	29.4	39.4	29.1	29.1	28.3	27.2	26.8	26.8
Average	30.8	30.6	30.3	27.5	27.3	26.9	26.2	26.1	25.7
SD	1.8	1.7	1.2	4.8	4.5	4.6	4.1	4.1	4.0

Appendix C. Continued.

C. Weight

Treatment/ replicate	Average weight (kg) Starting	1992 1 Sep	1 Dec	1993 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	0.231	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	0.1.	13.247	0.3351	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	9.077	0.123	0.172	0.310	0.426	0.573
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.

C. Weight

Treatment/ replicate	Average Weight (kg) 1994 1 May	1 Sep
Freshwater tanks[a]		
1.	1.809	2.360
2.	1.708	2.031
3.	2.847	2.400
Average	1.788	2.264
SD	0.072	0.202
Seawater net-pens[a]		
1.	1.452	1.485
2.	1.249	1.550
3.	1.270	1.680
Average	1.324	1.572
SD	0.112	0.099
Seawater net-pens[a]		
1.	0.853	1.223
2.	0.944	2.077
3.	0.974	1.178
Average	0.924	1.493
SD	0.063	0.507

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 1993.

[c] Includes 80 fish sacrificed for reproductive physiology sampling from May to September 1994.

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 Jul	Aug	Sep	Oct	Nov	Dec	1994 Jan	Feb	Mar	Apr	May	Jun
Freshwater tanks[a]													
1.	323	320	320	320	320	320	319	319	319	318	317	317	316
2.	323	305	305	305	305	305	305	304	304	304	303	302	302
3.	323	298	298	298	298	298	297	296	296	295	294	294	291
Total	969	923	923	923	923	923	921	919	919	917	914	913	909
Seawater tanks[a]													
1.	314	301	300	298	293	293	292	291	291	289	285	282	277
2.	314	299	299	298	293	291	291	291	291	288	283	282	279
3.	314	297	296	296	282	282	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]
Total	942	897	895	892	868	866	583	582	582	577	568	564	556
Seawater net-pens[a]													
1.	316	273	272	267	257	251	248	232	223	213	203	193	179
2.	326	298	298	294	286	282	277	267	255	244	240	228	215
3.	326	306	306	299	278	269	260	238	228	222	216	213	202
Total	968	877	876	860	821	802	785	737	706	679	659	634	596

Appendix D. Continued.

A. Number of fish (continued)

Treatment/ replicate	1994 Jul	Aug	Sep	Oct	Nov	Dec	Jan
Freshwater tanks[a]							
1.	316	316	316	314	313	307	285
2.	302	302	302	300	299	290	254
3.	290	290	289	287	286	278	253
Total	908	908	907	901	898	875	792
Seawater tanks[a]							
1.	268	258	252	226	180	173	172
2.	274	266	261	219	201	200	199
3.	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]
Total	542	524	513	445	381	373	371
Seawater net-pens[a]							
1.	169	167	156	---[c]	---[c]	---[c]	---[c]
2.	201	179	150	85	78	73	71
3.	194	186	171	120	111	106	104
Total	564	532	477	205	189	179	175

Appendix D. Continued.

B. Survival

Treatment/ replicate	Starting n	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
		Survival (%)								
		1993						1994		
Freshwater tanks[a]										
1.	323	99.1	99.1	99.1	99.1	99.1	98.8	98.8	98.8	98.5
2.	323	94.4	94.4	94.4	94.4	94.4	94.4	94.1	94.1	94.1
3.	323	97.3	92.3	97.3	92.3	92.3	92.0	91.6	91.6	91.3
Average		95.3	95.3	95.3	95.3	95.3	95.0	94.8	94.8	94.6
SD		3.5	3.5	3.5	3.5	3.5	3.5	3.7	3.7	3.6
Seawater tanks[a]										
1.	314	95.9	95.5	94.9	93.3	93.3	93.0	92.7	92.7	92.0
2.	314	95.2	95.2	94.9	93.3	92.7	92.7	92.7	92.7	91.7
3.	314	94.6	94.3	94.3	89.8	89.8	----[b]	----[b]	----[b]	----[b]
Average		95.2	95.0	94.7	92.1	91.9	92.8	92.7	92.7	91.9
SD		0.7	0.6	0.4	2.0	1.9	0.2	0.0	0.0	0.2
Seawater net-pens[a]										
1.	316	86.4	86.1	84.5	81.3	79.4	78.5	73.4	70.6	67.4
2.	326	91.4	91.4	90.2	87.7	86.5	85.0	81.9	78.2	74.8
3.	326	93.9	93.9	91.7	85.3	R2.5	79.8	73.0	69.9	68.1
Average		90.6	90.5	88.8	84.8	82.8	81.1	76.1	72.9	70.1
SD		3.8	4.0	3.8	3.2	3.6	3.4	5.0	4.6	4.1

Appendix D. Continued.

B. Survival (continued)

Treatment/ replicate	Survival (%) 1994 Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Freshwater tanks[a]										
1.	98.1	98.1	97.8	97.8	97.8	97.8	97.5	97.2	97.2	97.2
2.	93.8	93.5	93.5	93.5	93.5	93.5	93.5	93.5	93.5	93.2
3.	91.0	91.0	90.1	89.8	89.8	89.5	89.5	89.2	89.2	89.2
Average	94.3	94.2	93.8	93.7	93.7	93.7	93.5	93.3	93.3	93.2
SD	3.6	3.6	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Seawater tanks[a]										
1.	90.8	89.8	88.2	85.4	82.2	80.6	77.7	66.9	65.3	65.0
2.	90.1	89.8	88.9	87.3	84.7	83.4	83.4	7'1.7	77.4	77.1
3.	----[b]	----[b]	----[b]	----[b]	----[b]	----[b]	----[b]	----[b]	----[b]	----[b]
Average	90.5	89.8	88.6	86.4	83.5	82.0	80.6	72.3	71.4	71.1
SD	0.5	0.0	0.5	1.3	1.8	2.0	4.0	7.6	8.6	8.6
Seawater net-pens[a]										
1.	64.2	61.1	56.6	53.5	52.8	49.4	----[c]	----[c]	----[c]	----[c]
2.	73.6	69.9	66.0	61.7	54.9	46.0	26.1	23.9	22.4	21.8
3.	66.3	65.3	62.0	59.5	57.1	52.5	36.8	34.0	32.5	31.9
Average	68.0	65.4	61.5	58.2	54.9	49.3	31.5	29.0	27.5	26.9
SD	4.9	4.4	4.7	4.2	2.2	3.3	7.6	7.1	7.1	7.1

Appendix D. Continued.

C. Weight

Treatment/ replicate	Average weight (kg) 1993 Starting	1993 1 Nov	1994 1 Feb	1994 1 Apr	1994 1 Jul
Freshwater tanks[a]					
1.	0.038	0.109	0.200	0.245	0.364
2.	0.045	0.114	0.208	0.252	0.392
3.	0.044	0.113	0.203	0.266	0.374
Average	0.042	0.112	0.204	0.254	0.377
SD	0.004	0.003	0.004	0.011	0.014
Seawater tanks[a]					
1.	0.038	0.112	0.159	0.200	0.270
2.	0.039	0.115	0.174	0.183	0.263
3.	0.039	0.120	-----[h]	-----[b]	-----[b]
Average	0.039	0.116	0.167	0.192	0.267
SD	0.001	0.004	0.011	0.013	0.005
Seawater net-pens[a]					
1.	0.035	0.095	0.179	0.210	0.294
2.	0.037	0.093	0.167	0.205	0.321
3.	0.037	0.099	0.162	0.182	9.266
Average	0.036	0.096	0.169	0.199	0.294
SD	0.001	0.003	0.009	0.015	0.028

Appendix D. Continued.

[a] Freshwater replicates established at the Seattle hatchery in late May 1993 and moved to 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 of inflow line.

[c] Replicate lost in September 1994 to predation by river otters.