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Evaluating Reintroduction Strategies for Redfish Lake Sockeye Salmon Captive Broodstock Progeny

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Abstract.—Snake River sockeye salmon *Oncorhynchus nerka* were listed as endangered in 1991. Prior to listing, a captive broodstock program was initiated to prevent species extinction and to begin rebuilding the population. Reintroduction plans for captive broodstock progeny have followed a "spread-the-risk" philosophy incorporating multiple release strategies and lakes. Since 1993, more than 860,000 presmolts, 158,000 smolts, 325,000 eyed eggs and 880 adults have been reintroduced to the habitat. From this production, 312 anadromous sockeye salmon have returned to adult trapping facilities in the Sawtooth Valley of Idaho. Monitoring and evaluation efforts have focused on maximizing the use of limited hatchery-rearing space and on identifying and prioritizing the most successful reintroduction strategies. Comparisons of presmolt overwinter survival and out-migration success from nursery lakes have shown that (1) presmolts released directly to Redfish Lake in October have emigrated more successfully than presmolts reared in Redfish Lake net pens prior to release, (2) presmolts released directly to Alturas and Pettit lakes in October have emigrated more successfully than presmolts released directly to lakes in July, and (3) presmolts reared at the Idaho Department of Fish and Game (IDFG) Sawtooth Fish Hatchery emigrated more successfully than presmolts reared at the IDFG Eagle Fish Hatchery following July releases to Alturas and Pettit lakes. Presmolts that spent one winter in Redfish Lake prior to out-migration were interrogated more successfully at lower Snake and Columbia River dams than smolts released in the outlet of Redfish Lake. Smolt-to-adult return rates for anadromous adults produced by the captive broodstock program from 2000 to 2002 varied from 0.6% for unmarked fish returning in 2002 to 0.4% for a combined smolt and presmolt release group in 2000. Using captive broodstock techniques, the program has successfully prevented the extinction of Snake River sockeye salmon and increased population abundance in the habitat. However, without substantive improvements in smolt-to-adult survival, program efforts will likely be insufficient to rebuild the population to self-sustaining levels.

Introduction

Declines of Pacific salmon *Oncorhynchus* sp. stocks in the northwest have been a concern to federal, state, and tribal fisheries managers for well over a decade (Nehlsen et al. 1991; Slaney et al. 1996). In the Columbia River basin, 13 stocks of Pacific salmon and steelhead *O. mykiss* are listed as threatened or endangered under the Endangered Species Act (Myers et al. 1998). The causes for these declines include habitat alteration, irrigation withdrawal, overfishing, and hydroelectric development (Nehlsen et al. 1991; Slaney et al. 1996; Nemeth and Kiefer 1999).

Strategies for recovering Columbia River basin salmon and steelhead populations are detailed in the Federal Basinwide Salmon Recovery Strategy (Federal Caucus 2000) and the Federal Columbia River Power System Biological Opinion (NMFS 2000). These documents identified four general areas where recovery actions should focus: (1) habitat measures, (2) harvest limits, (3) hydropower improvements, and (4) hatchery reforms. Recommended habitat improvement measures include actions designed to prevent further degradation, increase habitat quality, and restore complexity to the range of habitats for all life stages of fish. Harvest limits include reduction of impacts on listed fish, where necessary, while allowing selective fisheries to continue. Hydropower improvements call for increased flow, increased spill, and improvements to dams to improve juvenile and adult fish passage. Proposed hatchery reforms focus on reducing production, minimizing ecological and genetic risks to wild fish, and using captive intervention techniques (e.g., supplementation, captive broodstock development, and conservation hatchery practices) to aide in the recovery of severely depressed stocks of Pacific salmon and steelhead.

Captive broodstock programs are specialized forms of artificial production that take advantage of the high fecundity of Pacific salmon and steelhead and the increased survival benefits provided by protective culture. Captive broodstock programs differ from conventional salmon hatchery programs in that F_1 progeny (produced from spawning wild parents) are held through maturation and spawning in the hatchery. Captive programs are designed to minimize the loss of population genetic diversity, minimize inbreeding risk and artificial selection, and grow populations to self-sustaining levels as quickly as possible (Schiewe et al. 1997; Flagg and Nash 1999; Flagg and Mahnken 2000; Flagg et al. 2000a, 2000b).

Conservation hatchery programs are still considered experimental and remain largely unproven (Hard et al. 1992; NWPPC 1999; Flagg and Mahnken 2000; Flagg et al. 2004, this volume) due largely to the fact that programs of this nature have been implemented only recently to curb the decline of Pacific salmon and steelhead (Berejikian et al. 2004, this volume). Captive broodstock programs are considered an extreme form of intervention described by the Northwest Power Planning Council (NWPPC 1999) as "...an undesirable result of not identifying and addressing a situation with a population that should have been addressed at an earlier point in its decline with a less extreme approach." Nevertheless, despite uncertainties related to their success and their experimental nature, these programs are recognized as emergency measures that can be effective in curbing population declines, preventing localized extinctions, and recolonizing vacant habitats (Schiewe et al. 1997; Anders 1998; Young 1999; Pollard and Flagg 2004, this volume).

Background

Snake River sockeye salmon *O. nerka* were listed as Endangered under the U.S. Endangered Species Act in 1991 (ESA, 16 USC §1531). Waples (1991) described Snake River sockeye salmon as a prime example of a species on the threshold of extinction. In Idaho, only the lakes of the upper Salmon River (Sawtooth Valley) remain as potential habitat for sockeye salmon. Historically, five Sawtooth Valley lakes (Redfish, Alturas, Pettit, Stanley, and Yellow Belly) supported sockeye salmon (Bjornn et al. 1968; Chapman et al. 1990). By 1962, sockeye salmon were no longer returning to Stanley, Pettit, and Yellow Belly lakes (Chapman et al. 1990). Currently, only Redfish Lake receives a remnant anadromous run (between 1990 and 1998, only 16 wild adults returned to Redfish Lake).

Due to the precipitous decline of returning anadromous adults, the Snake River sockeye salmon captive broodstock program was initiated in 1991. Adult, Redfish Lake sockeye salmon that returned from 1990 to 1998, out-migrating smolts captured between 1991 and 1993, and residual sockeye salmon captured between 1992 and 1995 were used to develop the captive broodstock program. For details on the development and history of the hatchery element of the program, see Flagg et al. (1995) and Flagg et al. (2004). The program is coordinated by the Stanley Basin Sockeye Technical Oversight Committee (SBSTOC), a team of biologists representing the Idaho Department of Fish and Game (IDFG), the Shoshone-Bannock Tribes, the National Oceanic and Atmospheric Administration (NOAA Fisheries), and the University of Idaho. The Bonneville Power Administration is the coordinating and funding agency for Snake River sockeye salmon recovery actions.

The development of captive broodstock program reintroduction plans follows a "spread-the-risk" philosophy incorporating multiple release strategies and lakes. Progeny from the captive broodstock program are reintroduced to Sawtooth Valley waters at different life stages using a variety of release options, including (1) eyed egg plants to in-lake incubator boxes, (2) presmolt releases direct to lakes, (3) presmolt transfers to net pens for in-lake rearing and release in Redfish Lake, (4) smolt releases to the outlet of Redfish Lake and to the upper Salmon River, and (5) adult releases direct to lakes. All sockeye salmon spawning and early rearing is conducted at the IDFG Eagle Fish Hatchery and at NOAA Fisheries facilities in Washington State.

Due to the conservation focus of the captive broodstock program, release plans are heavily influenced by the life history traits exhibited by wild sockeye salmon. The program is fortunate to have a very detailed account of sockeye salmon life history in Redfish Lake from out-migration and adult return monitoring work conducted between 1954 and 1966 by Bjornn et al. (1968). Smolt out-migration from Redfish Lake begins in early April, peaks in mid-May, and is complete by mid-June. Smolts out-migrate at either age 1 or age 2, and the percentage of each varies from year to year. Smolt fork length varies between 45 mm and greater than 120 mm. Adult sockeye salmon arrive at Redfish Lake Creek in mid-July and continue migrating into the lake through early September. Spawning takes place over submerged beach substrate of the lake with peak activity occurring in mid-October. Returning adults are primarily two-ocean fish and sex ratios are nearly equal (Bjornn et al. 1968).

The objective of this paper is to review reintroduction strategies used to reintroduce sockeye salmon from the captive broodstock program back to the habitat and to examine the relative success of different reintroduction strategies in producing smolts and anadromous adults.

Study Area

Recovery efforts for Idaho sockeye salmon focus on Redfish, Pettit, and Alturas lakes in the Sawtooth Valley of the upper Salmon River watershed (Figure 1). Lakes in the Sawtooth Valley are glacial-carved, range in elevation from 1,985 to 2,138 m, are considered oligotrophic, and range from 1,445 to 1,469 km from the Pacific Ocean. Redfish Lake is the largest of the three lakes (615 ha), Pettit Lake is the smallest (160 ha), and Alturas Lake (338 ha) is intermediate in surface area. Reintroduction efforts have been ongoing in Redfish Lake since 1993, Pettit Lake since 1995, and Alturas Lake since 1997.

Monitoring and Evaluation

Smolt monitoring traps are operated annually on outlet creeks of lakes receiving releases of sockeye salmon presmolts, eyed eggs, and prespawn adults. The IDFG

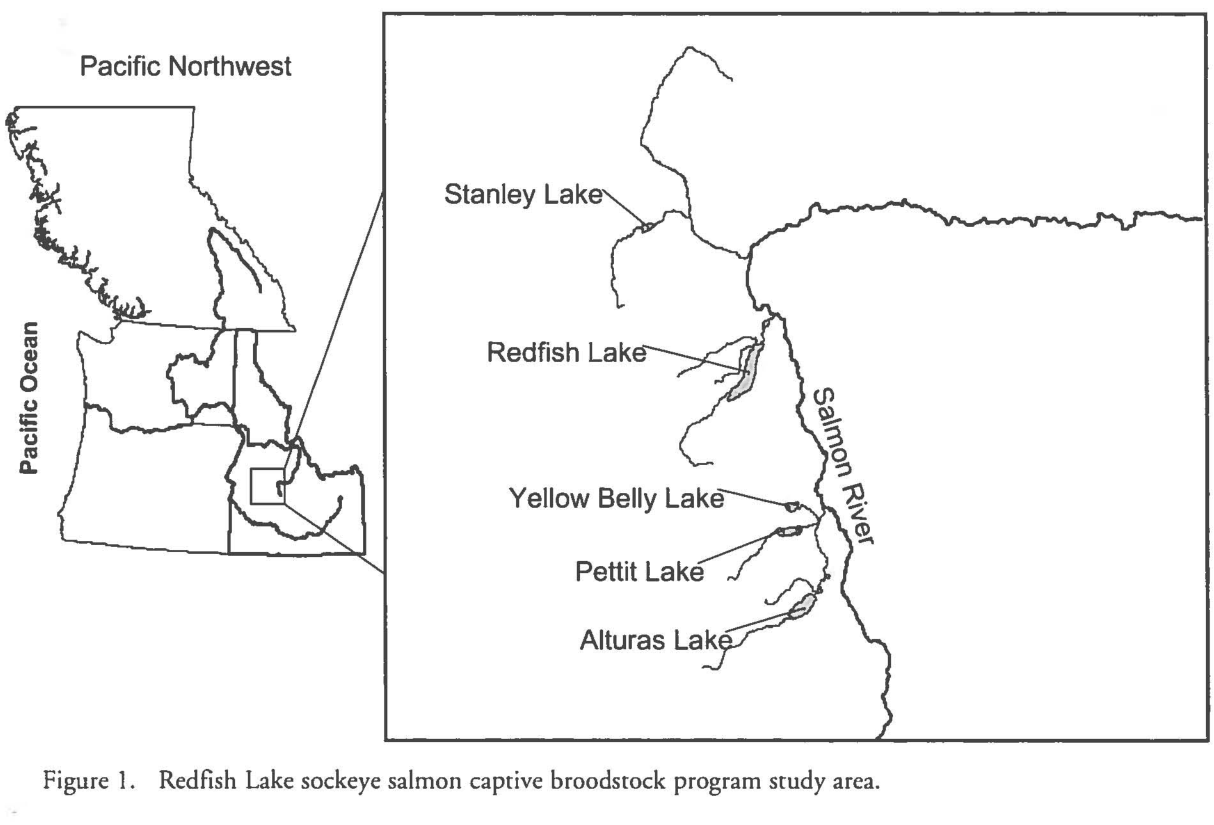

Figure 1. Redfish Lake sockeye salmon captive broodstock program study area.

operates a smolt trap on the outlet of Redfish Lake and the Shoshone-Bannock tribes operate smolt traps on the outlets of Pettit and Alturas lakes. Unexpanded passive integrated transponder (PIT) tag and unique fin clip information are used to make overwinter survival and out-migration success comparisons at lake outlet monitoring sites. Estimates of out-migration run size are developed using methods described by Steinhorst et al. (in press).

Cumulative, unique PIT tag interrogation data from lower Snake and Columbia River dams are used to compare survival and out-migration success of smolts through the lower Snake and Columbia rivers. Interrogation data are retrieved from the PIT Tag Information System (PTAGIS) maintained by the Pacific States Marine Fish Commission (Gladstone, Oregon).

Release group interrogation data are compared using contingency tables (2 × 2) and Fisher's exact tests ($\alpha = 0.05$). A priori power analysis for testing hypotheses concerning differences between proportions was conducted to detect an effect size of 0.10 and to identify the test group sample size required to attain a desired level of power of 0.80 (Cohen 1988).

Presmolt Release Strategy

Age-0 presmolts have been released yearly since 1994. Final presmolt rearing is conducted at IDFG's Eagle and Sawtooth fish hatcheries. Presmolts are released in the summer or fall directly to the lakes or into in-lake net-pens (Redfish Lake only) where they rear for 3–4 months before being released to lakes. Net-pen fish receive a daily ration of a commercial salmon diet. Prior to 1997, direct-lake releases were made at nearshore locations. Since 1997, a transport barge has been used to release presmolts at mid-lake locations.

Presmolts are adipose fin-clipped and ventral fin clips or PIT tags may be used to track specific release groups. To date, presmolt evaluations have focused on the following comparisons: (1) direct-lake fall versus net pen releases in Redfish Lake, (2) summer versus fall direct-lake releases in Pettit and Alturas lakes, and (3) Eagle Fish Hatchery-reared versus Sawtooth Fish Hatchery-reared summer releases in Pettit and Alturas lakes. Presmolt releases have been timed as follows: (1) Fall direct-lake releases have occurred in October, (2) summer direct-lake releases have occurred in July, and (3) net-pen presmolts were released from net pens to Redfish Lake in October.

Smolt Release Strategy

Age-1 smolts were first released in 1995. Smolts have been reared at IDFG's Eagle and Sawtooth fish hatcheries and the Oregon Department of Fish and Wildlife's Bonneville Fish Hatchery. Smolts are released from transport trucks downstream of weirs on Redfish Lake Creek (1.4 km downstream from the lake) and on the upper Salmon River at the Sawtooth Fish Hatchery (approximately 2.0 km upstream of the confluence of Redfish Lake Creek with the Salmon River). Smolts are released in early May just prior to peak smolt out-migration. Smolts are adipose fin-clipped prior to release and may receive coded wire tags and ventral fin clips to facilitate adult return evaluations. Smolt out-migration evaluations compare the migratory success of PIT-tagged smolts released below the Redfish Lake Creek smolt trap in May with smolts produced from fall-released presmolt groups PIT-tagged at the Redfish Lake Creek smolt trap during out-migration.

Eyed Egg Plant Strategy

The Redfish Lake captive broodstock program has conducted eyed egg plants since 1996. Eggs remain at the IDFG Eagle Fish Hatchery or at NOAA Fisheries hatcheries until they reach the eyed stage of development (approximately 380–430 accumulated Celsius temperature units). Eyed eggs are placed in incubation boxes and transferred to Sawtooth Valley lakes where they are positioned over submerged shoreline substrate at water depths of 1.5–7.5 m. Eyed egg planting occurs from late November through early December. Hatch success is estimated the following spring by subtracting the number of dead eggs from the number of eggs placed in each incubation box. Parentage assignment testing using nuclear DNA microsatellite markers was initiated in 2003 to help associate unmarked smolts with this reintroduction strategy.

Prespawn Adult Release Strategy

Prespawn adult sockeye salmon from the Redfish Lake captive broodstock program have been released almost yearly since 1993. Adults released for natural spawning are reared through release at IDFG and NOAA Fisheries hatcheries. Prior to 1999, all adults released for natural spawning were reared full-term in program hatcheries. Beginning in 1999, anadromous adults that were not needed for broodstock purposes were released for natural spawning. Adults are transferred to Sawtooth Valley lakes in early September. Evaluations of adults released for natural spawning focus on redd counts conducted weekly for 2 months by boat or fixed wing aircraft and by monitoring unmarked smolt production. Additionally, parentage assignment testing using nuclear DNA microsatellite markers was initiated in 2003 to help associate unmarked smolts with this release strategy.

Results and Discussion

The IDFG and NOAA Fisheries captive broodstock programs have produced in excess of 860,000 presmolts, 158,000 smolts, 880 adults, and 325,000 eyed eggs for reintroduction to waters in the Sawtooth Valley (Figure 2). An estimated 310,000 sockeye salmon smolts have been produced through these releases. To date, 312 hatchery-produced, anadromous adults have returned from this production.

Out-Migration Survival Comparisons for Fish from the Presmolt Release Strategy

Presmolt releases represent the primary component of the reintroduction effort accounting for more fish released than all other release options combined (Figure 2). Overwinter and out-migration survival comparisons between net-pen and direct-lake presmolt release groups were conducted for 5 years. In 3 of the 5 years of investigation, out-migrants produced from the fall direct-lake release option overwintered and out-migrated significantly better to the trapping facility on Redfish Lake Creek than fish released to Redfish Lake from a net-pen rearing environment (Table 1). Fish produced from the fall direct-lake release also had significantly higher recapture rates at downstream dams in three of the five investigation years (Table 1). Presmolts released to Pettit and Alturas lakes in the fall overwintered and out-migrated significantly better than summer-released groups (Table 2).

In 2000 and 2001, presmolts reared at the Eagle and Sawtooth fish hatcheries were released to Pettit and Alturas lakes in the summer. Over both years in Pettit Lake, presmolts reared at the Sawtooth Fish Hatchery overwintered and out-migrated significantly better to lake outlet monitoring traps than presmolts reared at the Eagle Fish Hatchery. Sawtooth Fish Hatchery-reared presmolts released to Alturas Lake in 2000 overwintered and out-migrated significantly

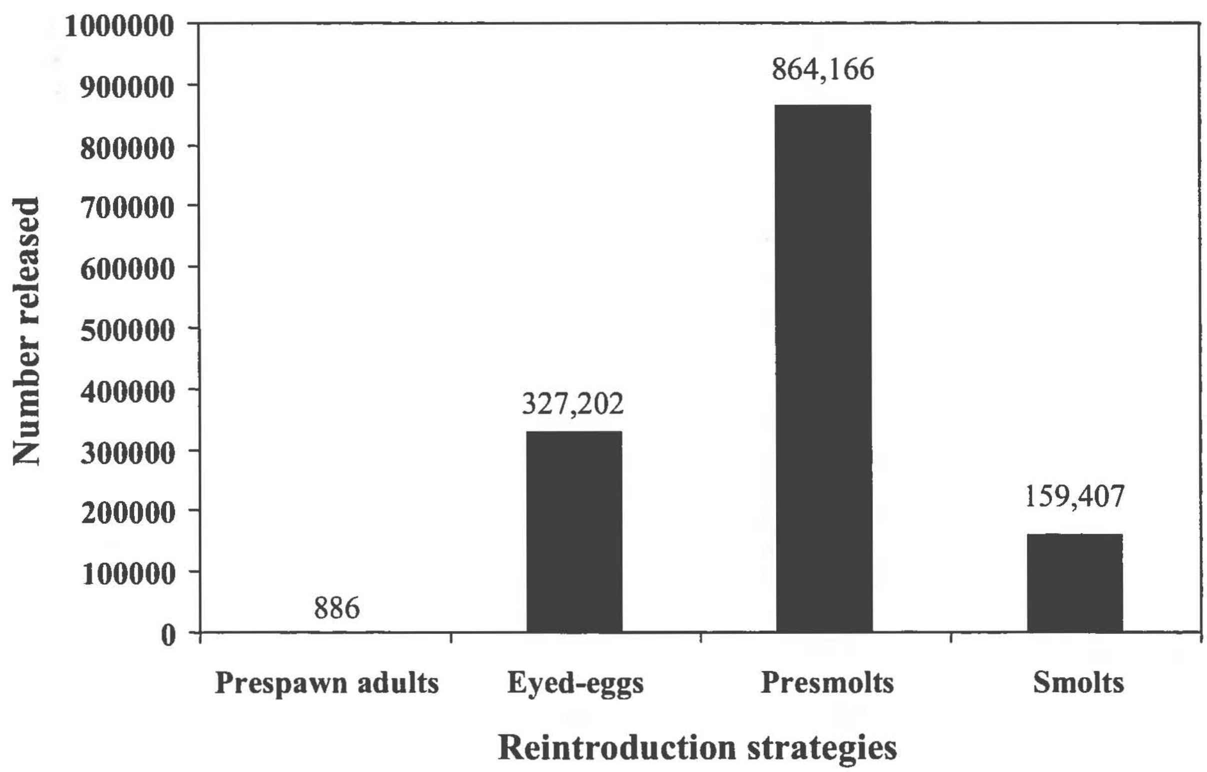

Figure 2. Sockeye salmon prespawn adult, eyed egg, presmolt, and smolt reintroduction history. Numbers represent combined reintroductions to Redfish, Pettit, and Alturas lakes between 1993 and 2002.

Table 1. Fisher's exact test results of recapture data collected at Redfish Lake Creek trap and lower Snake and Columbia River dams for paired sockeye salmon presmolt releases (net pen v. fall direct-lake) made to Redfish Lake between 1994 and 2001.

Year planted	Presmolt release strategy	Number of presmolts PIT-tagged	Number of out-migrants interrogated[a]	Recapture rate (%)	*P* value
Redfish Lake Creek					
1994	Net pens	1,874	26	1.39	0.004
1994	Fall direct-lake	854	2	0.23	
1995	Net pens	1,721	18	1.05	0.410
1995	Fall direct-lake	2,520	20	0.79	
1997	Net pens	2,563	56	2.18	<0.001
1997	Fall direct-lake	2,010	101	5.02	
1998	Net pens	2,973	19	0.64	<0.001
1998	Fall direct-lake	1,206	66	5.47	
2001	Net pens	41,474[b]	1,390[c]	3.35	<0.001
2001	Fall direct-lake	41,529[b]	9,724[c]	23.42	
Lower Snake and Columbia River dams					
1994	Net pens	1,874	31	1.65	0.111
1994	Fall direct-lake	854	7	0.82	
1995	Net pens	1,721	106	6.16	0.486
1995	Fall direct-lake	2,520	170	6.75	
1997	Net pens	2,563	39	1.52	<0.001
1997	Fall direct-lake	2,010	112	5.57	
1998	Net pens	2,973	32	1.08	<0.001
1998	Fall direct-lake	1,206	144	11.94	
2001	Net pens	586	71	12.12	<0.001
2001	Fall direct-lake	1,179	377	31.98	

[a] Actual (unexpanded) PIT-tag interrogations.
[b] Unique fin clips used in lieu of PIT tags in release year 2001.
[c] Unique fin clip observations.

Table 2. Fisher's exact test results of recapture data collected at Pettit and Alturas lake trap sites for paired sockeye salmon presmolt releases (summer direct-lake v. fall direct-lake) made to Pettit and Alturas lakes in 2000 and 2001.

Year planted	Presmolt release strategy	Number of presmolts uniquely marked	Number of marked out-migrants observed[a]	Recapture rate (%)	*P* value
Pettit Lake					
2000	Summer direct-lake	3,092	156	5.04	<0.001
2000	Fall direct-lake	6,067	1,756	28.94	
2001	Summer direct-lake	2,998	200	6.67	<0.001
2001	Fall direct-lake	4,993	1,451	29.06	
Alturas Lake					
2000	Summer direct-lake	3,069	67	2.18	<0.001
2000	Fall direct-lake	6,003	636	10.59	
2001	Summer direct-lake	3,059	12	0.39	<0.001
2001	Fall direct-lake	5,990	482	8.05	

[a] Unique fin clips used in lieu of PIT tags in release years 2000 and 2001.

better than presmolts reared at the Eagle Fish Hatchery. In 2001, there was no detectable difference in recapture rates between Alturas Lake hatchery groups (Table 3).

Smolt and Presmolt Migration Comparisons

Between 1995 and 2002, 110,516 and 48,891 age-I smolts were released to Redfish Lake Creek and to the upper Salmon River, respectively. Smolt releases have occurred yearly in Redfish Lake Creek (except 1997) and in 1998 and 1999 in the upper Salmon River.

Unlike age-0 presmolts, smolts experience no lake residency time, migrating downstream immediately. In 2001 and 2002, smolts that originated from presmolt releases the previous fall were interrogated significantly better at lower Snake and Columbia River dams than smolts released directly to Redfish Lake Creek in the spring (Table 4).

Survival Estimates for Eyed Eggs

Through 2002, 327,202 eyed eggs have been planted in Sawtooth Valley lakes (Figure 2). The average hatch rate for the 5 years that sockeye salmon eyed eggs have been planted in in-lake incubation boxes in Sawtooth Valley lakes is 86% (Table 5).

Redd Production from Prespawn Adult Releases

Of the 886 prespawn adults released to Sawtooth Valley lakes through 2002 (Table 6), 657 were reared to maturity in the hatchery and 229 were anadro-

Table 3. Fisher's exact test results of recapture data collected at Pettit and Alturas lake trap sites for paired sockeye salmon presmolt releases (Eagle Fish Hatchery-reared v. Sawtooth Fish Hatchery-reared) made to Pettit and Alturas lakes in 2000 and 2001. Summer direct-lake release information is presented.

Year planted	Rearing hatchery	Number of presmolts uniquely marked	Number of marked out-migrants observed[a]	*P* value
Pettit Lake				
2000	Eagle Fish Hatchery	2,915	57	<0.001
2000	Sawtooth Fish Hatchery	3,092	156	
2001	Eagle Fish Hatchery	3,059	152	0.005
2001	Sawtooth Fish Hatchery	2,998	200	
Alturas Lake				
2000	Eagle Fish Hatchery	2,917	2	<0.001
2000	Sawtooth Fish Hatchery	3,069	67	
2001	Eagle Fish Hatchery	3,064	8	0.382
2001	Sawtooth Fish Hatchery	3,059	12	

[a] Unique fin clips used in lieu of PIT tags in release years 2000 and 2001.

Table 4. Fisher's exact test results of recapture data collected at lower Snake and Columbia River dams for paired presmolt and smolt releases (fall direct-lake presmolt v. smolt) made to Redfish Lake and Redfish Lake Creek, respectively between 2000 and 2002.

Year planted	Release strategy	Number of fish PIT-tagged	Number of out-migrants interrogated[a]	Recapture rate (%)	*P* value
Lower Snake and Columbia River dams					
2000	Fall direct-lake presmolt	997	393	39.42	<0.001
2001	Smolt	870	130	14.94	
2001	Fall direct-lake presmolt	1,179	377	31.98	<0.001
2002	Smolt	867	128	14.76	

[a] Actual (unexpanded) PIT-tag interrogations.

Table 5. Planting history and estimated hatching rates for the Redfish Lake sockeye salmon captive broodstock program eyed egg reintroduction strategy.

Year planted	Planting location	Number of eyed eggs planted	Estimate hatching rate (%)
1996	Redfish Lake	105,000	97
1997	Redfish Lake	85,378	98
1997	Alturas Lake	20,389	72
1999	Pettit Lake	20,311	74
2000	Pettit Lake	65,200	79
2002	Pettit Lake	30,924	96

mous returns from captive broodstock program releases. Adults spawn over submerged substrate along lake shorelines. Areas of excavation are large (~3 × 3 m) and support multiple pairs of spawning adults. Spawn timing is synchronous with that described by Bjornn et al. (1968) for Redfish Lake sockeye salmon.

The number of suspected redds identified in lakes following the release of prespawn adult sockeye salmon has been variable ranging from 0 to 30 per year (Table 6). Field methods used to identify redds have remained consistent and are not suspected of contributing to this variability. Annual variability in redd count data are influenced primarily by the number of adults released to spawn and the reproductive potential of specific release groups.

Unmarked Smolt Production from Eyed Egg and Prespawn Adult Releases

Unmarked sockeye salmon smolts are produced from the eyed egg plants and prespawn adult releases, but production of unmarked smolts by residual sockeye salmon in Redfish Lake potentially confounds the interpretation of these data. Although no anadromous adult sockeye salmon were allowed to spawn in Redfish Lake between 1991 and 1998, unmarked sockeye salmon smolts continued to emigrate from Redfish Lake (Figure 3). Redfish Lake residual sockeye salmon are genetically similar to Redfish Lake anadromous sockeye salmon and both spawn in the same locations at the same time of the year (Winans et al. 1996). Both anadromous and residual forms of *O. nerka* can produce either resident or anadromous offspring (Rieman et al. 1994). We believe that unmarked sockeye salmon smolt out-migration from Redfish Lake was not influenced by program eyed egg plants or prespawn adult releases until 1998, which suggests that all unmarked production from 1993 to 1997 (Figure 3) was the result of residual sockeye salmon

Table 6. Reintroduction history and estimated spawning success for the Redfish Lake sockeye salmon captive broodstock program prespawn adult reintroduction strategy.

Year released	Origin of fish released	Number released	Number of suspected redds observed
Redfish Lake			
1993	Full-term, hatchery origin	20	0
1994	Full-term, hatchery origin	65	0
1996	Full-term, hatchery origin	120	30
1997	Full-term, hatchery origin	80	30
1999	Full-term, hatchery origin	18	8
1999	Anadromous, hatchery origin	3	
2000	Full-term, hatchery origin	46	20 to 30
2000	Anadromous, hatchery origin	120	
2001	Full-term, hatchery origin	65	12 to 15
2001	Anadromous, hatchery origin	14	
2002	Full-term, hatchery origin	178	10
2002	Anadromous, hatchery origin	12	
Pettit Lake			
1997	Full-term, hatchery origin	20	1
2000	Anadromous, hatchery origin	28	0
Alturas Lake			
1997	Full-term, hatchery origin	20	0
2000	Full-term, hatchery origin	25	14 to 19
2000	Anadromous, hatchery origin	52	

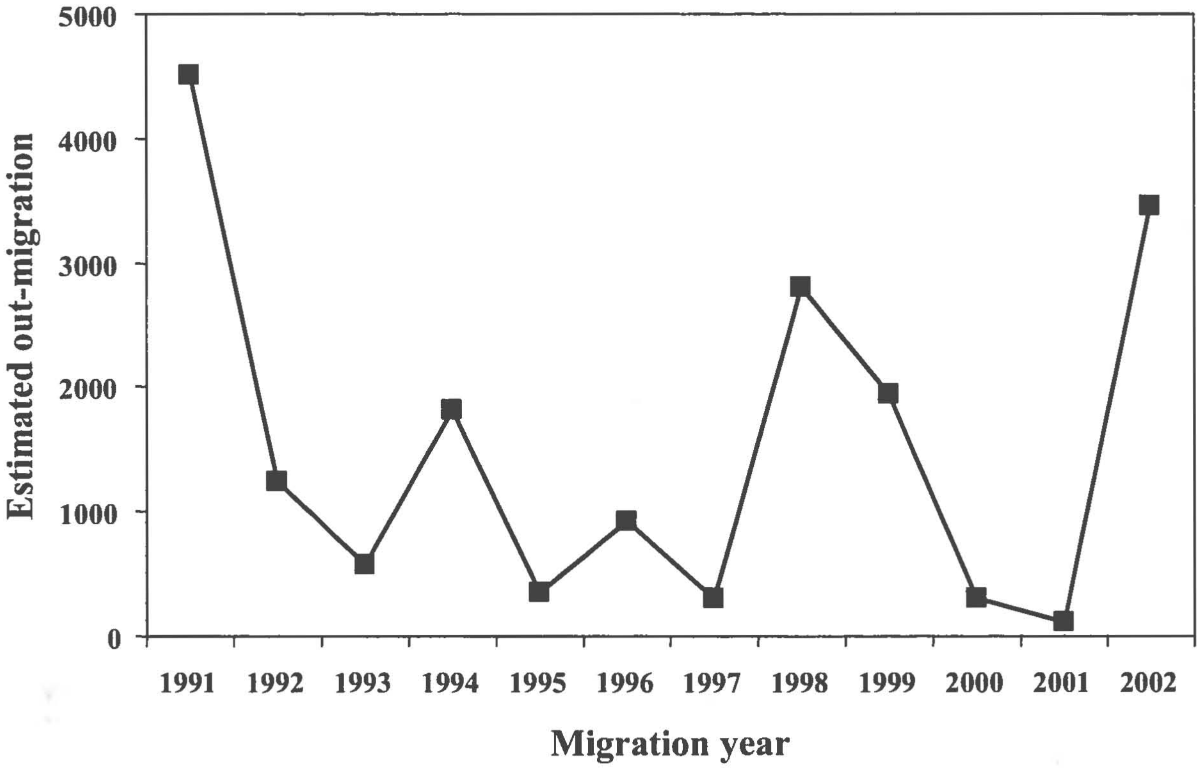

Figure 3. Redfish Lake unmarked smolt out-migration, 1991–2002.

spawning. Although prespawn adults were released in Redfish Lake in 1993 and 1994, no redds were identified in either year. Additionally, eyed eggs were not planted in Redfish Lake until 1996. Out-migrants produced from these plants would have emigrated in 1998 and 1999.

Since 1998, we believe that the planting of eyed eggs and the release of prespawn adults for natural spawning has been providing benefit to the population through the production of unmarked smolts. Unmarked smolt emigration from Redfish Lake declined from more than 4,000 fish in 1991 to 300 fish in 1997 (Figure 3). In 1998, unmarked smolt numbers increased to an estimated 2,799 fish. We believe the majority of this production is associated with adult sockeye salmon spawning and eyed egg plants conducted in 1996 (Tables 5 and 6). In 1999, unmarked smolt production was estimated at more than 1,900 fish. We believe this increase in unmarked smolt out-migration was the result of adult sockeye salmon spawning and eyed egg plants in Redfish Lake in 1997. No eyed eggs or prespawn adults were planted in Redfish Lake in 1998, and only 21 adult sockeye salmon were released to spawn in 1999 (Tables 5 and 6). Unmarked out-migrants produced from 1999 prespawn adult releases would have emigrated from Redfish Lake in 2000 and 2001. The estimated unmarked smolt out-migration was only 412 smolts for both the 2000 and 2001 out-migration years combined. Following the release of 166 adults in 2000, the number of unmarked out-migrants increased in 2002 to 3,461 smolts. Age-2 emigration from this adult release will be complete in 2003.

In an effort to isolate release strategies that produce unmarked smolts, eyed eggs and prespawn adults have not been planted together since 1997. Additionally, parentage assignment testing using nuclear DNA microsatellite markers is underway to help associate unmarked smolts with eyed egg and prespawn adult release strategies.

Hatchery-Produced Adult Returns

In 1999, the first hatchery-produced sockeye salmon returned to the Sawtooth Valley (Table 7). In that year, seven age-3 adults (six males and one female) were captured at the adult trap on the upper Salmon River. Unique fin clips and coded wire tags identified the origin of these fish as being produced from a Bonneville Fish Hatchery smolt release that occurred in 1998 to the upper Salmon River.

In 2000, 257 hatchery-produced adults returned

Table 7. Hatchery-origin adult return history for the Redfish Lake sockeye salmon captive broodstock program. Information is presented for trap sites on Redfish Lake Creek and the upper Salmon River at the Sawtooth Fish Hatchery.

Adult return year	Number of returning adults
Redfish Lake Creek trap	
1999	0
2000	119
2001	15
2002	8
Sawtooth Fish Hatchery trap[a]	
1999	7
2000	138
2001	11
2002	14

[a] Includes adults that were observed below the trap, but were not handled: 14 in 2000, 3 in 2001, 7 in 2002.

to the Sawtooth Valley (Table 7). Traps on Redfish Lake Creek and the upper Salmon River at the Sawtooth Fish Hatchery intercepted 119 and 124 adults, respectively (243 total adults). Fourteen adult sockeye salmon were observed immediately downstream of the adult trap on the upper Salmon River, but these fish were not handled. Based on fin marks and the presence of coded wire tags, 190 adults originated from the Bonneville Fish Hatchery smolt release conducted in 1998. Ninety-two and 98 of these adults were collected at Redfish Lake Creek and the Sawtooth Fish Hatchery, respectively. Ten unmarked adults were captured at the Redfish Lake Creek trap, suggesting that they originated from eyed egg plants and prespawn adult releases that occurred in 1996. No unmarked adults were collected at the Sawtooth Fish Hatchery trap in 2000. The remaining 43 adults resulted from a combination of presmolt releases conducted in 1997 and the release of Sawtooth Fish Hatchery-reared smolts in 1998. Seventeen and 26 of these adults were collected at Redfish Lake Creek and Sawtooth Fish Hatchery, respectively.

In 2001, 26 anadromous sockeye salmon were observed at collection facilities on Redfish Lake Creek and the upper Salmon River (Table 7). Twenty-three of these fish were collected. Two of the 23 adults were identified as age-5 fish produced from the 1998 Bonneville Fish Hatchery smolt release; one age-5 adult was captured at the Redfish Lake Creek trap and one at the Sawtooth Fish Hatchery trap. Four adults collected in 2001 were unmarked, indicating that they originated from prespawn adult releases or eyed egg plants conducted in 1997. All four unmarked adults were captured at Redfish Lake Creek. The remaining 17 adults were produced from presmolt releases conducted in 1998 and smolt releases conducted in 1999. Ten of these adults were captured at the Redfish Lake Creek trap and seven at the Sawtooth Fish Hatchery trap. Three adults were observed immediately downstream of the Sawtooth Fish Hatchery trap but not collected.

In 2002, 22 anadromous sockeye salmon returned to the Sawtooth Valley (Table 7). Eight adults were captured at Redfish Lake Creek and seven were captured at the Sawtooth Fish Hatchery on the upper Salmon River. The remaining seven adult sockeye salmon were observed immediately downstream of the adult trap on the upper Salmon River but were not handled. Six unmarked adults were captured in 2002, two at the trap on Redfish Lake Creek and six at the Sawtooth Fish Hatchery trap. Unmarked adults originated from eyed egg plants and prespawn adult releases conducted in 1998. Nine of the 15 adults captured in 2002 originated from presmolt releases conducted in 2000. Six and three of these adults were captured at the Redfish Lake and Sawtooth Fish Hatchery traps, respectively.

Smolt-to-Adult Return Rates

Out-migration and adult return information were used to develop estimates of smolt-to-adult return rates (SAR) from Redfish Lake Creek trap to Redfish Lake Creek trap for adult return years 2000, 2001, and 2002 (Table 8). Smolt-to-adult return rates were calculated by dividing the number of adult returns by the estimated number of out-migrating smolts multiplied by 100. Redfish Lake sockeye salmon return primarily as two-ocean adults, and for evaluation purposes, we assumed that all adults were two-ocean unless a unique mark indicated otherwise. In 2000, SARs for unmarked adults produced from eyed egg plants and presmolt adult releases (combined) and for adults produced from Sawtooth Fish Hatchery presmolt and smolt releases (combined) were 0.36% and 0.04%, respectively. The 2000 SAR for adults produced from the Bonneville Fish Hatchery smolt release was 0.38%. In 2001, the SAR for unmarked adults was 0.21%. Adults produced from Sawtooth Fish Hatchery presmolt and smolt releases returned at a rate of 0.04%. In 2002, SARs for unmarked adults and for Sawtooth Fish Hatchery presmolts were 0.66% and 0.09%, respectively.

Management Implications

Of the three presmolt release options used to date (summer direct-lake, fall direct-lake and Redfish Lake

Table 8. Redfish Lake sockeye salmon captive broodstock program smolt-to-adult return information for return years 2000–2002. Out-migration and adult return information is presented for Redfish Lake only.

Smolt out-migration year	Estimated number of out-migrants	Juvenile release strategy	Number of adult returns	Smolt-to-adult return rate (%)
Year 2000 adult returns				
1998	2,799	Eyed egg and prespawn adult combined	10	0.36
1998	41,653	Sawtooth Fish Hatchery-reared presmolt and smolt combined	17	0.04
1998	24,365	Bonneville Fish Hatchery-reared smolt	92	0.38
Year 2001 adult returns[a]				
1999	1,929	Eyedegg and prespawn adult combined	4	0.21
1999	27,154	Sawtooth Fish Hatchery-reared presmolt and smolt combined	10	0.04
Year 2002 adult returns				
2000	302	Eyed egg and prespawn adult combined	2	0.66
2000	6,692	Sawtooth Fish Hatchery-reared presmolt	6	0.09

[a] The single age-5 adult that returned to the trap on Redfish Lake Creek in 2001 was not included in the SAR calculation.

net-pens), summer direct-lake and net-pen options have been less successful than the fall direct-lake release option at producing out-migrants. The fall direct-lake release option has performed consistently well in Redfish, Alturas, and Pettit lakes. As a result, summer direct-lake and Redfish Lake net-pen release options are being deemphasized in favor of fall direct-lake and smolt release options in future management scenarios being developed by the SBTOC (Flagg et al. 2004).

Our results also indicate that juvenile sockeye salmon reared at the IDFG Eagle Fish Hatchery and released to Alturas and Pettit lakes overwinter and out-migrate less successfully than presmolts reared at the IDFG Sawtooth Fish Hatchery. Different hatchery water temperature profiles and fish culture protocols applied to compensate for water temperature differences are likely responsible to some degree for the observed differences in out-migration success. Rearing temperature ranges from 1.0°C to 10.0°C at the Sawtooth Fish Hatchery, while the Eagle Fish Hatchery water temperature remains a constant 13.5°C throughout the year. Water chilling equipment allows Eagle Fish Hatchery to cool incubation and rearing water temperatures to between 8.0°C and 10.0°C. However, higher water temperatures at the Eagle Fish Hatchery result in earlier hatch, swim-up, and first feeding by fry. To compensate, diet ration (in addition to water temperature) is manipulated to modulate growth to prevent fish from exceeding specific size targets in place to reduce the risk of fish residualizing in lakes following release. The exact mechanisms responsible for the observed performance differences are unknown, but Sawtooth Fish Hatchery is now considered by the SBTOC as the preferred rearing location for presmolt release groups.

Smolt releases have been more successful than other release options when it comes to getting the greatest number of juveniles downstream in relation to the number of fish released by strategy (see Flagg et al. 2004). In addition, 69% of the 288 hatchery-produced anadromous adults captured at collection facilities were the product of a single smolt release (the 1998 release of smolts reared at the Bonneville Fish Hatchery). However, the SBSTOC has been reluctant to overprioritize this option to the point where it creates an imbalance in the program's "spread-the-risk" reintroduction philosophy. The concern remains that sockeye salmon released as smolts might not have the same opportunity to imprint as fish produced from natural options (e.g., eyed egg plants and prespawn adult releases) or released to lakes as presmolts and, therefore, not return as effectively as adults (Berejikian et al. 2004). In addition, placing disproportionately high reliance on one reintroduction strategy and rearing facility can have potentially disastrous effects. In an attempt to reproduce the high adult returns observed in 2000 that resulted from the release of brood year 1996 smolts reared at the Bonneville Fish Hatchery, approximately 50% of the program's brood year 2000 egg production was dedicated to this same rearing and reintroduction option. Unfortunately, due to an epizootic of infectious hematopoietic necrosis virus, all fish had to be destroyed in 2002 prior to release. This example underscores the importance of maintaining programs of this nature on specific pathogen free water supplies, using multiple rearing facilities, and maintaining a "spread the risk" approach to reintroducing fish to the habitat. The smolt release option also requires more hatchery rearing space, water supply, and maintenance costs than eyed egg or presmolt release options. Currently, the lack of appropriate hatchery rearing space is limiting any increase in the use of this rearing and reintroduction option.

Natural production options (e.g., eyed egg plants and prespawn adult releases) are viable and are contributing to the success of the program. Eyed eggs planted in incubation boxes in Sawtooth Valley lakes hatch successfully and produce viable fry. Prespawn adults released for volitional spawning select spawn sites, pair, and construct successful redds. In 1998, the number of unmarked out-migrants from Redfish Lake (presumably the result of egg and prespawn adult plants) increased 400% over the mean number observed leaving the lake between 1995 and 1997. Between 2000 and 2002, 16 hatchery-produced adults produced by these strategies returned to Redfish Lake. The SBSTOC believes that natural production options are valuable and provide a level of natural selection and behavioral conditioning that presmolt and smolt release options do not offer (Berejikian et al. 2004). To help assign unmarked smolt production to these reintroduction strategies, parentage assignment testing using nuclear DNA microsatellite markers was initiated in 2003.

Based on current and historic SARs, Snake River sockeye salmon would now be extinct in the habitat without reintroductions from the current captive broodstock program. The program is continuing to refine reintroduction efforts using monitoring and evaluation data to increase the efficient use of available hatchery rearing space. Program release options are being selected to maximize program success and to make the best use of the existing hatchery infrastructure. While the captive broodstock program can maintain returning adult numbers at the current level, substantial increases in smolt-to-adult return rates must occur if complete recovery of this population is to occur.

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