FISHERY RESEARCH

SNAKE RIVER SOCKEYE SALMON CAPTIVE BROODSTOCK PROGRAM

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SNAKE RIVER SOCKEYE SALMON CAPTIVE BROODSTOCK PROGRAM

Project Progress Report

2021 Annual Report

By

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EXECUTIVE SUMMARY

The Idaho Department of Fish and Game (IDFG) initiated the Snake River Sockeye Salmon *Oncorhynchus nerka* Captive Broodstock Program in May 1991, in response to the decline of anadromous returns to the Sawtooth Valley in central Idaho. Factors contributing to the decline of Snake River Sockeye Salmon include hydropower development, water withdrawal and diversions, water storage, harvest, predation, and inadequate regulatory mechanisms (Federal Register 1991). The initial goals of the program were to utilize captive broodstock technology to avoid extinction and conserve genetic diversity of this ESU. Long-term programmatic goals include increasing the number of individuals in the population with future plans to recover and de-list the ESU and provide sport and treaty harvest opportunities. Idaho Department of Fish and Game's participation in the Snake River Sockeye Salmon Captive Propagation project is comprised of three areas of effort: 1) captive broodstock culture, 2) hatchery and field monitoring and evaluations, and 3) genetic evaluations. This report describes the following activities: *O. nerka* juvenile population monitoring on Redfish, Alturas, and Pettit lakes; Sockeye Salmon juvenile emigrant monitoring and evaluation from Redfish Lake Creek through the Federal Columbia River Power System (FCRPS); anadromous monitoring from Bonneville Dam through the FCRPS; trapping activities in the Sawtooth Valley; and natural production monitoring and evaluations from Redfish Lake.

Mid-water trawl surveys have been conducted annually since 1990 to quantify non-listed resident kokanee and Snake River Sockeye Salmon stocks found within the lakes. Abundance estimates in 2021 for Snake River Sockeye Salmon in Redfish and Pettit lakes have declined over the past 10 years, concomitant with termination of eyed-egg and presmolt reintroduction strategies. In Alturas Lake, Snake River Sockeye Salmon have not been observed in trawl samples since initiating genetic monitoring in 2006. Juvenile Sockeye Salmon abundance estimates derived from trawling were also very poor predictors of emigration. Additional analyses may be needed to better evaluate densities or to identify a specific population change going forward. Due to the size selectivity of the trawling gear and the low density of *O. nerka* populations in Alturas, Pettit, and Redfish lakes, additional monitoring methods using hydroacoustics may be useful to help interpret mid-water trawl data (Kline et al. 2019).

Captive and anadromous adults have been released into the natal lakes for volitional spawning since 1993, and there continues to be a positive correlation between the numbers of females released and estimated natural juvenile emigrants. The estimated abundance of Redfish Lake natural emigrants in 2021 was 40% higher than last year's estimate but represented a 51% reduction from the 2010-2020 average. Lower than average abundance may have been caused by releasing fewer captive and anadromous adults into Redfish Lake in 2018 and 2019 to naturally spawn. Predicted abundance of Redfish Lake emigrants in 2021 should have been similar to 2020 given similar numbers of captive adults that were released both years; however, emigration estimates were 40% higher in 2021. More females were released in 2019 (n = 321) compared to 2018 (n = 304), and Eaton et al. (2021) found that zooplankton biomass (specifically *Bosmina* and *Daphnia* biomass) was nearly 3 times higher in 2020 compared to 2019 in Redfish Lake. In 2021 survival estimates to LGR remained high among all groups relative to historic sockeye smolt production facilities. Our results indicate that manipulating smolt size did not impact immediate post-release survival; however, the effects of smolt size on smolt-to-adult survival cannot be determined at this time.

As PIT-tagged adults began to arrive at Bonneville Dam, water temperature, and conversion rates were closely monitored. Conversion rates and travel times in the Lower Columbia and Snake rivers indicated fish passage concerns between Bonneville and Lower

Granite dams. In early July emergency trap and haul activities were initiated with adult Sockeye Salmon collected at LGR between July 6 and July 29, 2021. A total of 240 anadromous Snake River Sockeye Salmon adults were collected at fish traps in 2021. One hundred and eighty-five adults were trapped at LGR, 50 adults were trapped at the RFLC trap, and 5 were trapped at the SFH weir. Temperatures in the Snake River upstream of the Clearwater River confluence and in the lower Salmon River were observed near or above lethal levels for salmonids, and survival of the PIT and genetically tagged fish that were not collected for transport at LGR was low (3%-13%). Returning adult's size-at-age was larger than adults returning in 2020, but similar to previous years, indicating ocean conditions have improved for Sockeye Salmon.

The composition of the returning adults was primarily from SFH-reared smolts released into RFLC in 2019 (81%). Adult returns originating from SpFH (14%), Redfish Lake (3%), and Pettit Lake (2%) were also observed. No out-of-basin Sockeye Salmon were trapped in the Sawtooth Valley. The variation observed in productivity among smolt production facilities indicates that smolt releases are not one size fits all. Smolt-to-adult survival of SpFH-reared smolts was approximately 11 times lower than SFH-reared smolts. A working group consisting of fish physiologists, fish health, fish production, and monitoring staff from IDFG, NOAA, SBT and a Northwest Power and Conservation Council member was established in the fall of 2020 to identify the possible mechanisms leading to poor ocean survival of hatchery-reared smolts due to lower-than-expected smolt-to-adult survival of BY2016-17 SpFH smolts. The working group has identified three assessments that are being implemented to determine the causes for this poor ocean survival. They are 1) use isotopic analysis from scales to determine the oceanic distribution of hatchery-origin and natural-origin Snake River Sockeye Salmon, 2) identifying the effects of size-at-release on SAR, and 3) tracking smolt development to determine the ability of SpFH smolts to make the transition into the saltwater environment.

PART 1—SNAKE RIVER SOCKEYE SALMON CAPTIVE BROODSTOCK PROGRAM OVERVIEW

The Idaho Department of Fish and Game (IDFG) initiated the Snake River Sockeye Salmon *Oncorhynchus nerka* Captive Broodstock Program in May 1991, in response to the decline of anadromous returns to the Sawtooth Valley in central Idaho. Historically, Redfish, Alturas, Pettit, Stanley, and Yellowbelly lakes supported Sockeye Salmon in the Sawtooth Valley (Chapman et al. 1990; Evermann 1895; Bjornn et al. 1968; Figure 1). Historical observations and discussions with local residents (Evermann 1895 and 1896) described the Sawtooth Valley lakes as being important spawning and rearing areas for Sockeye Salmon; however, actual adult escapement enumeration or estimations were not conducted at that time. Adult Sockeye Salmon escapement to Redfish Lake was enumerated from 1954 through 1966 by the IDFG, University of Idaho, and the United States Bureau of Commercial Fisheries. During this time, adult escapement ranged from a high of 4,361 in 1955 to a low of 11 in 1961 (Bjornn et al. 1968). Adult escapement enumeration was reinitiated in 1985 by the IDFG. Between 1985 and 1990, 61 adults were estimated to have returned to the Sawtooth Valley (Table 1). This number declined to zero anadromous adults or redds observed in Redfish Lake in 1990. Hydropower development, water withdrawal and diversions, water storage, harvest, predation, and inadequate regulatory mechanisms were outlined as factors contributing to the decline of Snake River Sockeye Salmon (Federal Register 1991).

As a result of the declines, the National Marine Fisheries Service (NMFS) listed Snake River Sockeye Salmon as an endangered evolutionarily significant unit (ESU) under the Endangered Species Act in November of 1991 (Federal Register 1991). To be considered an

ESU for listing determinations, a stock must satisfy two criteria: 1) it must be reproductively isolated from other conspecific population units; and 2) it must represent an important component in the evolutionary legacy of the biological species (Waples 1991). At the time of listing, the Redfish Lake Sockeye Salmon population was the only remaining population of the Snake River Sockeye Salmon stock. Snake River Sockeye Salmon are also only one of three remaining stocks of Sockeye Salmon in the Columbia River system; the other two stocks, Okanagan Lake and Lake Wenatchee Sockeye Salmon, are located in tributaries of the upper Columbia River. Approximately 1,127 river kilometers separate Snake River Sockeye Salmon from the nearest Sockeye Salmon populations in the upper Columbia River. Genetic analysis showed genetic differentiation of Snake River Sockeye Salmon from the upper Columbia River stocks (Waples et al. 2011; Winans et al. 1996). Mitochondrial DNA analyses confirmed the genetic isolation of the upper Columbia River stocks from the Snake River Sockeye Salmon stock (Faler and Powell 2003). Sockeye Salmon returning to Redfish Lake travel a greater distance from the Pacific Ocean (1,448 river kilometers) and to a higher elevation (2,138 meters) than any other Sockeye Salmon population in the world. Additionally, Redfish Lake supports the species' southernmost population within its recognized range (Burgner 1991). Together these characteristics presented a strong argument for the reproductive discreetness and ecological uniqueness of the Snake River habitat and for the unique adaptive genetic characteristics of the Snake River Sockeye Salmon stock (Waples 1991).

Three distinct life histories of *O. nerka* (Sockeye Salmon) have been observed in Redfish Lake. Anadromous *O. nerka* spawn on the shoals of the lake in October and November. Juveniles emigrate during the spring at age-1 or age-2 and remain in the ocean for one to three years before returning to their natal area to spawn. Residual *O. nerka* spend their entire life in their nursery lake but can spawn with the anadromous life history on the shoals of the lake in October and November. Resident *O. nerka* (kokanee) also complete their life cycle in freshwater. They remain in Redfish Lake until maturation and spawn in Fishhook Creek, a tributary creek to Redfish Lake, in August and September. Kokanee are indigenous to Redfish Lake but were periodically stocked from a range of non-indigenous hatchery sources beginning in 1930 and continuing through 1972 (Bowler 1990). Redfish Lake anadromous, residual, and out-migrant Sockeye Salmon were determined to be genetically similar, whereas kokanee were found to be genetically different (Brannon et al. 1992, 1994; Cummings et al. 1997; Waples et al. 2011). Because of their genetic similarity, residual Sockeye Salmon were added to the ESU listing in 1992.

At the initiation of the program, IDFG collected fish from the following sources for broodstock and reintroduction purposes: 1) all wild anadromous adult returns that were trapped between 1991 and 1998 were retained for hatchery spawning, 2) residual adults trapped between 1992 and 1995 were retained for hatchery spawning, and 3) smolts trapped between 1991 and 1993 were reared until maturity and spawned in the hatchery. Both IDFG and National Oceanic and Atmospheric Administration (NOAA) Fisheries maintain Snake River Sockeye Salmon captive broodstocks. Groups of fish were reared at two facilities to avoid the potential catastrophic loss of the evolutionary lineage of Snake River Sockeye Salmon. The IDFG rears annual captive broodstocks from the egg stage to maturity at Eagle Fish Hatchery (EFH) in Eagle, Idaho (Baker et al. 2021). Additionally, NOAA Fisheries rears duplicate captive broodstock from the egg stage to maturity at the Manchester Research Station (MRS) and Burley Creek Hatchery (BCH) near Seattle, Washington (Frost et al. 2022). Historically, eyed eggs were shipped to two production hatcheries: Oxbow Fish Hatchery (OFH) located near Cascade Locks, Oregon and Sawtooth Fish Hatchery (SFH) located near Stanley, Idaho. To meet increased smolt production goals outlined in Phase 2 of Sockeye Master Plan, Springfield Fish Hatchery (SpFH) near Blackfoot, Idaho was completed in 2013. The program has phased out juvenile rearing at the OFH and SFH and focused on rearing larger numbers of smolts at the SpFH. The history of egg and fish

reintroductions from the Snake River Sockeye Salmon Captive Broodstock Program is summarized in Appendix A.

PROJECT GOALS

The initial goals of the program were to utilize captive broodstock technology to avoid extinction and conserve genetic diversity of this ESU. Long-term programmatic goals include increasing the number of individuals in the population with future plans to recover and de-list the ESU and provide sport and treaty harvest opportunities. Draft ESA delisting criteria for Snake River Sockeye Salmon include a ten-year geometric mean minimum spawning abundance threshold in both Redfish and Alturas lakes of 1,000 natural-origin spawners and 500 natural-origin spawners in Pettit Lake (NMFS 2015). In addition, population growth needs to be stable or increasing with low to moderate risk ratings for spatial structure and diversity. Current research and monitoring focuses on quantifying natural production and producing Viable Salmonid Population (VSP) metrics used to evaluate delisting criteria.

PROJECT OBJECTIVES

1. Develop captive broodstocks from Redfish Lake Sockeye Salmon, culture broodstocks, and produce smolts for reintroduction purposes.

2. Determine the contribution that hatchery-produced Sockeye Salmon make toward avoiding population extinction and increasing population abundance for long-term recovery goals.

3. Describe *O. nerka* population characteristics for Sawtooth Valley lakes in relation to carrying capacity and broodstock program reintroduction efforts.

4. Use genetic analysis to discern family relationships, origin (e.g., release strategy), and age of natural and hatchery Sockeye Salmon to provide maximum effectiveness in their utilization within the broodstock program.

5. Transfer technology through participation in the Stanley Basin Sockeye Technical Oversight Committee (SBSTOC) process, provide written activity reports, and participate in essential program management and planning activities.

Idaho Department of Fish and Game's participation in the Snake River Sockeye Salmon Captive Propagation project is comprised of three areas of effort: 1) captive broodstock culture, 2) hatchery and field monitoring and evaluations, and 3) genetic evaluations. Although objectives and tasks from all three components overlap and contribute to achieving the same goals, work directly related to the culture of Snake River Sockeye Salmon captive broodstock appears under a separate cover (Baker et al. 2022; Frost et al. 2022). Field and genetic monitoring and evaluation activities associated with Snake River Sockeye Salmon are permitted under NOAA permit No. 1124, FMEP, and 1454, which authorized the IDFG annual takes of Snake River Sockeye Salmon, Chinook Salmon, and steelhead trout associated with research to determine the distribution, abundance, and productivity of anadromous and resident fish stocks; measure the efficacy of harvest management strategies and the impact of proposed or existing habitat alteration projects; and monitor natural production levels, salmonid health, and the effectiveness of supplementation efforts. This report describes the following activities: *O. nerka* juvenile

population monitoring on Redfish, Alturas, and Pettit lakes; Sockeye Salmon juvenile emigrant monitoring and evaluation from Redfish Lake Creek through the Federal Columbia River Power System (FCRPS); anadromous monitoring from Bonneville Dam through the FCRPS; trapping activities in the Sawtooth Valley; and natural production monitoring and evaluations from Redfish Lake.

STUDY AREA

The program's recovery efforts focus on Redfish, Pettit, and Alturas lakes in the Sawtooth Valley located within the Sawtooth National Recreation Area (Figure 1). These lakes provide critical spawning and rearing habitat. Lakes in the Sawtooth Valley are glacial-carved and considered oligotrophic. The three lakes range in elevation from 1,996 m (Redfish Lake) to 2,138 m (Alturas Lake) and are located 1,448 km (Redfish Lake) to 1,469 km (Alturas Lake) 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 between 1997 and 2011.

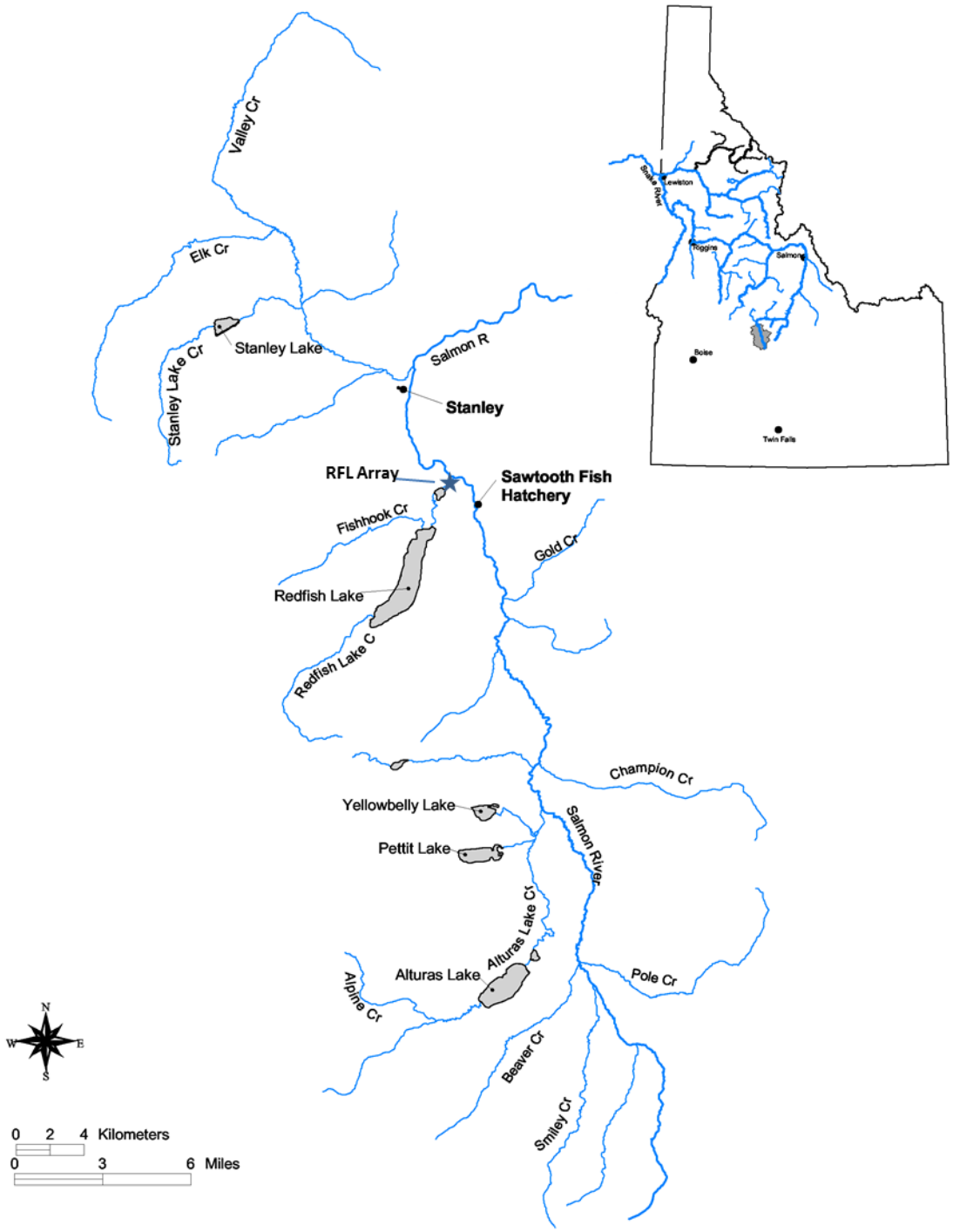

Figure 1. Map of the upper Salmon River watershed located in the Sawtooth Valley, Idaho.

Table 1. Trapped and observed anadromous adult Snake River Sockeye Salmon returns by origin to the Sawtooth Valley from 1985-2021.

Year	Anadromous adult trapped	Natural origin	Hatchery origin	Observed
1985	14	14	-	0
1986	29	29	-	0
1987	16	16	-	0
1988	1	1	-	0
1989	1	1	-	0
1990	0	0	-	0
1991	4	4	-	0
1992	1	1	-	0
1993	8	8	-	0
1994	1	1	-	0
1995	0	0	-	0
1996	1	1	-	0
1997	0	0	-	0
1998	1	1	-	0
1999	7	0	7	0
2000	243	10	233	14
2001	23	4	19	3
2002	15	6	9	7
2003	2	0	2	1
2004	24	4	20	3
2005	6	2	4	0
2006	3	1	2	0
2007	4	3	1	0
2008	598	140	458	51
2009	817	86	731	16
2010	1,322	178	1,144	33
2011	1,099	145	954	18
2012	242	52	190	15
2013	270	79	191	2
2014	1,516*	453	1,062	63
2015	91**	28	63	0
2016	572	33	539	23
2017	162	11	151	24
2018	113	13	100	3
2019	17	14	3	0
2020	151	125	26	1***
2021	240****	13	227	0

* one unknown origin (escaped while being handled from the trap).
** includes 35 Sockeye Salmon transported from Lower Granite Dam.
*** prespawn mortality recovered downstream of Redfish Lake Creek (RFLC) trap.
**** includes 185 Sockeye Salmon transported from Lower Granite Dam.

PART 2—*ONCORHYNCHUS NERKA* POPULATION MONITORING

INTRODUCTION

Understanding the dynamics of *O. nerka* populations in the Sawtooth Valley lakes is a vital part of Sockeye Salmon restoration efforts. Knowledge of juvenile *O. nerka* abundance coupled with limnology data (collected and reported by the Shoshone-Bannock Tribes [SBT]) is important for understanding abundance, biomass, and the carrying capacity of each lake. Redfish and Pettit lakes currently support both ESA-listed Sockeye Salmon as part of the program's reintroduction efforts, and non-listed resident kokanee populations. Productivity in the lakes varies annually and the presence of kokanee in the nursery lakes can create increased competition for limited food sources between kokanee and Sockeye Salmon in these oligotrophic systems. In this section, we report the use of mid-water trawl techniques to collect biological sample data and generate annual estimates of juvenile *O. nerka* abundance. This was coupled with genetic and scale aging data to provide stock composition (by age and lake). Currently, this information is used to obtain trend information regarding abundance, biomass, density, and assist with estimates of carrying capacity within the lakes as re-introduction efforts now focus on releasing increasing numbers of mature adults into the lakes for natural spawning.

METHODS

***Oncorhynchus nerka* Population Monitoring**

Mid-water trawling was conducted at night during the new moon in September to collect samples from juvenile *O. nerka* in the Sawtooth Valley lakes to estimate age composition and determine length and weight. In addition, trawl samples can be used to estimate total *O. nerka* (kokanee and Sockeye Salmon) abundance, density, and biomass in the lakes. Trawling was conducted in September, prior to adult releases, to reduce the risk associated with collection or disturbance of post-released adults in the trawl catch. Surveys were also conducted in September because juvenile *O. nerka* were tightly stratified during this time of the year due to water temperatures. Trawling was performed in a stepped-oblique fashion as described by Rieman and Myers (1992) and Kline (1994). Pettit Lake was towed for a total of six transects and Alturas Lake was towed for a total of four transects. Trawl samples in Redfish Lake varied annually. Prior to 2012, 6-7 transects were conducted. Between 2012 and 2014, trawling effort increased to 18 transects and reduced to 7 transects in 2015. Trawling efforts increased again to 18 transects in 2016. Due to the small surface area and width across the lakes, random towing direction and starting location for each transect was not possible. Therefore, the same transects each year were used based on GPS starting coordinates. Additional information regarding sampling methods can be found in https://www.monitoringresources.org/Document/Protocol/Details/1905.

Total *O. nerka* abundance was estimated using a program developed by Rieman (1992). Abundance estimates generated by this program were extrapolations of actual trawl catch data to the total area of the lake mid-depth in the observed *O. nerka* stratum. Confidence intervals were calculated using a Student's *t*-distribution following Scheaffer et al. (1996).

Age and size structure of the juvenile population, and biomass in the lakes, were also estimated. Scales were collected and returned to the laboratory for aging. Research suggests that Sockeye Salmon start developing scales at a fork length ranging from 36-40 mm (Clutter and Whitesel 1956); therefore, fish under 50 mm were assumed to be age-0 for these analyses. Fork length to the nearest 1 mm and weight to the nearest 0.1 g were recorded for all trawl-captured

O. nerka, and fin clips were taken from sampled individuals and delivered to the IDFG Genetics Laboratory for DNA analysis.

Genetic assignment methods (GSI) were used to assign each sample to either the Redfish Lake stock or Fishhook Creek/Alturas Lake kokanee stock using a single nucleotide polymorphism (SNP) baseline described in Hasselman et al. (2018). Samples were run in the program gsi_sim (Anderson et al. 2008, Anderson 2010a). The proportions of Snake River Sockeye Salmon and kokanee were independently derived for each lake based on the proportions observed in the trawl catch as determined by GSI. The number of Snake River Sockeye Salmon and kokanee were estimated by applying the proportion to the total *O. nerka* abundance estimate.

RESULTS

***Oncorhynchus nerka* Population Monitoring**

Redfish Lake

Eighteen mid-water trawl transects conducted in 2021 resulted in the collection of 101 *O. nerka* and produced an abundance estimate of 52,855 fish (95% CI ± 19,860; Appendix B). Density and biomass were estimated at 86.3 fish/ha and 0.1 kg/ha (Appendix C). Age-0 *O. nerka* was the predominant age class represented in the Redfish Lake trawl sample (92%), followed by age-1 (7%) and age-2 (1%).

In 2021, 6% of O. nerka captured in the trawl were assigned as Snake River Sockeye Salmon. Genotypes indicative of protected Snake River Sockeye Salmon ranged from 6% (2021) to 54% (2010) of the *O. nerka* sampled from trawling since 2006 (Figure 2). Abundance estimates of ESA listed Sockeye Salmon based on genetically assigned proportions was 3,171 fish (95% CI 2,981–3,584; Figure 3).

Alturas Lake

Four mid-water trawl transects conducted in 2021 resulted in the collection of 14 *O. nerka* and produced an abundance estimate of 11,682 fish (95% CI ± 5,291; Appendix B). In 2021, estimates of *O. nerka* density and biomass were 34.6 fish/ha, and 0.1 kg/ha, respectively (Appendix C). Fish sampled in the trawl in 2021 were predominantly age-0 fish (93%) followed by age-1 fish (7%). Of the 14 genetic samples collected during trawl activities on Alturas Lake, all samples produced genetic data identifying those fish as kokanee.

Pettit Lake

Abundance estimates, density, and biomass based on six transects and the collection of 1 *O. nerka* was 349 fish (95% CI ± 1,247), 2.2 fish/ha, and 0.1 kg/ha, respectively (Appendix B and C). This age-3 fish received a GSI assignment to the Pettit Lake sockeye population.

DISCUSSION

***Oncorhynchus nerka* Population Monitoring**

Mid-water trawl surveys have been conducted annually to quantify *O. nerka* abundance, density, and biomass within Redfish, Alturas, and Pettit lakes since 1990 and to develop population estimates. These population estimates represent both the non-listed resident kokanee and Snake River Sockeye Salmon stocks found within the lakes. The lack of morphological or phenotypic differences (e.g., no size differences at age) makes it difficult to differentiate between stocks. However, incorporating the use of genetic analyses has enabled the estimation of proportions for each stock identified within our trawl sample and overall abundance by stock within each lake. In addition, genetic analyses allowed the investigation of patterns of introgression between introduced kokanee and Snake River Sockeye Salmon in Pettit Lake (Eaton et al. 2021).

The abundance estimate in 2021 for Snake River Sockeye Salmon in Redfish Lake was consistent with past estimates (Figure 3). Historically, lake abundance estimates may have been influenced by reintroduction strategies that were employed such as eyed egg plants and presmolt releases and earlier trawl dates. Due to the smaller size (surface area) of Pettit Lake, trawl catch and corresponding abundance estimates are typically the lowest of the 3 lakes sampled. Concomitant with the termination of eyed egg releases in 2009, total *O. nerka* abundance estimates have declined over the past 10 years (Appendix B). In Alturas Lake, Snake River Sockeye Salmon have not been observed in trawl samples since initiating genetic monitoring in 2006. However, samples collected in 2008 indicated that Snake River Sockeye Salmon were in the smolt emigration (after being planted as eyed eggs in December of 2006) and made up 22% of the total emigration. This suggests that fish present in the lake may not always be sampled due to low densities, size selectivity, and avoidance (Rieman 1992; Parkinson et al. 1994; Kline et al. 2019). However, no release strategies were employed in recent years, so no Snake River Sockeye Salmon are expected to be found currently within Alturas Lake. Juvenile Sockeye Salmon abundance estimates derived from trawling were also very poor predictors of emigration. Taking into account the age composition, trawl catch explained about 5% of the variability in the following year's emigration for Redfish and Pettit lakes across the entire time series (Johnson et al. 2016). Rieman (1992) found that precision of abundance estimates can be increased by increasing the number of samples when average catch is greater than one fish per trawl. When restricting our population estimates to those years with the highest effort (i.e., 18 transects), trawl *O. nerka* abundance estimates are more strongly associated with the following year's emigration estimates (Pearson correlation coefficient of 0.78). Additional variability is likely explained by changes in annual capture probability since sampling is conducted on each of the lakes once a year (Glover et al. 2019).

Understanding the composition of kokanee and Sockeye Salmon in the lakes will be important for determining carrying capacity as adult releases increase in number. Additional analyses may be needed to better evaluate densities or to identify a specific population change going forward. Due to the size selectivity of the trawling gear and the low density of *O. nerka* populations in Alturas, Pettit, and Redfish lakes, additional monitoring methods using hydroacoustics may be useful to help interpret mid-water trawl data (Kline et al. 2019).

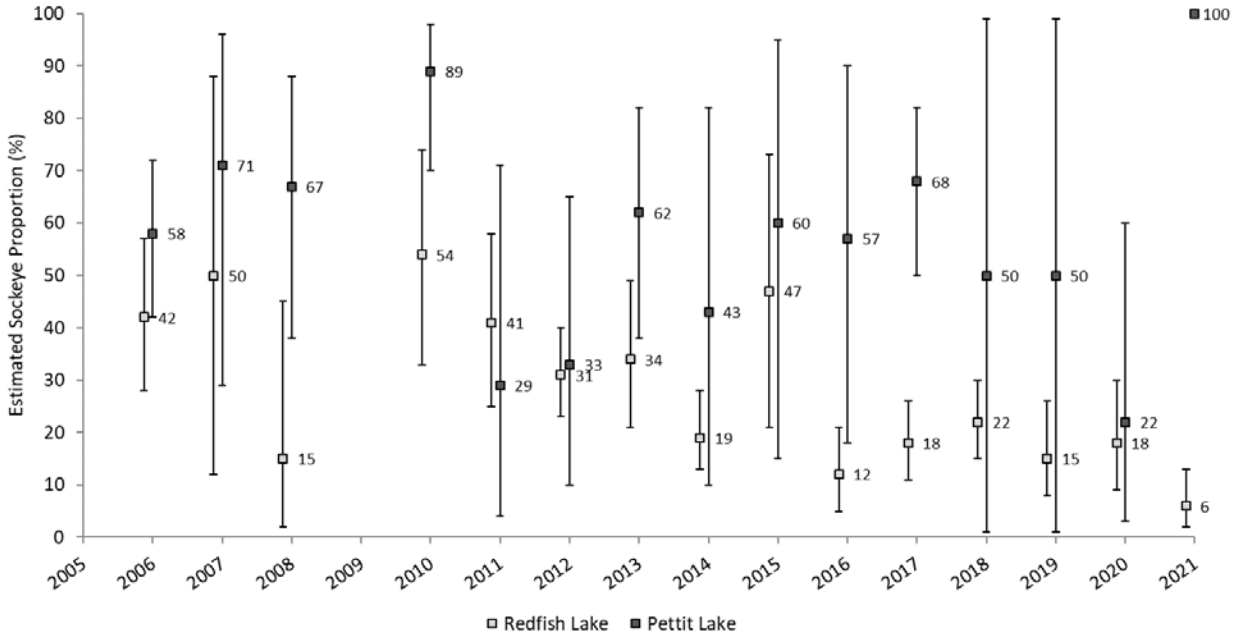

Figure 2. Proportions of Snake River Sockeye Salmon (assigned genetically) out of the total *O. nerka* population within Redfish and Pettit lakes collected using mid-water trawl from 2006-2021. Error bars represent 95% binomial exact confidence intervals.

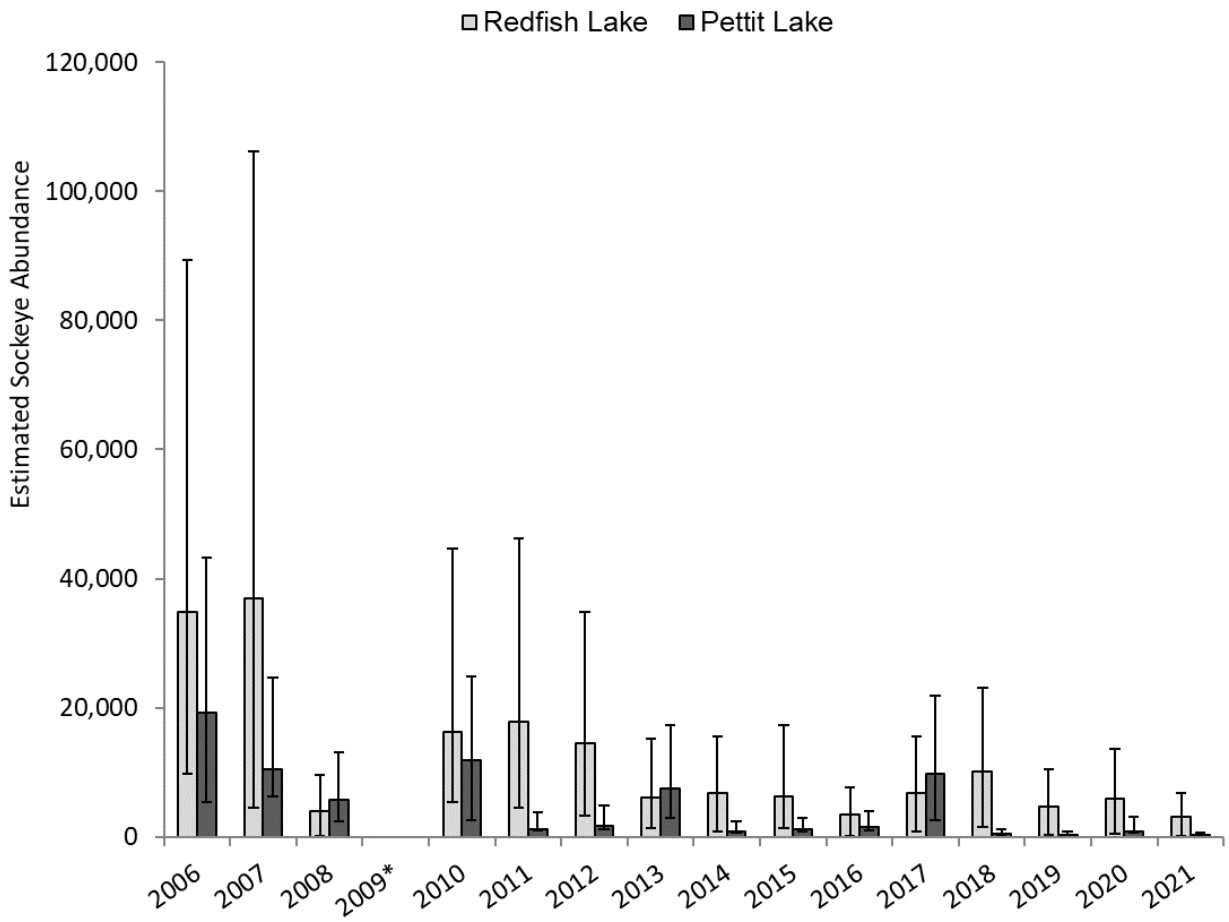

Figure 3. Abundance of Snake River Sockeye Salmon (assigned genetically) within Redfish and Pettit lakes collected using mid-water trawl from 2006-2021. Abundance data in 2009 is not reported due to sample contamination.

PART 3—SOCKEYE SALMON JUVENILE EMIGRANT MONITORING AND EVALUATION

INTRODUCTION

The development of reintroduction plans for Snake River Sockeye Salmon has traditionally followed a “spread-the-risk” philosophy incorporating multiple release strategies and multiple lakes over the course of the program (Hebdon et al. 2004; Johnson et al. 2020). Both adults and juveniles produced in excess of broodstock needs have been re-introduced into the environment to provide opportunities to increase the abundance of the population with returning anadromous adults. Progeny from the captive broodstock were historically reintroduced to Sawtooth Valley waters at different life stages using a variety of release options (Appendix A). Captive-reared Sockeye Salmon adults were first released back to the wild in 1993. Beginning in 1999, anadromous Sockeye Salmon have been released into valley lakes when available. In addition to natural production (resulting from captive and anadromous adult releases), hatchery-produced juveniles (smolts) are released annually into Redfish Lake Creek and the Salmon River. The program has phased out eyed egg (2011) and presmolt releases (2012), juvenile rearing at OFH (2016), and smolt releases into the Salmon River (2018). The current focus is on rearing a larger number of smolts at SpFH to be released into Redfish Lake Creek along with adult releases into Redfish and Pettit lakes. Unexpectedly high mortality rates were observed in the first cohorts (BY 2013-2015) of SpFH-reared smolts shortly after release and resulted in low survival estimates as fish moved downstream through the FCRPS. In response, a series of iterative experiments were conducted in 2017 and 2018 that identified the immediate transition from “hard” water (SpFH) to “soft” water (Redfish Lake Creek, RFLC) as the proximate cause of the high post-release mortality (Trushenski et al. 2019). Low smolt-to-adult survival of BY 2016 Springfield Hatchery reared Sockeye Salmon was observed (Johnson et al. 2021) and a Redfish Lake sockeye ocean survival working group was formed in the fall of 2020 to develop an assessment plan for identifying the causes for, and potential solutions to, the low observed SpFH SARs. The working group identified three hypothesis impacting low ocean survival: 1) current smolt growth profile (12 fpp) is not optimal for Springfield Hatchery, 2) desmoltification/parr reversion prior to ocean entry, and 3) ocean distribution of Springfield-reared smolts does not overlap with mid-Columbia and Sawtooth Valley natural-origin stocks. In concert with acclimating SpFH-reared smolts at the SFH, a group of SpFH-reared smolts were grown to a larger size (10 fpp), beginning the first phase of accessing size-at-release and survival.

Current evaluations of juvenile Sockeye Salmon focus on: 1) evaluating a mitigation strategy that includes various acclimation time at the SFH (intermediate water hardness) on survival, 2) evaluating changes in rearing profile (size-at-release) on survival, and 3) trapping emigrating juveniles from each of the three lakes and providing estimates of emigration timing, smolt size, age composition, and abundance. The Shoshone-Bannock Tribes conduct emigration monitoring on Alturas and Pettit lakes each year while IDFG conducts emigration monitoring on Redfish Lake. In this chapter, emigration monitoring activities for Redfish Lake are described. Emigration monitoring for Alturas and Pettit lakes is reported by the Shoshone-Bannock Tribes under a separate cover (Eaton et al. 2022).

METHODS

Total Sockeye Emigration

The juvenile trap on Redfish Lake Creek (RLCTRP) is located 1.4 km downstream from the lake outlet at a permanent weir site. The trap functions as a juvenile trap for emigrating fish,

and with minor modifications, as a trap for returning adults (Craddock 1958; Bjornn et al. 1968). The trap was operated from early April until fish stopped emigrating from the lake in mid-June.

All Sockeye Salmon smolts captured at RLCTRP were anesthetized in a 50 mg/L solution of buffered tricaine methanesulfonate (MS-222), measured for fork length (nearest 1 mm), and weighed (0.1 gram). Scales were removed from a subsample of ten natural-origin fish per five mm length group and returned to the laboratory for aging (Schrader et al. 2013). The proportions of age-1 and age-2 emigrants were determined by using the RMIX computer program developed by MacDonald and Green (1988). Fin-clip samples were taken from up to 100 natural smolts/day for genetic analyses. All captured non-target species were counted and released immediately.

Approximately 40% of the natural and hatchery origin Sockeye Salmon smolts trapped each day were marked with an upper caudal fin clip and released approximately 250 m upstream of the weir one-half hour after sunset to estimate trap efficiency. All remaining fish were counted and released 15 m downstream of the weir one-half hour after sunset. Flow-through live boxes with locking lids were used to hold fish until the evening release. Emigrant run size was derived using a modified Bailey estimator and 95% bootstrap confidence intervals using methods described by Steinhorst et al. (2004). Additional information regarding sampling methods can be found in https://www.monitoringresources.org/Document/Protocol/Details/1910.

Survival and Travel Time Estimation

Sockeye Salmon smolt survival and travel time to LGR for each SpFH smolt release group, based on size-at-release and acclimation time, was evaluated using PIT tag interrogation data collected at PIT tag detection facilities throughout the Snake and Columbia rivers. Interrogation data were retrieved from the PIT Tag Information System (PTAGIS) maintained by the Pacific States Marine Fisheries Commission (Portland, Oregon). These data were used by PitPro (Westhagen and Skalski 2009) to develop a data file for analysis using program SURPH (Lady et al. 2010). These models utilize PIT tag detections at various dams to develop a Cormack/Jolly-Seber estimate of LGR survival. Profile Likelihood Estimates using the Fletch optimizer were used to identify within-year survival estimates that were significantly different. PitPro also uses PIT tag detection data to estimate average travel time through the hydrosystem. Abundance estimates for each respective release group to LGR was estimated using the SURPH survival estimate multiplied by the emigration estimate of each release group.

Acclimation and Size at Release

The effects of acclimation length on juvenile survival were opportunistically tested by tracking transport and release date of fish PIT tagged to evaluate smolt-to-adult return (SAR) rates. An emergency release of smolts from raceways at the Sawtooth Fish Hatchery into the Salmon River was conducted due to rising water temperatures and turbidity. The first tag group was transported from the SpFH April 19 to the SFH and released directly into the Salmon River on April 30, resulting in an acclimation of 11 d at the SFH. The last tag group was transported from the SpFH on April 28 to the SFH and released into the Salmon River on April 30, resulting in an acclimation of 2 d at the SFH. To test the effects of fish size-at-release, a subsample of smolts (146,885 of the 1,013,340 released) was reared to 10 fish per pound (fpp) relative to the standard 12 fpp at release.

RESULTS

Total Sockeye Emigration

A total of 1,945 natural-origin and 11,539 hatchery-origin Sockeye Salmon smolts were trapped between April 8–June 13, and 783 natural-origin (40% of total trapped) and 2,949 hatchery-origin fish (26% of total trapped) were clipped (Figure 4). Annual trapping efficiency was 26% (Figure 5). Based on observed trapping efficiencies and discharge during emigration monitoring, four intervals were used in the Lincoln-Petersen estimator to develop the abundance estimate for natural origin smolt emigration. Total natural-origin Sockeye Salmon smolt emigration was 7,824 fish (95% CI 6,887–9,010; Table 2). Total hatchery-origin Sockeye Salmon smolt emigration was 59,376 (95% CI 54,903–64,012). Emigrant ages determined from scales indicated that approximately 89% of the natural-origin fish emigrated from Redfish Lake 1 year after hatching and 11% emigrated 2 years after hatching.

Since initiation of the Captive Broodstock Program in the early 1990s, there has been an increasing trend in the number of Sockeye Salmon emigrants from the Sawtooth Valley, mainly from the production and release of hatchery-reared smolts (Figure 6). Total estimated emigration in 1993 was 569 fish (all from natural production) and has steadily increased to 1,089,661 fish in 2021 (1,013,340 smolts reared at SpFH, 59,376 presmolts reared at SpFH, and 16,945 naturally produced fish from Redfish, Pettit, and Alturas lakes).

Survival and Travel Time Estimation

Survival for SpFH-reared smolts from release to LGR in 2021 was 76% (95% CI = 74%–78%) when combining tag groups. This represents a 12% increase in survival from 2020 and a 31% increase from the 2015-2020 average survival (45%; Figure 7). Abundance of SpFH smolts at LGR was 768,112 (Figure 8).

Estimated mean travel time from release to LGR in 2021 for SpFH smolts was 9.3 d. Across a larger time period, annual mean travel times for SpFH smolts ranged from 7.8 d (2018) to 20 d (2017). For juvenile hatchery produced Sockeye Salmon, we observed negative correlations between survival and the mean number of days to migrate to LGR. Mean travel time explained 72% of the variability in survival to LGR for SpFH smolts.

Acclimation and Size at Release

We did not observe significant differences in survival to LGR among release groups based on acclimation time or size-at-release. Smolts survival to LGR for the 12 fpp releases acclimated at the SFH between 2 and 11 d ranged from 73% to 80% (Figure 9). Smolt survival to LGR for the 10 fpp releases acclimated at the SFH between 2 and 7 d ranged from 69% to 78% (Figure 9).

DISCUSSION

Total Sockeye Emigration

The IDFG and SBT monitor natural populations of Sockeye Salmon in Redfish, Alturas, and Pettit lakes as a way to monitor population status and evaluate success of captive and anadromous adult releases. The estimated abundance of Redfish Lake natural emigrants in 2021 was 40% higher than last year's estimate but represented a 51% reduction from the 2010-2020

average. Lower than average abundance may have been caused by releasing fewer captive and anadromous adults into Redfish Lake in 2018 and 2019 to naturally spawn (see Part 4). A total of 510 captive adults produced age-1 emigrants, and 531 captive outplants and 1 anadromous outplant in 2018 produced a smaller proportion of age-2 emigrants. Predicted abundance of Redfish Lake emigrants in 2021 should have been similar to 2020 given similar numbers of captive adults that were released both years; however, more females were released in 2019 (n = 321) compared to 2018 (n = 304). Furthermore, *Bosmina* and *Daphnia* biomass was nearly 3 times higher in 2020 compared to 2019 in Redfish Lake (Eaton et al. 2021), which would have positively impacted cohort abundance of the dominant age-1 year class emigrating from the lake in 2021.

Bjornn et al. (1968) conducted smolt emigration and adult return monitoring between 1954 and 1966; their work provides a detailed account of Sockeye Salmon life history in Redfish Lake. Smolts emigrate at either age-1 or age-2 and the proportions vary every year. Bjornn et al. (1968) observed a positive relationship between the age that juvenile Sockeye Salmon migrated from Redfish Lake and their growth during the first summer. When mean length of a year class approached 100 mm, over 90% migrated as yearlings. During their 11-year study, Bjornn et al. (1968) noted a dominance of age-1 smolts for six of the 11 years. The dominance of age 1 smolts (range 69% in 2009 to 98% in 2013) has been observed over the past 21 years (2001-2021) in Redfish Lake. Age at emigration suggests adequate dietary resources and nutrient availability for juvenile Sockeye Salmon in Redfish Lake.

Survival and Travel Time Estimation

Beginning in the late 1990s, the IDFG began juvenile monitoring using PIT-tagged emigrants to estimate total natural-origin abundance and to estimate survival of natural-origin and hatchery-reared emigrants from the Sawtooth Valley to LGR. In 2021, PIT tagging natural origin and hatchery presmolts was discontinued and replaced with an upper caudal fin clip to identify fish recaptured in the trap. Variability in survival of natural-origin emigrants that were PIT tagged did not show any clear pattern with observed survival with hatchery-origin smolts and SARs for PIT-tagged natural-origin fish was disproportionally low compared to SARs for PIT-tagged hatchery-reared smolts. Across a larger time series, variability in survival of natural origin emigrants was not explained by travel time and supports the hypothesis that either mortality is more immediate in the upper river for the lower density natural emigrants or there is a possible tagging effect.

Environmental conditions in the spring of 2021 were characterized by average water temperature, above average flow, and high spill during most of the migration season and resulted in survival estimates to LGR that were higher than average for acclimated SpFH-reared smolts. These higher survival rates may have also been attributed to releasing smolts directly into the Salmon River rather than Redfish Lake Creek. Besides travel time, which explained 41% of the variability in survival for SpFH produced smolts, it is not clear what other processes are driving variable survival between years. Environmental conditions such as water temperature and turbidity could all be contributing factors in addition to size-at-release, fish health, and release numbers (predator saturation).

Acclimation and Size at Release

A focus of the program has been developing best management practices at the new SpFH. In-hatchery performance and survival at the SpFH have been typical for the species (Baker et al. 2021; Filloon 2021); however, unexpectedly high post-release mortality rates were observed in the first cohorts of SpFH-reared smolts (BY 2013-2015). Water chemistry differences (i.e.,

hardness levels) between SpFH Hatchery and RFLC were identified as the causes of the observed reduction in emigration survival (Trushenski et al. 2019). A variety of mitigation strategies were tested, but stepwise acclimation from high to medium hardness water at the SFH, then medium to low hardness water proved to be the most effective means of addressing water chemistry differences (Trushenski et al. 2019). Acclimation testing in 2020 suggested that 10-17 d was sufficient to mitigate effects of stress caused by changes in water chemistry on post-release survival. High survival to LGR for a smaller group of fish acclimated for 7 d in 2019, supports the hypothesis that shorter acclimation times may be sufficient to mitigate effects of water chemistry (Johnson et al. 2020). Smolt releases were acclimated for a fourth year at the SFH. Relatively high survival estimates at LGR for an experimental group acclimated for 2 d indicated that shorter acclimation times could mitigate the effects of water chemistry differences. Identifying minimum acclimation time at the SFH allows project managers the greatest flexibility to acclimate sockeye, enabling them to respond to unforeseen circumstances such as disease outbreaks or changes in environmental conditions (e.g., increased water temperature and turbidity).

Our results indicate that manipulating smolt size did not impact immediate post-release survival; however, the effects of smolt size on smolt-to-adult survival cannot be inferred at this time. Several studies indicate survival advantages for larger smolts entering the ocean particularly during periods of low upwelling and poor marine survival (Holtby et al. 1990, Miyakoshi et al. 2001, Henderson and Cass 2011).

Understanding differences in survival between release groups and factors that affect these differences continues to be an important component of the program. Studies of SpFH-reared smolts that are PIT tagged and acclimated at varying times at the SFH will be continued along with growth studies (size-at-release) to further investigate the combination of factors that yields the highest downstream survival and SARs. It is clear that the immediate post-release morbidity and mortality observed in previous years can be addressed through short-term (>2 d) acclimation of smolts to receiving water, and releasing larger smolts did not impair immediate survival.

Table 2. Estimated numbers of natural origin Sockeye Salmon smolts emigrating from Redfish Lake Creek. Includes emigrants from egg box releases and any natural production within the lakes.

	Estimated Unmarked Emigration RFLC	**Confidence Interval (Upper)**	**Confidence Interval (Lower)**
1993[a]	569		
1994[a]	1,820		
1995[a]	357		
1996[a]	923		
1997[a]	304		
1998[a]	2,799		
1999	1,936	2,401	1,607
2000	302	400	237
2001	110	189	71
2002	4,951	5,471	4,524
2003	4,637	4,935	4,360
2004	4,476	4,894	4,122
2005	7,870	8,538	7,255
2006	6,065	7,504	4,837
2007	5,280	6,352	4,504
2008	6,237	7,624	5,210
2009	4,552	5,125	4,051
2010	14,012	15,621	12,615
2011	6,879	7,748	6,144
2012	31,297	38,338	27,463
2013	18,673	20,918	16,790
2014	3,583	3,853	3,343
2015	9,734	10,374	9,113
2016	19,863	21,378	18,475
2017	3,151	3,667	3,729
2018	27,557	37,971	20,742
2019	35,655	38,212	33,372
2020	4,709	5,378	4,118
2021	7,824	9,010	6,887

[a] Confidence limits not available.

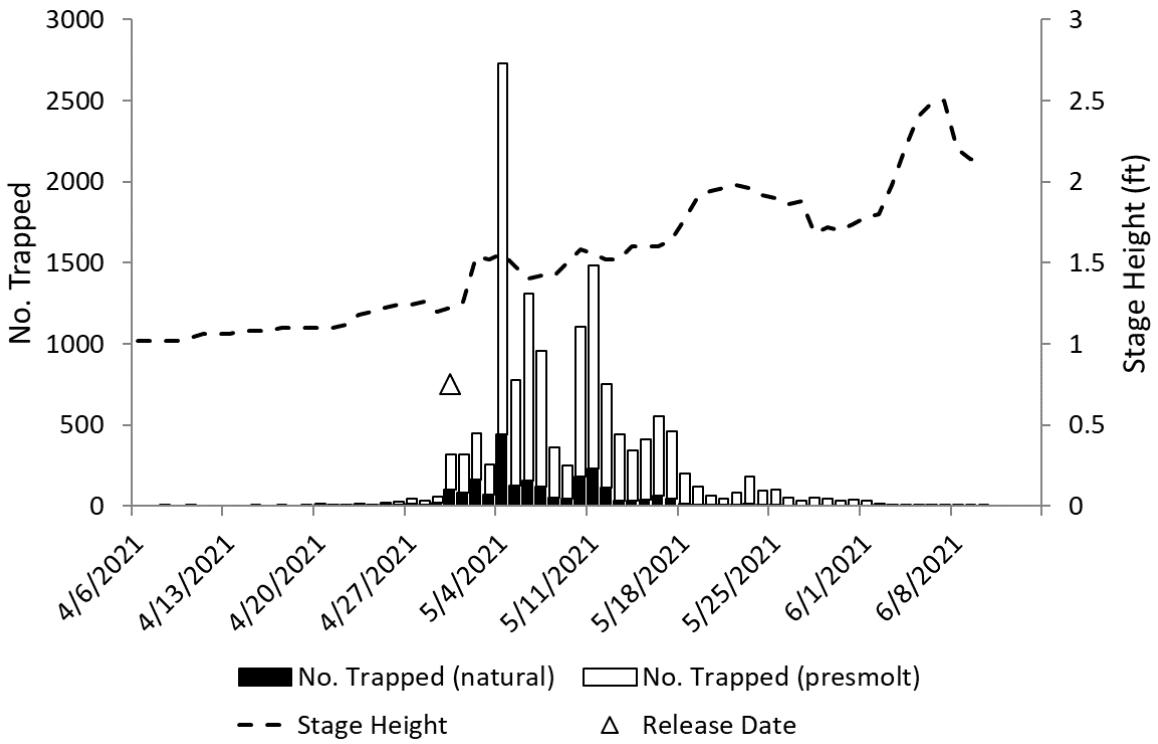

Figure 4. Numbers of natural and hatchery-origin fish trapped daily at Redfish Lake Creek trap and timing of hatchery smolt releases, 2021.

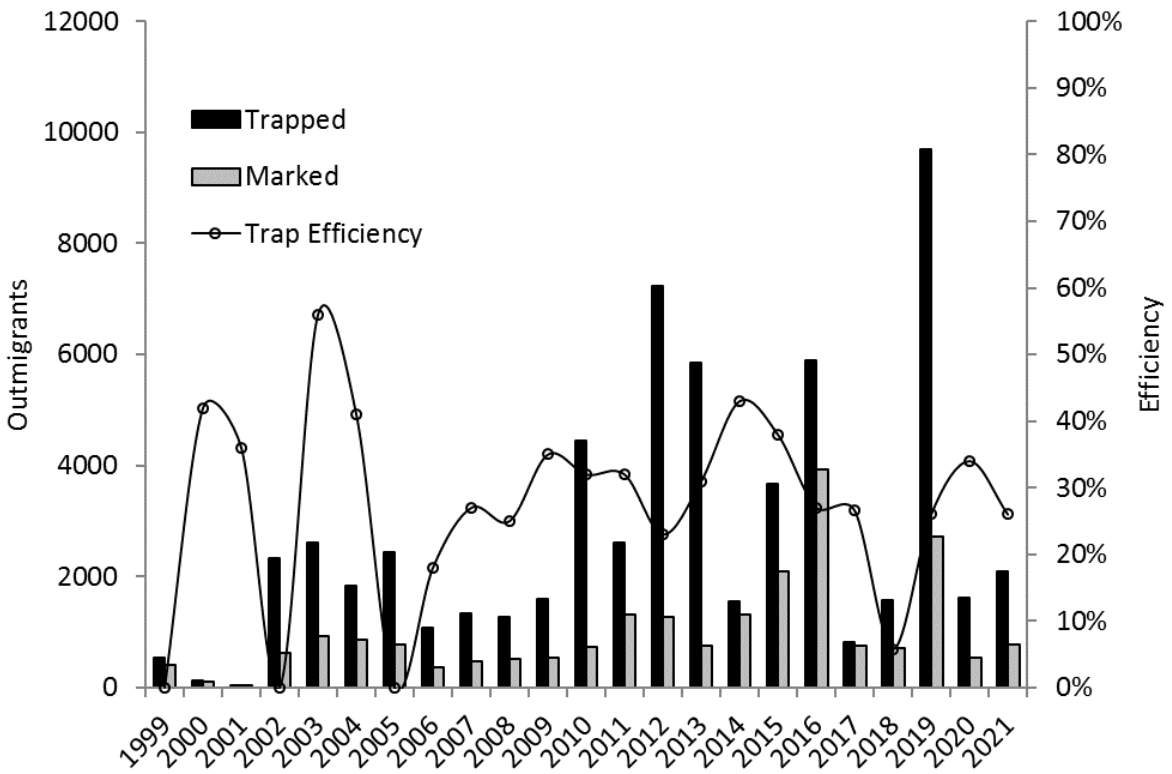

Figure 5. Number of natural-origin Sockeye Salmon emigrants trapped and either PIT-tagged (prior to 2020) or upper caudal fin-clipped (2021) and the trap efficiency at the Redfish Lake Creek trap.

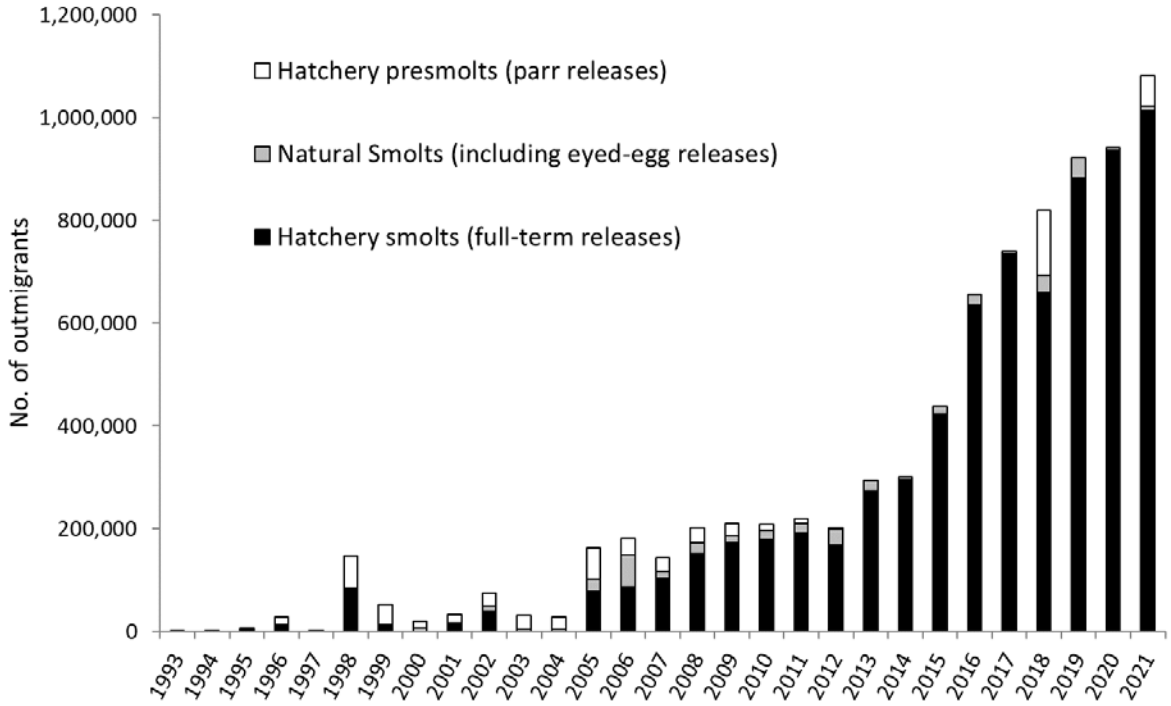

Figure 6. Estimated annual numbers of Sockeye Salmon smolt emigrants from the Sawtooth Valley. This includes all hatchery smolt releases, known emigrants originating from hatchery presmolts, and estimates of unmarked juveniles from Redfish, Alturas, and Pettit lakes.

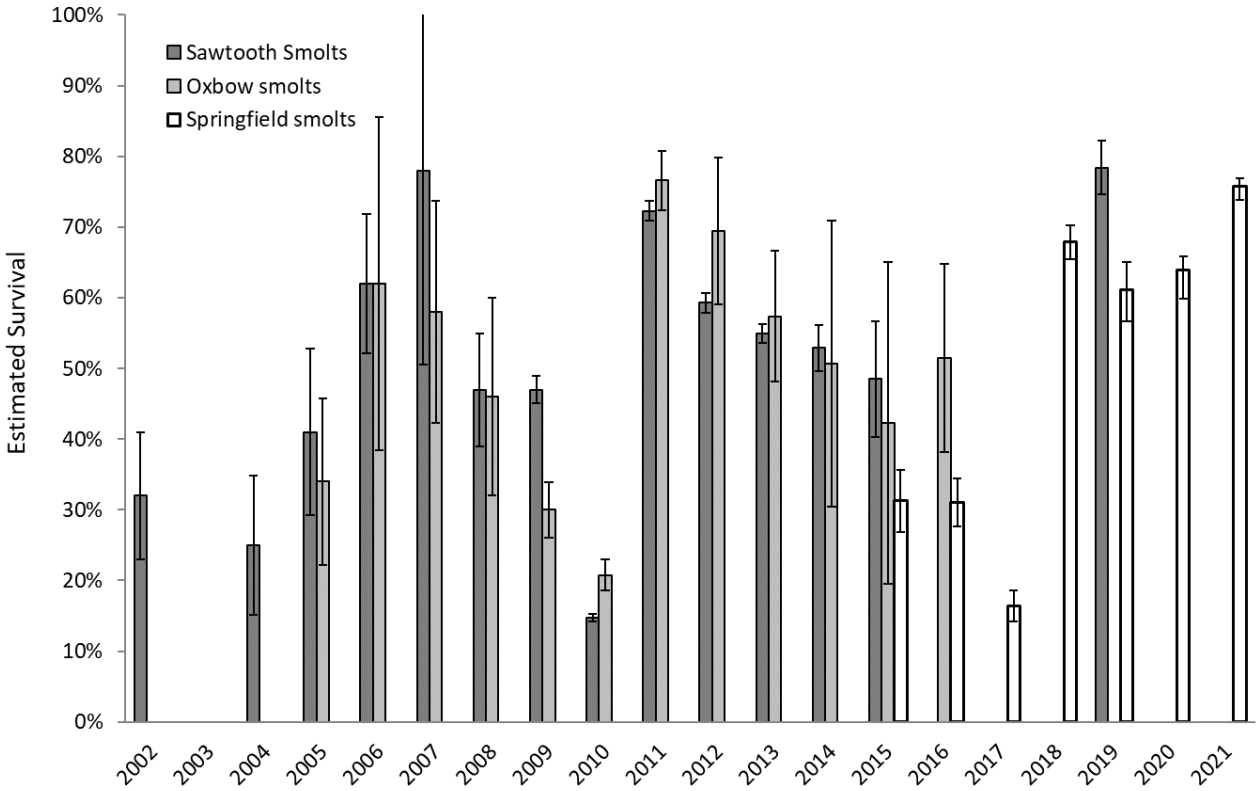

Figure 7. Estimated survival to LGR for Sawtooth Hatchery smolts from 2002-2019, Oxbow Hatchery smolts from 2005-2016, and Springfield Hatchery smolts, 2015-2021. Error bars represent 95% CIs.

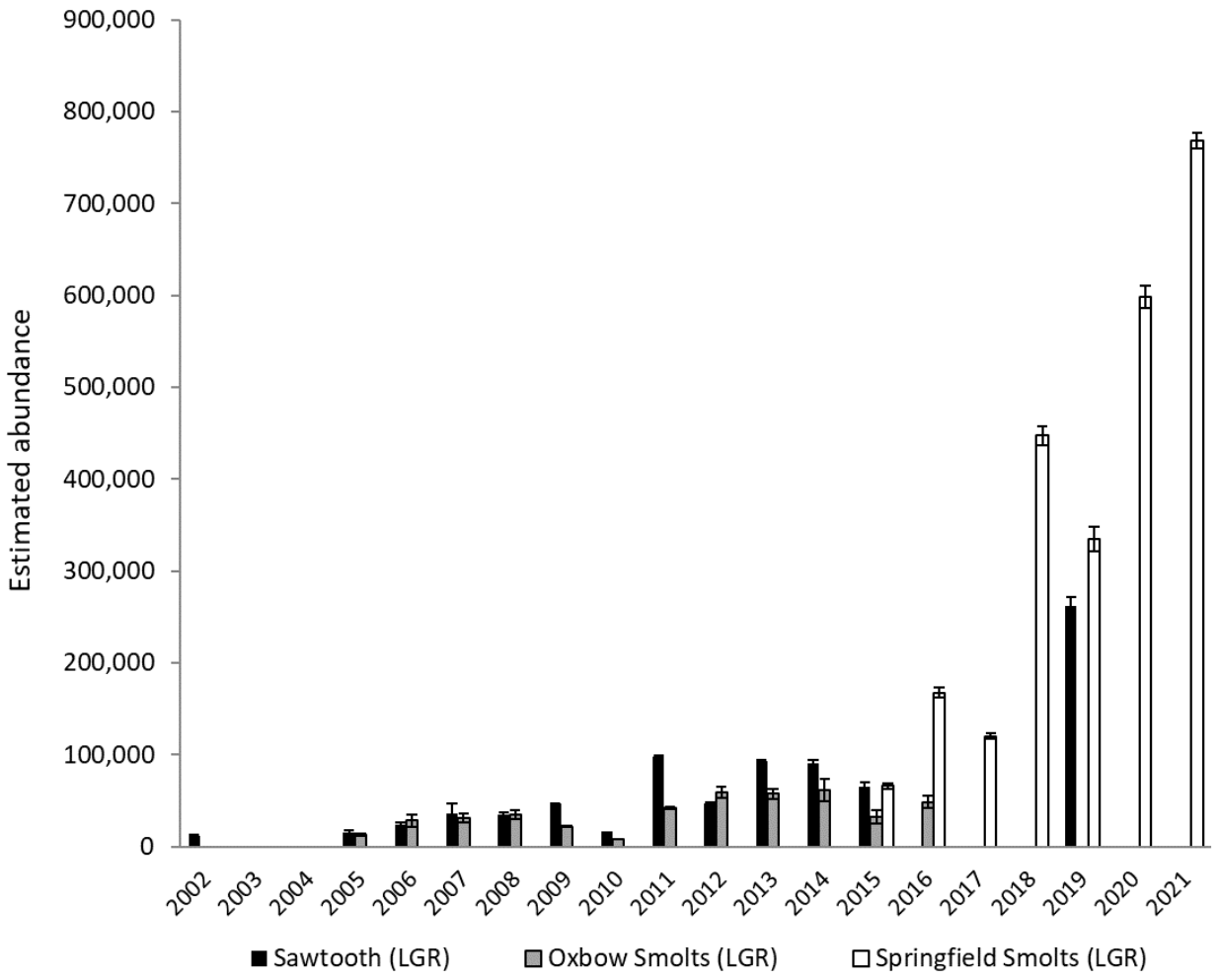

Figure 8. Estimated abundance of Oxbow, Sawtooth, and Springfield hatchery smolts at LGR, 2002-2021. Error bars represent 95% CIs.

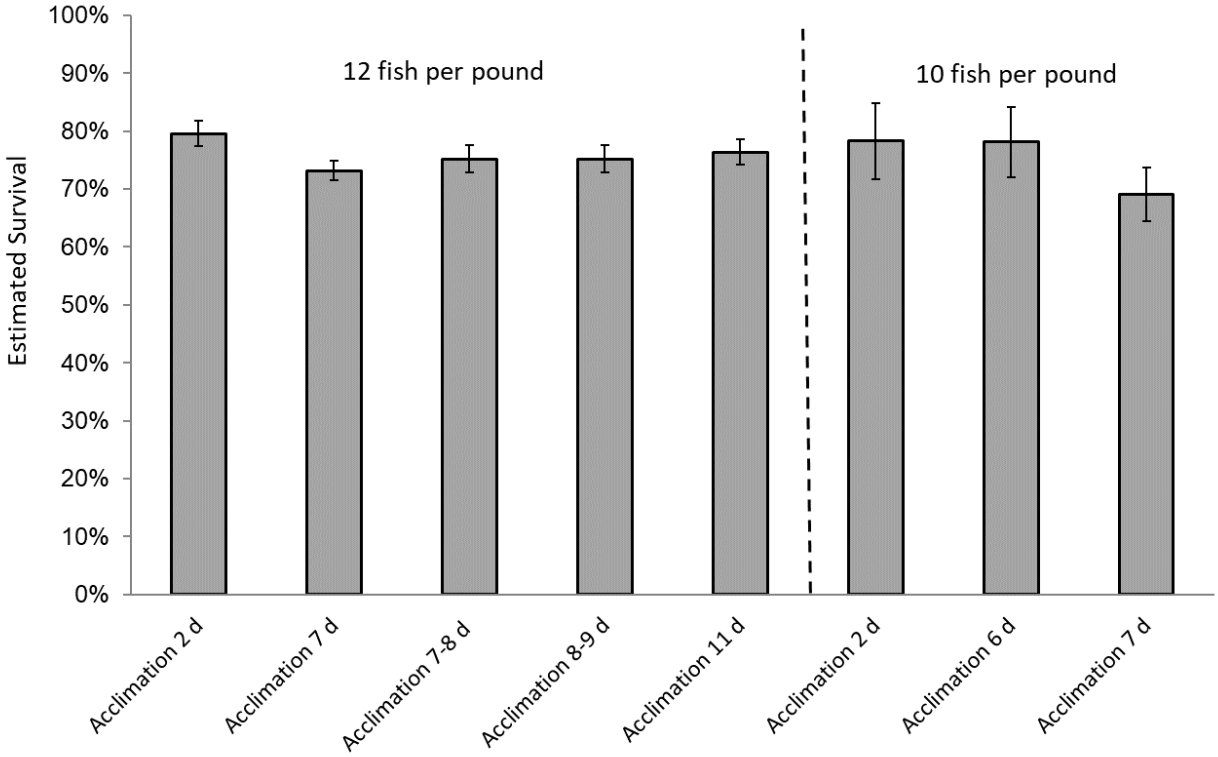

Figure 9. Estimated survival to LGR for Springfield Hatchery-reared smolts, 2021. Error bars represent 95% confidence intervals.

PART 4—ANADROMOUS ADULT TRAPPING AND NATURAL PRODUCTION MONITORING AND EVALUATIONS

INTRODUCTION

Research on adult Snake River Sockeye Salmon focuses on collecting data for all four viable salmonid population (VSP) parameters: abundance, productivity or population growth rate, diversity, and spatial structure. The current focus of the program is centered on Redfish Lake as it offers the greatest production potential, but spatial structure and diversity have been addressed for this ESU by releasing fish at various life stages into other nursery lakes as well (Alturas and Pettit). Spatial structure will become more of an emphasis in the recolonization phase of the program as adults are released into multiple lakes for natural spawning. A viable salmonid population is defined as a population that has a negligible risk of extinction due to threats from demographic, environmental, or genetic variation over a 100-year time period (McElhany et al. 2000). The recovery plan for Snake River Sockeye Salmon has been completed (NMFS 2015), and VSP information will be vital for future status assessments and the delisting or reclassification (i.e., from endangered to threatened) of this ESU. In order to meet biological and broad sense recovery goals, a minimum abundance threshold of 1,000 natural-origin spawners is needed for Redfish and Alturas lakes, while 500 natural-origin spawners are needed for Pettit Lake. In addition, the population growth rate must be stable or increasing, and there must be a moderate risk rating for spatial structure and diversity for a viable population (NMFS 2015).

In this report, we provide information regarding adult migration through the FCRPS, trapping activities, adult releases, and genetic analyses to estimate abundance and productivity for natural and hatchery origin fish. Genetic analyses of returning adults and corresponding PIT tag interrogations through the FCRPS also provide the program with biological metrics such as run timing and migration rates, sex ratios, age structure, and survival of adults from Bonneville Dam to the Sawtooth Valley for the anadromous component. These parameters were measured by collecting information across a variety of life stages and time points. Data from adults reported here paired with associated juvenile life-stage metrics reported above allows us to adaptively manage over time and help inform critical aspects to focus recovery efforts.

METHODS

Trapping of Anadromous Adult Returns

Two adult collection facilities were used to capture anadromous returning adult Snake River Sockeye Salmon. The first trap was located on Redfish Lake Creek, 1.4 km downstream from the lake outlet. The second trap is located at the SFH on the upper Salmon River approximately 10.1 river km upstream from the town of Stanley, Idaho. The traps were placed into operation in July and operated until no adults had been trapped for 5-7 consecutive days, weather prohibited trap operation, or permitted take of bull trout (*Salvelinus confluentus*) was reached.

Traps were checked upon arrival each morning. Collected adults were transported from the Sawtooth Valley to the EFH, released upstream to continue their migration (Redfish Lake Creek weir), or released into Pettit Lake (SFH weir). Adults collected in the SFH weir received a caudal fin punch to facilitate identification of trapping location at EFH. The adults that were brought to EFH were anesthetized in a 50 mg/L solution of MS-222 and checked for the presence of a PIT tag. Fork length (mm), sex, differential marks (such as adipose clips), and body injuries (if present) were recorded. Untagged fish were assigned a PIT tag (shrink wrapped to a cable zip tie) so

individuals could be identified during sorting and either released for volitional spawning or incorporated into the captive broodstock pending results from genetic analysis.

Lower Granite Biological Sampling

Sockeye Salmon were trapped five days per week (Mon-Fri) at LGR at a rate of 20% from 28 June through 30 August. Adults trapped between 6-29 July were transported to the EFH (see Trap and Haul Operations below). Tissue samples were collected and genotyped from all adults trapped in the LGR fishway and compared to those sampled at Sawtooth Valley basin traps to determine which fish survived and were recaptured in the basin.

Trap and Haul Operations

The Army Corp of Engineers, NOAA, and IDFG personnel began emergency trapping of adult Sockeye Salmon at the LGR adult fish trap on 6 July when high water temperatures in the Columbia and Snake rivers resulted in delayed passage and reduced hydrosystem conversion. Emergency trapping ended on 29 July. Genetic samples were taken from all of the fish trapped at LGR so that genetic assignments could be performed with a larger baseline of *O. nerka* throughout the Columbia River Basin to exclude Columbia River stocks from inclusion in the broodstock or release into Sawtooth Valley lakes.

Run Timing and Hydrosystem Survival

Utilizing the data collected from PIT tag interrogation sites throughout the FCRPS and adult trapping locations, run timing and upriver conversion (e.g., survival or escapement) rates were estimated from Bonneville Dam to the Sawtooth Valley. Window and nighttime counts generated at LGR were queried through the Columbia River Daily Access in Real Time (DART) website (http://www.cbr.washington.edu/dart/query/adult_daily) after adjusting adult numbers at LGR using PIT tag fallback percentage (http://www.cbr.washington.edu/fallback). These window counts were decomposed into escapement estimates using the SCOBI (Salmon Composition Bootstrap Intervals) model which combined the window counts with the adult trap sample data on a stratified basis to account for changes in the trapping rate and run characteristics to decompose window counts at LGR through time (Delomas and Hess 2020).

Adult Spawning in Redfish Lake

On September 14 and 15, adult Sockeye Salmon were released to Redfish Lake for volitional spawning. An annual evaluation of spawning activity was conducted on Redfish Lake on 5 November by visually counting areas of excavation from a boat. Areas of excavation (possible redds) were generally 3 m x 3 m in size and likely represented spawning events by multiple parents. The number of redds produced per female released was estimated by dividing the total number of excavated areas by the number of females released. This metric assumes that all released females produced a redd and that all redds were visible and counted during the count.

Productivity

Productivity was measured as: 1) basin-to-basin SARs to evaluate smolt performance and 2) recruitment per female to evaluate relative contribution of each reintroduction strategy. Adults returning to the Sawtooth Valley included marked (ad-clipped) and/or tagged (PIT and PBT)

hatchery-origin and natural-origin adults, and unmarked, untagged natural-origin fish. In order to assign age and origin to each returning adult, PBT assignment, marks, and fork length were used.

All returning fish were screened for a parentage-based tag, which are used to determine the origin (release strategy) and age of fish. A fin tissue sample was taken for genetic analyses from all fish trapped at the RFLC or SFH weirs. Potential parents are genetically sampled in the hatchery prior to spawning or release into the natural environment using methods described in Kozfkay et al. (2019). Parentage assignments are performed using the program SNPPIT (Anderson 2010b) allowing up to 10% missing genotype data. An estimated SNP genotyping error rate of 1% per locus is used, and assignments are accepted if LOD scores are ≥14, false discovery rate (FDR) <1%, and posterior probability relationship identifies a parent-offspring trio (C_Se_Se).

Genetic stock of origin is assigned to each individual without a PBT assignment using the method of Smouse et al. (1990) as implemented in the program *gsi_sim* (Anderson et al. 2008; Anderson 2010a). A reference baseline of 21 kokanee and Sockeye Salmon stocks distributed throughout the Columbia River basin was developed by the Columbia River Inter-Tribal Fish Commission (CRITFC) and allows for identification of resident and anadromous *O. nerka* in the Sawtooth Valley lakes (version 3.0; Hess et al. 2018). Additional information regarding methods for genetic analysis of Sockeye Salmon can be found at https://www.monitoringresources.org/Document/Protocol/Details/3557.

Ages for the unassigned fish were estimated using an age-length key (fishR Vignette-Age-Length keys) to assign age from lengths (Ogle 2013). Genetic ages and lengths of the assigned fish were used as known fish to populate the key. The trapping location of the fish was used to designate a release strategy for unassigned adults for productivity metric development (discussed below). Basin-to-basin SAR estimates were generated by summing age-3, age-4, and age-5 returns from the appropriate release strategy or group and dividing by the estimated emigration number from the appropriate BY for each release strategy or group.

With the completion of the 2021 return year, we were able to finalize productivity metrics for BY2016. SAR estimates for BY2017 are only a minimum estimate, as they do not include any 5-year-old fish. Smolt production was summed using age-1 and age-2 smolt estimates emigrating from basin lakes for natural production for Redfish, Alturas, and Pettit lakes and using release numbers for the full-term hatchery smolt components. Juvenile emigration data used to calculate SARs for BY04-17 are presented in Appendix D.

Recruitment was measured as the number of returning adults (recruits) per average captive female because factorial mating designs were used in the hatchery. Therefore, while we could assign all individuals to a release strategy, we could not directly calculate recruitment at the release strategy scale because a single female could contribute eggs to multiple strategies. To calculate recruitment we divided the number of eggs assigned to each release strategy by the average fecundity of a captive Snake River Sockeye Salmon of 1,641 eggs (Kozfkay et al. 2019) to estimate the number of "female equivalents"' Finally, the number of returning anadromous adults was then divided by the number of female equivalents to estimate recruitment for each brood year (Kozfkay et al. 2019; Johnson et al. 2020).

RESULTS

Trapping Of Anadromous Adult Returns

A total of 240 anadromous Snake River Sockeye Salmon adults were collected at fish traps in 2021. Fifty adults were trapped at the RFLC trap, five were trapped at the SFH weir, and 185 were trapped at LGR and transported to the EFH. Of the 240 fish that were trapped, 238 were successfully genotyped (99.2% genotyping rate). Using both mark information and assignment data, the composition of the returning adults was primarily (81%) from SFH-reared smolts released into RFLC in 2019. Adult returns originating from SpFH (14%), Redfish Lake (3%), and Pettit Lake (2%) were also observed (Figure 10). No out-of-basin Sockeye Salmon were trapped in the Sawtooth Valley.

The age structure of returning adults in 2021 consisted mostly of 4-year-olds (Appendix D). Average fork lengths of 4-year-old natural-origin and hatchery-origin returns in 2021 were 501 mm and 526 mm, respectively. Average size-at-age was 8-10% larger than in 2020 but similar to previous years, which ranged from 516 mm (2018) to 550 mm (2017) for 4-year-old natural-origin returns and 520 mm (2018) to 556 mm (2009) for 4-year-old hatchery-origin returns (Figure 11; Johnson et al. 2020).

Lower Granite Biological Sampling

From 28 June—30 August, 267 unique adult Sockeye Salmon were trapped and sampled at LGR (36 unclipped and 231 adipose fin clipped). Two hundred and one adult Sockeye Salmon were transported to EFH (see Trap and Haul Operations section below) and the remaining 66 adults (8 unclipped and 58 adipose fin clipped) were released back into the fishway. Genetic analysis indicated that two of the fish released into the fishway were out-of-basin stocks (one originated from the Columbia River Wenatchee population and the other from the Speelyai population). Conversion rates for the 64 Stanley-basin origin adult Sockeye Salmon genetically sampled at the LGR trap was 3%.

Trap and Haul Operations

From 6-29 July, 201 adult Sockeye Salmon (28 unclipped and 173 adipose fin clipped) were trapped at the LGR adult trap and transported to the EFH. Genetic analysis indicated that 16 of the unclipped fish transported to the EFH originated from the Columbia River Wenatchee population and were moved to the MK Nature Center in Boise, Idaho for public viewing.

Run Timing and Hydrosystem Survival

Run timing of adult Sockeye Salmon (aggregate) in 2021 closely tracked the long-term average for arrival at Bonneville Dam. Based on PIT tag detections, Snake River Sockeye Salmon began arriving earlier at Lower Granite Dam as the run progressed and later to Sawtooth Valley traps (Figure 12). Late run timing to the basin was an artifact of trapping and transporting a disproportionately large number of PIT-tagged fish arriving early at LGR. Of the 15 PIT-tagged fish detected at LGR, 7 (47%) were trapped and transferred to the EFH between 6 July and 29 July.

During 2021, the average migration time through the Lower Columbia River (between Bonneville and McNary dams) and Lower Snake River (between Ice Harbor Dam and LGR) was

5.5 d (n = 56) and 7.2 d (n = 25), respectively (Table 5). The travel time from LGR to the RFLCT for the only PIT-tagged Sockeye Salmon that returned was 48 d.

Conversion rates in the Lower Columbia and Snake rivers between Bonneville and Lower Granite dams were below average in 2021 based on PIT tag interrogations at Lower Columbia and Snake River dams (Table 5). Survival through the lower Columbia River from Bonneville Dam to LGR was 27% (15 of 56 fish detected at Bonneville were detected at LGR). Conversion rates from LGR to the Sawtooth Valley for PIT-tagged fish was 13% (n = 8; Table 6).

Adult Spawning in Redfish, Alturas, and Pettit Lakes

Prespawn adults from the Captive Broodstock Program have been released almost every year since 1993 (Hebdon et al. 2004) and beginning in 2008, anadromous fish have been released into the Sawtooth Valley lakes. The number of anadromous Sockeye Salmon released into Redfish, Alturas, and Pettit lakes has varied in response to returns to the Sawtooth Valley.

In 2021, 1,063 captive (553 females) and 61 anadromous (23 females) adults were released into Redfish Lake for volitional spawning. The number of females released (anadromous and captive) has explained 64% of the variability in the estimated number brood year of emigrants leaving Redfish Lake (Figure 13).

Two hundred sixty-eight areas of excavation were observed in Redfish Lake (0.5 redds/female; Figure 14). Areas of excavation were identified near the U.S. Forest Service Transfer dock, on the beach southeast of the Redfish Lake Creek inlet, within the southern snorkel transect area, at Sockeye Salmon Beach, and along the west shore.

Productivity

Productivity as measured by the ratio of smolt-to-adult returns (SARs) is presented in Appendix D for brood years (BY) 2004-2017. With the return of 5-year-old adults in 2021, SARs for BY2016 are 0.31% for natural-origin smolts migrating from Redfish Lake, 0.61% for natural-origin smolts migrating from Pettit and Alturas lakes, <0.01% for SpFH-reared smolts, and <0.01% for SpFH-reared presmolt releases. Current SARs for BY2017 are <0.01% for SpFH-reared smolts, 0.06% for Sawtooth Hatchery-reared smolts, 0.01% for natural-origin smolts migrating from Redfish Lake, and 0.06% for natural-origin smolts migrating from Pettit and Alturas lakes. Low adult returns to the basin the last six years have resulted in below average productivity. Mean SARs for natural production (BY 2012-2016) was 0.22% and have ranged from 0.66% (BY2012) to 0.02% (BY2015). SARs for hatchery produced smolts has also been below average; mean SARs were: 0.31% for OFH smolts (BY2010-2014), 0.09% for SFH smolts (BY2010-2013), and <0.01% for SpFH smolts (BY2013-2016).

Recruitment has averaged 6.44 recruits per female for OFH smolts (BY 2004-2014), 2.75 recruits per female for SFH smolts (BY 2004-2013), 0.32 recruits per female for natural spawning adults in Redfish Lake (BY 2004-2016; Table 7), and <0.01 recruits per female for SpFH smolts (BY 2013-2016; Figure 15).

DISCUSSION

Anadromous Adult Returns, Run Timing, and Hydrosystem Survival

The incorporation of anadromous adults into the captive broodstock continues to be an important part of the program to prevent divergence between the captive and wild populations. Increases in the numbers of anadromous Snake River Sockeye Salmon returns from 2008-2016 (excluding 2015) was the result of a combination of factors, which include increased hatchery production (primarily from smolt releases) and favorable marine conditions (Williams et al. 2014). More recently, marginal to poor survival and growth in the ocean have negatively impacted adult returns to the Sawtooth Valley, which can be seen in reduced natural production in Redfish Lake (Table 6). Suboptimal sea surface temperatures may also result in increased predation due to predator/prey mismatches in timing (Bakun 2015). We also expected to see impacts of increased competition for adults returning in 2021 with pink salmon (*Oncorhynchus gorbuscha*), which are more abundant than Sockeye Salmon in the North Pacific Ocean and share ecological requirements (Ruggerone and Connors 2015). Historically, we observe an approximately 50% decrease in adult returns of Sockeye Salmon to both Bonneville Dam and the Sawtooth basin associated with high pink salmon abundance in odd years (Figure 16).

The summer migration timing of Snake River Sockeye Salmon makes them highly susceptible to water temperature related passage issues resulting in migration delays, reduced conversion rates, and increased mortality. As PIT-tagged adults began to arrive at Bonneville Dam, water temperature, and conversion rates were closely monitored and reported on a weekly basis. Conversion rates and travel times in the Lower Columbia and Snake rivers based on PIT tag records indicated fish passage concerns between Bonneville and Lower Granite dams. In late June, IDFG and NOAA became increasingly concerned that temperature related environmental conditions were resulting in passage delays and below average conversion. Emergency adult trap and haul from LGR was initiated and resulted in the collection of 20% of the estimated adult return to Lower Granite. Temperatures in the Snake River upstream of the Clearwater River confluence and in the lower Salmon River were observed near or above lethal levels for salmonids and survival of the PIT and genetically tagged fish that were not collected for transport was low (3-13%). LGR-to-basin conversion rates are likely biased since more early-arriving rather than late-arriving fish were transported and conversion rates to the Sawtooth Valley are highly dependent on arrival time at LGR (Johnson et al. 2021).

Genotyping adult Sockeye Salmon at the LGR fish ladder using a genetic marker panel that differentiates between Columbia River Sockeye Salmon stocks began in 2015, and we have identified Columbia River Sockeye Salmon in 2015 and from 2018-2021. Based on tissue samples collected at LGR, 47% of Sockeye Salmon passing LGR were from Columbia River stocks which was concerning when evaluating in-season passage metrics. Identification of these fish appears dependent on 1) being able to sample late in the return when they may be passing LGR as a result of cool water additions in the fish ladder, and 2) having a marker panel that is able to differentiate these stocks. It is important to note that the vast differences in run size between Columbia and Snake river Sockeye stocks means that very small stray rates for Columbia River stocks can have a large effect on conversion rate estimates using window counts in the Lower Snake River for the Snake River sockeye run as we observed in 2019 and 2020 (Johnson et al. 2021).

Adult Spawning in Redfish, Alturas, and Pettit lakes

Spawning locations were similar among years with the majority of redds at two locations in the south end of Redfish Lake (Johnson et al. 2019; Peterson et al. 2014). Redd counts were conducted in one day at the end of the season which may explain, in part, some of the observed variability between the number of females released and the number of redds per female (e.g., 2010, 2013, and 2016). A variety of factors may affect our ability to accurately count redds during the final count and may include water clarity, viewing conditions (weather related issues such as storms vs. sunny), and adult densities released into the lake. The number of residual adults present on the spawning grounds may also skew our estimates, because residual production was not estimated within Redfish Lake. Despite these difficulties, redd count data is an important measure of reproductive success and provides valuable trend data of the reproductive component of populations (Al-Chokhachy and Budy 2005).

Natural productivity metrics provide additional information to monitor the success of volitional spawning within the natural environment. Maturing captive and anadromous adults have been released for volitional spawning since 1993, and there has been a high correlation ($r^2 = 0.64$) between the number of females released and estimated natural juvenile emigrants. In years in which more females were released, we observed higher production of smolts. Although strongly correlated, the contribution of emigrants by residual Sockeye Salmon in Redfish Lake likely explains some of the variability observed between the number of released anadromous and captive females and the number of observed emigrants. Rieman et al. (1994) reported that both anadromous and residual forms of *O. nerka* can produce either resident or anadromous offspring. Additional variability is likely attributed to annual differences in egg-to-fry survival, precision of emigration estimates, and variability in emigration age. Regardless, these results highlight the success of the program and the ability to increase and restore a naturally spawning population in Redfish Lake by using adult releases.

Productivity

Parentage based tagging provides key information regarding the age and origin of returning fish (Campana 2001; Seamons et al. 2009). Generating accurate ages for adult returns is important for assigning fish back to a specific BY for SAR estimation. Accurate age information is critical to calculate productivity estimates (i.e. smolt-to-adult return ratios) and to determine the viability and trajectory of the Sockeye Salmon population for recovery monitoring.

Smolt-to-adult return rates suggest that volitional spawning within Redfish Lake is important to the success of the Snake River Sockeye Salmon Captive Broodstock Program (Kozfkay et al. 2019). Naturally produced emigrants from Redfish Lake have the highest overall survival rates from the smolt-to-adult life stage. Survival of natural-origin smolts to returning adults at Redfish Lake across eight BYs (2004-2011) was similar to those observed by Bjornn et al. (1968) between 1955 and 1964 (Kozfkay et al. 2019). Snake River SARs have been found to be lower than those from upper Columbia River populations (Williams et al. 2014). A larger proportion of juveniles from the Snake River are barged below Bonneville Dam compared to upper Columbia River juveniles that migrate in-river. Migration distance and altitude is also greater for Snake River Sockeye Salmon, and this stock is the southernmost in the species range. Differences in stock productivity (such as size and growth) and migration timing are also likely contributing factors to this reduced survival of Snake River Sockeye Salmon (Williams et al. 2014).

Smolt stocking was observed to produce the highest recruitment among the juvenile release strategies and is the only strategy with returns exceeding replacement in most years

(Johnson et al. 2020). However, the variation observed in productivity among smolt production facilities indicates that smolt releases are not one size fits all. Smolt-to-adult survival of BY2017 SpFH-reared smolts was approximately 11 times lower than BY2017 SFH-reared smolts. Because the BY2017 SpFH and BY2017 SFH smolts had high survival during outmigration, we can infer that the differential survival between the BY2017 SpFH and SFH smolts occurred in the estuary or ocean environments. Evaluations of gill ATPase, lactate, hematocrit levels, and other smoltification indices will begin in 2022 to track smolt development leading up to release. Post-release saltwater challenges will also be performed in 2022 on acclimated (RFLC held) and control (SpFH held) groups to evaluate survival with the transition to seawater.

Adaptive Management—Lessons Learned

Captive broodstock technologies for Sockeye Salmon were considered experimental when the program was initiated; however, the program has taken advantage of the high fecundity of Pacific Salmon and survival benefits that aquaculture provides to successfully avoid population extinction. Snake River Sockeye Salmon anadromous returns remain sporadic as a result of variable and oftentimes marginal in-river and ocean environments. Therefore, the captive broodstock continues to be an important recovery strategy to rebuild the population. Monitoring and evaluation have identified two strategies that result in the highest number of anadromous returns: 1) captive and anadromous adult releases, and 2) hatchery-reared smolt releases. Releasing captive and anadromous adults to volitionally spawn produces the greatest benefits in terms of smolt-to-adult returns (SARs, Kline and Flagg 2014) at the cost of high egg to smolt mortality, and springtime releases of hatchery-reared smolts provides the greatest benefits in terms of recruits per female spawner (R/F, Johnson et al. 2020). This demonstrates the importance of using a two life-stage approach to maximize recovery of this stock.

A working group consisting of fish physiologists, fish health, fish production, and monitoring staff from IDFG, NOAA, SBT, and a Northwest Power and Conservation Council member was established in the fall of 2020 to identify the possible mechanisms leading to poor ocean survival of hatchery-reared smolts due to lower-than-expected smolt-to-adult survival of BY 2016 SpFH smolts. The working group has identified three assessments that will be implemented to determine the causes for this poor ocean survival. They are 1) use isotopic analysis from scales to determine the oceanic distribution of hatchery-origin and natural-origin Snake River Sockeye Salmon, 2) identifying the effects of size-at-release on SAR, and 3) tracking smolt development to determine the ability of SpFH smolts to make the transition into the saltwater environment.

Table 4. Stock assignments for unique putatively natural-origin Sockeye Salmon sampled at the Lower Granite Dam adult trap from 2015-2021.

Return Year	Sample Dates	n	% Snake River
2015	7/13-8/13	19	16%
2016	6/29-7/26	9	100%
2017	6/30-7/21	6	100%
2018	6/29-8/1	23	44%
2019	7/11-8/25	21	5%
2020	7/3-8/27	167	23%
2021	6/28-8/28	36	53%

Table 5. Migration time of PIT-tagged adult Snake River Sockeye Salmon from Bonneville Dam to the Sawtooth Valley.

	2016-2020 Avg. Conv.	2016-2020 Avg. (d)	2021 Avg. Conv.	2021 Avg. (d)
Bonneville – McNary	85%	4.7	55% (n = 56)	5.5
McNary – Ice Harbor	98%	1.7	81% (n = 31)	1.8
Ice Harbor–Lower Granite	97%	4.4	60% (n = 25)	7.2
Lower Granite–Sawtooth basin	51%	49.0	13% (n = 8)	48 (n=1)

Table 6. Survival of PIT-tagged fish from Lower Granite Dam to the Sawtooth Valley, 2008-2021.

Year	# of PIT tags at LGR	# of PIT tags trapped	Conversion rate
2008	10	3	30%
2009	17	11	65%
2010	31	19	74%
2011	332	231	70%
2012	64	34	58%
2013	92	26	28%
2014	198	117	59%
2015	27	7	26%
2016	124	75	60%
2017	42	28	67%
2018	5	2	40%
2019	2	1	50%
2020	5	2	40%
2021*	8	1	13%

*15 PIT tags detected at LGR, 7 PIT tags transported via trap/haul (47%)

Table 7. Natural-origin recruits per female for Snake River Sockeye Salmon, brood years 2004-2016.

Brood year	Redfish Lake
2004	0.36
2005	1.70
2006	0.81
2007	0.13
2008	0.11
2009	0.21
2010	0.54
2011	0.04
2012	0.07
2013	0.07
2014	0.02
2015	<0.01
2016	0.15

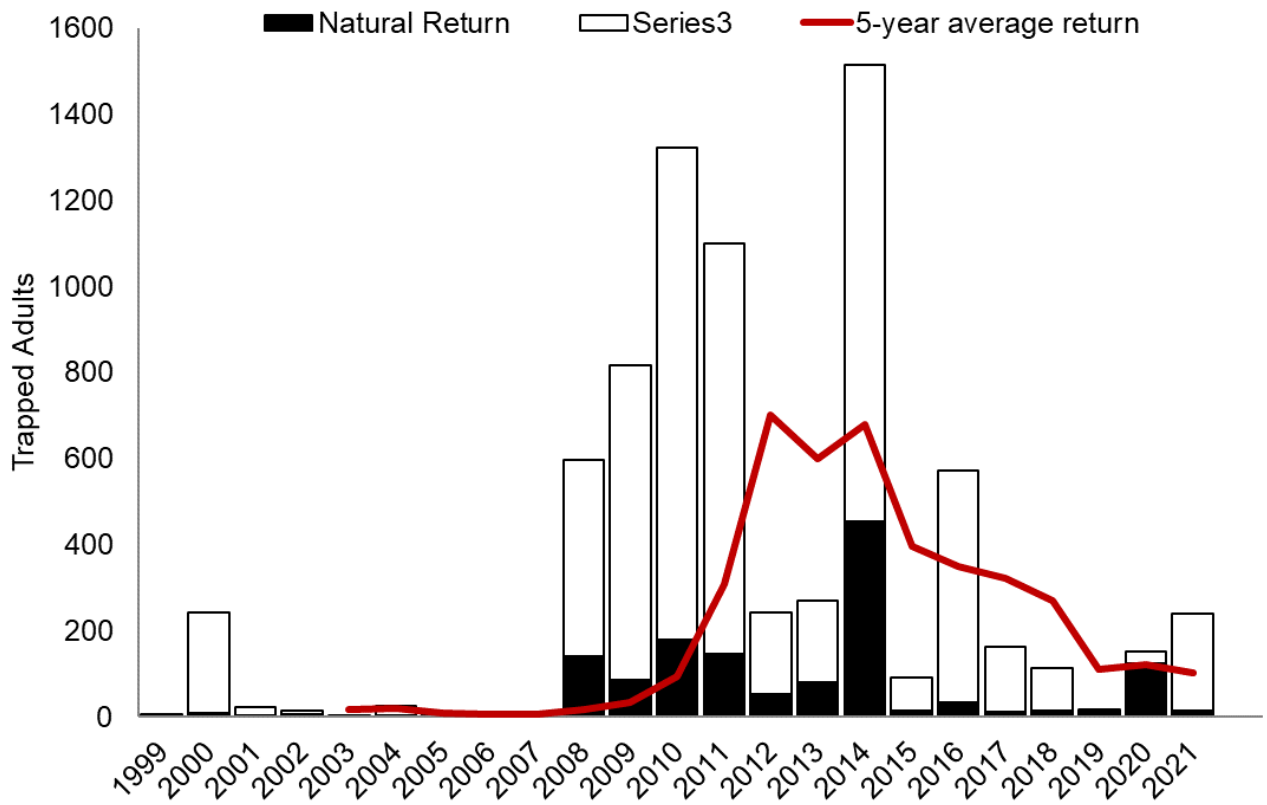

Figure 10. Anadromous Sockeye Salmon adults returning to the Sawtooth Valley traps. Includes adults that were trapped and transported from Lower Granite Dam in 2015 (n = 35) and 2021 (n = 185).

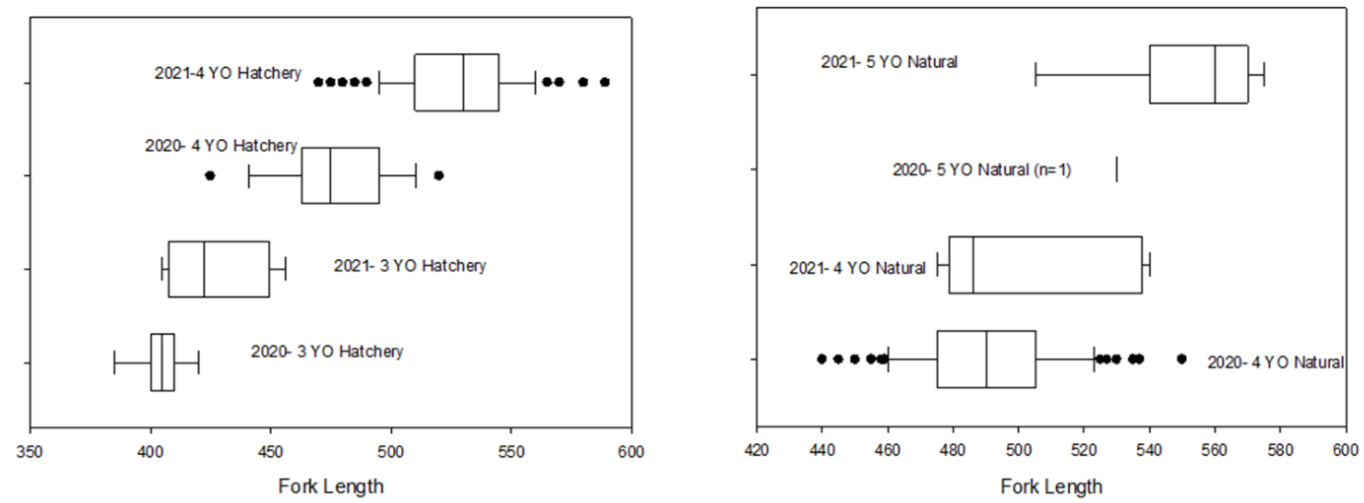

Figure 11. Size-at-age for anadromous Sockeye Salmon adults returning to the Sawtooth Valley traps, 2020 and 2021.

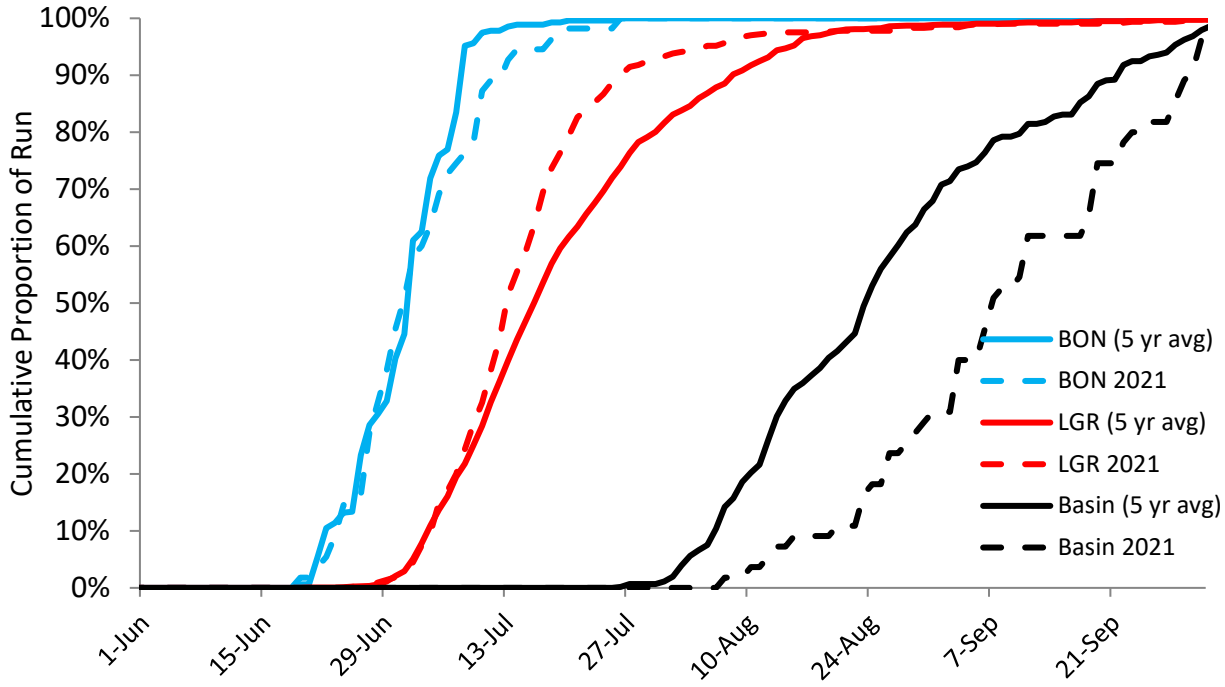

Figure 12. Adult Snake River Sockeye Salmon return timing to Bonneville Dam (BON) based on PIT tag detections, LGR window counts, and Sawtooth Valley traps.

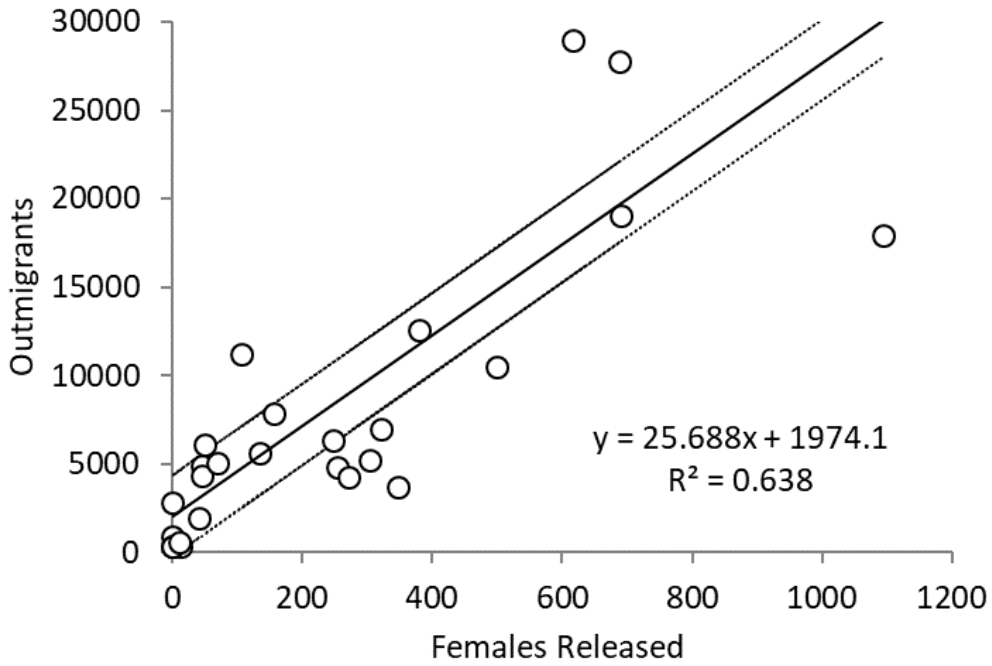

Figure 13. Relationship between the number of females released (both captive and anadromous) and the estimated number of emigrants leaving Redfish Lake from 1993-2021 Upper and lower 95% CI are indicated by dotted lines.

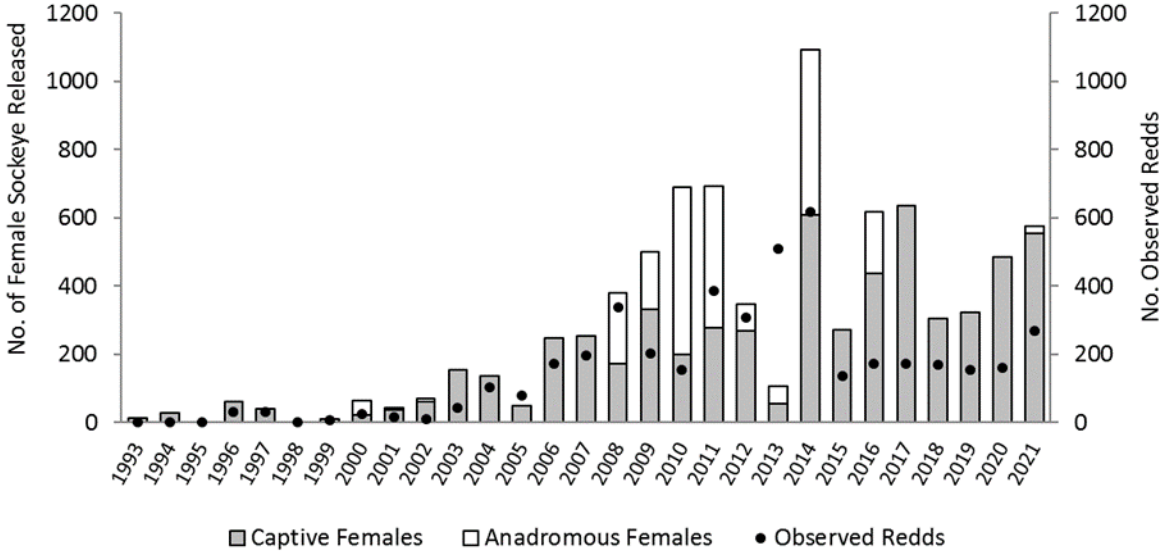

Figure 14. Releases of Snake River Sockeye Salmon from the captive brood program into Redfish Lake and Redfish Lake Creek upstream of weir.

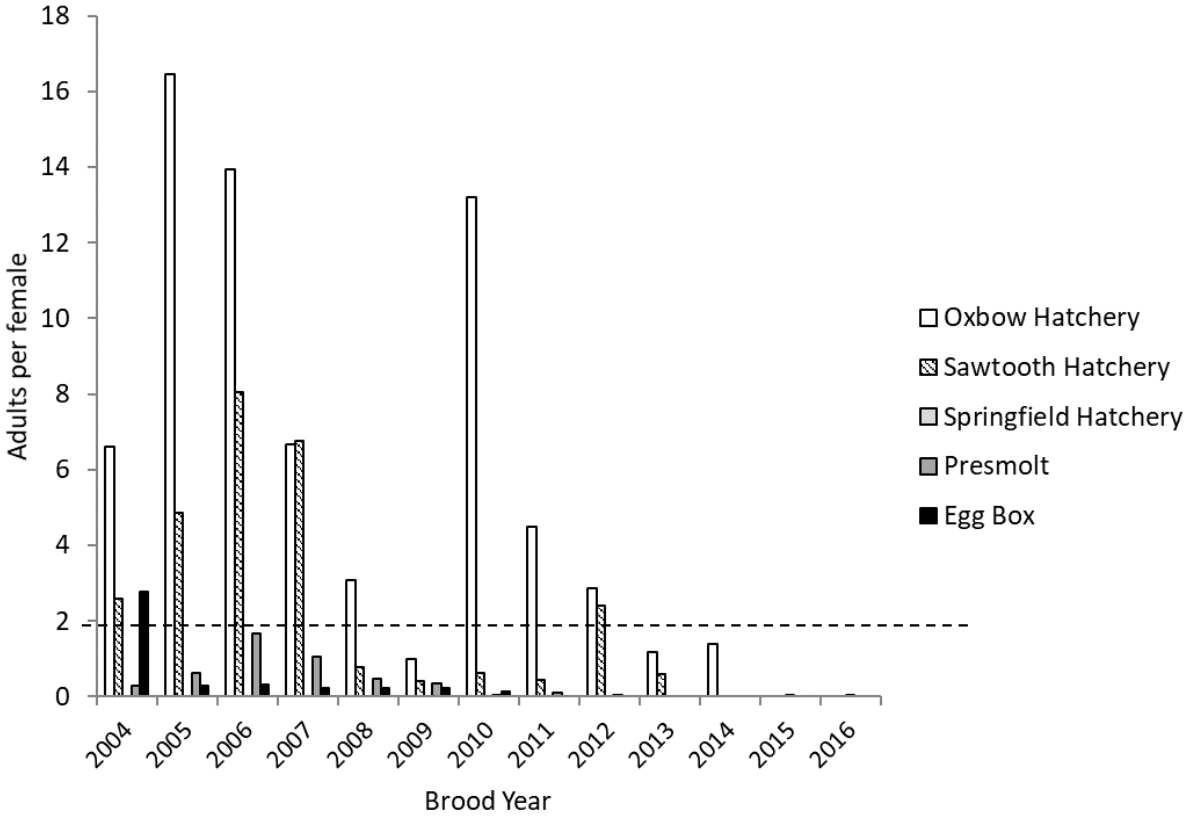

Figure 15. Estimated number of adult returns per female for eyed-egg box, presmolt, and smolt releases, BY 2004-2016. The dashed line represents replacement.

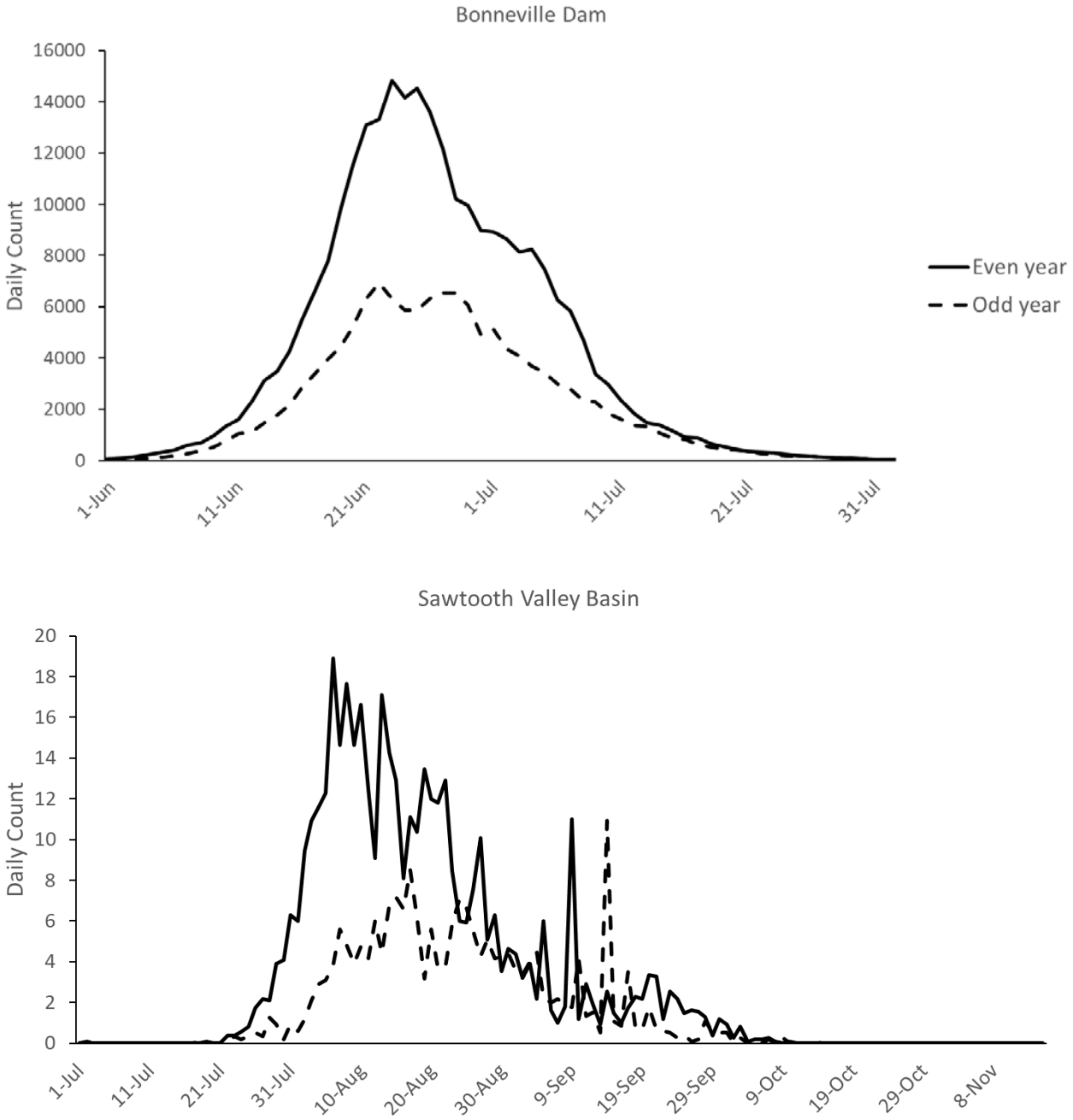

Figure 16. Mean daily Sockeye Salmon window counts at Bonneville Dam and the mean daily number of trapped Sockeye Salmon in the Sawtooth Valley during even years (solid lines, low pink salmon abundance in North Pacific Ocean) and odd years (dashed lines, high pink salmon abundance in North Pacific Ocean) from 1999-2021.

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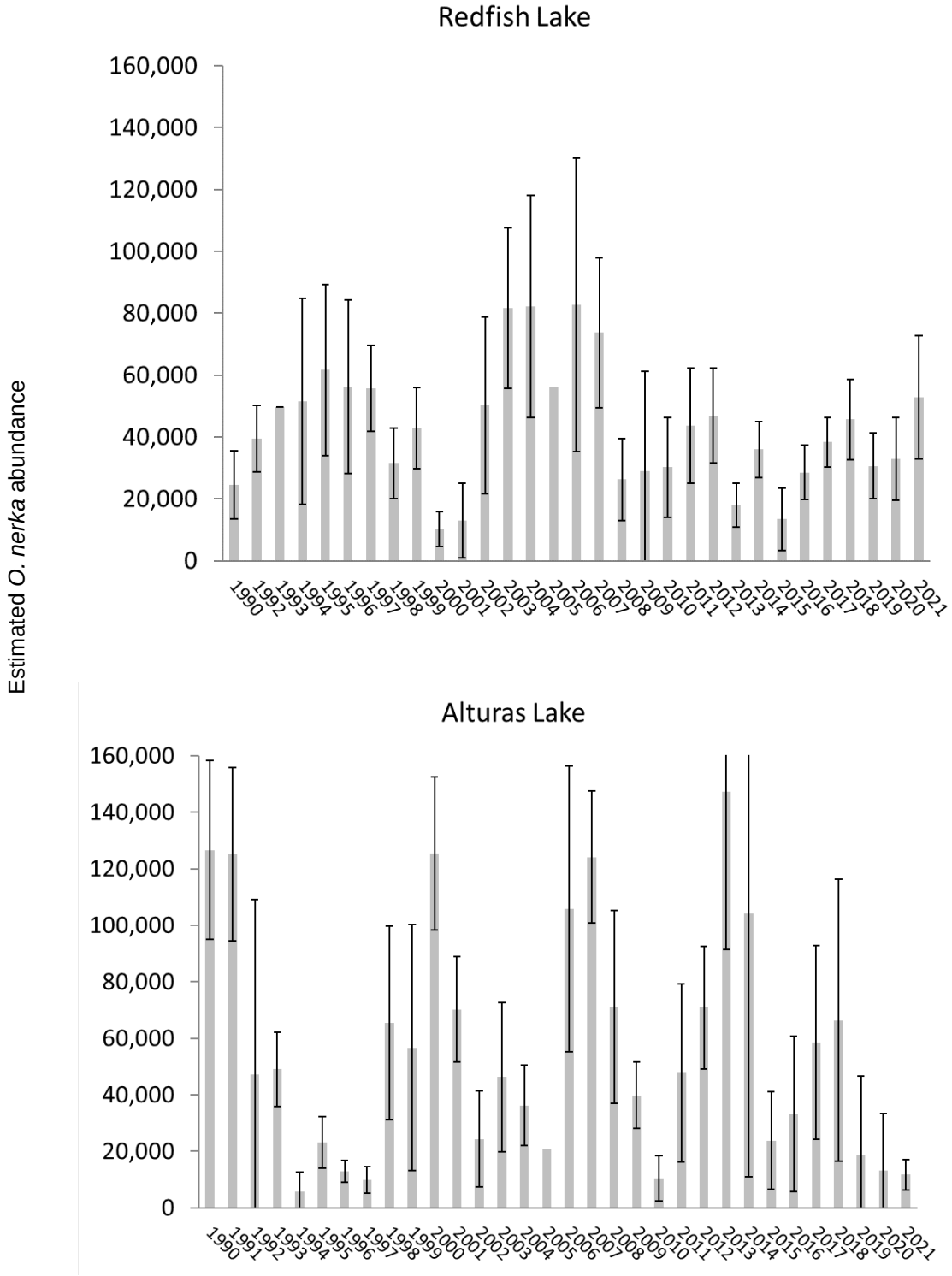
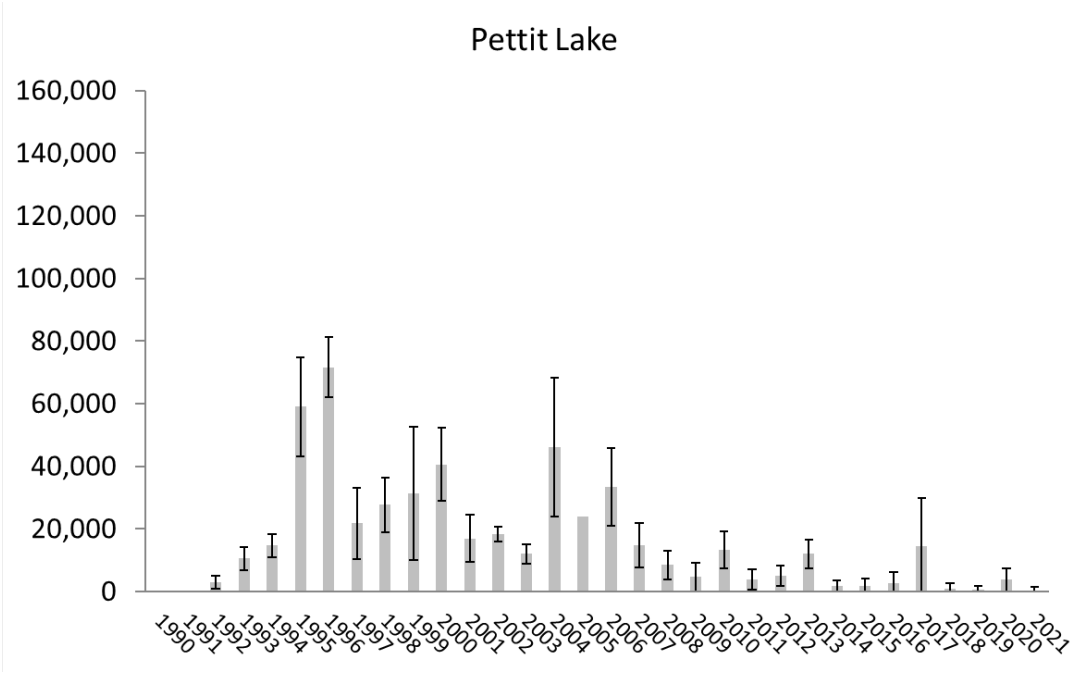
APPENDICES

Appendix A. Snake River Sockeye Salmon Captive Broodstock Program egg and fish reintroduction history for Alturas, Pettit, and Redfish lakes, 1993-2021.

Year of Reintroduction	Eyed Eggs	Presmolts	Smolts	Hatchery-Reared Adults	Anadromous Adults
1993	0	0	0	24	0
1994	0	14,119	0	65	0
1995	0	91,572	3,794	0	0
1996	105,000	1,932	11,545	120	0
1997	105,767	255,711	0	120	0
1998	0	141,871	81,615	0	0
1999	20,311	40,271	9,718	18	3
2000	65,200	72,114	148	71	200
2001	0	106,166	13,915	65	14
2002	30,924	140,410	38,672	177	12
2003	199,666	76,788	0	309	0
2004	49,134	130,716	96	244	0
2005	51,239	72,108	78,330	176	0
2006	184,596	107,292	86,052	465	0
2007	51,008	82,105	101,676	498	0
2008	67,984	84,005	150,395	396	567
2009	75,079	59,538	173,055	680	650
2010	59,683	65,851	179,278	369	1,208
2011	42,665	50,054	191,048	558	989
2012	0	11,354	166,652	622	173
2013	0	0	273,080	162	184
2014	0	0	296,389	1,098	1,073
2015	0	0	423,103	587	5
2016	0	0	635,021	880	326
2017	0	0	734,492	1,228	1
2018	0	239,288	658,692	630	1
2019	0	0	882,386	607	3
2020	3,268	112,275	937,108	994	37
2021	0	0	1,013,340	1,162	64
Total	1,111,524	1,955,540	7,139,600	12,325	5,510

Appendix B. *O. nerka* population estimates for Redfish, Alturas, and Pettit lakes, 1990-2021.




Pettit Lake
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1990
1991
1992
1993
1994
1995
1996
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2020
2021

Appendix C. Numbers and mean length and weights of *O. nerka* captured during August-September trawls in Redfish Lake (615 surface ha) and the estimated abundance, density (fish/ha), and biomass (kg/ha) in the lake.

Year	No. Captured	Mean Length (mm)	Mean Weight (g)	Abundance	95% CI High	95% CI Low	Density (fish/ha)	Biomass (kg/ha)
1990	NA	NA	NA	24431	35431	13431	63.9	1.3
1991	NA	NA	NA	NA	NA	NA	NA	NA
1992	NA	NA	NA	39481	50248	28714	95.9	1.5
1993	NA	NA	NA	49628	NA	NA	120.4	2.3
1994	NA	NA	NA	51529	84708	18350	125.1	2.1
1995	NA	NA	NA	61646	89285	34007	149.6	6.5
1996	NA	NA	NA	56213	84315	28111	91.4	2.8
1997	NA	NA	NA	55762	69723	41801	90.7	2.5
1998	NA	NA	NA	31486	42835	20137	51.2	1.8
1999	53	NA	NA	42916	56093	29739	70	0.9
2000	11	NA	NA	10267	15942	4592	17	<0.1
2001	16	NA	NA	12980	25060	900	21	0.1
2002	44	NA	NA	50204	78689	21719	81.6	1.0
2003	85	NA	NA	81727	107723	55732	133	1.6
2004	102	NA	NA	82258	85743	78772	133	0.3
2005	65	NA	NA	56220	60412	52028	91.4	0.3
2006	70	NA	NA	82796	130203	35389	135	2.4
2007	53	NA	NA	73702	97897	49507	119.8	0.8
2008	20	NA	NA	26284	39510	13058	42.7	0.3
2009	20	58.7	2.3	28923	61120	0	47.0	0.1
2010	25	105.4	17.3	30194	46333	14055	49.1	0.2
2011	37	55.6	1.6	43671	62301	25041	71	0.1
2012	122	55	2.2	46861	62171	31551	76.2	0.2
2013	47	65	4.2	17911	25017	10805	29.1	0.1
2014	98	70.7	6.2	36013	45063	26963	58.6	0.4
2015	15	58.2	1.9	13432	24573	3291	21.8	<0.1
2016	77	54.7	4.2	28527	37264	19790	46.0	0.3
2017	110	55.3	1.4	38317	46279	30355	62.3	<0.1
2018	127	54.7	4.2	45639	58690	32588	74.2	0.1
2019	66	59.7	4.5	30650	41216	20084	49.8	0.2
2020	64	59.0	3.2	33017	46374	19660	53.7	0.2
2021	101	57.8	1.6	52855	72715	32995	85.3	0.1

Appendix C (Cont.). Numbers and mean length and weights of *O. nerka* captured during August-September trawls in Alturas Lake (338 surface ha) and the estimated abundance, density (fish/ha), and biomass (kg/ha) in the lake.

Year	No. Captured	Mean Length (mm)	Mean Weight (g)	Abundance	95% CI High	95% CI Low	Density (fish/ha)	Biomass (kg/ha)
1990	NA	NA	NA	126644	158255	95033	597	5.2
1991	NA	NA	NA	125045	155753	94337	594	6.3
1992	NA	NA	NA	47237	109105	0	222.8	3.9
1993	NA	NA	NA	49037	62212	35862	230.2	4.1
1994	NA	NA	NA	5785	12704	0	27.1	0.7
1995	NA	NA	NA	23061	32243	13879	108.7	2.6
1996	NA	NA	NA	13012	16872	9152	38.5	1.4
1997	NA	NA	NA	9761	14425	5097	28.9	2.1
1998	NA	NA	NA	65468	99751	31185	193.7	1.4
1999	91	NA	NA	56675	100152	13198	167.7	0.4
2000	285	NA	NA	125463	152500	98426	371	2.1
2001	116	NA	NA	70159	51517	88801	208	2.4
2002	51	NA	NA	24374	41342	7406	72.1	2.2
2003	25	NA	NA	46234	72676	19792	137	5.5
2004	29	NA	NA	36206	38785	33627	107	2.0
2005	32	NA	NA	20956	23092	18820	98.8	0.3
2006	150	NA	NA	105779	156481	55077	313	3.5
2007	176	NA	NA	124073	147400	100746	367.1	3.4
2008	85	NA	NA	71088	105277	36899	210.3	2.7
2009	54	133.8	29.4	39781	51478	28084	117.7	3.5
2010	21	146.8	48.1	10366	18413	2319	30.7	1.4
2011	81	54.4	2.4	47739	79259	16219	141.2	0.3
2012	120	62.9	3.5	70895	92553	49237	209.8	0.7
2013	257	64.4	4.7	147204	203075	91333	435.5	2.0
2014	180	71.6	3.6	104095	197332	10858	308	1.1
2015	43	114.4	18.3	23760	40982	6538	70.3	1.3
2016	58	49.5	3.0	33151	60722	5584	156.4	0.5
2017	67	53.1	1.8	58466	92798	24134	173.0	0.3
2018	62	46.1	2.8	66382	116241	16523	196.4	0.6
2019	29	54.1	2.8	18803	46763	0	55.6	0.2
2020	21	96.2	15.9	13266	33248	0	39.3	0.6
2021	14	60.1	2.1	11682	16973	6391	34.6	0.1

Appendix C (Cont.). Numbers and mean length and weights of *O. nerka* captured during August-September trawls in Pettit Lake (160 surface ha) and the estimated abundance, density (fish/ha), and biomass (kg/ha) in the lake.

Year	No. Captured	Mean Length (mm)	Mean Weight (g)	Abundance	95% CI High	95% CI Low	Density (fish/ha)	Biomass (kg/ha)
1991	NA	NA	NA	NA	NA	NA	NA	NA
1992	NA	NA	NA	3009	5140	878	26.2	3.5
1993	NA	NA	NA	10511	14207	6815	101	1.1
1994	NA	NA	NA	14743	18426	11060	128.2	4.4
1995	NA	NA	NA	59002	74737	43267	513.1	20.8
1996	NA	NA	NA	71654	81312	61996	447.8	15.3
1997	NA	NA	NA	21730	32992	10468	135.8	5.1
1998	NA	NA	NA	27654	36418	18890	172.8	9.7
1999	58	NA	NA	31422	50944	11900	196.4	6.4
2000	75	NA	NA	40559	45750	35369	253	10.3
2001	30	NA	NA	16931	33862	0	106	6.1
2002	36	NA	NA	18328	20679	15977	114.5	12.1
2003	24	NA	NA	11961	15216	8706	75	3.3
2004	44	NA	NA	46065	49354	42777	288	9.8
2005	44	NA	NA	23970	25699	22241	150	2.2
2006	54	NA	NA	33246	45662	20830	208	7.4
2007	20	NA	NA	14746	21845	7647	92.2	3.8
2008	17	NA	NA	6933	10726	3140	43.3	1.1
2009	9	60	2.1	4623	9159	87	40.2	0.1
2010	26	120.2	10.3	13246	19207	7285	82.8	0.6
2011	7	88.1	10.5	3733	7040	426	23.3	0.2
2012	12	132.7	26.5	4995	8114	1876	31.2	0.8
2013	28	112.3	27.3	11978	16446	7510	74.9	2.1
2014	5	72.8	5.7	1862	3627	97	11.6	0.1
2015	5	84.2	11.7	1842	4124	0	11.5	0.1
2016	7	47.7	1.2	2663	6184	0	16.6	<0.1
2017	37	63.5	3.4	14553	29890	0	91.0	0.3
2018	2	47.5	1.2	743	2651	0	4.6	<0.1
2019	2	112.5	20.9	542	1767	0	3.4	<0.1
2020	9	134.0	32.3	3694	7447	0	23.1	0.8
2021	1	184.0	56.2	349	1596	0	2.2	0.1

Appendix D. Estimates of smolt-to-adult return rates (SAR) for natural emigrants and smolts released for the different production strategies into the Sawtooth Valley for BY2004-BY2017. These are considered minimum estimates since they do not include fish observed in the basin that were not trapped.

Release Strategies and Brood Year		Adult returns by year and age			SAR
Brood Year 2004	Smolts	2007 (age 3)	2008 (age 4)	2009 (age 5)	
Presmolt releases	32,158	0	18	0	0.06%
Oxbow Smolts	46,430	1	192	8	0.43%
Sawtooth Smolts	39,622	0	85	2	0.22%
Natural Production (RFL only)	5,608	0	45	3	0.86%
Natural Production (Pettit and Alturas)	54,746	0	83	1	0.15%
Brood Year 2005	Smolts	2008 (age3)	2009 (age 4)	2010 (age 5)	
Presmolt releases	27,144	2	31	14	0.17%
Oxbow Smolts	54,582	126	458	0	1.07%
Sawtooth Smolts	46,765	28	132	1	0.34%
Natural Production (RFL only)	6,088	1	70	14	1.40%
Natural Production (Pettit and Alturas)	11,211	1	8	0	0.08%
Brood Year 2006	Smolts	2009 (age3)	2010 (age 4)	2011 (age 5)	
Presmolt releases	28,136	1	79	17	0.34%
Oxbow Smolts	76,587	90	588	1	0.89%
Sawtooth Smolts	73,808	5	383	33	0.57%
Natural Production (RFL only)	6,338	1	123	77	3.17%
Natural Production (Pettit and Alturas)	14,908	0	26	27	0.36%
Brood Year 2007	Smolts	2010 (age3)	2011 (age 4)	2012 (age 5)	
Presmolt releases	24,001	1	64	3	0.28%
Oxbow Smolts	73,681	70	265	0	0.45%
Sawtooth Smolts	99,374	5	499	13	0.52%
Natural Production (RFL only)	4,822	1	26	7	0.71%
Natural Production (Pettit and Alturas)	7,457	0	11	3	0.19%
Brood Year 2008	Smolts	2011 (age3)	2012 (age 4)	2013 (age 5)	
Presmolt releases	10,184	4	14	3	0.21%
Oxbow Smolts	79,886	63	99	1	0.20%
Sawtooth Smolts	99,392	3	51	3	0.06%
Natural Production (RFL only)	12,558	0	29	13	0.33%
Natural Production (Pettit and Alturas)	3,871	0	12	6	0.46%
Brood Year 2009	Smolts	2012 (age3)	2013 (age 4)	2014 (age 5)	
Presmolt releases	8,804	0	7	9	0.18%
Oxbow Smolts	54,761	8	55	0	0.12%
Sawtooth Smolts	135,614	0	34	7	0.03%
Natural Production (RFL only)	10,502	0	30	74	0.99%
Natural Production (Pettit and Alturas)	11,544	0	22	3	0.22%

Appendix D. (Cont.)

Release Strategies and Brood Year		Adult returns by year and age			SAR
Brood Year 2010	Smolts	2013 (age3)	2014 (age 4)	2015 (age 5)	
Presmolt releases	2,082	0	2	0	0.10%
Oxbow Smolts	85,346	86	668	0	0.88%
Sawtooth Smolts	79,673	2	60	0	0.08%
Natural Production (RFL only)	27,765	6	364	4	1.33%
Natural Production (Pettit and Alturas)	374	2	12	1	4.01%
Brood Year 2011	Smolts	2014 (age3)	2015 (age 4)	2016 (age 5)	
Presmolt releases	74	1	0	0	1.35%
Oxbow Smolts	100,775	248	43*	0	0.29%
Sawtooth Smolts	170,086	26	32*	3	0.04%
Natural Production (RFL only)	19,033	5	9	14	0.15%
Natural Production (Pettit and Alturas)	708	0	0	0	0.00%
Brood Year 2012	Smolts	2015 (age 3)	2016 (age 4)	2017 (age 5)	
Presmolt releases	Discontinued				
Oxbow Smolts	122,021	1	232	3	0.19%
Sawtooth Smolts	172,090	0	295	12	0.18%
Natural Production (RFL only)	3,655	0	19	5	0.66%
Natural Production (Pettit and Alturas)	1,586	0	0	0	0.00%
Brood Year 2013	Smolts	2016 (age 3)	2017 (age 4)	2018 (age 5)	
Springfield Smolts	214,876	0	0	0	0.00%
Oxbow Smolts	77,238	5	61	0	0.09%
Sawtooth Smolts	134,660	2	71	0	0.05%
Natural Production (RFL only)	11,209	0	6	1	0.06%
Natural Production (Pettit and Alturas)	3,334	0	0	0	0.00%
Brood Year 2014	Smolts	2017 (age 3)	2018 (age 4)	2019 (age 5)	
Springfield Smolts	540,665	0	0	0	0.00%
Oxbow Smolts	94,356	0	100	2	0.11%
Sawtooth Smolts	Discontinued				
Natural Production (RFL only)	17,959	0	12	11	0.13%
Natural Production (Pettit and Alturas)	354	0	0	2	0.56%
Brood Year 2015	Smolts	2018 (age 3)	2019 (age 4)	2020 (age 5)	
Springfield Smolts	734,492	0	1	0	<0.01%
Natural Production (RFL only)	4,232	0	0	1	0.02%
Natural Production (Pettit and Alturas)	2,308	0	1	0	0.04%
Brood Year 2016	Smolts	2019 (age 3)	2020 (age 4)	2021 (age 5)	
Springfield Smolts	658,692	0	17	0	<0.01%
Redfish Lake Presmolts	126,139	0	2	0	<0.01%
Natural Production (RFL only)	29,325	0	85	5*	0.31%
Natural Production (Pettit and Alturas)	6,479	0	38	2*	0.62%

Appendix D. (Cont.)

Release Strategies and Brood Year		Adult returns by year and age			SAR
Brood Year 2017	Smolts	2020 (age 3)	2021 (age 4)	2022 (age 5)	
Springfield Smolts	549,630	1*	29*	na	<0.01%**
Sawtooth Smolts	332,756	8*	194*	na	0.06%**
Natural Production (RFL only)	32,844	0	4*	na	0.01%**
Natural Production (Pettit and Alturas)	3,223	0	2*	na	0.06%**

* SAR includes LGR trap and haul sample

** Incomplete SAR (does not include 2022 return year)

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