FISHERY RESEARCH

WILD JUVENILE STEELHEAD AND CHINOOK SALMON ABUNDANCE AND COMPOSITION AT LOWER GRANITE DAM, MIGRATORY YEAR 2019

2019 ANNUAL REPORT

Photo: Scott Putnam, IDFG

Prepared by:

Jonathan D. Ebel, Fisheries Staff Biologist
Timothy Copeland, Fisheries Program Coordinator
John S. Hargrove, Fishery Biologist 2
Micah Davison, Supervisory Fisheries Biologist
Marika E. Dobos, Fisheries Staff Biologist
William C. Schrader, Principal Fisheries Biologist
Matthew R. Campbell, Fisheries Program Coordinator

IDFG Report Number 22-08
May 2022

Wild Juvenile Steelhead and Chinook Salmon Abundance and Composition at Lower Granite Dam, Migratory Year 2019

2019 Annual Report

By

Jonathan D. Ebel
Timothy Copeland
John S. Hargrove
Micah Davison
Marika E. Dobos
William C. Schrader
Matthew R. Campbell

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707

IDFG Report Number 22-08
May 2022

ACKNOWLEDGEMENTS

Report Authors:

Jonathan D. Ebel (IDFG)

Timothy Copeland (IDFG)

John S. Hargrove (IDFG / PSMFC)

Micah Davison (IDFG / PSMFC)

Marika E. Dobos (IDFG)

William C. Schrader (IDFG)

Matthew R. Campbell (IDFG)

Report Contributors: Data, reviews, and other assistance (*alphabetical*)

IDFG

- Eli Felts
- Lance Hebdon
- Eric Stark

IDFG / PSMFC

- Amanda Boone
- Julianna Browning
- Paul Bunn
- Karen Gregory
- Brent Haverkamp
- Kelly Heindel
- Kyle King
- Dylan Kovis
- Jesse McCane
- Leslie Reinhardt
- Maxwell Reinhardt
- Lynn Schrader
- Craig Steele
- Patrick Vrablik
- Shelby Wallace
- Tyler Zumwalt

Columbia River Inter-Tribal Fish Commission

- Stephanie Harmon
- Rebekah Horn
- Shawn Narum
- Jeff Stephenson

Fish Passage Center

- Brandon Chockley

NMFS Northwest Fisheries Science Center

- Amber Barenberg
- Ross Gleason
- Tiffani Marsh
- Darren Ogden

PSMFC (Smolt Monitoring Project)

- Allan Martin
- Jenna Fortier

ACKNOWLEDGEMENTS (CONTINUED)

Project Administration: Funding and other assistance (*alphabetical*)

- Bonneville Power Administration (BPA) projects:
  1987-127-00 Smolt Monitoring by Non-Federal Entities
  1990-055-00 Idaho Steelhead Monitoring and Evaluation Studies
  1991-073-00 Idaho Natural Production Monitoring and Evaluation Program
  2010-026-00 Chinook and Steelhead Genotyping for Genetic Stock Identification (GSI) at Lower Granite Dam
  2010-031-00 Snake River Chinook and Steelhead Parental Based Tagging

- Idaho Office of Species Conservation (IOSC)

- Pacific States Marine Fisheries Commission (PSMFC)

- U. S. Fish and Wildlife Service, Lower Snake River Compensation Program (LSRCP)

Suggested citation:

Ebel, J. D., T. Copeland, J. S. Hargrove, M. Davison, M. E. Dobos, W. C. Schrader, and M. R. Campbell. 2022. Wild juvenile steelhead and Chinook Salmon abundance and composition at Lower Granite Dam, migratory year 2019. Annual report 2019. Idaho Department of Fish and Game Report 22-08.

ABBREVIATIONS AND ACRONYMS

BPA	Bonneville Power Administration
BY	Brood Year
CHMBLN	Chamberlain Creek Genetic Stock
CI	Confidence Interval
CLRWTR	Clearwater River Major Population Group
CWT	Coded Wire Tag
DPS	Distinct Population Segment
EFGL	Eagle Fish Genetics Lab
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
F	Female
FALL	Snake River Fall Chinook Salmon Genetic Stock
FANR	Females Available for Natural Reproduction
FL	Fork Length
FPC	Fish Passage Center
GRROND	Grande Ronde River Genetic Stock
GSI	Genetic Stock Identification
GT-seq	Genotyping-in-Thousands by Sequencing
H	Adipose Fin Clipped Hatchery
HELLSC	Hells Canyon Genetic Stock
HNC	Adipose Fin Intact Hatchery
ICBTRT	Interior Columbia Basin Technical Recovery Team
IDFG	Idaho Department of Fish and Game
IMNAHA	Imnaha River Genetic Stock
IOSC	Idaho Office of Species Conservation
IPC	Idaho Power Company
LGR	Lower Granite Dam
LOCLWR	Lower Clearwater River Genetic Stock
LOSALM	Lower Salmon River Genetic Stock
LSNAKE	Lower Snake River Genetic Stock
LSRCP	Lower Snake River Compensation Plan
M	Male
MCMC	Markov Chain Monte Carlo

MFSALM	Middle Fork Salmon River Genetic Stock
MM	Mixture Modelling
MPG	Major Population Group
MSA	Mixed Stock Analysis
MY	Smolt Migration Year
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWFSC	Northwest Fisheries Science Center
PBT	Parentage Based Tagging
PCR	Polymerase Chain Reaction
PIT	Passive Integrated Transponder
PSMFC	Pacific States Marine Fisheries Commission
QCI	Quantitative Consultants, Inc.
SALMON	Salmon River Major Population Group
SAR	Smolt-to-adult return rate
SCOBI	Salmonid Compositional Bootstrap Intervals
SFCLWR	South Fork Clearwater River Genetic Stock
SFSALM	South Fork Salmon River Genetic Stock
SNP	Single Nucleotide Polymorphism
SY	Spawn Year
TAC	Technical Advisory Committee, *US v. Oregon*
TUCANO	Tucannon River Genetic Stock
UPCLWR	Upper Clearwater River Genetic Stock
UPSALM	Upper Salmon River Genetic Stock
USACE	U. S. Army Corps of Engineers
VSP	Viable Salmonid Population
W	Wild
WDFW	Washington Department of Fish and Wildlife

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS i
ACKNOWLEDGEMENTS (continued) ii
ABBREVIATIONS AND ACRONYMS iii
ABSTRACT 1
INTRODUCTION 2
METHODS 3
Juvenile Trap Operations at Lower Granite Dam 3
Scale and Genetic Tissue Processing and Analysis 4
Emigration by Origin, Age, Sex, and Genetic Stock 6
Steelhead and Chinook Salmon Adult-to-Juvenile Productivity 9
RESULTS 11
Wild Steelhead Emigration 11
Wild Steelhead Productivity 11
Wild Chinook Salmon Yearling Emigration 11
Wild Chinook Salmon Productivity 12
DISCUSSION 12
RECOMMENDATIONS 15
LITERATURE CITED 16
TABLES 22
FIGURES 27
APPENDICES 34

LIST OF TABLES

Page

Table 1. Major population groups and independent populations within the Snake River steelhead distinct population segment (DPS) and spring-summer Chinook Salmon evolutionary significant unit (ESU; ICBTRT 2003, 2005). 23

Table 2. Estimated abundance of steelhead wild and hatchery female parents available for natural reproduction (FANR) followed by estimated abundance of wild smolts at Lower Granite Dam. The empirical data are used to construct adult-to-juvenile productivity estimates (juveniles/FANR). 25

Table 3. Estimated abundance of Chinook Salmon wild and hatchery female parents available for natural reproduction (FANR) followed by estimated abundance of wild yearling smolts at Lower Granite Dam. The empirical data are used to construct adult-to-juvenile productivity estimates (juveniles/FANR) and the Beverton-Holt stock-recruit model.....26

LIST OF FIGURES

Figure 1. Genetic stocks and baseline collections used for steelhead mixed stock analysis at Lower Granite Dam since 2016 (Powell et al. 2018). The Hells Canyon Tributaries major population group (shaded gray) does not support independent populations and is considered extirpated (NMFS 2011). See text for genetic stock abbreviations. 28

Figure 2. Genetic stocks and baseline collections used for Chinook Salmon mixed stock analysis at Lower Granite Dam since 2016 (Powell et al. 2018). Reintroduced fish exist in functionally extirpated TRT populations as mapped. See text for genetic stock abbreviations. 29

Figure 3. Schematic of the juvenile companion (SCRAPI) to the Salmonid Compositional Bootstrap Intervals (SCOBI) Lower Granite Dam decomposition model. 30

Figure 4. Wild steelhead and Chinook Salmon juvenile emigrant estimates at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 31

Figure 5. Time series of the aggregate productivity of wild steelhead and spring/summer Chinook Salmon (smolts per female parent) at Lower Granite Dam. Only completed brood years are shown. 32

Figure 6. Relationship of wild yearling Chinook Salmon smolt abundance at Lower Granite Dam and females available for natural reproduction upstream of LGR for brood years 1990-2017. The shaded area represents the 95% confidence interval for the fitted Beverton-Holt model. The red point represents the most recent data point, brood year 2017 (MY 2019). 33

LIST OF APPENDICES

Page

Appendix A: Lower Granite Dam juvenile trapping operations, migration year 2019.....35

Appendix A-1. Weekly Fish Passage Center trap collection and valid trap samples of juvenile steelhead at Lower Granite Dam, migration year 2019.....36

Appendix A-2. Weekly Fish Passage Center trap collection and valid trap samples of yearling Chinook Salmon at Lower Granite Dam, migration year 2019.....37

Appendix B: Wild steelhead juveniles at Lower Granite Dam, migration year 2019. 38

Appendix B-1. Wild juvenile steelhead emigration estimates by sex for each genetic stock at Lower Granite Dam, migration year 2019. L = lower bound and U = upper bound of 90% confidence intervals. See text for stock abbreviations. 39

Appendix B-2. Wild juvenile steelhead emigration estimates by genetic stock at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 40

Appendix B-3. Wild juvenile steelhead emigration estimates by sex at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 41

Appendix B-4. Wild juvenile steelhead emigration estimates by genetic stock and sex at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 42

Appendix B-5. Wild juvenile steelhead emigration estimates by freshwater age at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 43

Appendix B-6. Wild juvenile steelhead emigration estimates by genetic stock and freshwater age at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 44

Appendix C: Wild Chinook Salmon yearling juveniles at Lower Granite Dam, migration year 2019.....45

Appendix C-1. Wild juvenile Chinook Salmon yearling emigration estimates by sex for each genetic stock at Lower Granite Dam, migration year 2019. L = lower bound and U = upper bound of 90% confidence intervals. See text for stock abbreviations. 46

Appendix C-2. Wild juvenile Chinook Salmon yearling emigration estimates by genetic stock at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 47

Appendix C-3. Wild juvenile Chinook Salmon yearling emigration estimates by at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 48

Appendix C-4. Wild juvenile Chinook Salmon yearling emigration by genetic stock and sex at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%. 49

ABSTRACT

This report summarizes the abundance, composition, and productivity of wild juvenile steelhead and yearling spring-summer Chinook Salmon emigrating past Lower Granite Dam, migratory year 2019. We used systematic biological samples from the Juvenile Fish Facility to decompose each species by origin, age, sex, and genetic stock. Juvenile and returning adult data from Lower Granite Dam were combined to calculate adult-to-juvenile productivity for the aggregate populations of Snake River summer steelhead and Snake River spring-summer Chinook Salmon. Estimated wild steelhead emigration was 845,815 smolts. The Grande Ronde River genetic stock had the highest relative abundance (29%) followed by the upper Salmon River (15%). Sex ratios were female biased at 64% for the aggregate juvenile emigration. Juvenile ages ranged from age-1 to age-4 with the majority of emigrants comprised of age-2 and age-3 smolts. Migratory year 2019 completed emigration for brood year 2014. The aggregate productivity of brood year 2014 was 32 juveniles per female parent that returned to Lower Granite Dam. Brood year 2015 is nearly completed and productivity is tentatively 17 smolts per female parent. Estimated wild Chinook Salmon emigration was 794,695 yearling smolts. The Hells Canyon genetic stock had the highest relative abundance (37%) followed by the South Fork Salmon River (22%). Sex ratios were female biased at 57% for the aggregate juvenile emigration. Migratory year 2019 completed emigration for brood year 2017. The aggregate productivity of brood year 2017 was 94 yearling smolts per female parent that returned to Lower Granite Dam. Based on a Beverton-Holt stock-recruit model, aggregate intrinsic productivity was 445.2 yearling smolts per female parent and asymptotic production was 1,400,440 yearling smolts. For BY2018, the model predicted production of 1,419,649 yearling smolts, implying productivity should be 460 wild yearling smolts per female.

Authors:

Jonathan D. Ebel, Fisheries Staff Biologist

Timothy Copeland, Fisheries Program Coordinator

John S. Hargrove, Fishery Biologist 2

Micah Davison, Supervisory Fisheries Biologist

Marika E. Dobos, Fisheries Staff Biologist

William C. Schrader, Principal Fisheries Biologist

Matthew R. Campbell, Fisheries Program Coordinator

INTRODUCTION

Populations of steelhead trout *Oncorhynchus mykiss* and Chinook Salmon *O. tshawytscha* in the Snake River basin declined substantially following the construction of hydroelectric dams in the Snake and Columbia rivers. Raymond (1988) documented a decrease in survival of emigrating steelhead trout and Chinook Salmon from the Snake River following the construction of dams on the lower Snake River during the late 1960s and early 1970s. Abundance rebounded slightly in the 1980s, but then adult escapement over Lower Granite Dam (LGR) into the Snake River basin declined again (Matthews and Waples 1991; Busby et al. 1996). In recent years, abundances in the Snake River basin have slightly increased. However, the increase has been dominated by hatchery fish, while returns of naturally produced steelhead and Chinook Salmon remain critically low.

Snake River summer steelhead were classified as threatened under the Endangered Species Act (ESA) in 1997. Within the Snake River steelhead distinct population segment (DPS), there are six major population groups (MPGs): Lower Snake River, Grande Ronde River, Imnaha River, Clearwater River, Salmon River, and Hells Canyon Tributaries (Table 1; ICBTRT 2003, 2005). The Hells Canyon MPG is considered to be extirpated. Twenty-four extant demographically independent populations have been identified within the DPS.

Snake River spring-summer Chinook Salmon were classified as threatened in 1992 under the ESA. Within the Snake River spring-summer Chinook Salmon evolutionarily significant unit (ESU), there are five major population groups (MPGs): Lower Snake River, Grande Ronde/Imnaha rivers, South Fork Salmon River, Middle Fork Salmon River, and Upper Salmon River (Table 1; ICBTRT 2003, 2005). Twenty-eight extant demographically independent populations have been identified within these five MPGs. Spring-summer Chinook Salmon from the Clearwater River basin are considered a re-introduced stock and not protected under the ESA. There are two MPGs: the Dry Clearwater and Wet Clearwater. A population structure for the Clearwater has been proposed but not all are currently occupied. (ICBTRT 2005).

Anadromous fish management programs in the Snake River basin include large-scale hatchery programs intended to mitigate for the impacts of hydroelectric dam construction and operation and recovery planning and implementation efforts aimed at recovering ESA-listed wild steelhead and salmon stocks. The long-range goal of Idaho Department of Fish and Game's (IDFG) anadromous fish program, consistent with basinwide mitigation and recovery programs, is to preserve Idaho's salmon and steelhead runs and recover them to provide benefit to all users (IDFG 2019). Management to achieve these goals requires an understanding of how salmonid populations function as well as regular status assessments (McElhany et al. 2000). However, specific data on Snake River summer steelhead and Snake River spring-summer Chinook Salmon populations were lacking during ESA listing and in the first status reviews, particularly key parameters such as population abundance, age composition, genetic diversity, recruits per spawner, and survival rates (ICBTRT 2003).

Idaho Department of Fish and Game provides research, monitoring, and evaluation of the status of the state's populations of anadromous salmon and steelhead. Recommendations for monitoring populations across the Columbia River basin include: 1) annual estimation of juvenile emigrant abundance across major populations, and 2) estimation of the adult-to-juvenile productivity of emigrants (Crawford and Rumsey 2011). These are two of several critical metrics necessary to assess overall trends in abundance and productivity within freshwater habitat.

The aggregate emigration of juveniles from Snake River summer steelhead and Snake River spring-summer Chinook Salmon populations is measured at LGR, with the exception of the Tucannon River (Washington) populations. Some wild fish originate from Washington or Oregon tributaries, but the majority are from Idaho. Age, sex, and genetic stock composition data obtained at the LGR juvenile fish trap facilitate estimation of productivity and survival metrics that are important for monitoring recovery of wild fish for both species. Estimates of wild juvenile abundance and composition will be combined with similar information for adults (e.g., Camacho et al. 2017, 2018a; Lawry 2020), enabling us to estimate adult-to-juvenile productivity and juvenile-to-adult productivity for each component of the aggregate populations sampled at LGR.

This report focuses on three main objectives to summarize wild Snake River summer steelhead (hereafter steelhead) and wild Snake River spring-summer Chinook Salmon (hereafter Chinook Salmon) emigrating past LGR during migratory year (MY) 2019. The first objective is to estimate wild steelhead and yearling Chinook Salmon juvenile abundance for the aggregate and for each stock passing Lower Granite Dam. The second objective is to estimate freshwater productivity rates through brood-year cohort analysis for each stock. The third objective is to estimate juvenile production potential using juvenile-to-female stock recruitment models for the aggregate and for each stock. Our working hypothesis was that each stock has its own characteristic compositional structure.

METHODS

Juvenile Trap Operations at Lower Granite Dam

Samples of steelhead and Chinook Salmon juveniles passing LGR were collected during daily operation of the Juvenile Fish Facility by Washington Department of Fish and Wildlife (WDFW; DeHart 2019). The juvenile trap is located on the LGR juvenile bypass system. The trap captured a systematic sample of fish passing through the Juvenile Fish Facility by operating two trap gates according to a predetermined sample rate. The sample rate regulated how long the trap gates remain open, up to six times per hour. Although the trap was operational 24 hours per day, and fish were processed every morning seven days a week, we only sampled during weekdays. Additional details on the juvenile trap can be found in Mensik et al. (2010). Our weekday sample rate was predetermined daily to collect 250-750 fish per day (all species combined) and was based on the expected number of fish entrained in the bypass system that day. Sample rates were not determined for weekend days because samples were not collected on weekends.

Standard methods were used by WDFW and IDFG staff to process juvenile fish (see Mensik et al. 2010). All fish captured were anesthetized; identified to species; examined for external marks, tags, and injuries; and scanned for an internal coded wire tag (CWT) or passive integrated transponder (PIT) tag. All fish were classified by origin (wild or hatchery) and the presence or absence of the adipose fin (hereafter ad-intact or ad-clipped). Wild fish have an intact adipose fin. The majority of hatchery-origin steelhead and Chinook Salmon have a clipped adipose fin; some are released ad-intact for population supplementation purposes. For ad-intact steelhead, hatchery origin was additionally determined by the presence of dorsal or ventral fin erosion, which was assumed to occur only in hatchery-reared fish (Latremouille 2003). Captured fish determined to be potentially wild were sampled for tissue (both species) and scales (steelhead only). The trap sample was sorted and processed by WDFW personnel and fish deemed wild passed to IDFG technicians. Fish bearing PIT tags and diseased or injured fish were omitted from the sample, as were fall Chinook Salmon based on external morphology (Tiffan et

al. 2000). Target sample sizes were 2,000 per species for steelhead and yearling Chinook Salmon for the trapping season. All sampled fish were measured for fork length (FL, to the nearest millimeter). After processing, fish were returned to the bypass system to resume downstream migration or diverted to holding tanks for transportation downriver as part of the hydropower mitigation effort.

Scale samples were taken from steelhead juveniles above the lateral line and posterior to the dorsal fin (Wright et al. 2015). Scales were stored in coin envelopes for transport to the IDFG ageing laboratory in Nampa, Idaho. Ages were used to assign steelhead to a brood year for cohort analysis. Age for Chinook Salmon was determined as either age-1 yearlings or age-0 subyearlings based on length and external morphology; therefore, scales were not needed to determine brood year (Camacho et al. 2017). Only age-1 yearlings were sampled. Tissue samples from both species were taken via a small clip of the caudal fin. Tissues were stored in a vial with 200-proof non-denatured ethyl alcohol or on Whatman sheets for transport to the IDFG Eagle Fish Genetics Laboratory (EFGL) in Eagle, Idaho.

Lower Granite Dam juvenile trapping data were stored in and accessed from the Lower Granite Dam Trapping database (https://collaboration.idfg.idaho.gov/qci/default.aspx). Scale ageing data were stored in and accessed from the BioSamples database (https://collaboration.idfg.idaho.gov/qci/default.aspx). Each database was exported into an Excel Pivot file each morning and placed on the collaboration site for easy downloading. The reader will need to contact the author for a username and password to access this file.

Scale and Genetic Tissue Processing and Analysis

Technicians processed scale samples in the IDFG Nampa Research Anadromous Ageing Laboratory according to protocols detailed in Wright et al. (2015). Briefly, 6-10 non-regenerated scales were cleaned and mounted between two glass microscope slides. The best scales were imaged at 40x magnification on a computer video monitor using a Leica DM4000B microscope and a Leica DC500 digital camera. Two technicians independently viewed each image to assign ages without reference to fish length. If there was no age consensus among the readers, a third reader viewed the image and all readers collectively examined the image to resolve their differences before a final age was assigned. If a consensus age was not attained, the sample was excluded from further analysis. In this report, total age equals freshwater age, so we did not use the ageing designations developed for anadromous salmonids, which also account for time spent in the ocean, and instead reported age as an integer.

The EFGL utilized a methodology developed by scientists at the Columbia River Inter-Tribal Fish Commission referred to as “Genotyping-in-Thousands by sequencing” (GT-seq). This involved the genotyping of SNP genetic markers panels (50-500) on thousands of pooled individuals at a time (Campbell et al. 2015). These pooled reactions were made possible through the use of sample-specific barcodes that were incorporated during the polymerase chain reaction (PCR) process. Following PCR, SNP amplicons were sequenced on an Illumina HiSeq DNA sequencer. Detailed methods for GT-seq library preparation and genotyping are provided in Campbell et al. (2015). The GSI panels consisted of 368 SNP markers for steelhead and 343 SNP markers for Chinook Salmon. Data for the SNP marker panels described above (‘CRITFC/IDFG Steelhead GTseq v5.0 368’, ‘CRITFC IDFG Chinook GTseq v4.0 343’) can be accessed via the FishGen webpage (https://www.fishgen.net/Home.aspx). Detailed methods for extraction of genomic DNA from tissue samples, DNA amplification, and maintaining the genetic baselines were described in Vu et al. (2015). Samples were processed at either the EFGL or the

Columbia River Inter-Tribal Fish Commission's genetics laboratory in Hagerman, Idaho (BPA project 2010-026-00).

Parentage-based tagging (PBT) involves sampling and genotyping hatchery broodstock on an annual basis, with the resulting parental genotypes added to a genetic database (Steele et al. 2013; 2019). Subsequently, progeny of these parents (collected either as juveniles or adults) that are genotyped can be assigned back to their parents via parentage analysis. Beginning in MY2012, parentage analysis was conducted on targeted unmarked juveniles captured and sampled at the LGR trap to identify hatchery fish that were phenotypically wild but had no internal tags or external marks detected. Fin tissue was sampled from nearly all adult steelhead and spring-summer Chinook Salmon broodstock spawned at Snake River hatcheries in Idaho, Oregon, and Washington since 2008 (Steele et al. 2019). The PBT project genotyped broodstock tissue samples at a core set of 95 SNPs that occurred within the larger panels described above for both species. The near-complete sampling of all hatchery broodstock in the Snake River basin effectively "tagged" all hatchery-origin steelhead and Chinook Salmon. Parentage assignment using SNP genotypes was performed using the program SNPPIT (Anderson 2010). Fish assigning to hatchery parents were removed from analysis. The remainder were subjected to genetic stock identification.

Genetic stock identification (GSI) is a complimentary genetic technique to PBT that seeks to identify the source of origin of wild fish. Briefly, this technique involves genotyping wild fish sampled on the landscape and using these population-level allele frequencies to assign individual fish of unknown origin (e.g., juveniles sampled at LGR) to reporting groups (hereafter genetic stocks). Juvenile genotypes were analyzed against genetic baseline populations to assign each individual to the genetic stock in which the probability of its genotype occurring is the greatest. Vu et al. (2015) and Powell et al. (2018) provided a detailed description of the Snake River genetic baselines used for both steelhead and Chinook Salmon GSI analyses (Figure 1; Figure 2). Genetic stocks are assemblages of baseline populations grouped primarily by genetic and geographic similarities and secondarily by political boundaries and management units (Ackerman et al. 2012). Individuals were assigned to genetic stocks using the algorithms implemented in rubias (Moran and Anderson 2019). An individual's genetic stock was assigned as the reporting unit with the maximum probability of membership.

Ten wild steelhead genetic stocks were used (Figure 1). The genetic stocks included: 1) UPSALM: upper Salmon River (including Panther Creek and upstream); 2) MFSALM: Middle Fork Salmon River (including Chamberlain and Bargamin creeks); 3) SFSALM: South Fork Salmon River; 4) LOSALM: Little Salmon River and tributaries of the lower Salmon River; 5) UPCLWR: upper Clearwater River (Lochsa and Selway rivers); 6) SFCLWR: South Fork Clearwater River (including Clear Creek); 7) LOCLWR: lower Clearwater River; 8) IMNAHA: Imnaha River; 9) GRROND: Grande Ronde River; and 10) LSNAKE: tributaries of the lower Snake River both above (e.g., Alpowa and Asotin creeks) and below (primarily Tucannon River) LGR. Some Tucannon River steelhead ascended LGR Dam and either stayed upriver to spawn or fell back and spawned downriver. Results from some genetic stocks were aggregated to report by Snake River steelhead MPGs (Table 1).

Seven wild Chinook Salmon genetic stocks were used (Figure 2). The genetic stocks included: 1) UPSALM: upper Salmon River (including North Fork Salmon River and upstream); 2) MFSALM: Middle Fork Salmon River; 3) CHMBLN: Chamberlain Creek; 4) SFSALM: South Fork Salmon River; 5) HELLSC: Hells Canyon stock, an aggregate genetic stock that includes the Clearwater, Little Salmon, lower Salmon, Grande Ronde, Imnaha, and lower Snake rivers; 6) TUCANO: Tucannon River; and 7) FALL: Snake River fall Chinook Salmon. Chinook Salmon

populations in TUCANO can be distinguished from HELLSC in GSI analyses because they exhibit low levels of introgression with fall Chinook Salmon (Narum et al. 2010). The TUCANO genetic stock was included in the baseline to represent fish that originated below LGR, but may be the progeny of Tucannon River adults that ascended the dam and stayed upriver to spawn. Except for fall Chinook Salmon, these genetic stocks largely correspond to Snake River spring-summer Chinook Salmon MPGs (Table 1). The MFSALM and CHMBLN genetic stock results were aggregated to report the Middle Fork Salmon River MPG. Three collections of Snake River fall Chinook Salmon (Clearwater River, Nez Perce Tribal Hatchery, and Lyons Ferry Hatchery) were included in the baseline to distinguish fall Chinook Salmon from spring-summer Chinook Salmon using genetic data (Ackerman et al. 2012).

The resolution of the Snake River genetic baselines was evaluated in Vu et al. (2015) and updated by Powell et al. (2018). The GSI project will continue to update the genetic baselines periodically in an effort to improve resolution. Further, the GSI project will continue to develop methods and evaluate available tools to assess and improve the accuracy and precision of genetic stock proportion and abundance estimates in the future. These efforts are reported separately in the annual progress reports for the GSI project (e.g., Hargrove et al. 2020).

The accuracy of the sex-specific genetic assays was evaluated in Steele et al. (2016). Sex was not and generally cannot be reliably determined by personnel at the LGR trap; thus, a direct comparison was not attempted. Campbell et al. (2012) and references therein described in more detail the methods of sex-determination using genetic assays.

Emigration by Origin, Age, Sex, and Genetic Stock

Estimates were made using methods modified from Steinhorst et al. (2017) to reflect our working hypothesis. Those methods were modified to incorporate a hierarchical structure (Figure 3) and to allow variance in the initial point estimate. Juvenile emigration abundance was estimated using 1) daily counts of putative wild juveniles collected in the LGR juvenile fish trap, 2) the trap sample rate (the proportion of time the trap is open), and 3) estimated daily collection efficiencies (probability of entrainment in the juvenile bypass system at the dam). The daily counts of all steelhead and Chinook Salmon juveniles at LGR during March-July as well as the trap sample rates were obtained from the FPC. DeHart (2019) described juvenile collection procedures at LGR (also see http://www.fpc.org/documents/metadata/FPC_SMP_Metadata.html). The estimated daily juvenile collection (guidance) efficiencies were obtained from the NWFSC (Steve Smith, personal communication). Collection efficiencies for steelhead and yearling Chinook Salmon were estimated using procedures detailed in Sandford and Smith (2002).

First, an estimate of the total number of ad-intact juveniles emigrating past LGR was found by expanding the number of ad-intact juveniles caught in the trap each day by the probability that a juvenile was sampled. The total number of ad-intact juveniles were estimated as:

$$N_s = \sum_{d=1}^{D} \frac{c_{sd}}{t_d \times e_{sd}} = \sum_{d=1}^{D} N_{sd}$$

where s is species (steelhead, yearling Chinook Salmon), N_s is abundance by species, d is day of the year, c_{sd} is the daily count in the trap by species, t_d is the daily trapping rate, and e_{sd} is the estimated daily collection efficiency for each species. Total abundance for each species during a migratory year (MY) was then estimated from the sums of daily estimates beginning at initiation of trapping until the date of last recorded passage. Note that the realized population sampling rate was the product of t_d and e_{sd} and changes almost daily. the t_d estimates were obtained from the

Fish Passage Center (B. Chockley, *personal communication*) and the e_d estimates were obtained from the Northwest Fisheries Science Center (S. Smith, *personal communication*)

The total estimate of unmarked, untagged juveniles was then decomposed into estimates of W and ad-intact hatchery (HNC) juveniles. The sampling protocol at the juvenile fish facility excluded steelhead juveniles with eroded dorsal fins, so abundance estimates of steelhead HNC juveniles represent only a partial estimate. Abundance estimates of HNC juveniles were included in Camacho et al. (2018b), but were excluded from the present report. The estimate of wild juveniles was calculated by grouping the daily passage estimates, N_{sd} and the daily juvenile data into strata consisting of *T* "statistical weeks" formed by combining adjacent weeks (if needed to obtain sufficient sample sizes). The weekly juvenile estimates were $(N_{s1}, N_{s2}, \dots, N_{sT})$ where $N_{st} = \sum_{d \in t} N_{sd}$.

The rearing data were

$$R_{s1}, R_{s2}, \dots, R_{sM}$$
$$t_1 e_{s1}, t_2 e_{s2}, \dots, t_M e_{sM}$$

where R_{sk} is rear type (i.e., wild) and M is the number of juveniles trapped. Note that $e_{sk} = e_{sd}$ for all juveniles trapped on day *d*. We divided the data into strata and obtained the expanded number of wild juveniles by dividing each juvenile by its probability of being sampled, $t_k e_{sk}$. For stratum *t*, the expanded number of juveniles that were wild for stratum *t* was

$$f_{sRt} = \sum_{k \in t} \frac{\delta_{Rk}}{t_k e_{sk}}$$

where δ_{Rk} is 1 if R is wild and 0 otherwise giving the table

Rear/Stratum	1	2	…	T	
HNC	f_{sHNC1}	f_{sHNC2}	…	f_{sHNCT}	#HNC#
W	f_{sW1}	f_{sW2}		f_{sWT}	#W#
Column total	#1	#2	…	#T	#

Dividing by the marginal column totals, #1, #2,…,#T yielded proportions HNC and W by strata, p_{sRt}. If we wanted a pooled proportion, then we would use #HNC/# and #W/#.

We then multiplied the proportion W (or HNC) for each stratum by the stratum estimate of total juveniles, N_{st} and summed over strata that yielded,

$$W = \sum_{t=1}^{T} p_{sWt} N_{st} \text{ and } HNC = \sum_{t=1}^{T} p_{sHNCt} N_{st}$$

This method to estimate total W and HNC emigration was preferred if proportion W (or HNC) varies over the season and if there were sufficient samples to get stable estimates of proportion W (or HNC) by strata. Otherwise, one might use the pooled estimates of proportion wild.

The wild emigration estimates by strata $(W_{s1}, W_{s2}, \dots, W_{sT})$ were then decomposed by a PRIMARY category (usually genetic stock). Genetic stock proportions may change throughout the trapping season, but we assumed the genetic stock proportions were roughly equal within a stratum. We would like to know the true proportions, e.g., of genetic stocks A to E

$(\pi_{At}, \pi_{Bt}, \pi_{Ct}, \pi_{Dt}, \pi_{Et})$ for t = 1, where *T* is the number of strata. If all wild trapped juveniles were analyzed, then we could compute estimates of the proportions $(\pi_{At}, \pi_{Bt}, \pi_{Ct}, \pi_{Dt}, \pi_{Et})$ as above for W and HNC. However, not all trapped juveniles were analyzed every day so the realized capture rate of a group of fish analyzed on day *d* is $t_d \times e_{sd} \times \frac{a_{sd}}{c_{sd}}$ where a_{sd} is the number of juveniles analyzed on day d. If a_{jd} is the number of wild fish of group *j* on day *d*, we get an estimate of the number of wild juveniles of each group for stratum t as

$$A_{jt} = \sum_{d\ in\ t} \frac{a_{jd}}{t_d \times e_{sd} \times \frac{a_{sd}}{c_{sd}}} = \sum_{d\ in\ t} \sum_{fish\ k\ on\ day\ d} \frac{\delta_j}{t_k \times e_{sk} \times \frac{a_{sd}}{c_{sd}}}$$

where $\delta_j = 0$ except for fish of group A_j when $\delta_j = 1$. Note that we assumed that all fish analyzed on a given day had the same trapping rate and collection efficiency so $t_k \times e_{sk} = t_d \times e_{sd}$ and the second summation on the right sums to $a_{jd}/(t_d \times e_{sd} \times \frac{as_d}{c_{sd}})$ as indicated.

Except for the addition of the realized tissue sampling rate, $\frac{a_{sd}}{c_{sd}}$, we obtained the expanded group by stratum table as above for W and HNC,

Group/Stratum	1	2	…	T
A	A_{11}	A_{12}	…	A_{1T}
B	A_{21}	A_{22}	…	A_{2T}
…	…	…	…	…
E	A_{51}	A_{52}		A_{5T}
Column total	#1	#2	…	#T

Dividing by the column totals, we obtained estimates of the group proportions, π_{jt}, by stratum. The strata proportions were applied to the estimated total wild emigration estimate for each week. Summing over strata provided an estimate of the numbers of wild fish for each group $(A_A, \ldots, A_E)$. Note that strata were formed to try to provide a minimum sample size of approximately 100 analyzed fish per stratum. If there is a SECONDARY classification variable, then the A_{jt} expanded frequency table above is 3-dimensional where A_{ijt} is calculated as A_{jt} above with SECONDARY dimension *i*. For a given stratum and primary category, there may be no data for the secondary category. In this case the expanded frequencies were pooled over strata and a pooled estimate of the SECONDARY proportions was computed for each level of the PRIMARY variable. Using this hierarchical structure constrained point estimates for each subsequent variable to sum to its relevant parent class. For example, all abundance estimates by age for a given stock will sum to the abundance of that stock. Similarly, all stock estimates will sum to the relevant rear type abundance and W and HNC rear types will sum to the total estimate of ad-intact smolts at LGR.

Confidence intervals for all point estimates were computed using a bootstrapping algorithm (Manly 1997). There were three sources of sampling error in the decomposed emigration estimates: variance in the estimated number of fish trapped each day, variance in the proportion wild by stratum, and variance in estimates of age, sex, and genetic stock proportions. To account for these sources of variability when estimating abundance by age, sex, and genetic stock, we used a compound bootstrap routine: a parametric bootstrap by stratum, and a weighted nonparametric bootstrap by stratum of the biological sample data (age, sex, and genetic stock).

The number of juveniles trapped per day was considered a series of Bernoulli trials, where N_d was the true number of juveniles passing the trap for day *d* and each juvenile was trapped with probability $t_d e_{sd}$. A bootstrap value of trap catch *c* for day *d* was generated by taking a random value from $c_d^* \sim Binomial(N_{sd}, p_{sd})$, where $p_{sd} = t_d \times e_{sd}$ as above. Given a bootstrap value for the number of juveniles trapped on day *d*, we got a bootstrap value for the number of juveniles arriving for day *d* as $N_{sd}^* = c_{sd}^* / p_{sd}$. Summing over days in a stratum, we got a bootstrap value for the total number of juveniles emigrating during each stratum $(N_{s1}^*, N_{s2}^*, \ldots, N_{sT}^*)$. For each stratum, we got a bootstrap estimate of the proportion wild in the stratum using a weighted nonparametric bootstrap for the data for that stratum with weights p_k where *k* indexes fish in stratum *t*. Note that $p_k = p_d$ for all trapped fish on day *d*. This led to bootstrap values f_{sWt}^* and hence bootstrap proportion wild for each stratum. Multiplying these proportions by the bootstrap estimates of total juveniles emigrating during each stratum yielded bootstrap estimates of number wild by stratum. Summing over strata, we obtained bootstrap estimates of total wild.

Given the bootstrap values for total wild juveniles, we generated bootstrap values for the *numbers* of juveniles of each age, sex, and genetic stock if we generated bootstrap values for the *proportions* of juveniles in each respective group for each stratum. We did this by producing bootstrap values A_{jt}^* (or A_{ijt}^*) via a weighted bootstrap of the age, sex, or genetic stock data for that stratum with weights $t_k \times e_{sk} \times \frac{a_d}{c_{sd}}$. These were converted to proportions and bootstrap estimates of numbers of wild fish by age or sex or genetic stock by stratum were found by multiplying these proportions by the bootstrap estimates of wild juveniles for the stratum. We then summed over strata to obtain season long bootstrap estimates of numbers of juveniles by age or sex or genetic stock. We conducted the compound bootstrap procedure 5,000 times. For each iteration, the numbers of wild fish of various ages, sex, or stock were computed. The one-at-a-time bootstrap intervals were found by finding the 5th and 95th percentiles of the 5,000 ordered bootstrap values for each group (i.e., α = 0.10). The algorithm was written and implemented in the R programming environment (R Development Core Team 2015) by Kirk Steinhorst (University of Idaho) and can be found within the SCOBI package (https://github.com/mackerman44/SCOBI) as the SCRAPI function.

Steelhead and Chinook Salmon Adult-to-Juvenile Productivity

We examined adult-to-juvenile productivity for the aggregate population of steelhead and Chinook Salmon by relating the estimated number of emigrating juveniles at LGR to the estimated number of female parents that were available for natural reproduction. Juvenile estimates for both species were obtained from this report and from Camacho et al. (2018b, 2019a). Females available for natural reproduction (FANR) for both species was calculated by subtracting fish of known fates (i.e., harvest or retention at hatchery weirs) from estimates of adult females at LGR (Camacho et al. 2017; 2018a; 2019b).

The FANR for steelhead was estimated by applying the sex ratio at LGR to estimates of potential spawners for each rear type from the Snake River Basin Steelhead Run Reconstruction analysis (Copeland et al. 2013; 2014; 2015; Stark et al. 2016; 2017; 2018; 2019). The Snake River Basin Steelhead Run Reconstruction analysis estimated the number of hatchery and wild adults available to spawn by applying fallback and reascension, nighttime passage, and mortality (fishery related, broodstock collection, and other weir associated removals) rates to abundance estimates at LGR, thus tracking abundance through fisheries to the various spawning areas (see Stark et al. 2019 for details). Estimates were not decomposed by sex within the run reconstruction. We assumed the aggregate wild sex ratio derived at LGR was representative of the adults available for natural spawning (Camacho et al. 2017; 2018b; 2019b).

The FANR for Chinook Salmon was estimated by subtracting harvest and broodstock removals from the number of adults counted at LGR for the spring and summer run types. Unlike steelhead, adult Chinook Salmon counts were not adjusted for fallback and reascension or nighttime passage. The estimated number of adults per run type (excluding jacks) passing LGR during 2014 was obtained directly from the Fish Passage Center (www.fpc.org, accessed March 2019). COE designates jack Chinook Salmon as fish between 30 and 56 cm in length at Columbia River dams counting windows. Adult Chinook Salmon that passed LGR between March 3 and June 17 were defined as "spring run," and those passing LGR between June 18 and August 17 were defined as "summer run." The total number of adult Chinook Salmon (excluding jacks) captured at hatchery traps and the number of females taken into hatcheries was obtained with permission in read-only views from the Pacific States Marine Fish Commission Fish Inventory System hatchery database (FINS): https://www.finsnet.org/. Additional data were obtained from Oregon Department of Fish & Wildlife (ODFW; Joseph Feldhaus, personal communication), and the Shoshone-Bannock Tribes (SBT). McCall, Panther Creek, Pahsimeroi, and Lochsa River hatchery fish were considered summer run and all other hatchery stocks were considered spring run. The percentage of females, by run type, was estimated for all adult Chinook Salmon (excluding jacks) identified to sex at hatchery weirs. The estimated percentage of females was applied to the aggregate LGR counts for each run type to estimate the total number of female Chinook Salmon passing LGR. The total harvest estimates upstream of LGR were obtained from IDFG (Chris Sullivan, personal communication), ODFW (Kyle Bratcher, personal communication), and SBT (Ryan Blackadar, personal communication). A 10% mortality rate was applied to catch-and-release estimates of hatchery and wild fish. Female harvest was estimated by multiplying run-specific total harvest by the respective sex ratio. To estimate FANR, the adjusted hatchery female number and the adjusted number of females harvested upstream of LGR were subtracted from the estimated number of females passing LGR. Spring and summer FANR estimates were combined to estimate total FANR.

A Beverton-Holt function was used to update the Chinook Salmon stock-recruitment model last published in Camacho et al. (2019a) for BYs 1990-2015. The stock-recruitment model used the following formula (Beverton and Holt 1957).

$$R = \frac{\alpha P}{1 + \beta P}$$

where P = parent year spawning escapement (i.e. FANR), R = recruits (juveniles) produced by parent year spawning escapement (P), and α and β are fitted parameters. In this formulation, α is the density independent parameter and β is a density-dependent parameter. The Beverton-Holt model assumes that juvenile mortality increases as juvenile competition for finite resources of food and space increases (Wootton 1990). The result is asymptotic maximum (α/β) juvenile recruitment at high spawning stock abundances (Beverton and Holt 1957). Model parameters were estimated using the stock-recruitment scripts developed by Ogle (2016) implemented in the statistical program R (R Development Core Team 2020).

We did not produce a stock-recruit function to steelhead data because only five brood years were complete enough to establish female – juvenile productivity. Generally, 10-15 generations are required to establish a stock-recruit relationship (Hilborn and Walters 1992).

RESULTS

Wild Steelhead Emigration

Estimated wild steelhead emigration was 845,815 smolts (807,996–883,518 90% CI; Figure 4; Appendix A-1 and B-1). The first wild steelhead smolt was captured on March 28, 2019 and the last smolt was captured on June 27, 2019. There were 1,374 wild steelhead smolts sampled for analysis, of which 1,299 yielded a genetic stock, sex, and age. An additional nine ad-intact hatchery smolts were sampled but not used.

The Grand Ronde River genetic stock (GRROND) had the highest abundance at 245,952 fish (220,231–266,842 90% CI) or 29% of the aggregate total, followed by the upper Salmon River (UPSALM) at 126,099 fish (108,724–143,760 90% CI) or 15% of the total (Appendix B-1 and B-2). The abundance of the GRROND stock was more than an order of magnitude higher than the lowest stock — lower Salmon River (LOSALM) at 17,696 fish (13,450–26,054 90% CI) or 2% of the total.

Sex ratios were female biased. Females comprised 64% of the aggregate juvenile emigration (Appendix B-1 and B-3). All of the genetic stocks were also female-biased except IMNAHA, which was male-biased at slightly over 50% (Appendix B-4). However, juvenile male and female abundances in five of the ten genetic stocks did not differ significantly in a statistical sense, i.e. 90% CIs overlapped.

Juvenile ages ranged from 1 to 4 years with the majority of emigrants comprised of age-2 and age-3 smolts (Appendix B-5). Age-2 steelhead were the most abundant age class followed by age-3. Age-2 smolts dominated in six of the ten genetic stocks (SFCLWR, LOCLWR, GRROND, IMNAHA, UPSALM, and LSNAKE; Appendix B-6). Of the four Salmon River stocks, only the Upper Salmon River genetic stock (UPSALM) was dominated by age-2 smolts; the remainder were dominated by age-3 smolts.

Wild Steelhead Productivity

To continue the adult-to-juvenile productivity series that began with BY2011, we re-estimated FANR for all wild steelhead brood years reported by Camacho et al. (2019a) then added two new brood years, BY2017 and BY2018 (Table 2; Figure 5). Migratory year 2019 completed emigration of the BY2014 steelhead cohort with age-5 juveniles, of which none were collected. The aggregate productivity of BY2014 was 32 juveniles per female parent that returned to LGR. Brood year 2014 produced 698,721 juveniles at LGR from 21,499 potential female parents that escaped the fishery. Brood year 2015 is complete through age 4 and productivity is a tentative 17 smolts per female parent.

Wild Chinook Salmon Yearling Emigration

Estimated wild Chinook Salmon emigration was 794,695 yearling smolts (758,285–831,075 90% CI; Figure 4; Appendix A-2 and C-1). The first wild Chinook Salmon smolt was captured on March 26, 2019 and the last smolt was captured on June 26, 2019. There were 1,047 wild Chinook Salmon smolts sampled for analysis, of which 1,017 yielded a genetic stock, sex, and age. An additional 169 ad-intact hatchery smolts were sampled but not used.

The Hells Canyon genetic stock (HELLSC) had the highest abundance at 295,922 fish (271,608–326,059 90% CI) or 37% of the aggregate total, followed by the South Fork Salmon

River (SFSALM) at 171,313 fish (140,506–184,372 90% CI) or 22% of the total (Appendix C-1 and C-2). The abundance of these two stocks was an order of magnitude higher than the lowest stock detected — Chamberlain Creek (CHMBLN) at 6,762 fish (2,753–11,778 90% CI) or 1% of the total. However, the Tucannon River genetic stock (TUCANO) was not detected in MY 2019.

Sex ratios were female biased. Females comprised 57% of the aggregate juvenile emigration (Appendix C-1 and C-3). All of the genetic stocks were also female-biased (Appendix C-4). However, juvenile male and female abundances did not differ significantly in the genetic stocks, i.e. 90% CIs overlapped in each case.

Wild Chinook Salmon Productivity

We continued our adult-to-juvenile productivity series that began with BY1990 (Table 3; Figure 5). Migratory year 2019 completed emigration of the BY2017 Chinook Salmon cohort. The aggregate productivity of BY2017 was 94 wild yearling smolts per female parent that returned to LGR. Brood year 2017 produced 794,695 yearlings at LGR from 8,491 potential female parents that escaped the fishery.

The Beverton-Holt stock-recruit model used empirical data from wild yearling smolts and FANR over twenty-eight brood years, i.e. BY1990-2017 (Table 3; Figure 6). Intrinsic productivity (α) was 445.2 (319–637 95% CI) yearlings per FANR and asymptotic production was 1,400,440 yearlings. For BY2018, from the 10,339 hatchery and wild females available for natural reproduction, the model predicted production of 1,419,649 yearling smolts, implying productivity should be 460 wild yearling smolts per female.

DISCUSSION

This report presents a wild juvenile emigration stock assessment using genetic stock identification for the Snake River steelhead DPS and spring-summer Chinook Salmon ESU, exclusive of the Tucannon River. It is a continuation of the data series developed in Camacho et al. (2018b), who incorporated estimates of the juvenile emigration for aggregate and component genetic stock units and the implementation of PBT to distinguish ad-intact hatchery from wild fish (Steele et al. 2018). Furthermore, the report continues the stock-recruitment relationship for yearling Chinook Salmon. The ultimate goal of this report series is to develop productivity relationships at the aggregate, genetic stock, and MPG level, requiring stock-specific information relative to sex and age.

In this analysis, we assumed that the realized sampling rate adequately described the probability that any fish passing LGR could be sampled. There are three possible exceptions to this assumption. First, we assumed there was no size bias in collection at LGR (i.e., larger juveniles were less likely to enter the juvenile by-pass system); however, evidence for and against size bias has been presented in the peer-reviewed literature (e.g., see Faulkner et al. 2019 and Storch et al. 2020). Second, PIT-tagged fish were not sampled; therefore, populations in which there was a high rate of tagging may be underrepresented in the analysis. Third, subyearling and holdover yearling fall Chinook Salmon that were phenotypically distinguishable from spring-summer Chinook Salmon juveniles (Tiffan et al. 2000) were not sampled at the trap. Fall Chinook Salmon estimates presented in this report do not represent total emigration and caution should be used when interpreting those estimates. Lastly, recent increases in spill at LGR have greatly decreased daily collection efficiencies. It would be prudent to consider how the decreased efficiencies affect the reliability of the trap catch expansion and the compositional sampling.

The vast majority of Snake River steelhead and Chinook Salmon stocks spawn above Lower Granite Dam with three notable exceptions. First, Snake River fall Chinook spawn upstream and downstream of LGR. Many of them emigrate as subyearling smolts and are not sampled for this report. Second, the Tucannon River population of spring Chinook Salmon originates from downstream of LGR. The juvenile emigration estimates for yearling Chinook Salmon from the Tucannon River genetic stock reported in the past represent the number of offspring that were produced from adults originating from the Tucannon River and successfully strayed and reproduced upstream of LGR. Tucannon River populations demonstrate slight evidence for introgression (5.3%) with fall Chinook Salmon (Narum et al. 2010) and are generally highly identifiable (Ackerman et al. 2012). Third, some wild steelhead belonging to the LSNAKE (Lower Snake River) genetic stock spawn in Asotin Creek (61 rkm upstream from LGR) and minor tributaries to the LGR reservoir (e.g., Alpowa Creek). Furthermore, many steelhead from the Tucannon River stray extensively above LGR (Bumgarner and Dedloff 2011). Accounting of production by steelhead and Chinook Salmon populations that do not spawn exclusively above LGR is incomplete in this report but they must be identified for accurate assessment of the other Snake River stocks.

Variations in freshwater production by salmon and steelhead are important to understanding population dynamics. Steelhead and Chinook Salmon exhibit variable life history strategies both in freshwater and saltwater environments. Increased diversity of characteristics such as age-at-migration and sex bias towards anadromy increases resiliency and can benefit a species' persistence by spreading risk across space and time (Copeland et al. 2017; Quinn 2018; Dobos et al. 2020). Snake River steelhead juveniles can rear in freshwater environments from one to five years prior to emigrating to the ocean and can make ontogenetic shifts in habitat use such as from tributary to mainstem rivers as they grow. Spatial and temporal diversity in juvenile rearing buffers risk of stochastic events such as droughts, fire, and erosion that would otherwise be catastrophic, leading to year class failures. A cohort of spring-summer Chinook Salmon juveniles typically emigrates in a single year and can be more susceptible to stochastic events. Additionally, sex can influence the decision of a fish to exhibit an anadromous life history strategy. Theory suggests females benefit from anadromy by attaining larger adult body size and higher fecundity, while males can successfully mature and reproductively compete in a non-anadromous form (Hendry et al. 2004); therefore, we expect a female bias in emigrating juveniles. This appeared to be true for steelhead juveniles and Chinook Salmon yearlings. The fitness of a particular life history strategy may vary with density, frequency of other types, and condition of individuals (Hendry et al. 2004), all of which change with time and location. Certainly, sex ratios from juveniles varied among stocks, which may be influenced by the habitats in which they reared. For example, some tributaries can produce more female emigrants than others even within the same watershed (Mills et al. 2012). Life history and demographic patterns in data presented here may suggest smaller scale investigations to determine causes, and they also provide the means to test predictions at the emigrating juvenile stage, which is a convenient and meaningful stage to consider recruitment (Solomon 1985).

Accurately quantifying a juvenile steelhead cohort is difficult due to their life history diversity. Ages at juvenile emigration ranged up to four years in this report, but have been observed up to age-6 from adult scales (Camacho et al. 2017). Extended freshwater rearing times elongate the timeframe to consider a juvenile estimate complete for a single brood year. The aggregate emigration at Lower Granite Dam was composed of mostly age-2 migrants followed by age-3 emigrants. Age-1 and age-4 emigrants were uncommon but present, whereas freshwater age-5 migrants have been below detectable limits since MY 2015. At the aggregate level, the relative abundance of age-2 and age-3 emigrants was driven by the production by the two most

abundant genetic stocks — the Grand Ronde River and the Upper Salmon River stocks — that produce fairly stable numbers of age-3, but annually variable numbers of age-2 emigrants. Other stocks also contributed to the prevalence of age-2 migrants at the aggregate level, including the South Fork Clearwater River, Lower Clearwater River, and Lower Snake River stocks. Migratory year 2019 showed the second consecutive decline in age-2 abundance and second consecutive increase in age-3 abundance (Appendix B-5). Higher interannual variability in age-2 abundance than in age-3 abundance at the aggregate level is an emerging pattern. Additionally, an unknown portion of steelhead residualize in their natal stream and are never quantified, which effectively reduces the estimate of progeny created from a single cohort. Resident *O. mykiss* females could affect the true stock-recruitment relationship (see Berntson et al. 2011 and Courter et al. 2013). Unfortunately, feasible methods of assessing the rate of residualization for steelhead in the Snake River basin are lacking.

Methods of estimating FANR for steelhead and Chinook Salmon require assumptions that need to be evaluated when used for productivity analysis. The time series of juveniles per FANR shows a sharp shift in interannual variability following BY 2001 (Figure 5). This could arise from potential biological mechanisms (i.e., dynamics at low population abundance) or could be an artifact of the FANR estimate. The Chinook Salmon productivity analysis has assumed a constant 10% prespawn mortality in wild and 20% hatchery Chinook Salmon since its inception (Kiefer et al. 2004). Bowerman et al. (2021) modeled prespawn mortality in the interior Columbia River basin and that work could be used to assess the sensitivity of these results to those assumptions. Further, we assumed that hatchery and wild fish are equally effective at producing young, which is often not true (Fleming and Gross 1993; Janowitz-Koch et al. 2019). We recommend investigating the relationship between the proportion of naturally spawning hatchery females and the corresponding residuals of the cohort emigrant estimates.

In this report, we re-estimated the FANR values for steelhead presented by Camacho et al. (2019a) and presented only the aggregate results. Camacho et al. (2019a) used escapement values from the run reconstruction analysis that did not account for removals of hatchery fish at weirs, thus represented an overestimate of adults available for natural spawning. Here, we used the adjusted values contained in the run reconstruction reports (e.g., Stark et al. 2019). Further refinement of the run-reconstruction analysis is necessary to enable adult to juvenile productivity estimates at finer resolutions (e.g., Major Population Group). That work is ongoing but has not yet been incorporated into this report.

In conclusion, the juvenile estimates reported here will be used to evaluate the abundance, performance, and status of wild steelhead and spring-summer Chinook Salmon across the Snake River basin. The work presented in this report is an attempt to measure juvenile emigration at a basinwide scale and should be considered complimentary to the intensive smaller-scale rotary screw trap work (e.g., Poole et al. 2019) occurring in the Snake River basin. In addition, the combination of juvenile compositional analyses at LGR and similar adult data (Camacho et al. 2017, 2018a, 2019b) provide opportunities to evaluate the status and productivity performance of particular reporting groups throughout the lifecycle. In the future, estimates within this report will be combined with other datasets to explore relationships leading to a better understanding of how Snake River steelhead and spring-summer Chinook Salmon populations function.

RECOMMENDATIONS

- Continue genetic and scale sampling at LGR for emigration estimates at the aggregate and genetic stock level.
- Continue juvenile per female productivity for the aggregate and genetic stock for yearling Chinook Salmon and steelhead.
- Evaluate assumptions regarding the productivity calculations. Consider the effects of variable prespawn mortality and reproduction by naturally spawning hatchery fish.
- Continue the stock-recruitment relationships developed for the aggregate population of yearling Chinook Salmon.
- Develop stock-recruitment relationships for each genetic stock when sufficient estimates have accumulated.

LITERATURE CITED

Ackerman, M. W., J. McCane, C. A. Steele, M. R. Campbell, A. P. Matala, J. E. Hess, and S. R. Narum. 2012. Chinook and steelhead genotyping for genetic stock identification at Lower Granite Dam. Idaho Department of Fish and Game Report 12-15. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

Anderson, E. C. 2010. Computational algorithms and user-friendly software for parentage-based tagging of Pacific salmonids [online]. Final report submitted to the Pacific Salmon Commission's Chinook Technical Committee (US Section). http://swfsc.noaa.gov/textblock.aspx?Division=FED&ParentMenuId=54&id=16021.

Berntson, E. A., R. W. Carmichael, M. W. Flesher, E. J. Ward, and P. Moran. 2011. Diminished reproductive success of steelhead from a hatchery supplementation program (Little Sheep Creek, Imnaha Basin, Oregon). Transactions of the American Fisheries Society 140:685-698.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fisheries Investigations Series II volume 19. Ministry of Agriculture, Fisheries, and Food, Her Majesty's Stationery Office, London.

Bowerman, T.E., M. L. Keefer, and C. C. Caudill. 2021. Elevated stream temperature, origin, and individual size influence Chinook salmon prespawn mortality across the Columbia River Basin. Fisheries Research 237:105874 https://doi.org/10.1016/j.fishres.2021.105874.

Bumgarner, J. D., and J. Dedloff. 2011. Lyons Ferry Complex Hatchery evaluation: summer steelhead annual report 2008 and 2009 run years. Report to U.S. Fish and Wildlife Service, Lower Snake River Compensation Plan Office, Boise, Idaho. FPA 11-05.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Wauneta, and I. V. Lagomarsino. 1996. Status review of West Coast steelhead from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-27.

Camacho, C. A., K. K. Wright, J. Powell, W. C. Schrader, T. Copeland, M. W. Ackerman, M. Dobos, M. P. Corsi, and M. R. Campbell. 2017. Wild adult steelhead and Chinook Salmon abundance and composition at Lower Granite Dam, spawn years 2009-2016. Cumulative report 2009 through 2016. Idaho Department of Fish and Game Report 17-06. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

Camacho, C. A., J. Powell, M. Davison, M. E. Dobos, W. C. Schrader, T. Copeland, and M. R. Campbell. 2018a. Wild adult steelhead and Chinook Salmon abundance and composition at Lower Granite Dam, spawn year 2017. Annual report 2017. Idaho Department of Fish and Game Report 18-06. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

Camacho, C. A., K. K. Wright, J. Powell, W. C. Schrader, T. Copeland, M. W. Ackerman, M. E. Dobos, M. Davison, M. P. Corsi, and M. R. Campbell. 2018b. Wild juvenile steelhead and Chinook Salmon abundance and composition at Lower Granite Dam, migratory years 2010-2017. Cumulative report 2010 through 2017. Idaho Department of Fish and Game Report 18-05. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

Camacho, C. A., T. Delomas, M. Davison, M. E. Dobos, W. C. Schrader, M. R. Campbell, and T. Copeland. 2019a. Wild juvenile steelhead and Chinook Salmon abundance and composition at Lower Granite Dam, migratory year 2018. Annual report 2018. Idaho Department of Fish and Game Report 19-12.

Camacho, C. A., T. Delomas, M. Davison, M. E. Dobos, W. C. Schrader, T. Copeland, and M. R. Campbell. 2019b. Wild adult steelhead and Chinook Salmon abundance and composition at Lower Granite Dam, spawn year 2018. Annual report 2018. Idaho Department of Fish and Game Report 19-09. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

Campbell, N. R., S. A. Harmon, and S. R. Narum. 2015. Genotyping-in-Thousands by sequencing (GT-seq): A cost effective SNP genotyping method based on custom amplicon sequencing. Molecular Ecology Resources 15:855–867.

Campbell, M. R., C. C. Kozfkay, T. Copeland, W. C. Schrader, M. W. Ackerman, and S. R. Narum. 2012. Estimating abundance and life history characteristics of threatened wild Snake River steelhead stocks by using genetic stock identification. Transactions of the American Fisheries Society 141:1310-1327.

Copeland, T., J. D. Bumgarner, A. Byrne, L. Denny, J. L. Hebdon, M. Johnson, C. A. Peery, S. Rosenberger, E. R. Sedell, G. E. Shippentower, C. Stiefel, and S. P. Yundt. 2013. Reconstruction of the 2010/2011 steelhead spawning run into the Snake River basin. Report to Bonneville Power Administration, Portland, Oregon.

Copeland, T., J. D. Bumgarner, A. Byrne, L. Denny, J. L. Hebdon, M. Johnson, C. A. Peery, S. Rosenberger, E. R. Sedell, G. E. Shippentower, C. Stiefel, and S. P. Yundt. 2014. Reconstruction of the 2011/2012 steelhead spawning run into the Snake River basin. Report to Bonneville Power Administration, Portland, Oregon.

Copeland, T., J. D. Bumgarner, A. Byrne, P. Cleary, L. Denny, J. L. Hebdon, C. A. Peery, S. Rosenberger, E. R. Sedell, G. E. Shippentower, C. Warren, and S. P. Yundt. 2015. Reconstruction of the 2012/2013 steelhead spawning run into the Snake River basin. Report to Bonneville Power Administration, Portland, Oregon.

Copeland, T., M. W. Ackerman, K. K. Wright, and A. Byrne. 2017. Life History Diversity of Snake River Steelhead Populations between and within Management Categories. North American Journal of Fisheries Management 37:395-404.

Courter, I. I., D. B. Child, J. A. Hobbs, T. M. Garrison, J. J. G. Glessner, and S. Duery. 2013. Resident rainbow trout produce anadromous offspring in a large interior watershed. Canadian Journal of Fisheries and Aquatic Sciences 70:701-710.

Crawford, B. A., and S. M. Rumsey. 2011. Guidance for monitoring recovery of Pacific Northwest salmon and steelhead listed under the Federal Endangered Species Act. U.S. Department of Commerce, National Marine Fisheries Service, NW Region.

Dehart, M. 2019. Fish Passage Center 2019 Annual Report. Fish Passage Center. BPA Project 1994-033-00. Available at: http://www.fpc.org/documents/FPC_Annual_Reports.html

Dobos, M. E., B. J. Bowersox, T. Copeland, and E. J. Stark. 2020. Understanding life history diversity of a wild steelhead population and managing for resiliency. North American Journal of Fisheries Management 40:1087-1099.

Faulkner, J. R., B. L. Bellerud, D. L. Widener, and R. W. Zabel. 2019. Associations among fish length, dam passage history, and survival to adulthood in two at-risk species of Pacific salmon. Transactions of the American Fisheries Society 148:1069-1087.

Fleming, I. A., and M. R. Gross. 1993. Breeding success of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in competition. Ecological Applications 3:230-245.

Hargrove, J. S., T. A. Delomas, J. McCane, M. Davison, M. R. Campbell, R. L. Horn, and S. R. Narum. 2020. Chinook Salmon and steelhead genotyping for genetic stock identification at Lower Granite Dam. Idaho Department of Fish and Game Report 20-05. Annual Report 2019. BPA Project 2010-026-00.

Hendry, A. P., T. Bohlin, B. Jonsson, and O. K. Berg. 2004. To sea or not to sea? Anadromy versus non-anadromy in salmonids. Pages 92-125 in A. P. Hendry and S. C. Stearns, editors. Evolution Illuminated: Salmon and Their Relatives. Oxford University Press, New York.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment: choices, dynamics, and uncertainty. Kluwer Academic Publishers, Boston, Massachusetts

ICBTRT (Interior Columbia Technical Recovery Team). 2003. Independent populations of Chinook, steelhead, and sockeye for listed evolutionarily significant units within the interior Columbia River domain. Working Draft, July 2003.

ICBTRT (Interior Columbia Technical Recovery Team). 2005. Updated population delineation in the interior Columbia Basin. Memo to NMFS Northwest Regional Office May 11, 2005.

IDFG (Idaho Department of Fish and Game). 2019. Fisheries management plan 2019-2024. Idaho Department of Fish and Game, Boise.

Janowitz-Koch, I., C. Rabe, R. Kinzer, D. Nelson, M. A. Hess, and S. R. Narum. 2019. Long-term evaluation of fitness and demographic effects of a Chinook Salmon supplementation program. Evolutionary Applications 12:456-469.

Kiefer, R. B., J. Johnson, P. R. Bunn, and A. Bolton. 2004. Natural production monitoring and evaluation annual progress report, July 1, 2002-June 30, 2003. Idaho Department of Fish and Game Report 03-30. BPA Project 1991-073-00.

Latremouille, D. N. 2003. Fin erosion in aquaculture and natural environments. Reviews in Fisheries Science 11:315-335.

Lawry, K. M., C. A. Camacho., J. S. Hargrove, T. Delomas, M. Davison, M. E. Dobos, W. C. Schrader, T. Copeland, and M. R. Campbell. 2020. Wild adult steelhead and Chinook Salmon abundance and composition at Lower Granite Dam, spawn year 2019. Annual report 2019. Idaho Department of Fish and Game Report 20-12.

Manly, B. F. J. 1997. Randomization, bootstrap, and Monte Carlo methods in biology, 2nd edition. Chapman and Hall, New York.

Matthews, G. M., and R. S. Waples. 1991. Status review for Snake River spring and summer Chinook Salmon. National Oceanic and Atmospheric Administration Technical Memorandum NMFS F/NWC-200.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonids populations and the recovery of evolutionarily significant units. National Oceanic and Atmospheric Administration Technical Memorandum NMFS-NWFSC-42.

Mensik, F., S. Rapp, and D. Ross. 2010. Lower Granite Dam smolt monitoring program annual report March 2009-February 2010. Pacific States Marine Fisheries Commission. BPA Project 1987-127-00.

Mills, J. S., J. B. Dunham, G. H Reeves, J. R. McMillan, C. E. Zimmerman, and C. E. Jordan. 2012. Variability in expression of anadromy by female *Oncorhynchus mykiss* within a river network. Environmental Biology of Fishes 93:505-517.

Moran, B. M. and E. C. Anderson. 2019. Bayesian inference from the conditional genetic stock identification model. Canadian Journal of Fisheries and Aquatic Sciences 76:551-560.

Narum, S. R., J. E. Hess, and A. P. Matala. 2010. Examining genetic lineages of Chinook Salmon in the Columbia River Basin. Transactions of the American Fisheries Society 139:1465-1477.

Ogle, D. H. 2016. Introductory Fisheries Analyses with R. Chapman and Hall/CRC, Boca Raton, Florida.

Poole, J. R., E. Felts, M. Dobos, B. Barnett, M. Davison, M. Dobos, C. J. Roth, B. A. Knoth, and E. J. Stark. 2019. Idaho anadromous emigrant monitoring. 2018 Annual Report. Idaho Department of Fish and Game Report 19-11.

Powell, J. H., N. Vu, J. McCane, M. Davison, M. R. Campbell, D. J. Hasselman, and S. R. Narum. 2018. Chinook and Steelhead Genotyping for Genetic Stock Identification at Lower Granite Dam. Idaho Department of Fish and Game Report 18-03. Annual Report, BPA Project 2010-026-00.

Quinn, T. P. 2018. The behavior and ecology of Pacific salmon and trout, second edition. University of Washington Press. Seattle.

R Development Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org.

Raymond, H. L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer Chinook Salmon and steelhead in the Columba River basin. North American Journal of Fisheries Management 8:1-24.

Sandford, B. P., and S. G. Smith. 2002. Estimation of smolt-to-adult return percentages for Snake River basin anadromous salmonids, 1990-1997. Journal of Agricultural, Biological and Environmental Statistics 7:243-263.

Solomon, D. J. 1985. Salmon stock and recruitment, and stock enhancement. Journal of Fish Biology 27(Supplement A):45-57.

Stark, E. J., C. Bretz, A. Byrne, P. Cleary, T. Copeland, L. Denny, R. Engle, T. Miller, S. Rosenberger, E. R. Sedell, G. E. Shippentower, and C. Warren. 2016. Snake River basin steelhead 2013/2014 run reconstruction. Report to Bonneville Power Administration, Portland, Oregon.

Stark, E. J., A. Byrne, P. J. Cleary, T. Copeland, L. Denny, R. Engle, T. Miller, D. Nemeth, S. Rosenberger, E. R. Sedell, G. E. Shippentower, and C. Warren. 2017. Snake River basin steelhead 2014/2015 run reconstruction. Report to Bonneville Power Administration, Portland, Oregon.

Stark, E. J., A. Byrne, P. J. Cleary, J. Ebel, T. Miller, D. Nemeth, S. Rosenberger, E. R. Sedell, and C. Warren. 2018. Snake River Basin 2015-2016 steelhead run reconstruction. Report to Bonneville Power Administration, Portland, Oregon.

Stark, E. J., A. Byrne, P. J. Cleary, J. Ebel, T. Miller, S. Rosenberger, E. R. Sedell, and C. Warren. 2019. Snake River Basin 2016-2017 steelhead run reconstruction. Report to Bonneville Power Administration, Portland, Oregon.

Steele, C. A., E. C. Anderson, M. W. Ackerman, M. A. Hess, N. R. Campbell, S. R. Narum, and M. R. Campbell. 2013. A validation of parentage-based tagging using hatchery steelhead in the Snake River basin. Canadian Journal of Fisheries and Aquatic Sciences 70:1-9. http://dx.doi.org/10.1139/cjfas-2012-0451.

Steele, C., A., J. McCane, M. Ackerman, N. Vu, M. Campbell, M. Hess, and S. Narum. 2016. Parentage Based Tagging of Snake River hatchery steelhead and Chinook Salmon. SY2014. Idaho Department of Fish and Game Report 16-02. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

Steele, C. A., M. Campbell, J. Powell, J. McCane, D. Hasselman, N. Campbell, and S. Narum. 2018. Parentage Based Tagging of Snake River hatchery steelhead and Chinook Salmon. SY2016. Idaho Department of Fish and Game Report 18-04. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

Steele, C.A., Hess, M., Narum, S. and Campbell, M., 2019. Parentage-based tagging: Reviewing the implementation of a new tool for an old problem. Fisheries 44:412-422.

Steinhorst, K., T. Copeland, M. W. Ackerman, W. C. Schrader, Eric. C. Anderson. 2017. Abundance estimates and confidence intervals for the run composition of returning salmonids. Fishery Bulletin 115:1-12.

Storch, A J., S. L. Haeseker, G. Scheer, J. A. McCann, T. Copeland, and R. B. Lessard. 2021. Comment: Associations among fish length, dam passage history, and survival to adulthood in two at-risk species of Pacific salmon. Transactions of the American Fisheries 150: 189-195.

Tiffan, K. F., D. W. Rondorf, R. D. Garland, and P. A. Verhey. 2000. Identification of fall versus spring Chinook Salmon migrating through the lower Snake River based on body morphology. Transactions of the American Fisheries Society 129:1389-1395.

Vu, N., M. W. Ackerman, K. K. Wright, J. McCane, M. R. Campbell, J. E. Hess, and S. R. Narum. 2015. Chinook and steelhead genotyping for genetic stock identification at Lower Granite Dam. Idaho Department of Fish and Game Report 15-02. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

Wootton, R. J. 1990. Ecology of Teleost Fishes. Fish and Fisheries Series 1. Chapman and Hall.

Wright, K., W. Schrader, L. Reinhardt, K. Hernandez, C. Hohman, and T. Copeland. 2015. Process and methods for assigning ages to anadromous salmonids from scale samples. Idaho Department of Fish and Game Report 15-03. https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Forms/AllItems.aspx.

TABLES

Table 1. Major population groups and independent populations within the Snake River steelhead distinct population segment (DPS) and spring-summer Chinook Salmon evolutionary significant unit (ESU; ICBTRT 2003, 2005).

Snake River steelhead DPS	
Major population group	**Population name**
Lower Snake River	1. Tucannon River 2. Asotin Creek
Grande Ronde River	3. Lower Grande Ronde River 4. Joseph Creek 5. Wallowa River 6. Upper Grande Ronde River
Imnaha River	7. Imnaha River
Clearwater River	8. Lower Clearwater River 9. North Fork Clearwater River (extirpated) 10. Lolo Creek 11. Lochsa River 12. Selway River 13. South Fork Clearwater River
Salmon River	14. Little Salmon River 15. Chamberlain Creek 16. South Fork Salmon River 17. Secesh River 18. Panther Creek 19. Lower Middle Fork Salmon River 20. Upper Middle Fork Salmon River 21. North Fork Salmon River 22. Lemhi River 23. Pahsimeroi River 24. East Fork Salmon River 25. Upper Salmon River
Hells Canyon Tributaries (extirpated)	

Table 1. Continued.

Snake River spring-summer Chinook Salmon ESU	
Major population group	**Population name**
Lower Snake River	1. Tucannon River
	2. Asotin Creek (extirpated) [a]
Grande Ronde/Imnaha Rivers	3. Wenaha River
	4. Lostine River
	5. Minam River
	6. Catherine Creek
	7. Upper Grande Ronde River
	8. Imnaha River
	9. Big Sheep Creek (extirpated) [a]
	10. Lookinglass Creek (extirpated) [a]
South Fork Salmon River	11. Little Salmon River
	12. South Fork Salmon River
	13. Secesh River
	14. East Fork South Fork Salmon River
Middle Fork Salmon River	15. Chamberlain Creek
	16. Lower Middle Fork Salmon River
	17. Big Creek
	18. Camas Creek
	19. Loon Creek
	20. Upper Middle Fork Salmon River
	21. Sulphur Creek
	22. Bear Valley Creek
	23. Marsh Creek
Upper Salmon River	24. North Fork Salmon River
	25. Lemhi River
	26. Upper Salmon River Lower Mainstem
	27. Pahsimeroi River
	28. East Fork Salmon River
	29. Yankee Fork Salmon River
	30. Valley Creek
	31. Upper Salmon River Upper Mainstem
	32. Panther Creek (extirpated) [a]
Dry Clearwater River (extirpated) [a]	33. Potlatch River (extirpated) [a]
	34. Lapwai Creek (extirpated) [a]
	35. Lawyer Creek (extirpated) [a]
	36. Upper South Fork Clearwater River (extirpated) [a]
Wet Clearwater River (extirpated) [a]	37. Lower North Fork Clearwater River (extirpated)
	38. Upper North Fork Clearwater River (extirpated)
	39. Lolo Creek (extirpated) [a]
	40. Lochsa River (extirpated) [a]
	41. Meadow Creek (extirpated) [a]
	42. Moose Creek (extirpated) [a]
	43. Upper Selway River (extirpated) [a]

[a] Reintroduced fish exist in extirpated areas except the North Fork Clearwater River.

Table 2. Estimated abundance of steelhead wild and hatchery female parents available for natural reproduction (FANR) followed by estimated abundance of wild smolts at Lower Granite Dam. The empirical data are used to construct adult-to-juvenile productivity estimates (juveniles/FANR).

Brood year	FANR	Juveniles	Juveniles/FANR
2011	55,220	729,937	13
2012	40,560	820,613	20
2013	30,400	614,813	20
2014	21,499	698,271	32
2015	61,130	1,010,290	17[a]
2016	44,278	980,667	22[a]
2017	36,731	494,089	13[a]
2018	16,017	30,101	2[a]

[a] Incomplete brood year.

Table 3. Estimated abundance of Chinook Salmon wild and hatchery female parents available for natural reproduction (FANR) followed by estimated abundance of wild yearling smolts at Lower Granite Dam. The empirical data are used to construct adult-to-juvenile productivity estimates (juveniles/FANR) and the Beverton-Holt stock-recruit model.

Brood year	Migration or smolt year	FANR	Juveniles (Yearlings)	Juveniles/FANR
1990	1992	4,976	527,000	106
1991	1993	2,916	627,037	215
1992	1994	6,826	627,942	92
1993	1995	8,514	1,558,786	183
1994	1996	1,043	419,826	403
1995	1997	497	161,157	324
1996	1998	1,556	599,159	385
1997	1999	11,885	1,560,298	131
1998	2000	3,726	1,344,382	361
1999	2001	1,630	490,534	301
2000	2002	8,733	1,128,582	129
2001	2003	51,902	1,455,786	28
2002	2004	31,415	1,517,951	48
2003	2005	26,126	1,734,464	66
2004	2006	28,374	1,227,474	43
2005	2007	10,899	787,150	72
2006	2008	9,253	856,556	93
2007	2009	8,562	894,629	104
2008	2010	22,942	1,268,656	56
2009	2011	17,314	1,150,789	69
2010	2012	36,348	1,670,979	47
2011	2013	30,755	993,503	37
2012	2014	22,783	1,406,033	61
2013	2015	11,718	533,570	46
2014	2016	31,076	1,424,036	46
2015	2017	35,938	1,171,926	33
2016	2018	23,301	1,437,312	62
2017	2019	8,491	794,695	94
2018	2020	10,339	1,083,944[a]	105[a]

[a] Predicted values based on the Beverton-Holt model.

FIGURES

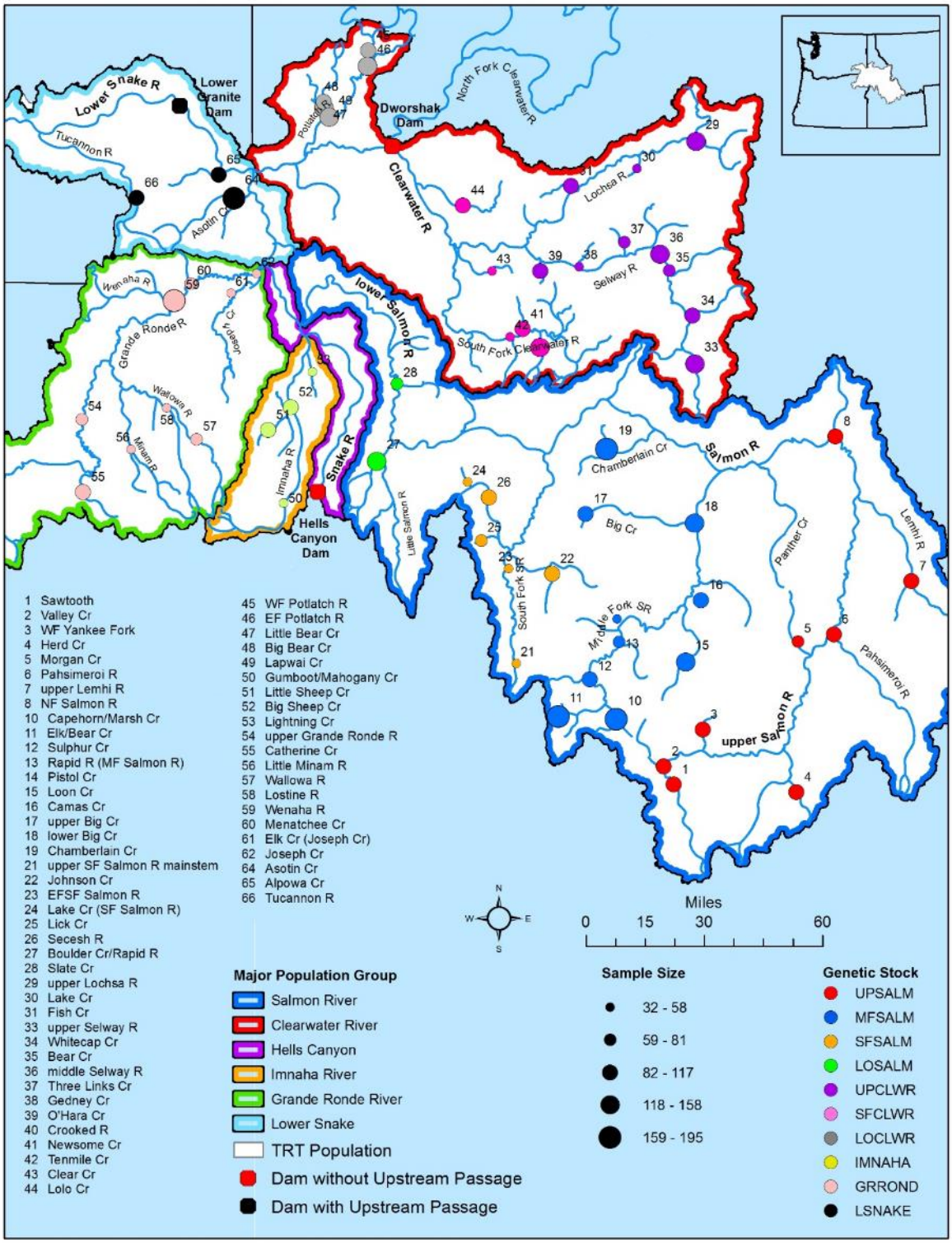


Figure 1. Genetic stocks and baseline collections used for steelhead mixed stock analysis at Lower Granite Dam since 2016 (Powell et al. 2018). The Hells Canyon Tributaries major population group (shaded gray) does not support independent populations and is considered extirpated (NMFS 2011). See text for genetic stock abbreviations.

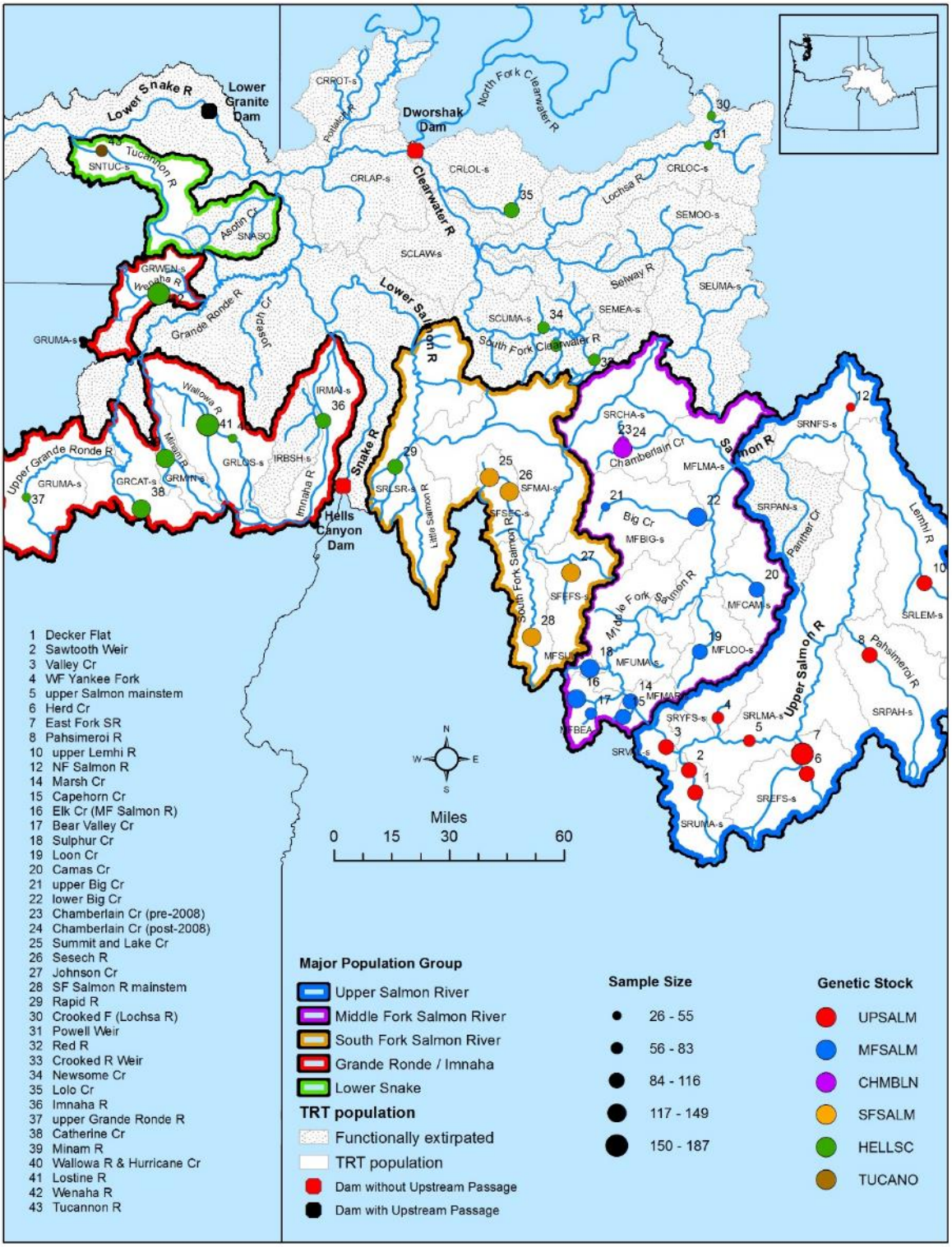


Figure 2. Genetic stocks and baseline collections used for Chinook Salmon mixed stock analysis at Lower Granite Dam since 2016 (Powell et al. 2018). Reintroduced fish exist in functionally extirpated TRT populations as mapped. See text for genetic stock abbreviations.

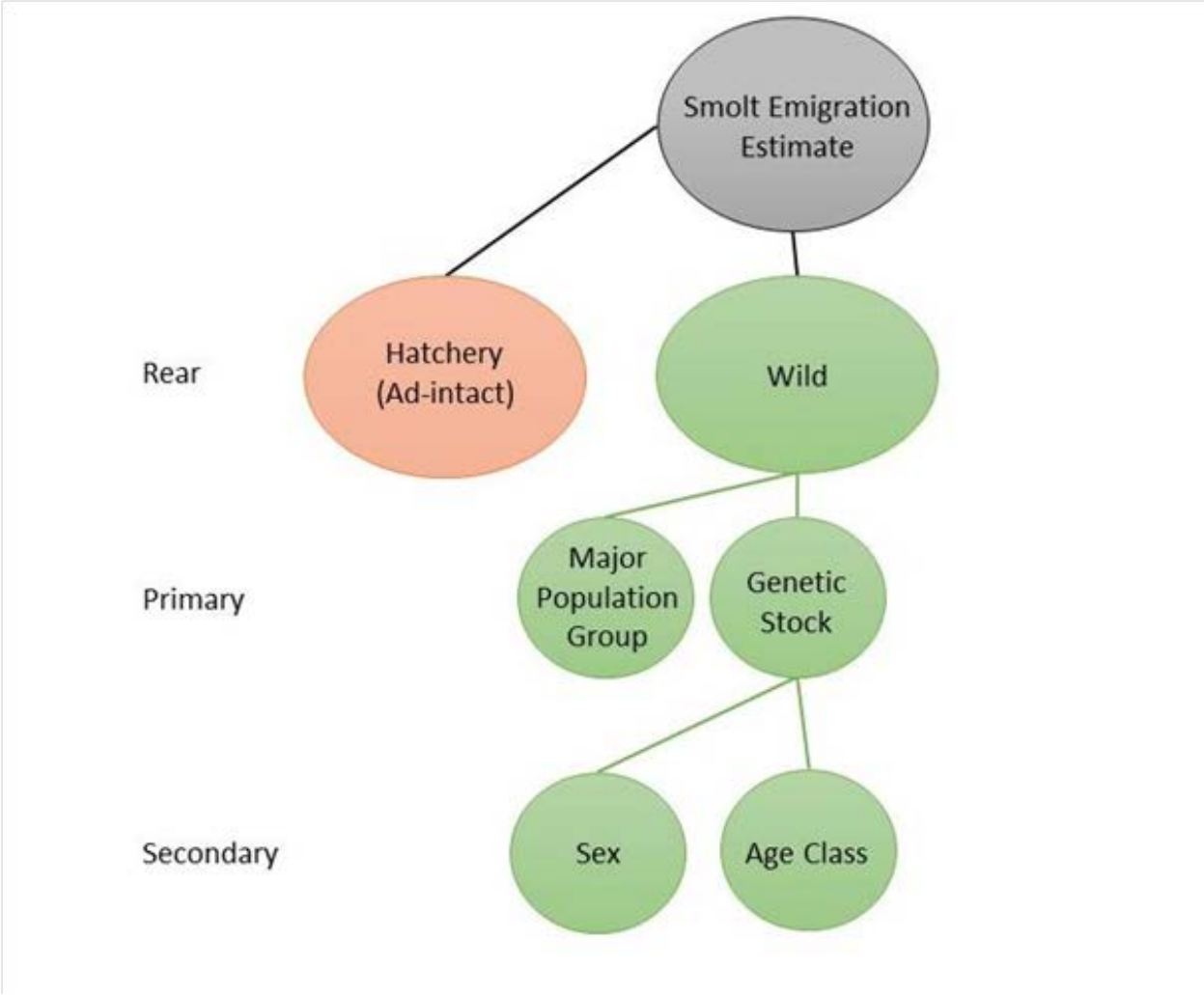


Figure 3. Schematic of the juvenile companion (SCRAPI) to the Salmonid Compositional Bootstrap Intervals (SCOBI) Lower Granite Dam decomposition model.

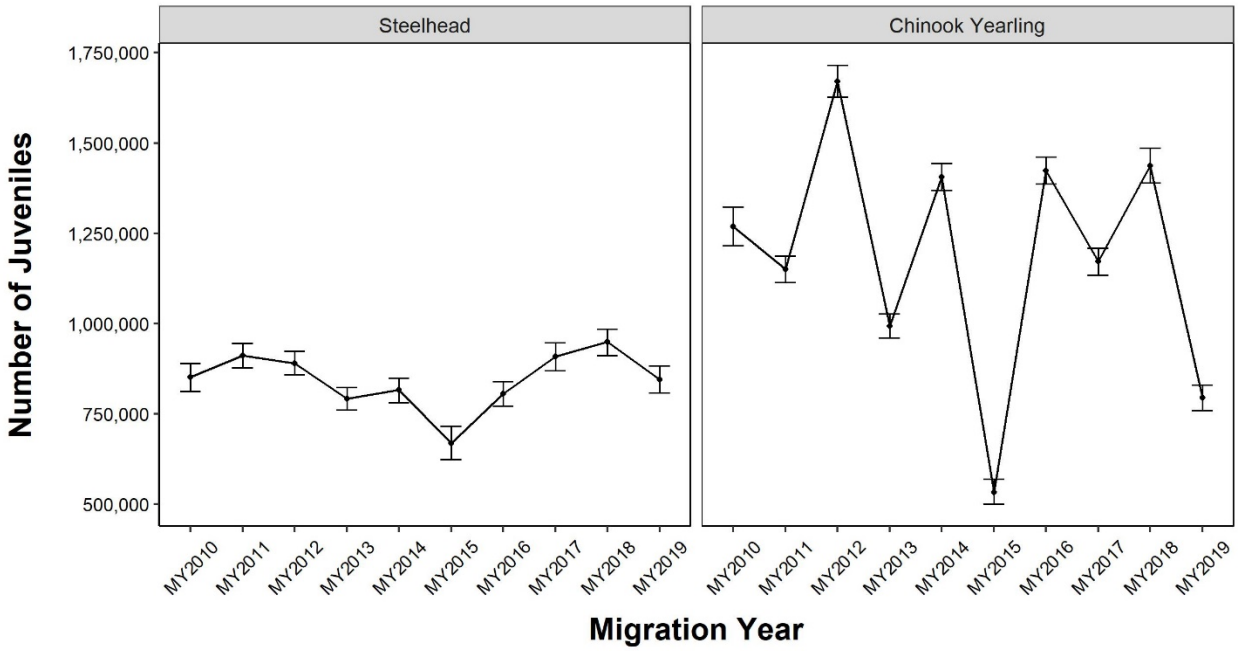


Figure 4. Wild steelhead and Chinook Salmon juvenile emigrant estimates at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.

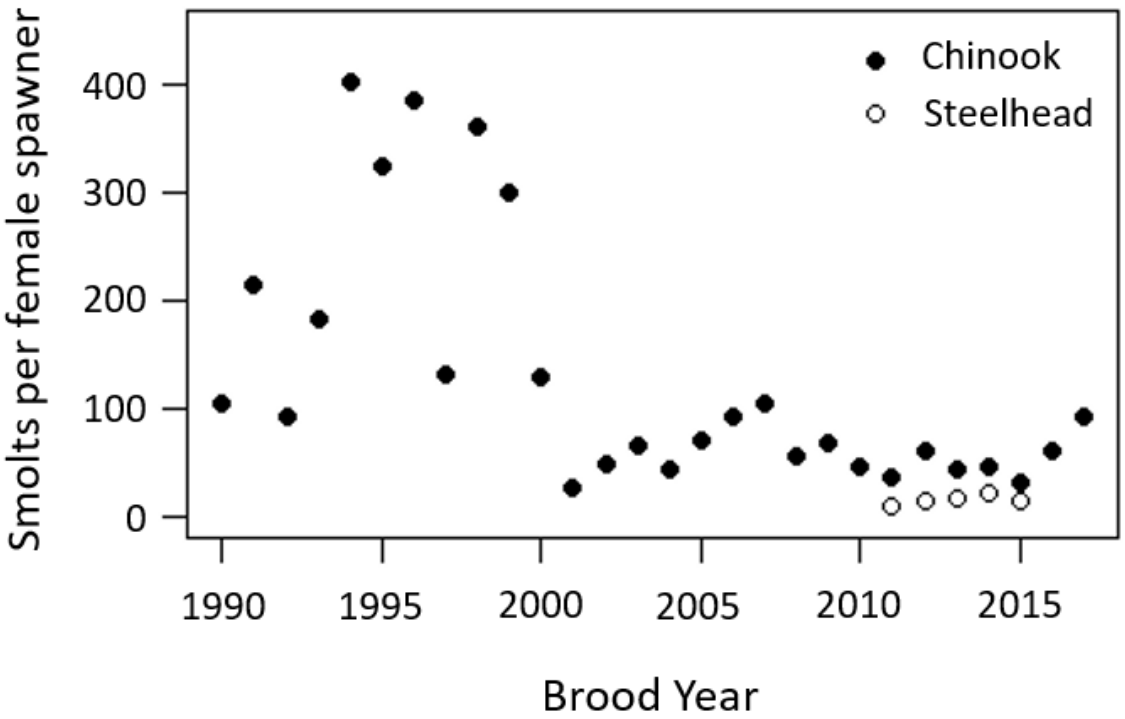


Figure 5. Time series of the aggregate productivity of wild steelhead and spring/summer Chinook Salmon (smolts per female parent) at Lower Granite Dam. Only completed brood years are shown.

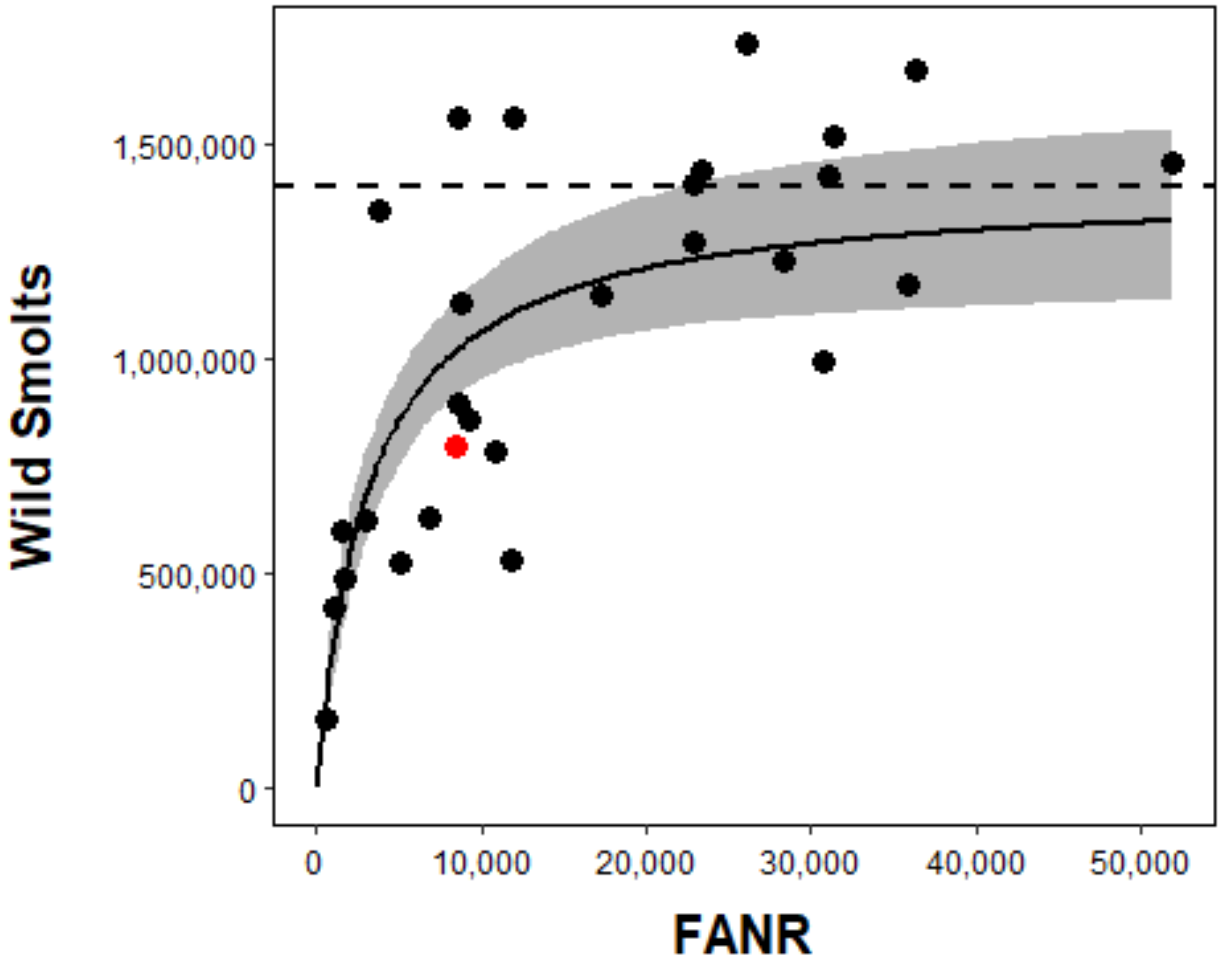


Figure 6. Relationship of wild yearling Chinook Salmon smolt abundance at Lower Granite Dam and females available for natural reproduction upstream of LGR for brood years 1990-2017. The shaded area represents the 95% confidence interval for the fitted Beverton-Holt model. The red point represents the most recent data point, brood year 2017 (MY 2019).

APPENDICES

Appendix A: Lower Granite Dam juvenile trapping operations, migration year 2019.

Appendix A-1. Weekly Fish Passage Center trap collection and valid trap samples of juvenile steelhead at Lower Granite Dam, migration year 2019.

					Number of valid samples used in SCRAPI analysis				
SCRAPI strata	**Statistical week**	**Sampling period**	**Days trap open**	**Days bio sample taken**	**Wild estimate**	**Wild fish trapped**	**Genetic stock**	**Sex**	**Age**
1	13-14[a]	3/26-4/7	14	6	18,446	232	74	74	72
2	15	4/8-4/14	7	5	80,158	177	141	141	141
3	16	4/15-4/21	7	5	90,480	157	127	127	127
4	17	4/22-4/28	7	5	244,633	457	272	272	272
5	18	4/29-5/5	7	5	104,077	181	131	131	131
6	19	5/6-5/12	7	5	116,776	102	65	65	65
7	20	5/13-5/19	7	5	118,105	244	175	175	175
8	21	5/20-5/26	7	5	35,338	156	75	75	75
9	22	5/27-6/02	7	5	27,731	236	146	146	146
10	23-26[a]	6/3-6/30	27	17	10,071	113	99	99	95
Total			97		845,815	2,055	1,305	1,305	1,299

[a] Statistical weeks are grouped to try to provide a minimum sample size of 100 valid fish with a genotype and age while maintaining relatively even sample sizes among strata.

Appendix A-2. Weekly Fish Passage Center trap collection and valid trap samples of yearling Chinook Salmon at Lower Granite Dam, migration year 2019.

					Number of valid samples used in SCRAPI analysis			
SCRAPI strata	**Statistical week**	**Sampling period**	**Days trap open**	**Days bio sample taken**	**Wild estimate**	**Wild fish trapped**	**Genetic stock**	**Sex**
1	13-14[a]	3/26-4/7	14	8	40,029	278	90	90
2	15-16[a]	4/8-4/21	14	10	211,964	347	174	174
3	17	4/22-4/28	7	5	158,911	267	167	167
4	18-19[a]	4/29-5/12	14	10	237,117	359	235	235
5	20-21[a]	5/13-5/26	14	10	107,898	282	186	186
6	22	5/27-6/2	7	5	19,058	148	98	98
7	23-26[a]	6/3-6/30	20	12	19,718	125	67	67
Total			90	60	794,695	1,806	1,017	1,017

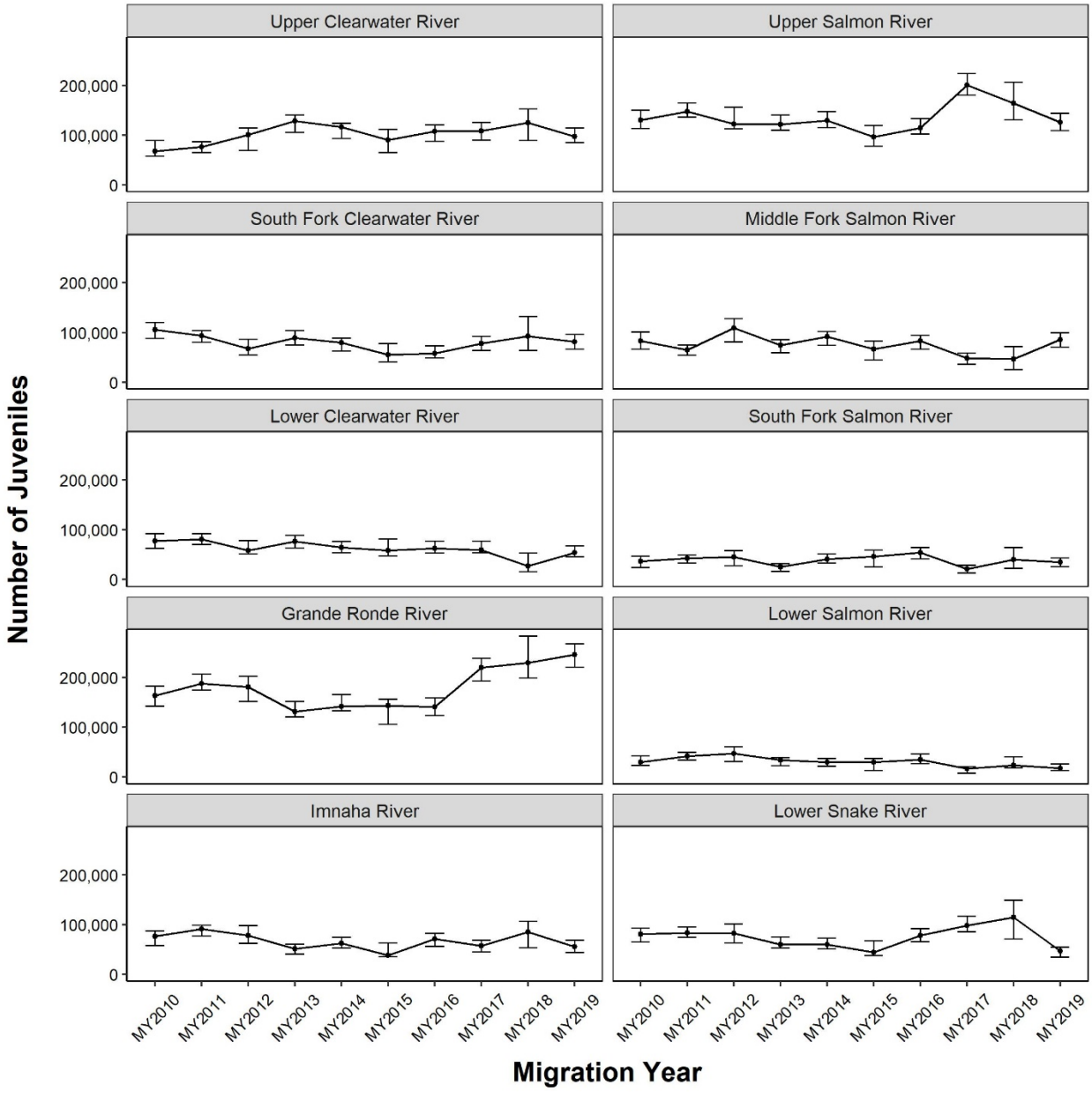
[a] Statistical weeks are grouped to try to provide a minimum sample size of 100 valid fish with a genotype and age while maintaining relatively even sample sizes among strata.

Appendix B: Wild steelhead juveniles at Lower Granite Dam, migration year 2019.

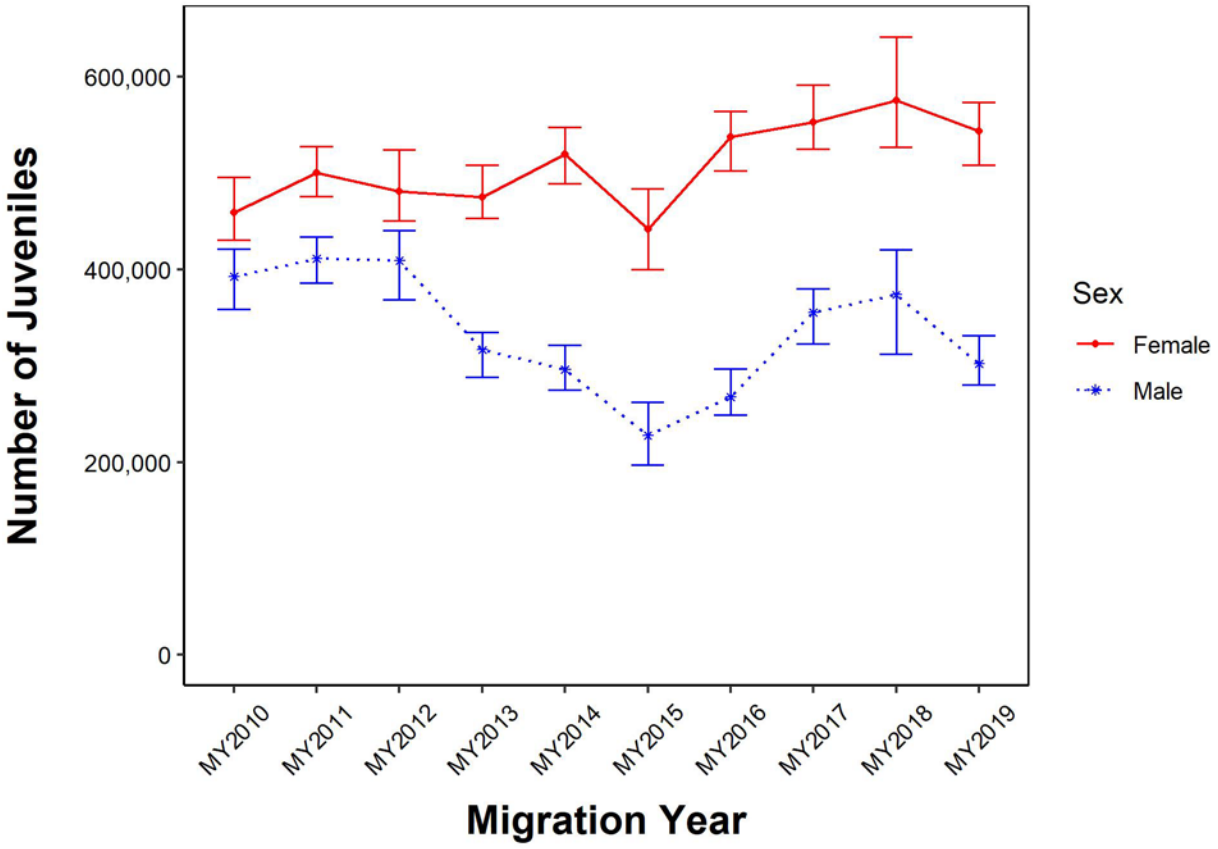
Appendix B-1. Wild juvenile steelhead emigration estimates by sex for each genetic stock at Lower Granite Dam, migration year 2019. L = lower bound and U = upper bound of 90% confidence intervals. See text for stock abbreviations.

Migration year & genetic stock	Estimated number of wild steelhead juveniles at Lower Granite Dam								
	Female			Male			Total wild		
	Estimate	L	U	Estimate	L	U	Estimate	L	U
UPSALM	82,645	70,036	97,375	43,454	32,138	53,256	126,099	108,724	143,760
MFSALM	63,701	49,841	75,062	21,843	15,743	29,955	85,544	70,694	99,946
SFSALM	25,871	17,938	33,147	9,480	5,468	13,995	35,351	26,578	43,878
LOSALM	11,536	7,081	17,605	6,160	4,057	11,293	17,696	13,450	26,054
UPCLWR	65,270	54,975	79,578	31,967	25,196	41,611	97,237	85,090	114,970
SFCLWR	43,912	32,314	52,911	37,024	29,243	48,495	80,936	67,165	95,399
LOCLWR	33,857	26,036	42,814	20,770	15,749	29,906	54,627	46,069	68,115
IMNAHA	27,890	20,707	37,827	28,034	19,327	36,507	55,924	44,644	68,775
GRROND	158,514	137,783	176,772	87,438	72,252	101,347	245,952	220,231	266,842
LSNAKE	30,591	21,662	36,719	15,858	9,710	21,316	46,449	35,211	54,182
Total	543,787	508,384	573,681	302,028	280,081	331,128	845,815	807,996	883,518

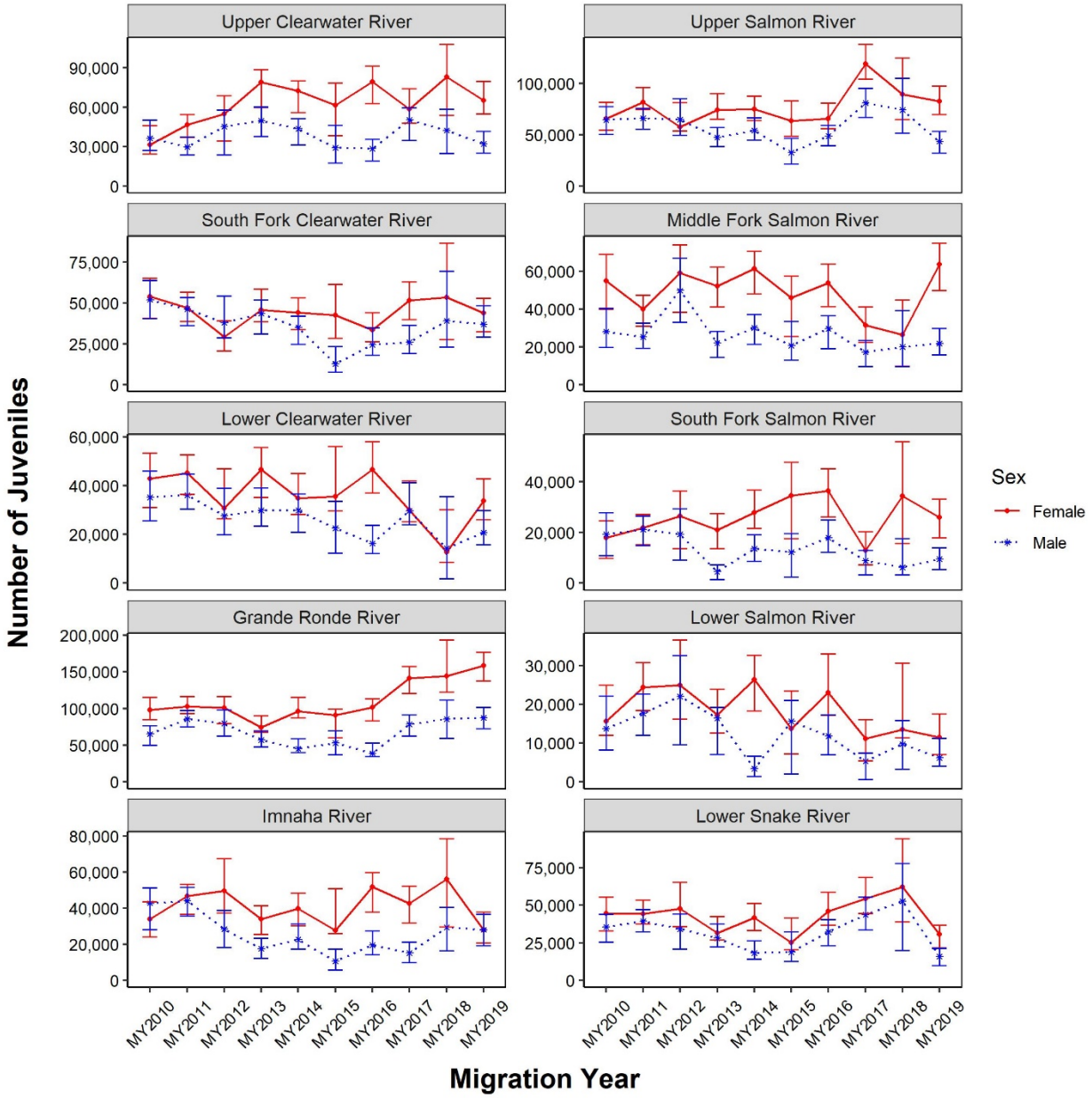
Appendix B-2. Wild juvenile steelhead emigration estimates by genetic stock at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.



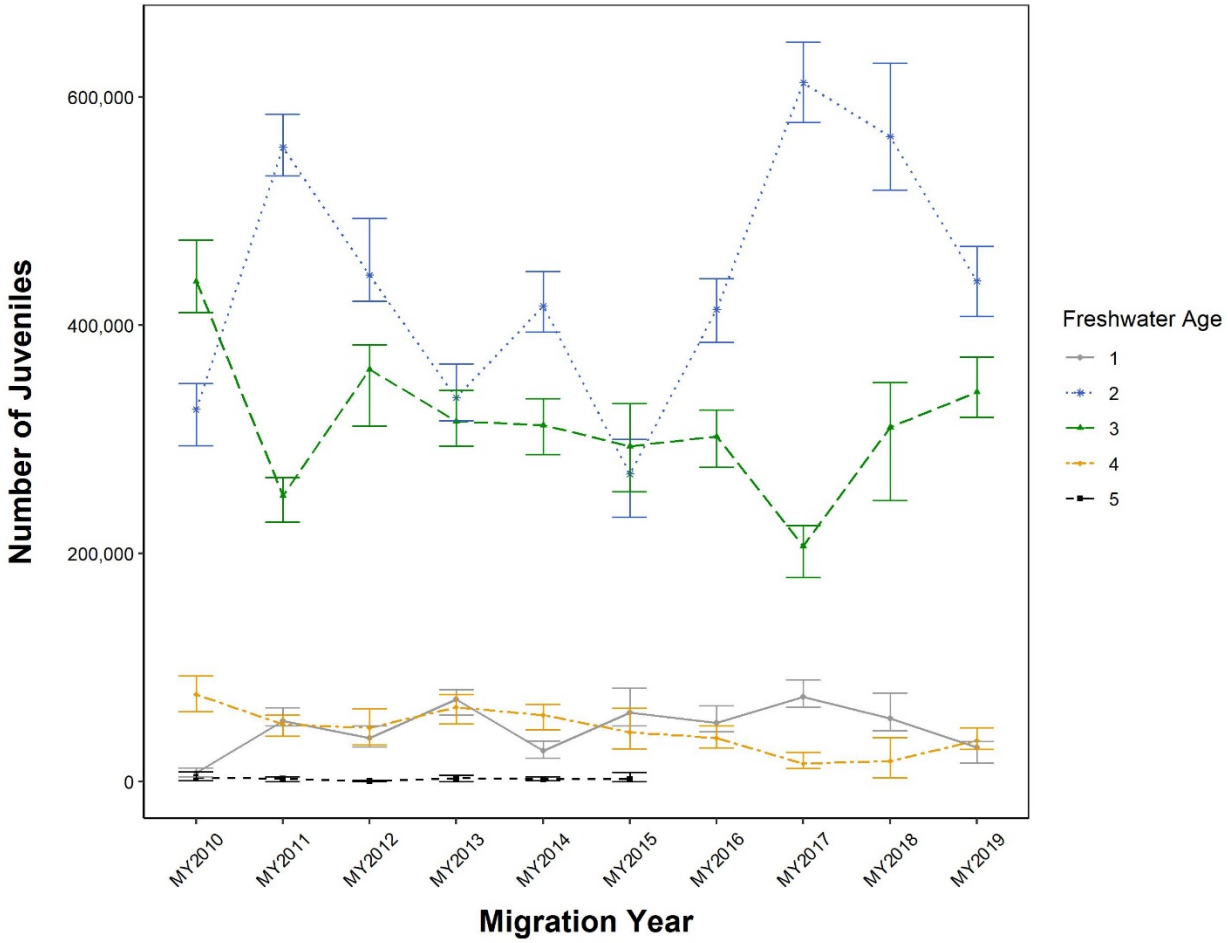
Appendix B-3. Wild juvenile steelhead emigration estimates by sex at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.



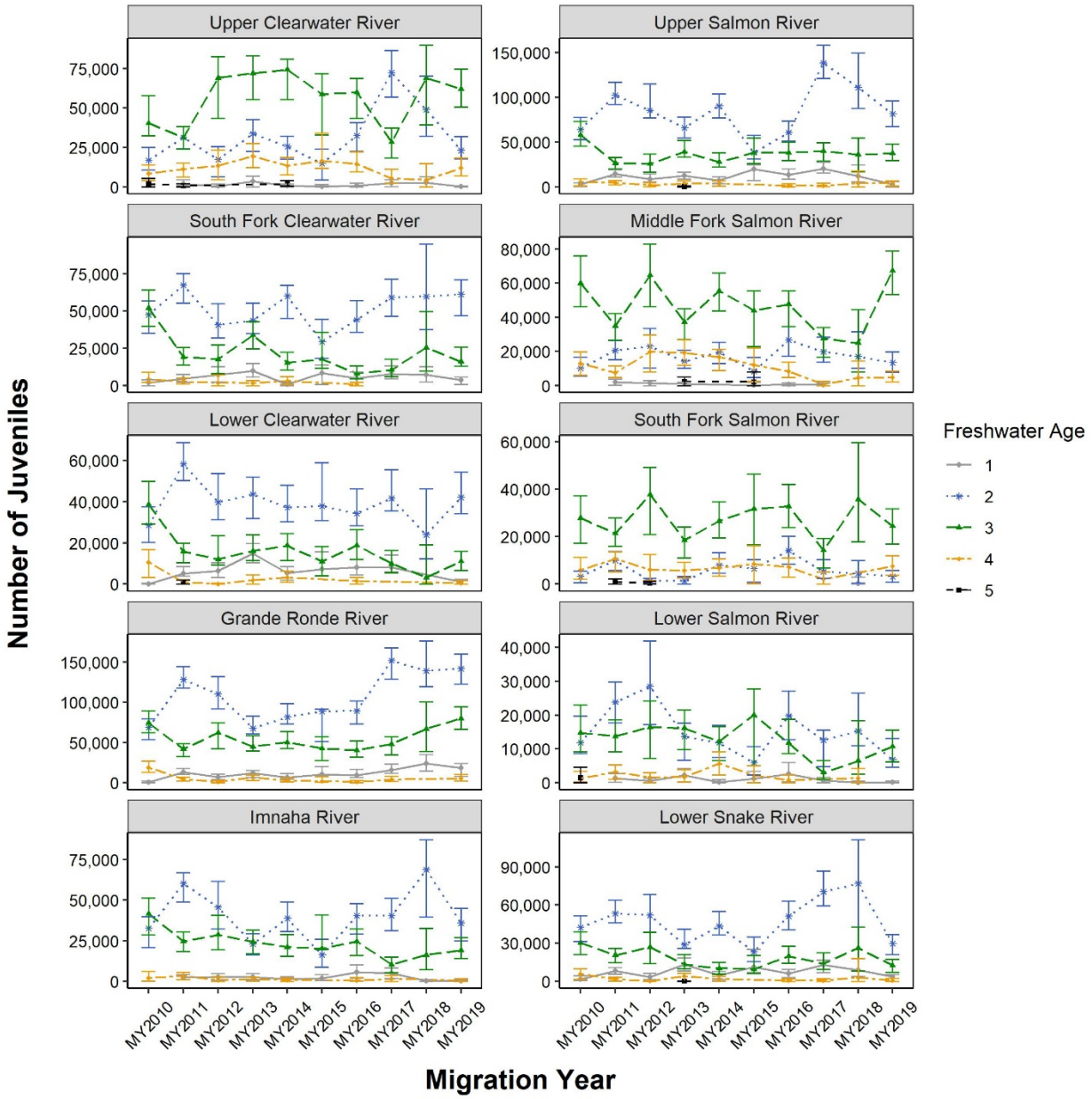
Appendix B-4. Wild juvenile steelhead emigration estimates by genetic stock and sex at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.



Appendix B-5. Wild juvenile steelhead emigration estimates by freshwater age at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.



Appendix B-6. Wild juvenile steelhead emigration estimates by genetic stock and freshwater age at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.

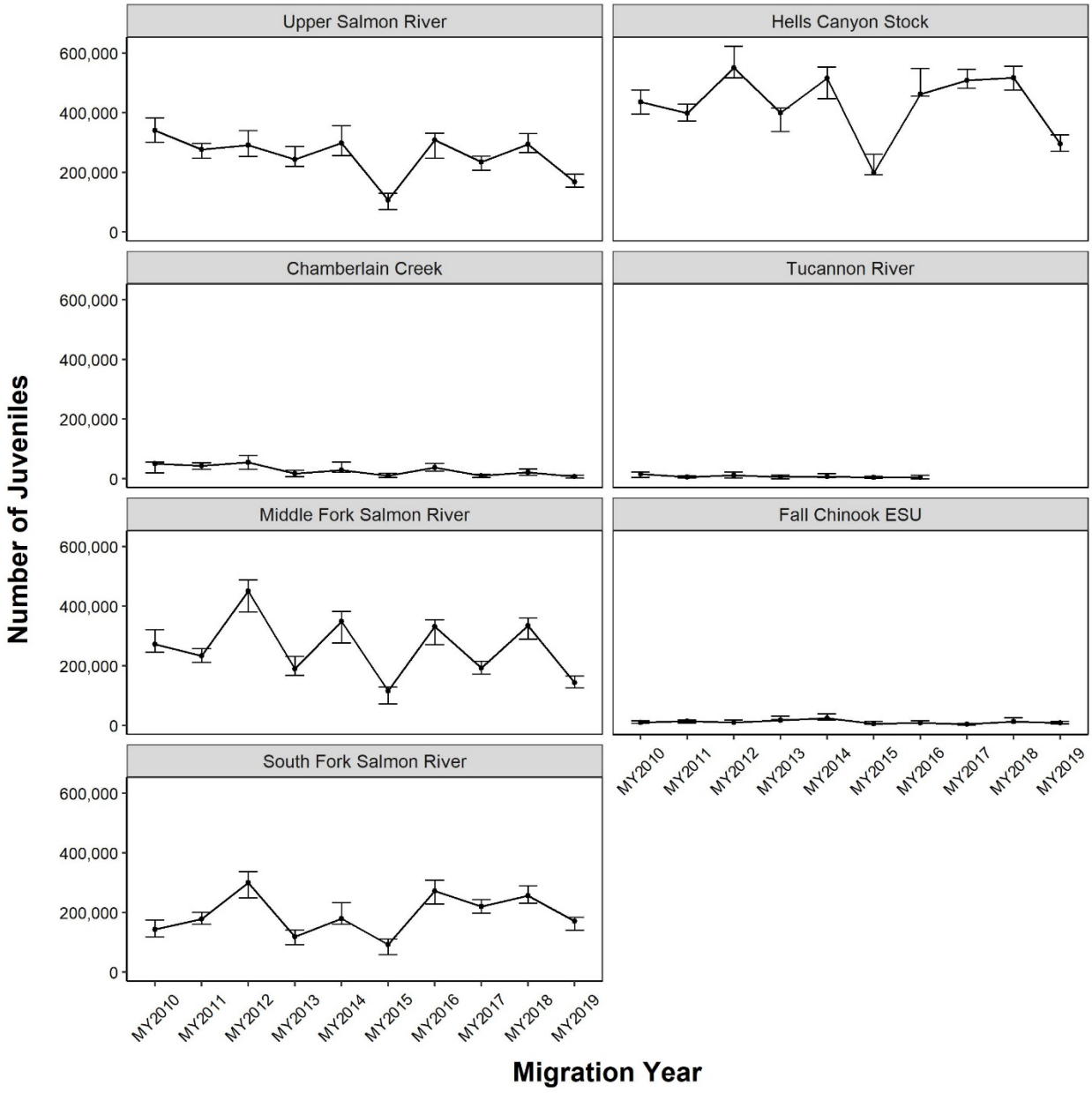


Appendix C: Wild Chinook Salmon yearling juveniles at Lower Granite Dam, migration year 2019.

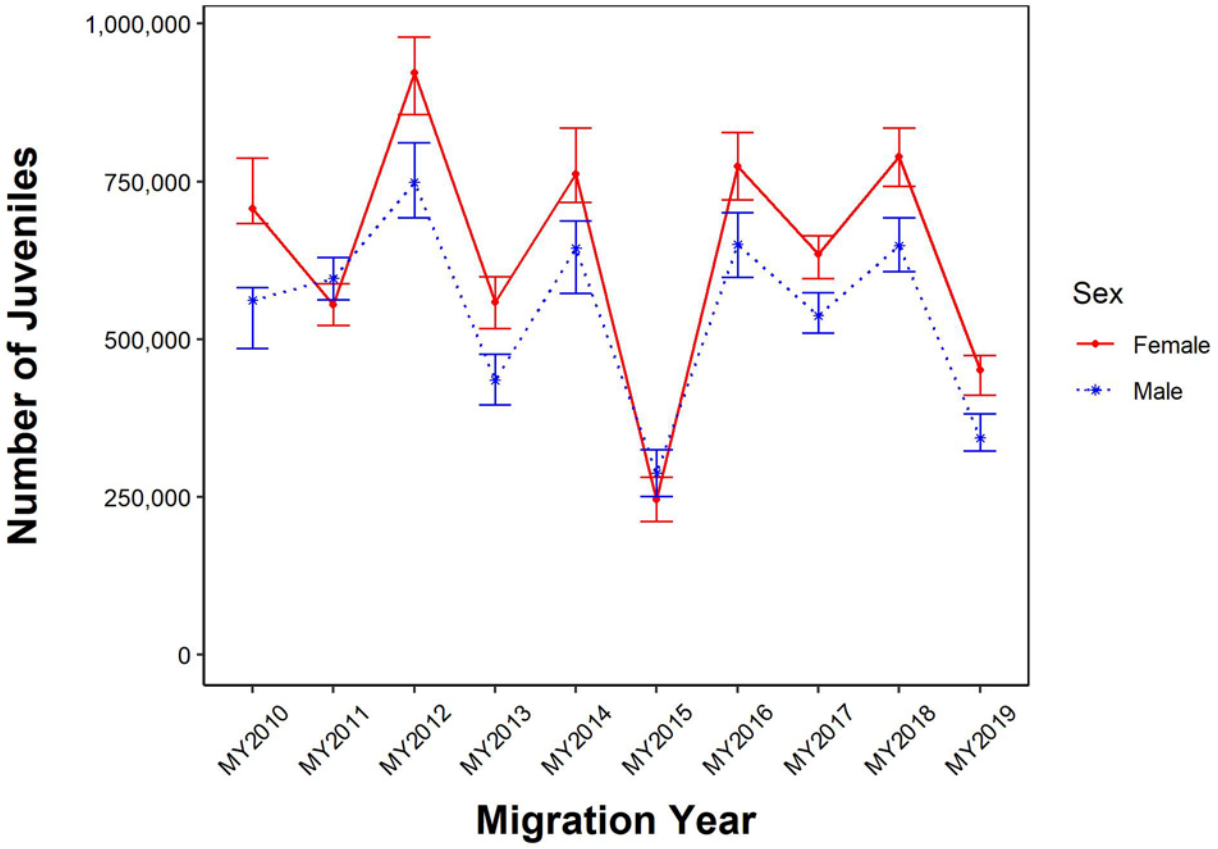
Appendix C-1. Wild juvenile Chinook Salmon yearling emigration estimates by sex for each genetic stock at Lower Granite Dam, migration year 2019. L = lower bound and U = upper bound of 90% confidence intervals. See text for stock abbreviations.

Migration year & genetic stock	Estimated number of wild Chinook Salmon yearling juveniles at Lower Granite Dam								
	Female			Male			Total wild		
	Estimate	L	U	Estimate	L	U	Estimate	L	U
UPSALM	100,058	83,043	117,099	68,603	57,587	87,406	168,661	150,220	194,266
CHMBLN	3,440	998	6,549	3,322	982	7,275	6,762	2,753	11,778
MFSALM	71,846	60,236	89,480	70,998	57,728	85,829	142,844	126,254	165,721
SFSALM	101,585	76,026	110,798	69,728	54,720	83,959	171,313	140,506	184,372
HELLSC	168,548	146,461	189,111	127,374	112,087	150,579	295,922	271,608	326,059
TUCANO	0	0	0	0	0	0	0	0	0
FALL	5,891	1,796	9,026	3,302	2,654	7,396	9,193	5,691	14,302
Total	451,368	410,864	474,680	343,327	322,979	382,127	794,695	758,285	831,075

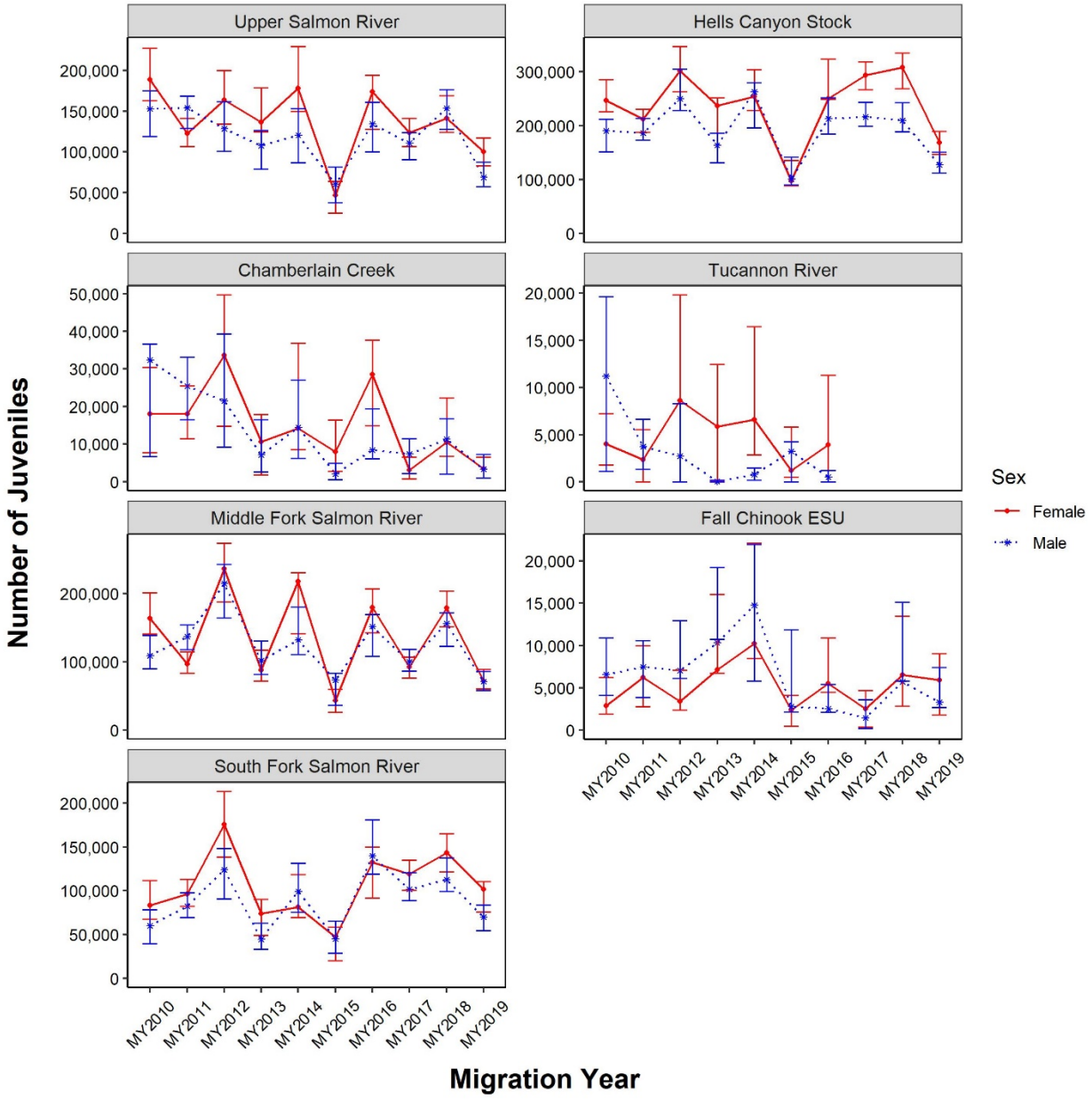
Appendix C-2. Wild juvenile Chinook Salmon yearling emigration estimates by genetic stock at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.



Appendix C-3. Wild juvenile Chinook Salmon yearling emigration estimates by at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.



Appendix C-4. Wild juvenile Chinook Salmon yearling emigration by genetic stock and sex at Lower Granite Dam, migration years 2010-2019. Confidence intervals are at 90%.



Prepared by:

Jonathan D. Ebel
Fisheries Staff Biologist

Timothy Copeland
Fisheries Program Coordinator

John S. Hargrove
Fishery Biologist 2

Micah Davison
Supervisory Fisheries Biologist

Marika E. Dobos
Fisheries Staff Biologist

William C. Schrader
Principal Fisheries Biologist

Matthew R. Campbell
Fisheries Program Coordinator

Approved by:

IDAHO DEPARTMENT OF FISH AND GAME

_____
John Cassinelli
Anadromous Fisheries Manager

_____
J. Lance Hebdon, Chief
Bureau of Fisheries