

Freshwater Creek 2023-2024 Salmonid Life Cycle Monitoring Station Report

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EXECUTIVE SUMMARY

Introduction

The California Department of Fish and Wildlife (CDFW) and the National Oceanic and Atmospheric Administration ~ Fisheries (NOAA~Fisheries) cooperatively developed the California Coastal Salmonid Monitoring Plan (CMP; Adams et al. 2011). Two complementary tasks are considered high priority in the Northern Monitoring Area and form the foundation of the CMP approach. The first task consists of probabilistic sampling of stream reaches within a defined region using spawning ground surveys (SGS) to establish the regional status and trends of adult salmonid abundance. The second task develops intensively monitored Life Cycle monitoring stations (LCM) nested within the regional sample frame of the SGS. LCM studies have four primary objectives:

- Define the relationship between SGS observations and adult escapement.
- Estimate juvenile and adult abundance as well as freshwater and marine survival rates.
- Provide a study framework to investigate habitat-productivity relationships.
- Characterize the diversity of life history patterns.

The Freshwater Creek Salmonid Monitoring Project is designed to be an LCM with these principal objectives. This report summarizes the results of yearly abundance and survival monitoring efforts from October 2023 to July 2024 and integrates project data to make inference on population trends and limiting factors for Coho Salmon in Freshwater Creek.

Methods

Abundance estimates are made for multiple life history stages, at multiple spatial scales for Coho Salmon, steelhead trout, and Chinook Salmon. Several methods were used to characterize abundance including:

- Adult escapement: weir-carcass mark-recapture experiment
- Spawning ground surveys
- Juvenile emigration trapping mark-recapture experiment

Survival estimates were made using the following mark-recapture experiments:

- Smolt-to-adult return (SAR) survival
- Coho Salmon pre-spring and spring migrant probability estimates

Multiple year comparisons are made for the relationship between Coho Salmon redd counts and adult escapement estimates.

Results

Adult Escapement: Tabular and graphical representations of the adult abundance of Coho Salmon, steelhead trout, and Chinook Salmon for the Freshwater Creek basin are presented in Table A, and Figures A, B, and C.

Table A. Adult salmonid escapement estimates for survey years 2000 to 2023. The escapement year includes fall through spring (e.g. Year 2000 is fall 2000 through spring 2001). Hatchery-produced Chinook Salmon returns contributed to counts in the years 2000-2003. *Indicates weir count rather than mark-recapture estimate.

Year	Coho Salmon N(hat)	Coho Salmon SD	steelhead trout N(hat)	steelhead trout SD	Chinook Salmon N(hat)	Chinook Salmon SD
2000	177*	-	99	23	154*	-
2001	701*	-	195	43	122*	-
2002	1807	213	153	22	135	32
2003	731	25	432	23	26*	-
2004	974	37	254	17	14*	-
2005	789	128	257	17	22*	-
2006	396	47	235	23	18*	-
2007	262	41	203	29	7*	-
2008	399	71	51	7	2*	-
2009	89	10	61	11	2*	-
2010	455	38	132	32	19*	-
2011	624	148	108	35	1*	-
2012	318	75	149	60	2*	-
2013	155	67	127	54	0*	-
2014	718	68	87	23	8*	-
2015	449	86	106	38	2*	-
2016	466	165	235	77	4*	-
2017	535	86	200	39	9*	-
2018	560	125	236	59	1*	-
2019	298	68	225	70	3*	-
2020	335	72	119	78	2*	-
2021	870	104	48	32	0*	-
2022	643	179	25	13	1*	-
2023	537	182	40	20	0*	-

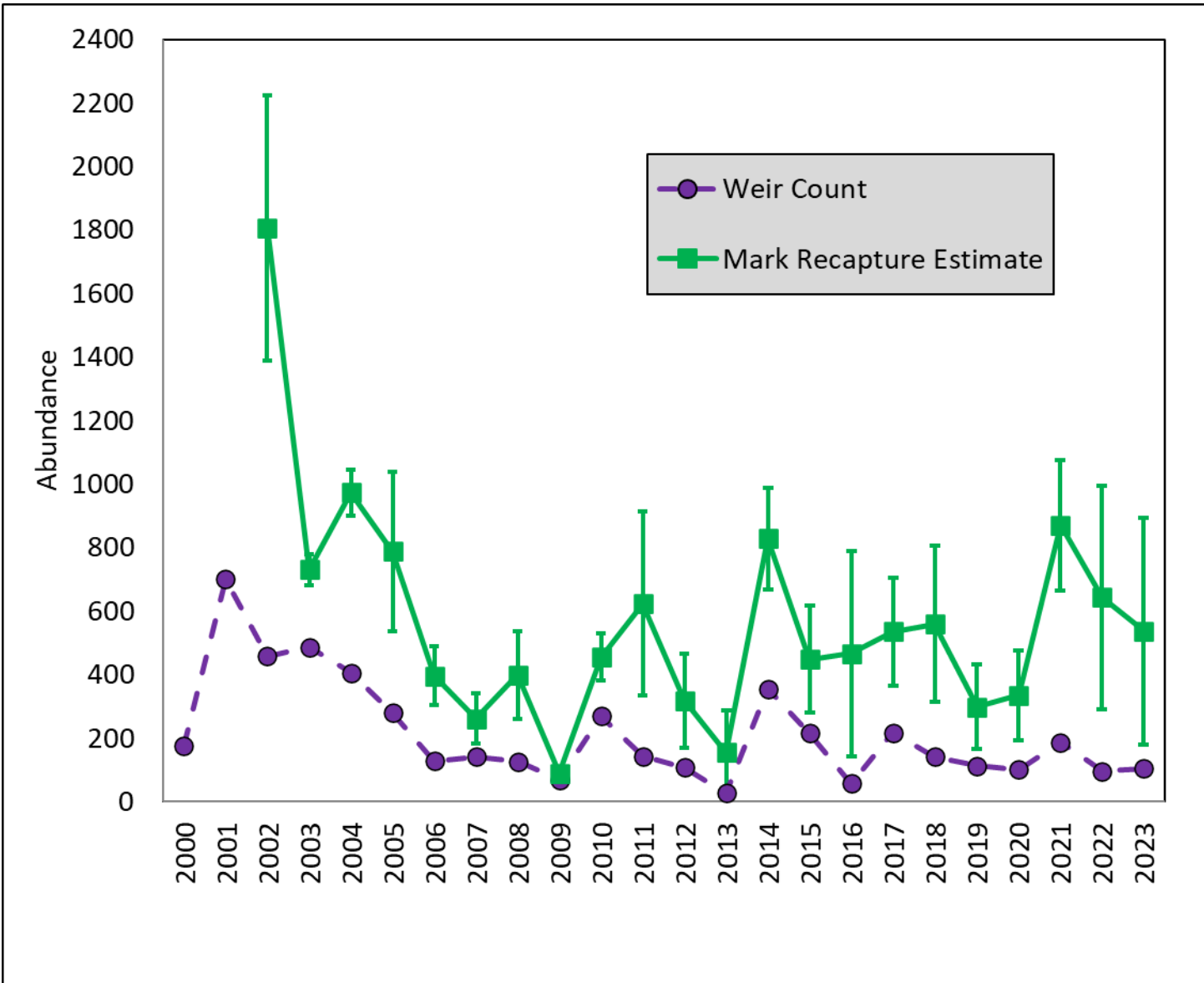


Figure A. Adult Coho Salmon weir counts 2000 through 2023 and escapement estimates (\pm 95% confidence intervals) in Freshwater Creek for survey years 2003 through 2023.

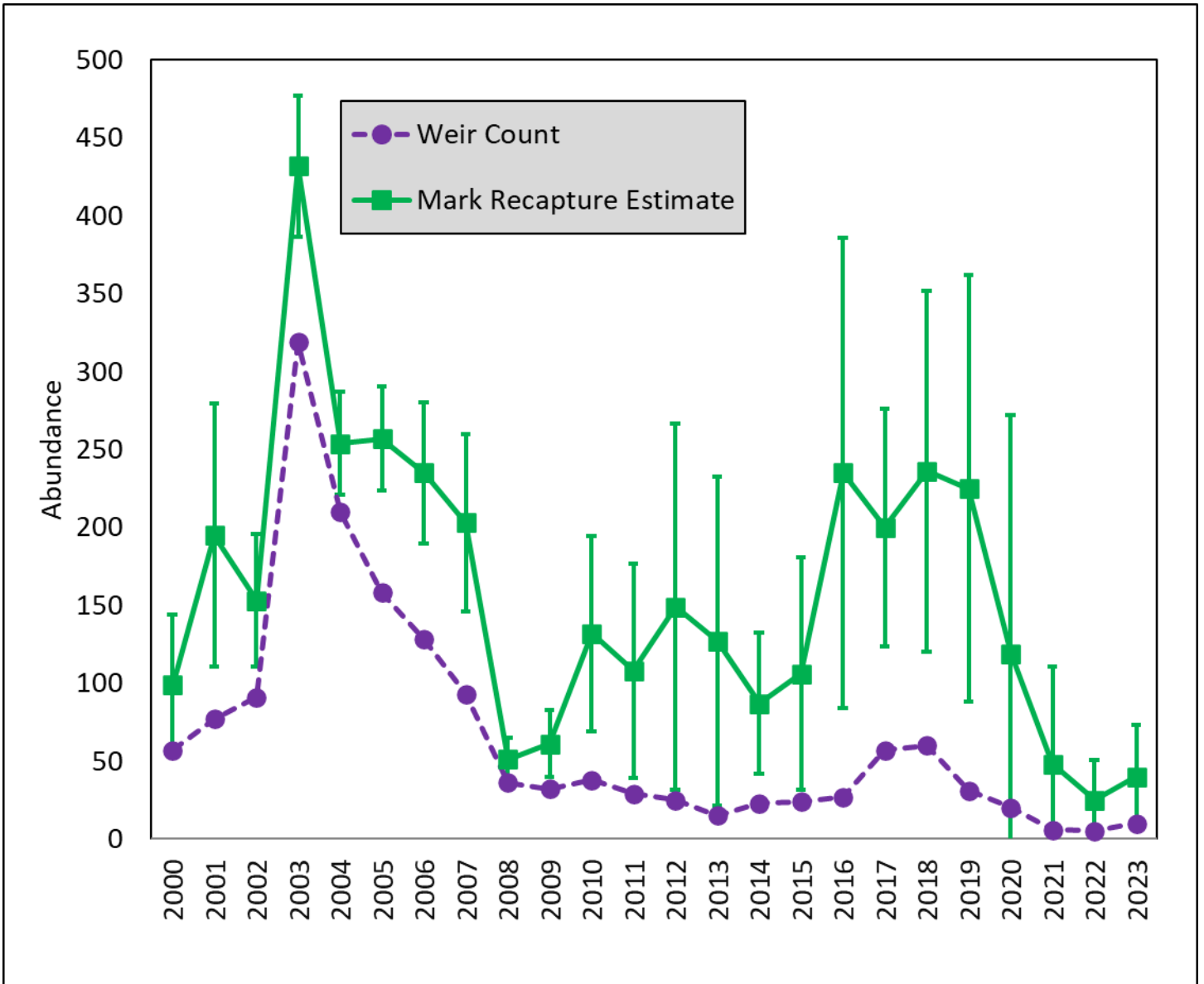


Figure B. Adult steelhead trout weir counts and escapement estimates (\pm 95% confidence intervals) in Freshwater Creek for survey years 2000 through 2023.

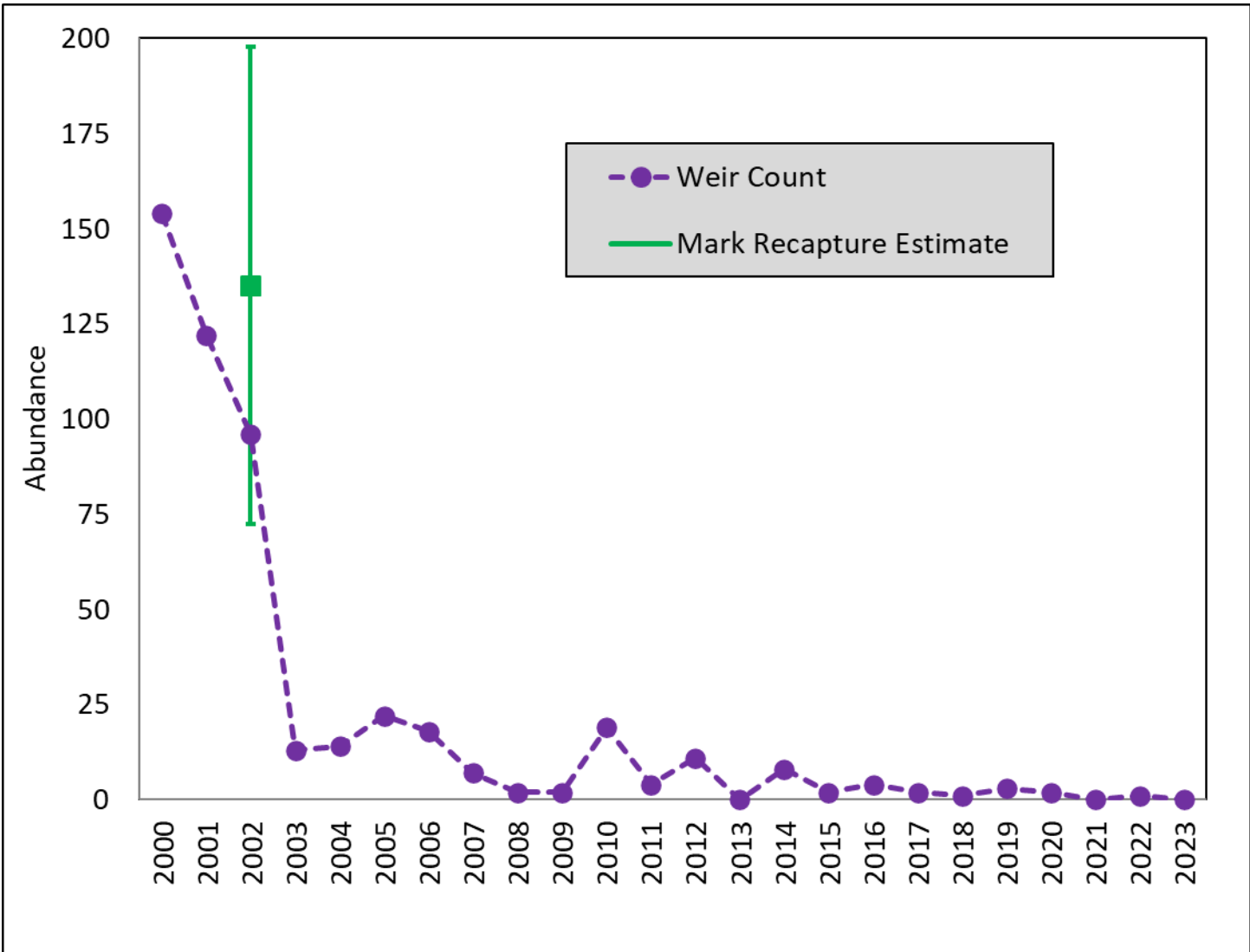


Figure C. Adult Chinook Salmon weir counts and escapement estimate (2002; \pm 95% confidence interval) in Freshwater Creek for survey years 2000 through 2023.

Juvenile salmonid spring emigrant trapping: Current trapping occurs at the freshwater-saltwater interface at the Freshwater Creek Weir (FWW) in a downstream migrant trap (DSMT). Mark and recapture data were stratified into weekly time intervals and analyzed with Darroch Analysis with Rank Reduction (DARR) to produce bounded estimates of abundance for Coho Salmon (Figure D) and steelhead trout (Figure E) smolts (Bjorkstedt 2004). Salmonid counts and DARR abundance estimates for all species captured at the trap are presented in Table B.

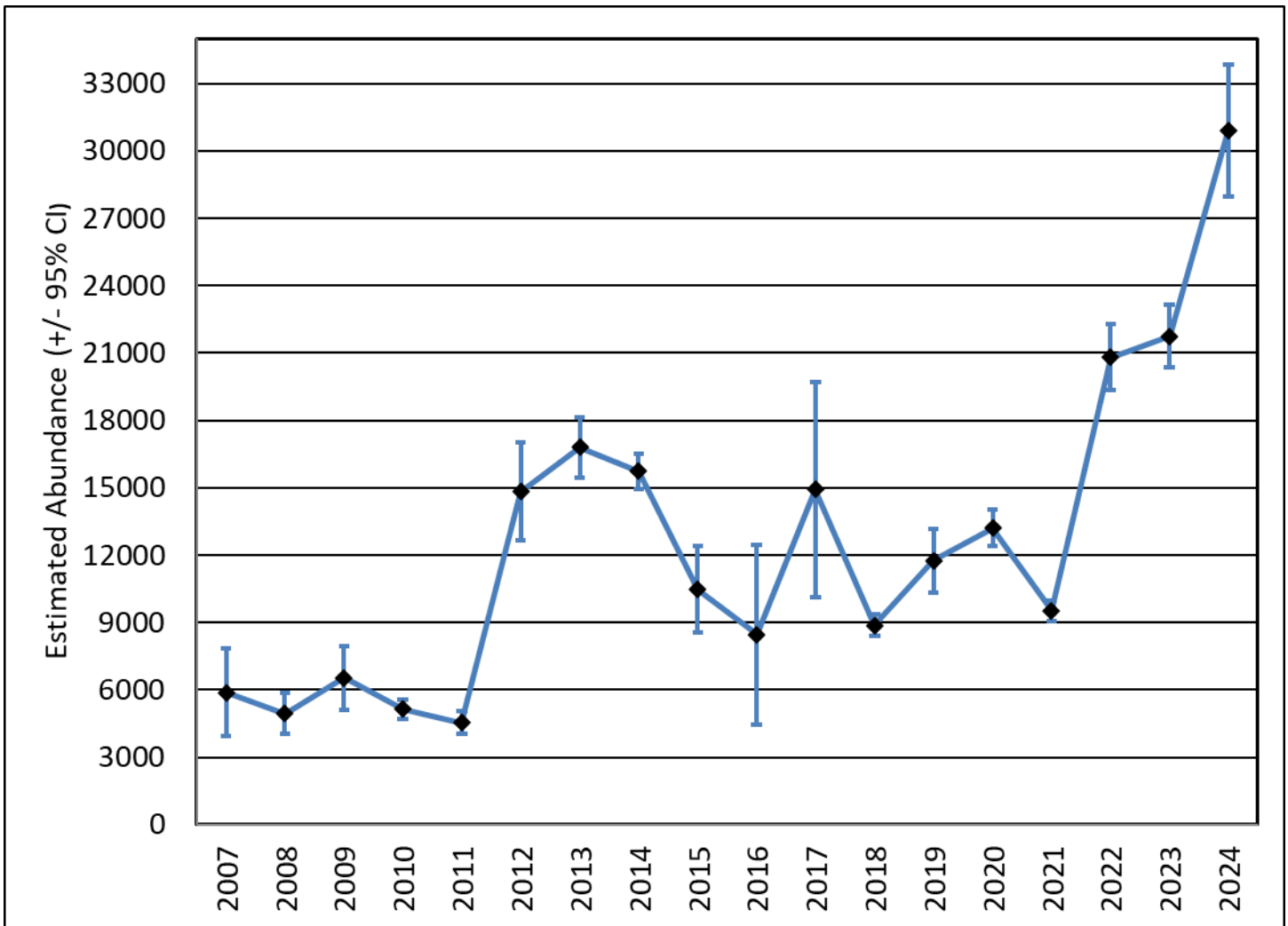


Figure D. Time series plot of Coho Salmon smolt emigration abundance estimates (\pm 95% confidence intervals) for the FWW trapping location, 2007-2024.

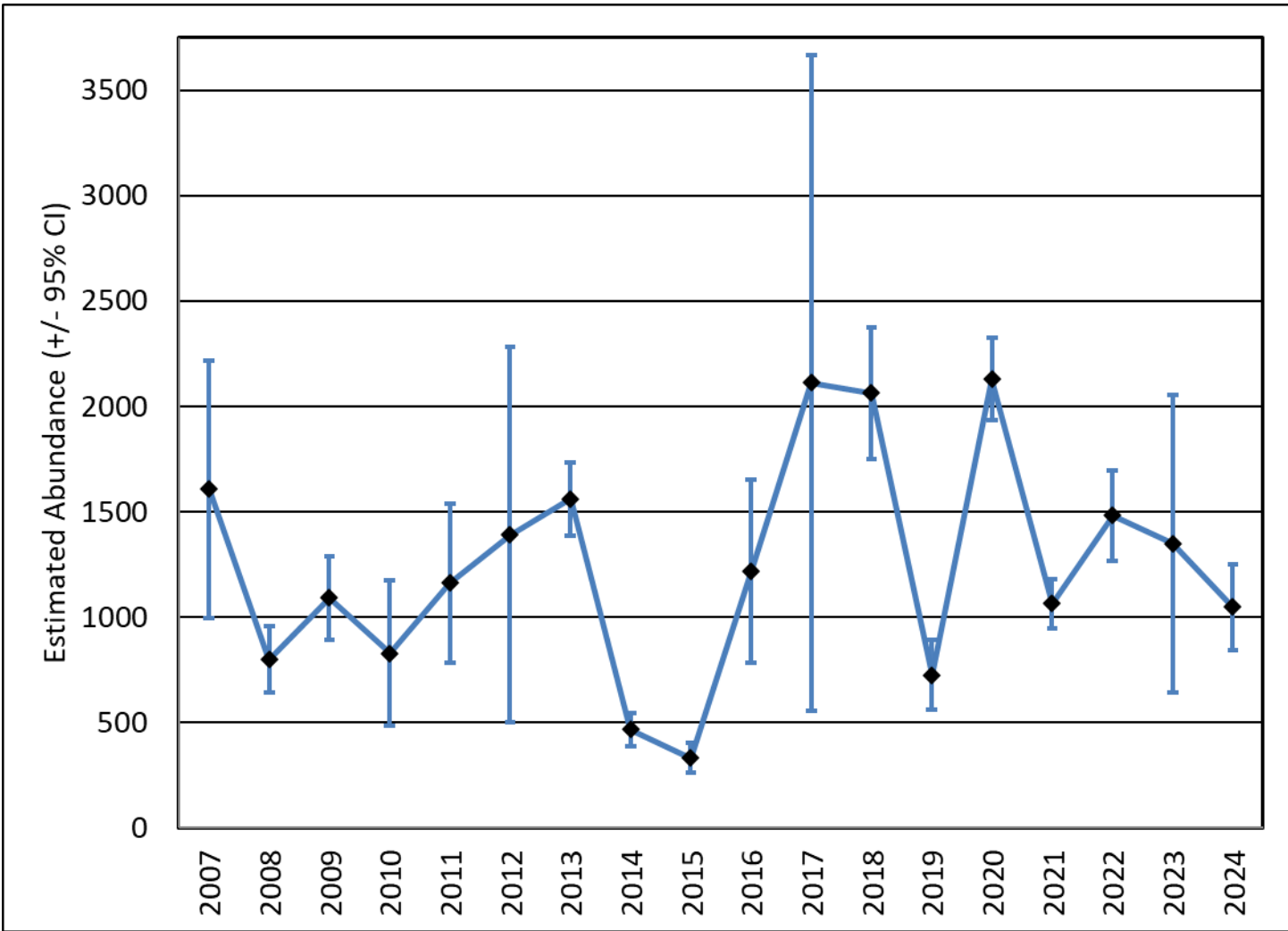


Figure E. Time series plot of steelhead trout smolt emigration abundance estimates (\pm 95% confidence intervals) for the FWW trapping location, 2007-2024.

Table B. Emigrant juvenile salmonid catch and abundance estimates (DARR) at the Freshwater Creek Weir trapping location 2007-2024.

Year	Coho Fry Catch	Coho Smolt N(hat)	Coho Smolt SE	Coho Super N(hat)	Coho Super SE	Steelhead Parr Catch	Steelhead Smolt N(hat)	Steelhead Smolt SE	Chinook Fry Catch	Cutthroat Parr Catch	Cutthroat Smolt Catch	Cutthroat Resident Catch
2007	0	5888	1006	22633	9399	259	1607	312	314*	85	12	2
2008	0	4945	464	9536	4365	146	798	80	253*	68	1	1
2009	0	6543	724	11253	1817	807	1091	101	0	169	7	32
2010	193*	5138	221	15444	2356	168	829	176	104*	114	4	53
2011	150*	4535	256	11862	2755	471	1161	192	2380*	132	9	63
2012	785*	14835	1104	35788	20017	297	1391	454	20*	63	7	160
2013	125*	16795	693	35712	6968	533	1561	89	306*	45	8	336
2014	3*	15724	405	25289	9641	55	456	41	0	22	3	265
2015	11*	10470	980	17577	5559	49	331	36	463*	8	2	206
2016	3*	8467	2046	24970	6969	180	1218	222	62*	59	1	77
2017	1*	14919	2445	38448	14230	40	2111	794	461*	8	1	129
2018	7*	8878	249	38515	11663	203	2063	160	3*	2	0	291
2019	2*	11746	730	19621	5720	102	725	84	0	4	0	165
2020	4*	13215	420	20272	3957	252	2129	99	1*	1	2	249
2021	0	9258	234	27623	8305	34	1064	59	0	0	0	110
2022	120*	20812	754	26562	7272	266	1482	110	0	46	5	113
2023	24*	21754	702	#	#	60	1349	360	0	2	0	71
2024	3*	30890	1499	#	#	44	1048	104	0	0	0	63

*Indicates catches where the DSMT trap was not designed to hold fry > 50mm fork length.

Y Indicates more years of data needed for estimate.

Back calculation of super-population of smolts: Estimates of the ‘super-population’ of smolts that would make up the returning adult run of Coho Salmon to Freshwater Creek (Figure F). Fish were tagged with passive integrated transponders (PIT) while emigrating from Freshwater Creek and recaptured at the adult life stage after spending either 1 or 2 years in the ocean. Production estimates were generated using a Petersen estimate.

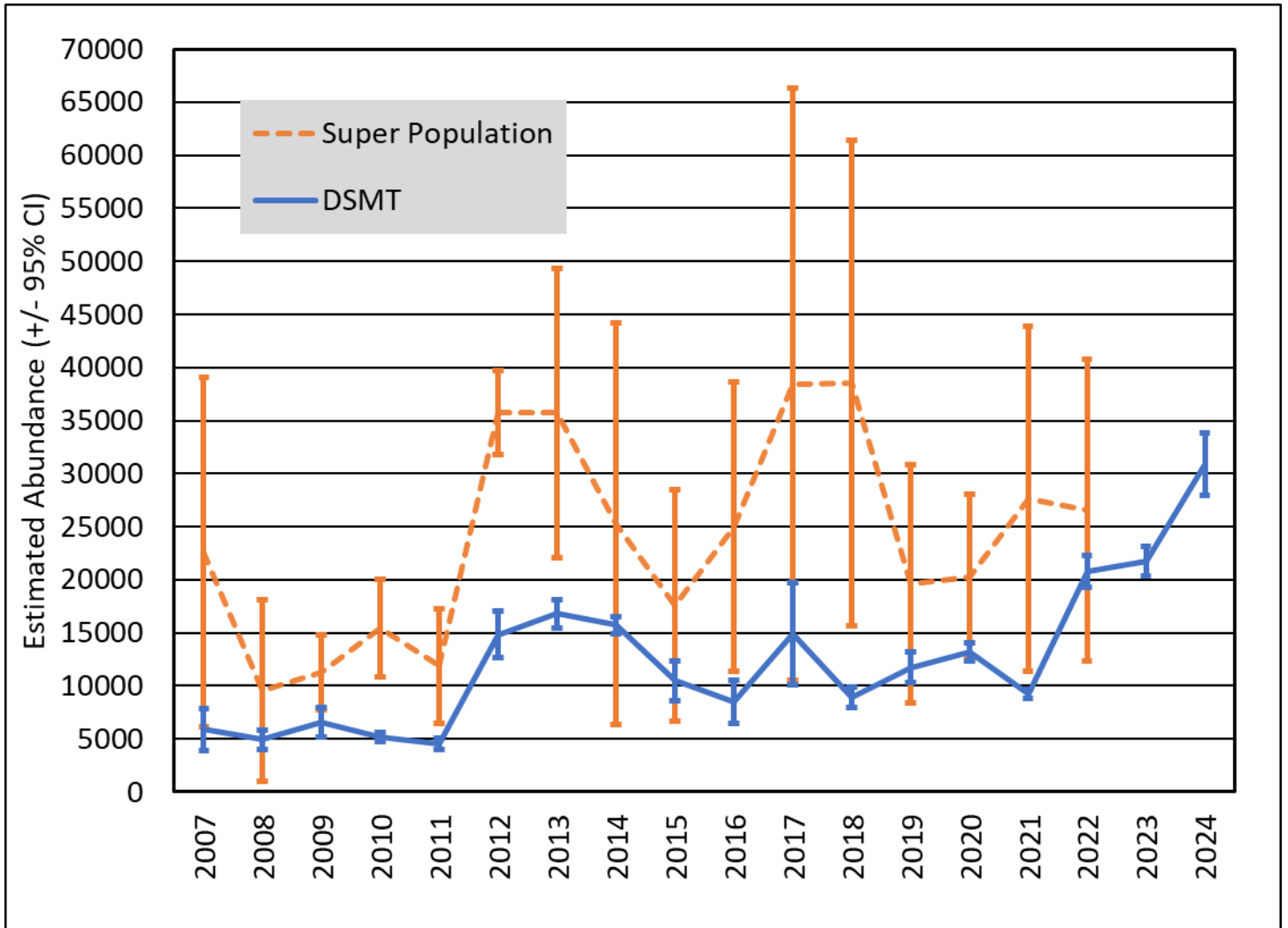


Figure F. Time series plot of juvenile Coho Salmon Spring emigration estimates (\pm 95% confidence intervals) 2007-2024 and super-population estimates (\pm 95% confidence intervals) 2007-2022.

Smolt to-adult return (SAR) marine survival: Estimates of marine survival of Coho Salmon smolt cohorts with four methods (Figure G). From 2007 to 2021 tag-based and abundance-based SAR were used. PIT Tag detection sites were added in 2016 enabling SAR estimates using one antenna site through 2022 and two antenna sites through 2020.

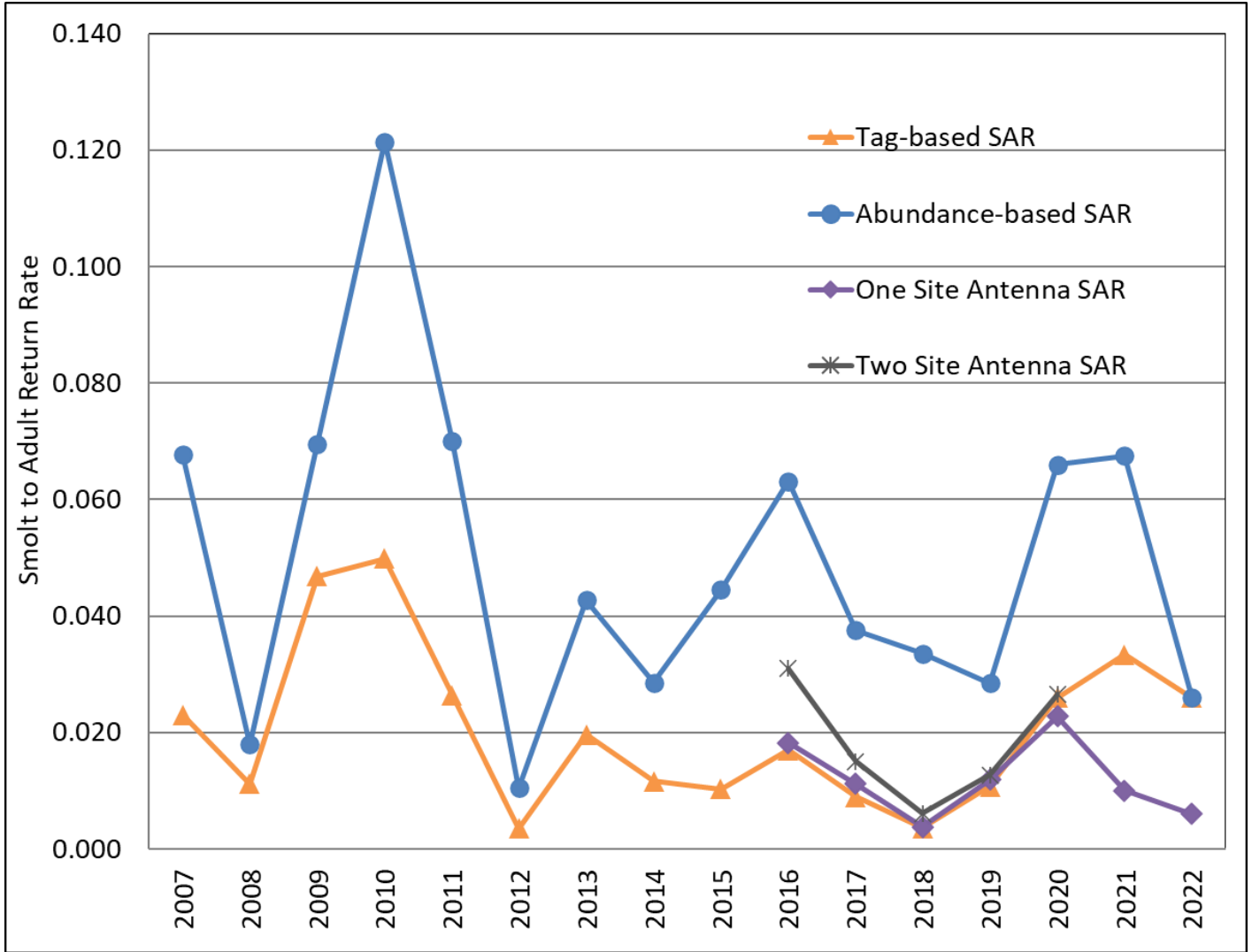


Figure G. Smolt-to-adult return estimates using four estimation methods for Freshwater Creek Coho Salmon smolts by year of ocean entry 2007-2022.

Coho Salmon redd counts vs. escapement: A significant empirical relationship was found between the natural-log (ln)-transformed escapement of adult Coho Salmon estimated with the weir-carcass mark-recapture experiment and the ln-transformed number of redds observed in Freshwater Creek ($F=41.1$, $P=0.000003$, $R^2=0.67$; Figure H.). Figure I presents the time series of Coho Salmon redd counts observed during spawning ground surveys and Lincoln-Peterson mark and recapture estimated adult escapement ($\pm 95\%$ confidence intervals) of adult females.

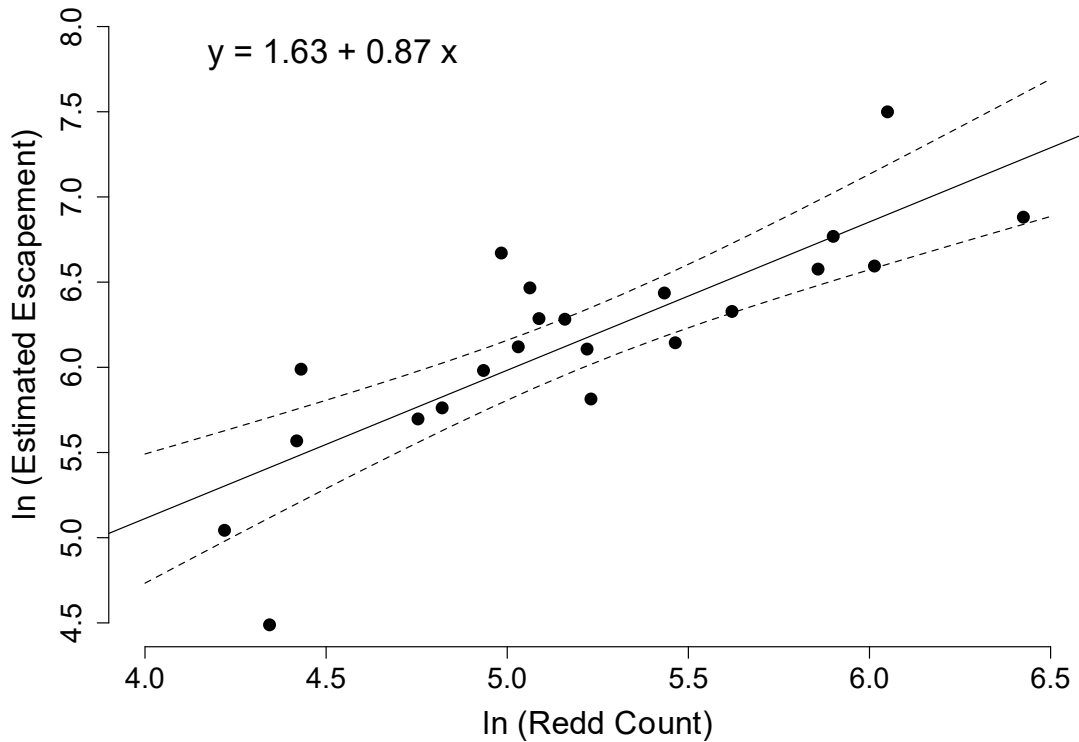


Figure H. Scatter plot with regression line of natural-log-transformed redd counts vs natural-log-transformed Coho Salmon estimated escapement, 2002-2023. Dotted lines indicate 95% confidence intervals for the fitted regression line.

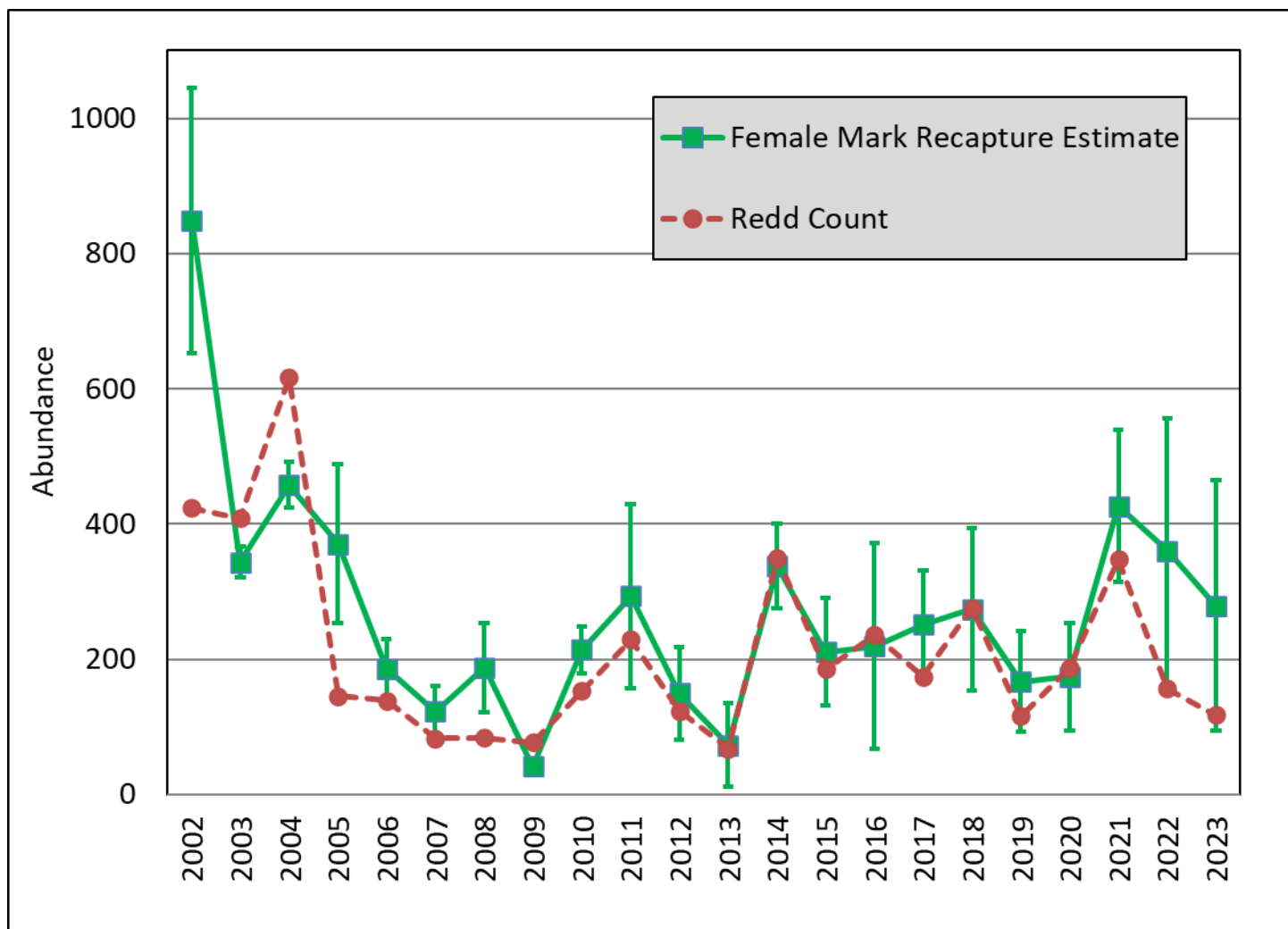
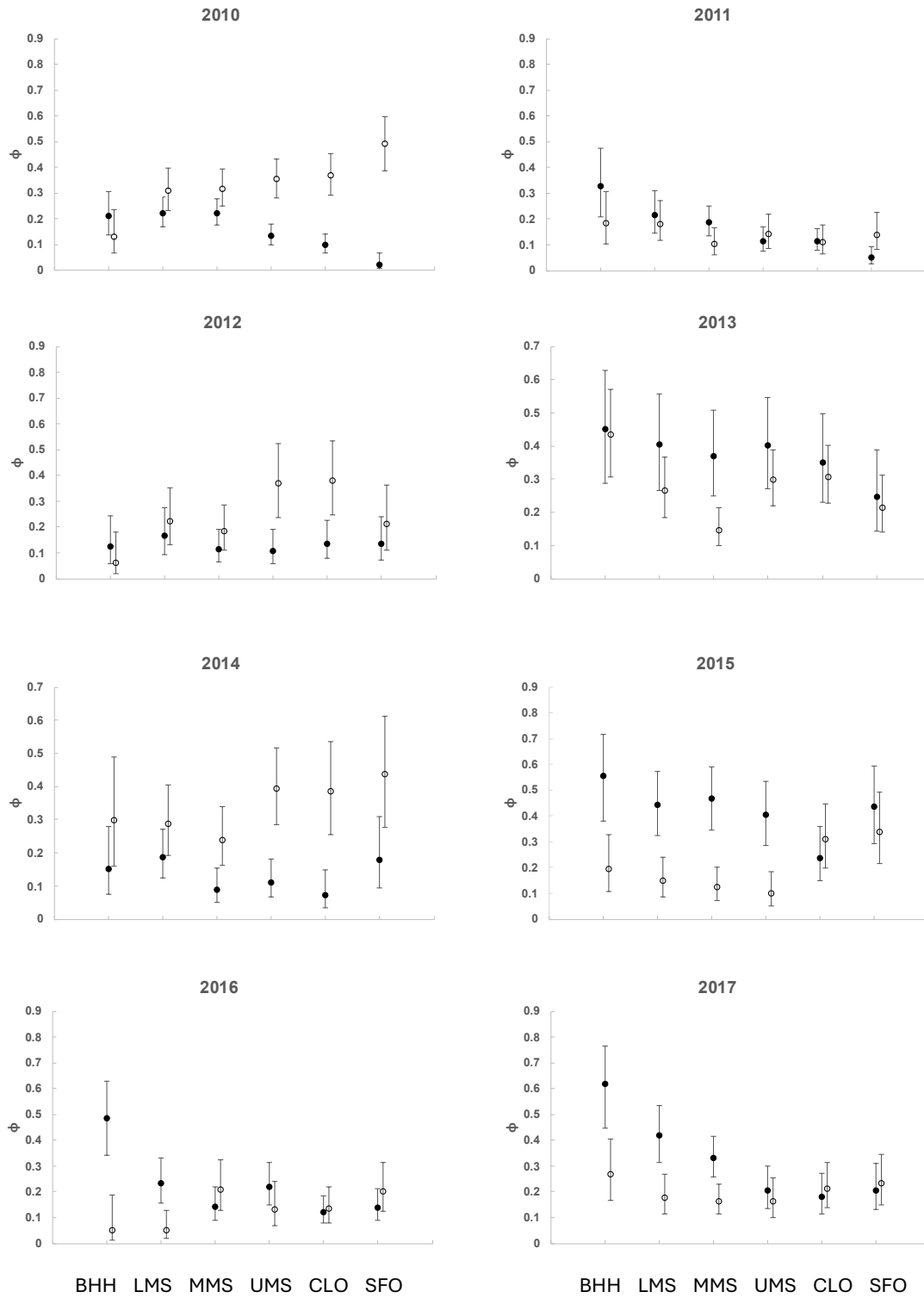


Figure I. Time series plot of Coho Salmon redd counts and estimated female Coho Salmon adult escapement (\pm 95% confidence intervals), 2002-2023.

Coho Salmon pre-spring and spring emigration estimates: Separate Cormack-Jolly-Seber (CJS) analyses were used to estimate the probability of fall-tagged Coho Salmon emigrating before spring and the probability of emigrating as spring smolts (Figure J). For a full description see Rebenack et al. 2015.



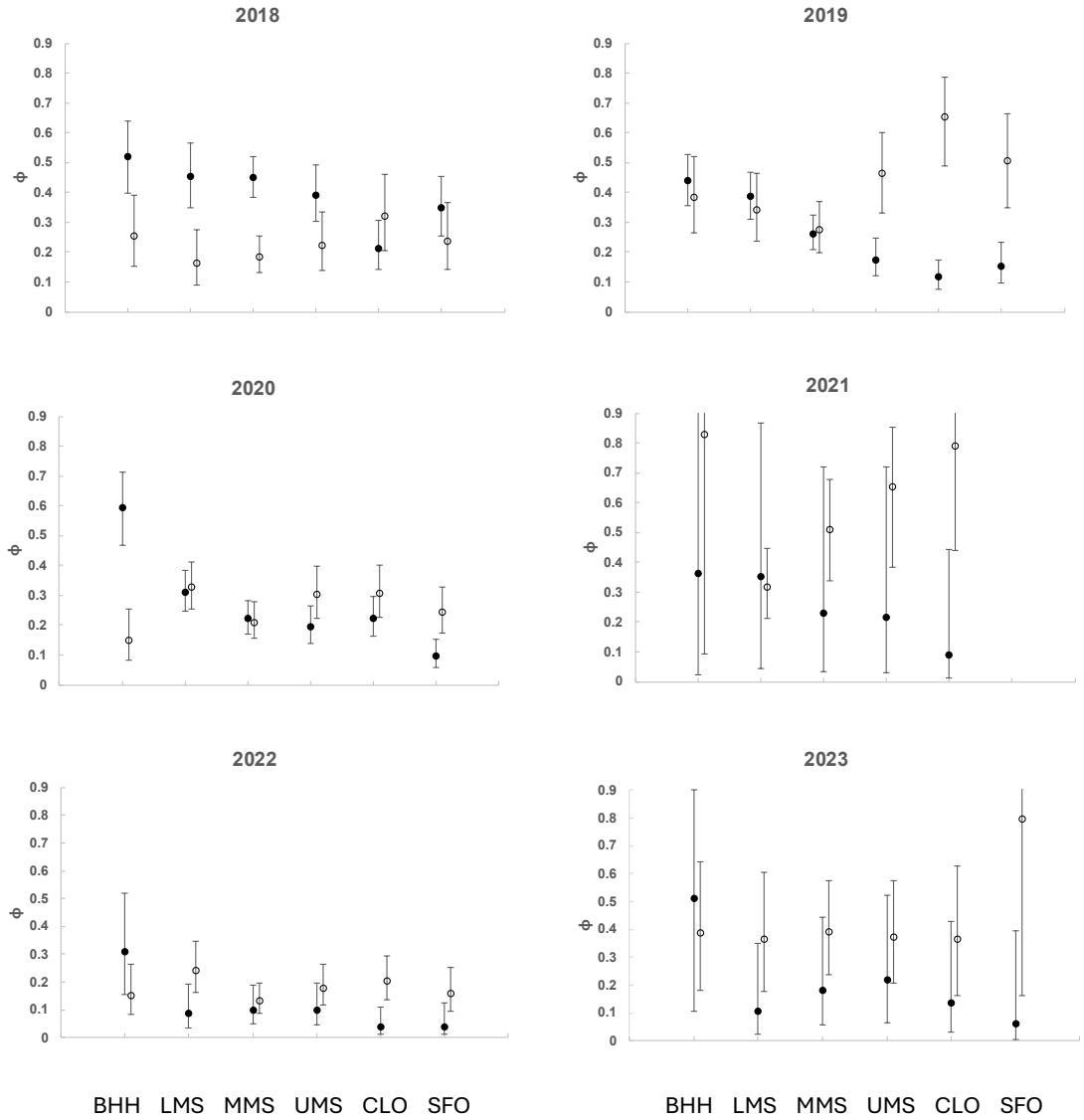


Figure J. The probability of fall-tagged Coho Salmon emigrating early (before the smolt trap was installed, closed points) or during smolt trapping (open points) for each study reach during the years 2010 through 2023. Mainstem reaches are arranged from downstream to upstream (BHH to UMS). Refer to Table 1 and Figure 1 for reach locations and details. Insufficient data to estimate probability parameters in SFO for 2021.

Recommendations:

Recent habitat restoration is focused on lower basin, off-channel, or seasonal habitat for enhancing overwinter capacity for juvenile Coho Salmon. The high rates of pre-spring emigration of Coho Salmon in Freshwater Creek to lower basin overwinter habitat supports this approach (Figure J) and we recommend that these efforts continue. We support projects to create off channel habitat in Wood Creek Phase 3, in upper Ryan Creek, and lower tidally influenced Ryan Creek. Projects in the Eureka Slough flood plain on Cooper Gulch will also provide non-natal rearing for early emigrants (EE).

In this study we estimate marine survival (SAR) using tag-based and abundance-based methods and compare those to antenna-based estimates. Abundance-based methods generate significantly higher SAR estimates, with a similar pattern to tag-based methods over the years. This is an intuitive outcome given the sizable fraction of early emigrants we estimate would not be accounted for in the smolt abundance side of the abundance-based SAR. The tag-based and both one and two site antenna-based methods yield similar results, however, antenna models would better incorporate the unmarked fraction of fish that emigrated below the DSMT prior to spring at adult recovery. This result indicates antenna-based methods of SAR estimation may be useful for LCM stations equipped with antenna stations without adult capture facilities.

Properly functioning radio frequency identification (RFID) stations are critical for estimating SAR and EE. In the 2022-2023 and 2023-2024 periods the RFID antenna at Freshwater Weir was reduced to one operational and one failing antenna. Low SAR estimates for the 2021 and 2022 cohorts are easily explained due to the lack of a properly functioning RFID site (Figure G). Poorly functioning RFID equipment created issues with estimating spring emigration (SE) estimates for the Below Howard Heights reach (BHH) (Figure J). We suggest that RFID equipment is refurbished yearly and works properly to generate the best estimates of EE, SE, and SAR.

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1 INTRODUCTION

1.1 Background

Pacific Salmon (*Oncorhynchus* spp.) have experienced a marked decline in abundance over the last 60 years. Due to this decline, Coho Salmon (*Oncorhynchus kisutch*) in the Southern Oregon/Northern California Coasts (SONCC) Evolutionary Significant Unit (ESU) were listed as threatened pursuant to the federal Endangered Species Act (ESA) in 1997 (NMFS 1997). This federal listing status was reviewed and reaffirmed in 2005, and 2016 (NMFS 2005, NMFS 2016). The California Fish and Game Commission found Coho Salmon populations within the SONCC warranted listing as threatened species under the California Endangered Species Act (CESA; CDFG 2002). All California steelhead trout (*O. mykiss*) south of the Klamath River are Federally ESA listed and coastal Chinook Salmon (*O. tshawytscha*) south of the Klamath River to the Russian River are federally ESA listed. In 2004 the California Department of Fish and Game developed a recovery strategy for Coho Salmon populations within California (CDFG 2004). This recovery strategy is intended to direct management and restoration actions needed to recover the species, provide basin by basin threat assessments, and prioritize management and restoration actions needed to recover the species. The Federal government requires that listed species have recovery plans developed that require objective, measurable criteria which when met, would result in the species being removed from the listing (16 USC 1531, Endangered Species Act 1973).

The California Department of Fish and Wildlife and the National Marine Fisheries Service (NMFS) recognize four key parameters for assessing the long-term viability of salmonid populations. These viable salmonid population (VSP) parameters are population size, population growth rate (productivity), population spatial structure, and life history diversity (McElhany et al. 2000). Monitoring these population parameters is essential to evaluating the success of recovery efforts.

To address data needs for viability assessment, CDFW and NMFS cooperatively developed the draft Coastal California Salmonid Monitoring Plan (CMP) (Adams et al. 2011). Two complementary tasks are considered high priority in the northern monitoring area and form the foundation of the CMP approach. The first task consists of probabilistic sampling of stream reaches within a defined region using spawning ground surveys (SGS) to establish the regional status and trends of adult salmonid abundance. The second task develops intensively monitored Life Cycle monitoring Stations (LCM) nested within the regional sample frame of the SGS. LCM studies have four primary objectives (not in order of importance): 1) define the relationship between SGS observations and adult escapement, 2) estimate juvenile and adult abundance as well as freshwater and marine survival rates, 3) provide a study framework to investigate habitat-productivity relationships, and 4) characterize the diversity of life history patterns. The Freshwater Creek Salmonid Monitoring Project is designed as an LCM with these principal objectives.

This report summarizes the results of yearly abundance and survival monitoring efforts from October 2023 to June 2024, as well as integrates all years of project data to make inference on population trajectories and limiting factors for Coho Salmon in Freshwater Creek.

1.2 Study Area

1.2.1 Freshwater Creek Life Cycle Monitoring Station

The Freshwater Creek watershed is in Humboldt County, California between the towns of Eureka to the south and Arcata to the north. Freshwater Creek is a fourth order stream with a drainage area of approximately 9227 hectares (31 sq. mi.), which drains into Humboldt Bay via the Eureka Slough. Elevations in the watershed range from sea level at the mouth to 823 meters at the headwaters (Figure 1).

Downstream of the weir, in the lower 6 km, Freshwater Slough drains into Humboldt Bay and is confined by levees for cattle grazing. Located adjacent to the slough is a restored, tidally influenced marsh connected to the small Wood Creek watershed. This marsh is 0.14 km² (NRLT, 2010) with four slough channel networks, totaling just over 1.1 km in length, and a freshwater pond with an area of 401 m² (Figure 1). The vegetation in the Wood Creek marsh includes reed canary grass (*Phalaris arundinacea*), tufted hairgrass (*Deschampsia cespitosa*), salt grass (*Distichlis spicata*), Lyngbye's sedge (*Carex lyngbyei*), and willows (*Salix* spp.).

The stream continues at low gradient from river kilometer (rk) 6 to rk 9.7 and is bordered mostly by small parcel residential properties. The remaining 7143 hectares of the watershed encompass 13 km of anadromous fish habitat and is owned and managed for timber production by the Humboldt Redwood Company. The riparian community transitions from poorly developed willow (*Salix* spp.), red alder (*Alnus rubra*), few black cottonwood (*Populus trichocarpa*), and abundant blackberry (*Rubus ursinus*), in the lower reaches to a complex of red alder, willow, redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), salmonberry (*Rubus spectabilis*) and other native herbaceous vegetation in the upper portion of the watershed.

The main stem of Freshwater Creek is approximately 23 km long and features 14.5 km of anadromous fish habitat. Five main tributaries provide 2 to 4 km of anadromous fish habitat each: Little Freshwater, Graham Gulch, Cloney Gulch, McCready Gulch, and South Fork Freshwater.

Annual rainfall is approximately 150 cm in the headwaters and 100 cm near the mouth, with nearly 90% accumulating between October and May. Less than 10% of the annual precipitation falls between June and September. Stream discharges range from 15 ft³/s to > 2000 ft³/s during the rainy season and decline to 2 ft³/s during the fall months.

The fishery resources of the basin include three species of salmon: Chinook salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*O. kisutch*), and steelhead trout (*O. mykiss*). Occasionally, Chum Salmon (*O. keta*) are observed. Other fish present in the basin include Pacific Lamprey (*Entosphenus tridentata*), Western Brook Lamprey (*Lampetra richardsoni*), Cutthroat Trout (*O. clarki clarki*), Prickly and Coast Range Sculpin (*Cottus asper*, *Cottus aleuticus*) and Threespine Stickleback (*Gasterosteus aculeatus*), Longfin Smelt (*Spirinchus thaleichthys*), and Eulachon (*Thaleichthys pacificus*).

The Amphibians and reptiles present include coastal giant salamanders (*Dicamptodon tenebrosus*), northern red-legged frogs (*Rana aurora*), foothill yellow-legged frogs (*Rana boylei*), coastal tailed frogs (*Ascaphus truei*), and northwestern pond turtles (*Emys marmorata*).

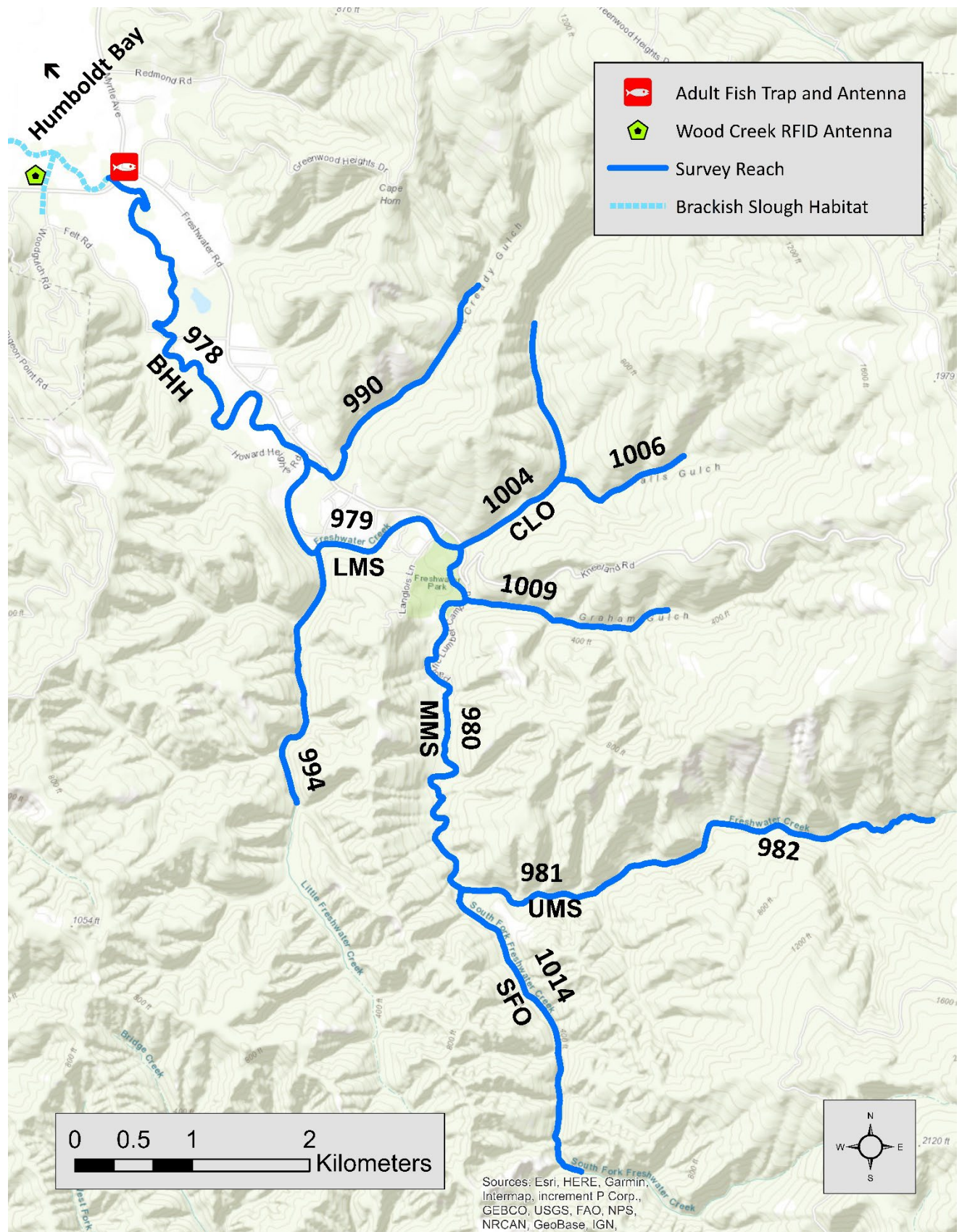


Figure 1. Freshwater Creek and Tributaries, Weir and RFID antenna location, survey reaches (numbered) and fall tagging reaches (abbreviations) in the Freshwater Creek LCM station.

2 METHODS

2.1 Spatial Reach Selection

We partitioned habitat within the Freshwater watershed into eight reaches based upon location and channel morphology (Figure 1). Each of the five anadromous tributaries and the upper main stem above the confluence with South Fork Freshwater Creek are considered the tributaries (Tlibs). Main-stem reaches below the South Fork confluence included the middle main-stem (MMS) which extends from the confluence of the South Fork down to the confluence with Cloney Gulch, the lower main-stem (LMS) which extends from Cloney Gulch to Howard Heights Bridge crossing and the lowest main-stem reach, and Below Howards Heights (BHH) which extends downstream from the Howard Heights bridge crossing into tidally influenced areas of the stream-estuary ecotone ending at the Freshwater Creek weir (FWW).

2.2 Temporal Life Stage Selection

Abundance was measured at two life stages: adult and spring smolts. Survival of Coho Salmon is measured at two critical periods: overwinter between fall and spring smolt emigration, and spring smolt-to-adult return (SAR).

The spatial and temporal extents of the abundance data are not in complete agreement. The adult weir-carcass mark-recapture estimate of escapement includes all fish returning to Freshwater Creek upstream of the FWW, and does not include any Ryan Creek returns that likely contribute to the Freshwater Creek population. Conversely, the back-calculations of the super-population of Coho Salmon smolts include a hypothetical 'population' of smolts which constitute the adult spawning population. The 'true' spatial extent of this population is unknown and may include a component that is 'stray' from Ryan Creek as well as other Humboldt Bay tributaries, such as the Elk River to the south or Jacoby Creek to the north. Table 1 provides a reference linking the survey component to the spatial extent of the abundance estimate.

2.3 Abundance Estimation

2.3.1 Adult Escapement

Adult fish migrating upstream were intercepted shortly after entering Freshwater Creek at the FWC weir (FWW) located approximately 8 river (rk) upstream from the mouth of Freshwater Creek at the entrance Humboldt Bay. The trap was operated intermittently from November until early June, during periods of moderate stream discharge when adult migration was occurring. The trap was made inoperable during low flow periods ($<10 \text{ ft}^3/\text{s}$) or during periods of high discharge ($>500 \text{ ft}^3/\text{s}$) when the water overtopped the panels. During these low and high discharge periods, weir panels were lowered allowing fish to pass unimpeded.

Captured fish were netted and placed in a tagging cradle for biological sampling. Each fish was identified to species, measured for fork length in centimeters, examined for fin-clips, punches, tags, predator marks and other wounds, and sexed. Scale samples were collected from an area located posterior to the dorsal fin between the lateral line and the dorsal. Prior to release, steelhead trout and Coho Salmon received a individual identifying passive integrated transponder (PIT) tag (Biomark, Inc., Boise, Idaho; full-duplex B, 12.5 mm long, 2.03 mm wide). The tag was injected between the skin and muscle, in the same area where the scales had been removed for sampling. Coho Salmon were also given a hole-punch to the operculum as a secondary durable external mark for subsequent recovery as carcasses on the spawning grounds. Processed fish were either immediately released upstream of the trapping facility at moderate stream flows or held in gated PVC pipe suspended in an aerated flow-through recovery tank for up to 2 hours to allow for fish recovery before upstream release at higher stream flows.

During each spawning ground survey (See Sec 2.3.2), all Coho Salmon carcasses were inspected for PIT tags and operculum punches, then given a uniquely numbered jaw tag. The ratio of the total number of carcasses with opercula punches to the total number inspected for punches was used to estimate weir trapping efficiency. The total number of fish trapped at the weir is expanded by the weir trap efficiency using a simple Lincoln-Peterson Capture-Mark-Recapture (CMR) model to estimate total adult escapement (Appendix 1). Only complete, opercula intact, carcasses observed for the first time were used as the recovery sample. Because few steelhead carcasses are found on spawning surveys, the recovery sample for steelhead consisted of downstream-migrating, post-spawn kelts captured at the weir. Similar to the model used for Coho Salmon, the ratio of the total number of steelhead kelts having PIT tags to the total number inspected for tags is used as the recapture sample to estimate weir trap efficiency of upstream pre-spawn migrants. The total number of steelhead trapped at the weir is expanded by the weir trap efficiency using the same Lincoln-Petersen Mark-Recapture model to estimate total escapement (Appendix 1).

2.3.2 Spawning Ground Surveys

Spawning ground surveys protocol closely followed that of Gallagher et al. (2007). All reaches upstream of and including the LMS were walked by two project personnel approximately once every 10 days or as stream visibility conditions permitted. Survey personnel walked upstream recording salmonid observations including carcasses, live fish, and redds. Live fish and carcasses were identified to species when possible. Live fish were visually estimated for length while carcasses were measured to fork length. Newly discovered carcasses were marked with uniquely numbered jaw tags, and jaw tag number was recorded on any previously tagged carcass. Newly observed redds were flagged, dated, assigned a unique record number, aged as category one- 'new to the survey'. Redds that were re-observed on subsequent surveys received categorical ages ranging from age two- 'still visible and measurable', age three- 'still visible but not measurable', and age four- 'no longer visible (flag only)'. All redds were assigned to a species if a fish was observed constructing, defending, or holding on a redd, otherwise

they were recorded as unidentified species origin. Measurements including redd size, pit depth, and substrate composition were collected following Gallagher et al. (2007) if no fish were in the vicinity of the redd and time constraints permitted. Spatial X-Y coordinates were collected on all fish and redd observations. Redds were assigned a species by identification of the fish observed guarding or digging. All unoccupied salmonid redds were recorded as unknown.

To assign species to unknown redds Ricker et al. (2014) applied a K-nearest neighbors (kNN) algorithm. The kNN uses distance in X-Y space and time to nearest 3 known species redd or live fish to make a prediction of species based on majority vote. Each unknown redd was assigned to a species for further analysis of species-specific redd abundance.

2.3.3 Juvenile Salmonid Smolt Production

2.3.3.1 Spring Down-Stream Migrant Trapping

A single downstream migrant trap (DSMT) was operated in the Freshwater Creek basin from early March through June 2024. The trap was located at the FWW at the saltwater-freshwater interface. To operate the weir as a juvenile salmonid downstream migration trap, the center weir panel was retrofitted with a 10" PVC pipe extending 20' from a 4' X 5' X 3' plywood entrance cone fixed to the panels of the weir at the upstream end, terminating in a 4' X 4' X 8' aluminum live car at the downstream end. Fish were directed to the entrance cone with a ¼" hole screened fence angled approximately 60 degrees to the direction of flow guiding fish down the pipe and depositing them in the floating live car. This configuration was effective at capturing a portion of the migrating population.

Capture probability and expanded numbers of migrants were estimated using a single trap CMR method. Each day, trapped fish were anaesthetized with tricaine methanesulfonate (MS-222), counted, and checked for marks. A sample of previously unmarked age 1+ Coho Salmon, greater than or equal to 70 mm FL, were marked by inserting a small, individually numbered PIT tag (Biomark, Inc., Boise, Idaho; full-duplex B, 12.5 mm long, 2.03 mm wide) directly into the body cavity (Prentice 1990, Prentice et al. 1994) just behind where the pectoral fin lies against the body. Once processed, those fish that were recaptured or did not receive marks were placed in a flow-through trough until they recovered from the anesthetic prior to being released downstream of the trap. Newly marked fish were held in a flow-through trough for up to one hour to check for handling and marking mortalities. Newly marked fish were then released one to three pool-riffle sequences upstream of the trap. The marking and recapture data were stratified into weekly time intervals and analyzed using Darroch Analysis with Rank Reduction (DARR v2.0 in R) to produce bounded estimates of abundance (Bjorkstedt 2005).

Estimates of the abundance of migrating juvenile salmonids using the single trap method, (i.e., releasing marked fish above the trap sites to estimate trap efficiency), relied upon the assumption that all released fish resume migration past the trap site. Coho Salmon and steelhead trout smolts are emigrating from the system to the marine environment and therefore satisfy this assumption. Parr and pre-smolt trout, however, may not commence downstream migration after marking and release (Ricker 2002). Due to the potential for substantial and unknown bias stemming from this behavior, estimates are not produced for parr and pre-smolt trout and only captures are reported. Age 0+ fry captures were simply counted, as we did not conduct mark-recapture experiments to estimate trap efficiencies. These data presented should therefore be considered an index of population size for these categories.

2.3.3.2 Back Calculation of Super-Population of Smolts

We estimated the ‘super-population’ of smolts that would make up the returning adult run of Coho Salmon to Freshwater Creek. Fish were PIT tagged emigrating from Freshwater Creek and recaptured at the adult life stage after spending either 1 or 2 years in the ocean. Production estimates were generated using a Petersen estimate (Chapman 1951, Seiler et al. 1994, Volkhardt et al. 2007; Appendix 1).

2.4 Survival Estimation

2.4.1 Juvenile Coho Salmon Overwinter Survival and Pre-Spring Emigration

We used a CMR experiment to estimate both pre-spring (early) emigration rate and apparent survival rate of fish from fall (October) capture and PIT tagging in upstream reaches, to spring trapping at the FWW near the upstream limit of tidal influence (see 2.3.3.1).

We partitioned the Freshwater Creek basin into six study reaches upstream of the FWW for initial marking of Coho Salmon, with reach divisions based on position in the watershed. The main stem was composed of four reaches: upper main-stem (981), middle main-stem (980), lower main-stem (979), and below Howard Heights (BHH). Smaller tributary study reaches in South Fork (1014) and Cloney Gulch (1004) were also included. Other stream areas in the basin were excluded from this study due to lack of access for sampling or because no adult Coho Salmon have been detected spawning in those areas. Excluded reaches include one main-stem reach 982, located above a partial log jam barrier and two small tributary reaches, McCready Gulch (990) and Little Freshwater (994).

Pre-survey snorkel surveys were completed in September 2023 to determine fish densities in the tagging reaches. The goal in this survey is to distribute tags in proportion to the population size in each reach. A secondary goal is to distribute the tags throughout the occupied portion of the reach.

Fish marking was conducted in October 2023. We used systematic random sampling within reaches to select pools and used a beach seine to capture juvenile Coho Salmon. All captured Coho Salmon were placed in a bucket and seining was repeated until we captured a target of 6-10 individuals depending on the relative abundance within the reach.

All juvenile Coho Salmon selected for marking were first anesthetized with MS-222, measured for fork length, and wet weight. Juvenile Coho Salmon with a fork length greater than or equal to 60 mm were marked with full-duplex PIT tags (Biomark, Inc., Boise, Idaho; full-duplex B, 9.0 mm long, 2.1 mm wide). Tags were inserted into the body cavity of the fish anterior to the pectoral fin using a sterile scalpel. Fish were given 10-30 minutes to recover prior to releasing them into their respective sampling locations.

Subsequent encounters with tagged fish occurred at radio frequency identification (RFID) PIT detection antenna arrays or at the FWW. Prior to the operation of the FWW as a migrant trap, early emigrants were detected at the PIT tag array (Figure 1), containing two stationary pass-over antennas separated 3 m apart. The array is located at FWW and separates the upper basin study area from the stream estuary ecotone and lower sloughs. The antenna site was operated continuously throughout the study, but fish detected at the antenna arrays were only considered early emigrants if the date of first detection was before the first day of smolt trapping at the weir. During the spring (March through June) PIT-tagged fish were recaptured at FWW and passed downstream (see section 2.3.3.1 for methods).

We used two separate Cormack-Jolly-Seber (CJS) CMR models to estimate: (1) the probability of fall-tagged fish emigrating before spring and (2) the probability of surviving and emigrating as spring smolts. A typical CJS model estimates apparent survival (ϕ) of tagged individuals between encounters adjusted for recapture probability (p). Apparent overwinter survival in our first CJS model is the probability that individuals both survive and remain in the study area upstream of FWW to spring trapping. In our second CJS model of early emigration, the apparent survival term is interpreted as an estimate of the probability of fall-tagged individuals surviving and emigrating past the FWW prior to initiation of spring trapping (Rebenack et al. 2015).

To facilitate comparison over time, we report the parameters for a model fit with a group covariate to produce a separate estimate of apparent survival for year and for fish from each of the six tagging reaches. All models were fit using the logit link function.

2.4.2 Smolt-to-Adult Return (SAR) Survival

Juvenile Coho Salmon smolts were captured at the downstream migrant trap (DSMT) and marked with PIT tags (see sec. 2.3.3.1 Downstream migrant trapping). Fish returning to the weir as adults in two winters, were captured, checked for PIT tags, and

if in good condition, (e.g., no large predator wounds, energetically vigorous) marked with an operculum punch and passed above the weir (see 2.3.1 Adult escapement). SAR rate (\hat{s}) was estimated with tag-based and abundance-based methods as outlined in Cochran et al. (2019), and a third novel antenna-based method that does not rely upon in-hand capture of adults.

The tag-based method is calculated as the number of Coho Salmon PIT tagged as smolts during spring outmigration and recaptured as adults at the weir divided by the number of PIT-tagged smolts of the same cohort (Appendix 1). Because all adult fish returning are not captured and cannot be checked for smolt PIT tags, the number of smolt PIT tags returning was estimated by expanding the actual number recaptured by the weir trapping efficiency. Weir trapping efficiency was estimated as the ratio of carcasses having operculum punches applied at the weir to all carcasses inspected for operculum punches. This approach is directly analogous to how weir trap efficiency is calculated for estimation of adult escapement (see sec 2.3.1)

The second method is the abundance-based SAR, and, as the name implies, is calculated from two independent CMR model estimates of abundance. Intuitively, abundance-based SAR rate is calculated as number of returning adults (Sec 2.3.1) divided by the DSMT smolt estimate (Sec 2.3.3.1) from two years prior.

A third, antenna-based SAR method was investigated as an alternative that does not rely upon 'in-hand' adult capture at return. The antenna-based method estimates the number of PIT-tagged smolts returning as adults using PIT tag codes detected at antennas. As with all CJS studies, the number of PIT-tagged smolts detected as returning adults are adjusted for detection efficiency (p). We estimate detection efficiency at individual antennas from the FWW site as two independent capture occasions (Figure 1; Appendix 2).

Assessment of statistical bias and construction of confidence bounds was accomplished via non-parametric bootstrap re-sampling. For each data set, individual capture histories were re-sampled with replacement equal to the sample size of the original data. One thousand bootstrap sample data sets were constructed, and 1000 estimates of SAR were generated. Statistical bias was assessed as the difference between the mean of the bootstrap replicates and the point estimate derived from the original data (Efron and Tishirani 1993). Percentiles of the bootstrap distribution of SAR values are used to construct 95% confidence intervals (Manly 1997).

Table 1. Abundance spatial extents in Freshwater Creek by Location codes, reach names, and life stage specific salmonid abundance estimates.

Location Code	Stream/Reach Name	Juvenile Emigrant Trapping	Juvenile Emigrant Trapping	Adult	Adult
990	McCready Gulch	Weir	Super Population	Spawning survey	Adult abundance
1004	Cloney Gulch (CLO)	Weir	Super Population	Spawning survey	Adult abundance
1009	Graham Gulch	Weir	Super Population	Spawning survey	Adult abundance
981	Upper Mainstem-A (UMS)	Weir	Super Population	Spawning survey	Adult abundance
982	Upper Mainstem-B	Weir	Super Population	Spawning survey	Adult abundance
1014	South Fork (SFO)	Weir	Super Population	Spawning survey	Adult abundance
994	Little Freshwater	Weir	Super Population	Spawning survey	Adult abundance
980	Middle Mainstem (MMS)	Weir	Super Population	Spawning survey	Adult abundance
979	Lower Mainstem (LMS)	Weir	Super Population	Spawning survey	Adult abundance
978	Below Howard Heights (BHH)	Weir	Super Population	Spawning survey	Adult abundance
FWW	Weir	Weir	Super Population	Spawning survey	Adult abundance
WC	Wood Creek		Super Population	Spawning survey	Adult abundance
RC	Ryan Creek		Super Population	Spawning survey	Adult abundance

3 RESULTS

3.1 Adult Escapement and Redd Counts

Field staff conducted 78 spawning ground surveys in nine reaches within the Freshwater Creek watershed between November 17, 2023, and June 25, 2024. Individual stream reaches were surveyed an average of 8.7 times at an average return interval of 16.8 days. Live fish observed include 95 Coho Salmon, six steelhead, four Coastal Cutthroat Trout, and four Pacific Lamprey. Carcass totals include one Chinook Salmon, 33 Coho Salmon, and 15 Pacific Lamprey. Redd counts include 44 Coho Salmon redds, two steelhead redds, 74 unknown redds, five Coastal Cutthroat Trout redds, and 179 Pacific Lamprey redds (Figure 2).

3.1.1 Steelhead Trout

Nine adult steelhead migrating upstream were captured at the FWW from December 4, 2023, to February 8, 2024. Females (N=6) ranged in size from 59 cm to 68 cm and averaged 64 cm. Males (N=3) ranged in size from 67 cm to 84 cm and averaged 73 cm. Out of the nine upstream migrating steelhead, eight were newly marked, and one was passed upstream without PIT tagging.

Seven steelhead kelts were recaptured moving downstream at the FWW, one of which was identified as having been PIT tagged. The adult steelhead escapement to Freshwater Creek was estimated to be 40 ± 14 (95% C.I.). During the spawner survey season six live steelhead and zero carcasses were observed.

3.1.2 Coho Salmon

A total of 117 upstream migrant adult Coho Salmon were captured at the FWW from December 3, 2023, to February 8, 2024. Females (N=59) ranged in size from 39 cm to 76 cm and averaged 64 cm. Males (N=54) ranged in size from 37 cm to 79 cm and averaged 67 cm. Out of 117 upstream migrating adult Coho Salmon, 95 were newly marked with PIT tags, 10 were recaptured with PIT tags, three were counted and released upstream, and 104 were marked with operculum punches during 2023-2024.

During spawner surveys 95 live Coho Salmon and 36 carcasses were observed. Out of this total, 30 had intact left opercula, of which five were identified as having received an operculum punch at the weir. The Lincoln-Petersen estimate of adult Coho Salmon escapement into Freshwater Creek is 537 ± 65 (95% C.I.).

3.1.3 Other Species

During spawning ground surveys one female Chinook Salmon carcass measuring 95 cm was observed. Coastal cutthroat trout were observed four times during spawning surveys. Pacific Lamprey observations included four live animals and 15 carcasses.

3.2 Spring Juvenile Downstream Migrant Production

The juvenile salmonid DSMT at Freshwater Creek was installed on March 19, 2024, and was fished 87 days through June 21, 2024. The trap was operated on all but one day during this period. In total 2,445 Coho Salmon smolts were PIT tagged and released back upstream of the trap during the season to estimate trap capture efficiencies. In total 272 steelhead smolts were clipped and released back upstream of the trap during the season to estimate trap capture efficiencies.

An estimated $30,890 \pm 1499$ (95% C.I.) age 1+ Coho Salmon smolts migrated past the DSMT during the spring trapping period of 2024 (Figure 3). Coho Salmon fork lengths (N=2443) ranged from 70 mm to 186 mm with a mean of 111 mm at the DSMT (Table 2 and Figure 4). The peak timing of Coho Salmon captures occurred during the week beginning May 12 at the DSMT (Figure 3).

An estimated 1048 ± 104 (95% C.I.) steelhead trout smolts migrated past the DSMT during the spring trapping period of 2024 (Figure 5). Steelhead trout smolt fork lengths (N=272) ranged from 105 mm to 248 mm with a mean of 189 mm at the FWW (Table 2 and Figure 6). The peak timing of steelhead trout captures occurred in the week beginning March 31 at the FWW (Figure 5).

3.3 Back Calculation of Super-Population of Coho Salmon Smolts 2022

The back-calculated super-population of Coho Salmon smolts from the 2022 cohort is estimated to be $26,562 \pm 14,253$ (95% C.I.). This estimate is considered the total population of smolts that make up the adult returns to Freshwater Creek as age 2 grilse less than 460 mm in 2022-2023 and as age 3 adults greater than 46 mm in 2023-2024.

3.4 Survival Estimation

3.4.1 Juvenile Coho Salmon Overwinter Survival and Pre-Spring Emigration

Estimated densities of Coho Salmon juveniles were determined for each reach during direct observation snorkel surveys prior to tagging effort. We PIT tagged 1,204 Coho Salmon during the 2023 fall sampling effort in Freshwater Creek upstream of FWW (Table 3). Of these tagged fish, 107 (8.9%) were subsequently detected at the DSMT the following spring.

PIT tag codes were detected throughout the winter and spring at continuously operating stream-width antenna arrays from late-October 2023 through early July 2024. Antennas detected 76 unique PIT tag codes from early emigrant Coho Salmon juveniles totaling 5.9% of the fall-marked cohort.

Nine Coho Salmon juveniles were detected moving between freshwater and estuarine environments. Capture histories show these individuals moved down to the estuary in

the winter then moved back into the freshwater habitat in the winter or early spring before smolting.

The fate of juveniles overwinter varied across reaches. In general, fish tagged in the fall of 2023 were more likely to emigrate early (before the smolt trap was installed) than to survive the winter in upstream habitats and migrate in the spring. Fish from the lowermost mainstem reach (BHH) were more likely to choose the opposite life history strategy. It should be noted, however, that the survivorship of the early emigrating portion of the population is not known after emigration. Overwinter “apparent survival,” interpreted as the probability that fall-tagged fish survived, stayed upstream overwinter and migrated during the spring smolt trapping period, ranged from 36-79% between reaches (Figure 7). All parameter estimates were generated with Program MARK.

3.4.2 Smolt-to-Adult Return Survival 2022

We PIT tagged 2,347 outmigrating Coho Salmon smolts and an additional 215 were recaptured with PIT tags from previous fall tagging efforts during the 2022 spring trapping season. Smolt releases for the tag-based and antenna-based SAR estimates included 2,562 tagged individuals. Ten of these PIT-tagged fish were recaptured as adults at the FWW. We recovered five weir-captured and opercula-punched carcasses out of the total 30 carcasses found on the spawning grounds, indicating a 16.66% weir capture efficiency. Non-bias-adjusted adult tag-based SAR for the 2022 smolt cohort is 2.6% (Figure 8).

The 2022 spring juvenile outmigration estimate was 20,812 and the Lincoln-Peterson mark and recapture estimate of spawning adults for the same cohort group was 537. Non-bias-adjusted adult abundance-based SAR for the 2022 smolt cohort is 2.6% (Figure 8).

Antenna-based SAR estimates for the 2,562 PIT-tagged smolt releases in 2022 is 0.6% for the one antenna site method (Figure 8). Tag recaptures from the 2022 cohort used to estimate the one-site antenna-based SAR and efficiency are presented in Table 4.

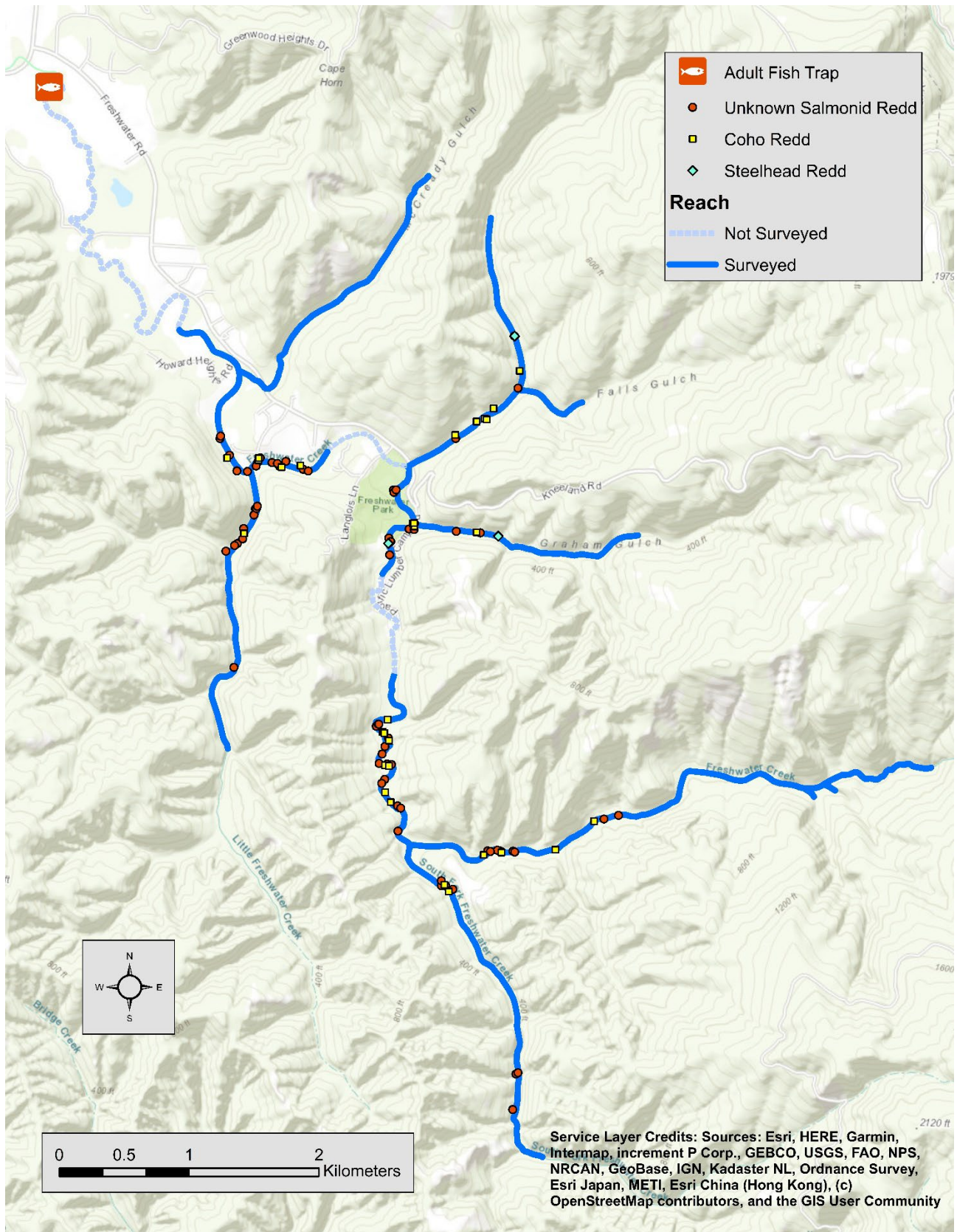


Figure 2. Salmonid redd locations in Freshwater Creek, winter 2023-2024.

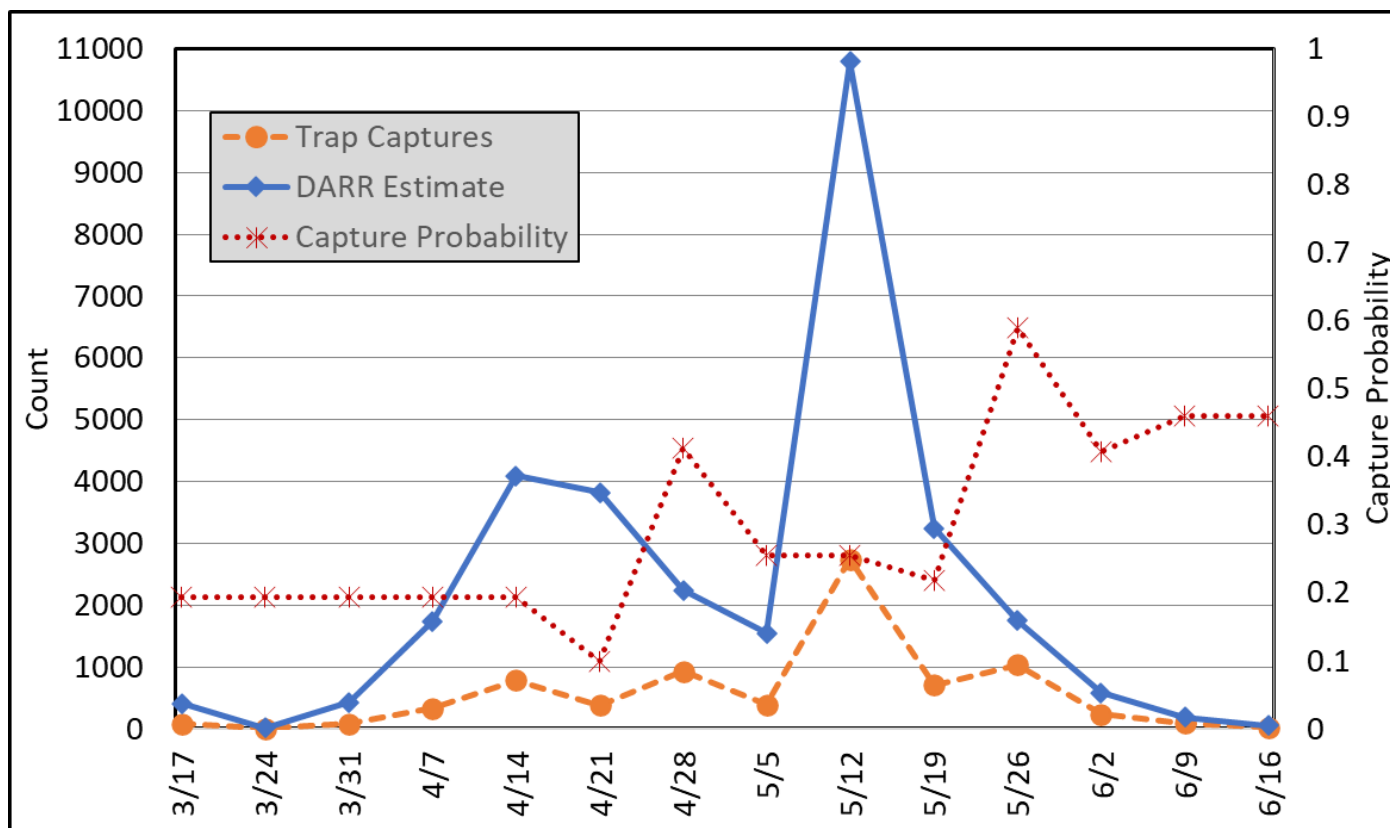


Figure 3. Coho Salmon smolt trap captures, DARR estimates, and DARR trap efficiency estimates, March through June 2024.

Table 2. Descriptive fork length statistics (mm) for all marked juvenile emigrant Coho Salmon and steelhead trout in Freshwater Creek at FWW trap, 2024.

Statistic	Coho Smolts	Steelhead Trout Smolts
Mean	111	189
Standard Error	0.3	1.3
Median	110	188
Standard Deviation	15.3	21.9
Minimum	70	105
Maximum	186	248
N	2443	272
C.I. Mean (95%)	0.61	2.6

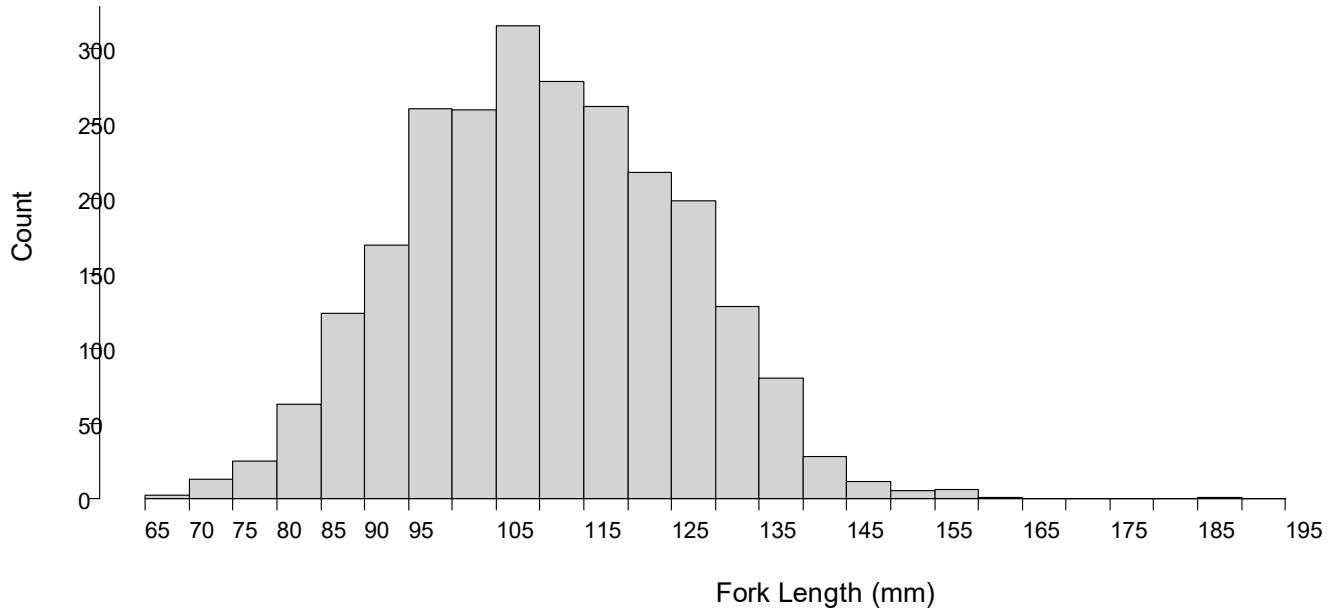


Figure 4. Histogram of emigrant juvenile Coho Salmon fork lengths (mm) in Freshwater Creek at FWW, 2024.

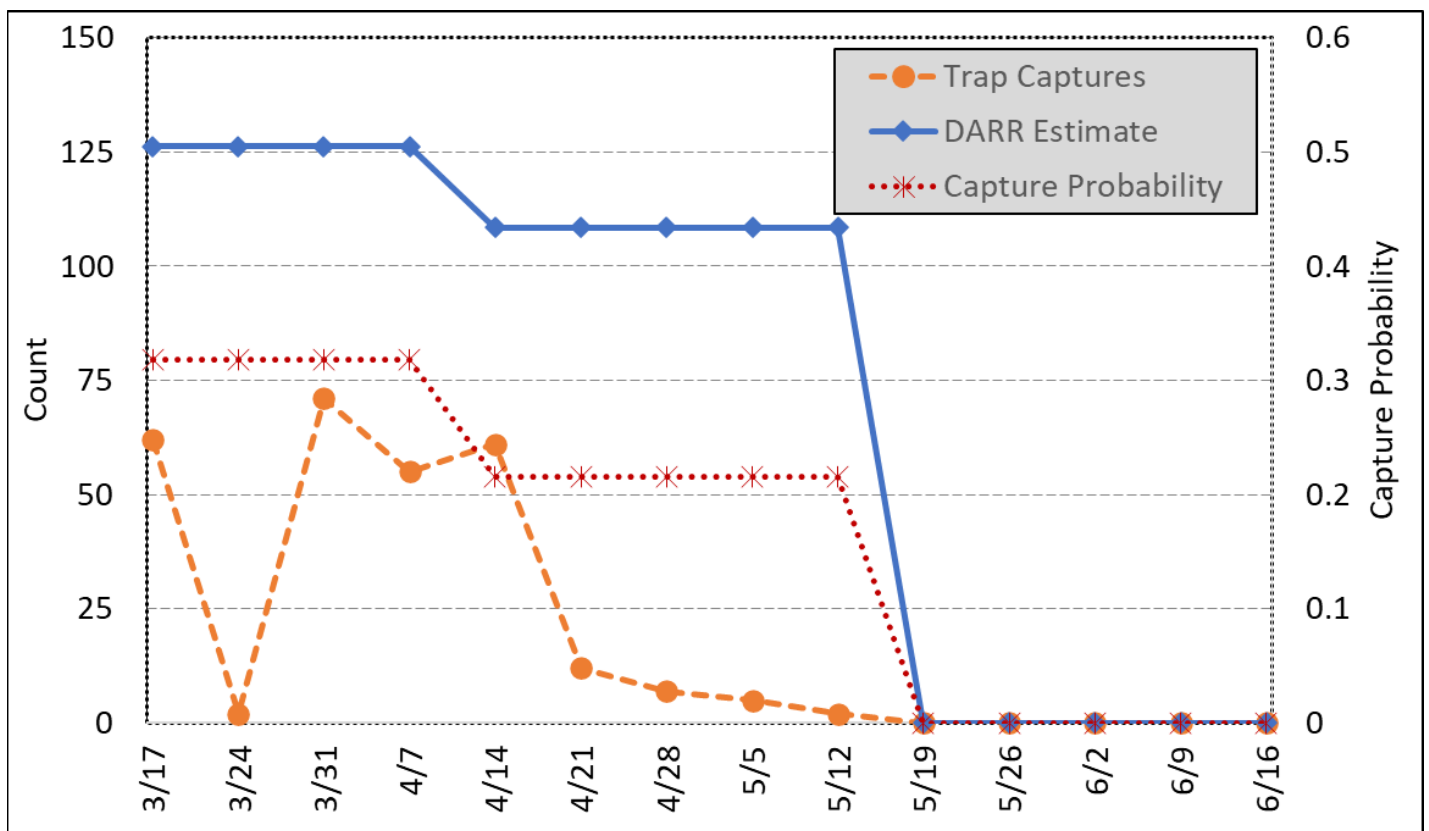


Figure 5. Steelhead trout smolt trap captures, DARR Estimates, and DARR trap efficiency estimates, March through June 2024.

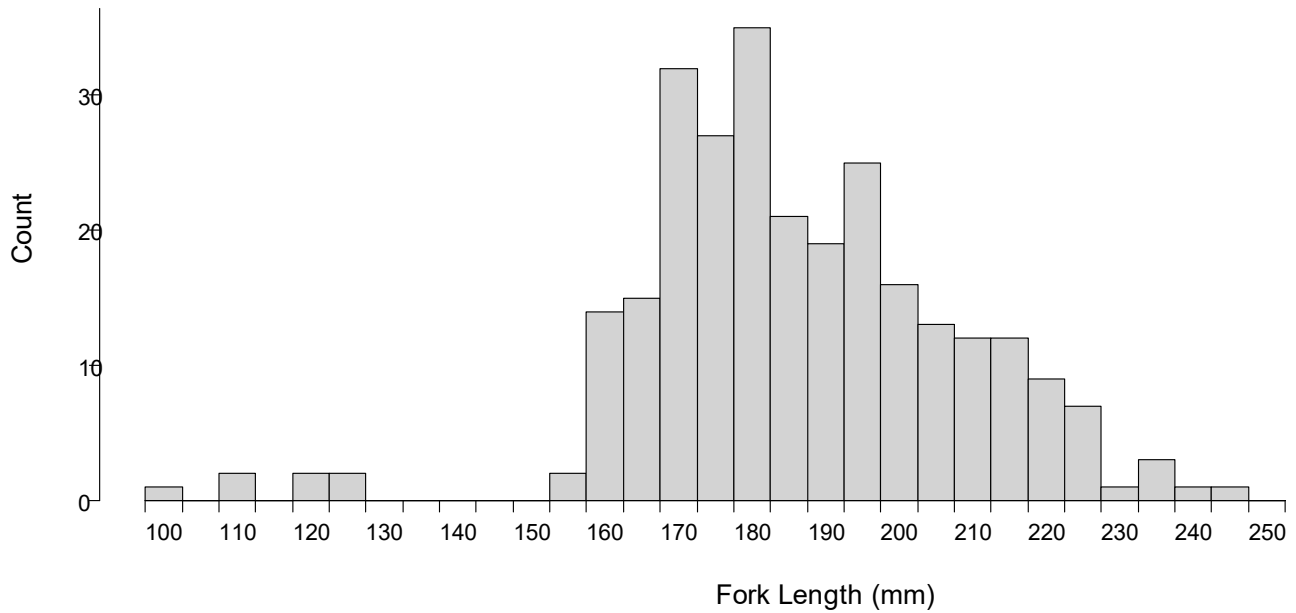


Figure 6. Histogram of emigrant juvenile steelhead trout smolt fork lengths (mm) in Freshwater Creek at FWW, 2024.

Table 3. Freshwater Creek fall 2023 juvenile Coho Salmon density fish per linear meter, fish distribution in reach, and number of tags applied in each reach.

Reach	978/BHH	979/LMS	980/MMS	981/UMS	1004/CLO	1014/SFO
Fish per linear meter	1.7	1.9	4.1	5.3	1.4	1.3
Reach length in meters	3966	3024	4972	2060	3201	1900
Number of tags applied	130	153	474	269	115	63

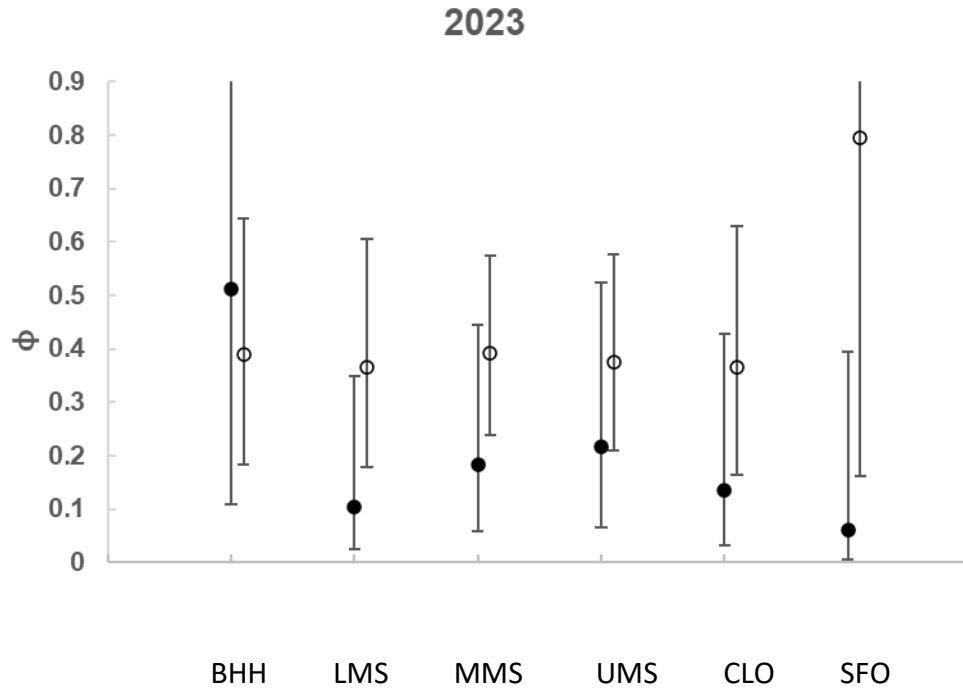


Figure 7. The probability of 2023 fall-tagged fish emigrating early (before the smolt trap was installed on March 19, 2024, closed points) or during smolt trapping (open points) for each study reach. Main-Stem reaches are arranged from downstream to upstream, BHH to UMS.

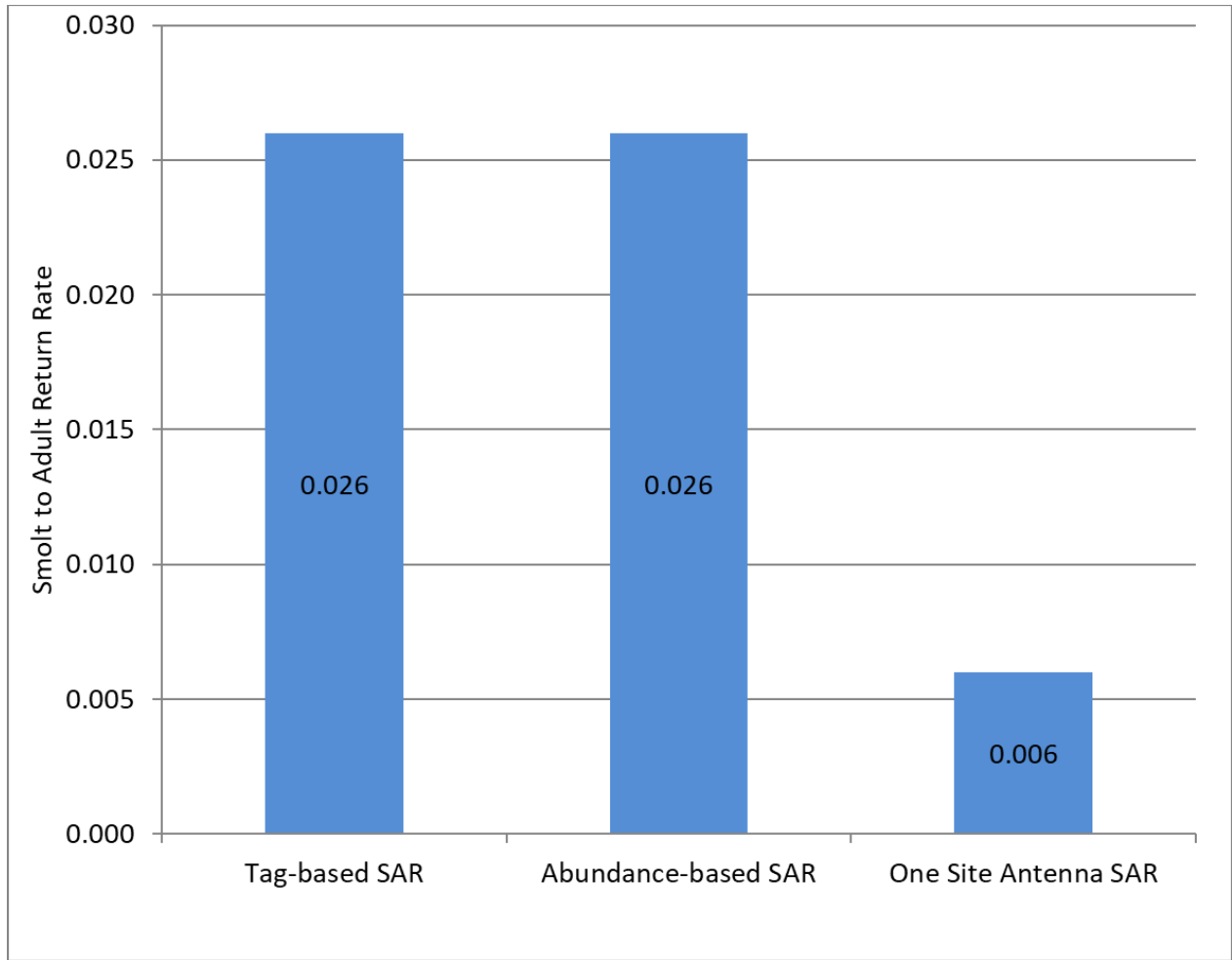


Figure 8. Smolt-to-adult return (SAR) rates for Freshwater Creek Coho Salmon smolts from the 2022 cohort.

Table 4. PIT tag recaptures of 2022 DSMT Coho Salmon smolts used to generate 2022 One Site Antenna SAR estimate. Passive antenna detections are for adults (two winters in ocean) returning in fall of 2023 through spring 2024. Intersection is the number of individual tag recaptures at both antennas (One Site).

Site / antenna #	Unique Tag Detections	Intersection	Total Tag Detections	Efficiency
FWW antenna #1	12	1	13	-
FWW antenna #2	1	1	2	7%

4 Multiple Year Comparisons

4.1 Adult Abundance Trends

Over the last three years the Coho Salmon adult escapement estimates are above or near the 22-year average of 569 (Table 5). Over the last four years the adult steelhead trout escapement estimates have been below the 24-year average of 157 (Table 5).

4.2 Redd Surveys vs Estimated Adult Coho Salmon Escapement

The pattern of observed redd counts and Lincoln-Peterson mark and recapture estimates of Coho Salmon escapement adjusted for percentage of females in the weir catch, appear to have the same relationship over the years (Figure 9). There is a significant empirical relationship between the natural-log-transformed estimate of total escapement for adult Coho Salmon and the natural-log-transformed number of redds observed in Freshwater Creek ($F=41.6$, $P=0.000003$, $R^2=0.67$) (Figure 10).

4.3 Spring Juvenile Down-Stream Migrant Abundance Estimates and Counts

Coho Salmon smolt abundance estimates ranged from 4,535 in 2011 up to 30,890 in 2024 (Figure 11) and averaged 12,504 over the 18-year study.

The super-population of Coho Salmon smolts is estimated from 2007 through 2022 (Table 6 and Figure 12). The super-population estimate of smolts is consistently 90%-280% higher than the spring juvenile down-stream migrant trap estimates at the Freshwater DSMT.

Steelhead trout smolt estimates have varied from a high of 2,129, in 2020, to a low of 331 in 2015 (Figure 13) and averaged 1,245 over the 18-year study.

Chinook Salmon juveniles are captured inconsistently over the last 18 years and yearly catches range from 0 to 2380 (Table 6).

4.4 Coho Salmon Pre-Spring Emigration and Apparent Overwinter Survival

In general, the fate of fall-tagged juveniles over the winter period varies considerably between reaches and years (Figure 14 and Figure 15). No consistent pattern can be observed in all years. In 2013 the probability of a fish emigrating early was higher than that detected during the smolt migration for all reaches and is the complete opposite for the 2014 cohort.

4.5 Smolt-to-Adult Return

SAR estimates vary dramatically over the years of this study (Figure 16). Estimates of SAR of Freshwater Creek Coho Salmon range between 0.4% up to 12% depending on method. Abundance-based estimates are higher than all other estimate types in all years while the tag-based and one- and two-site antenna-based methods are similar for 2017 through 2020 smolt cohorts.

Table 5. Adult salmonid escapement for survey years 2000 to 2023. The escapement year includes fall through spring (e.g. Year 2000 is fall 2000 through spring 2001). Hatchery produced Chinook returns contributed to counts in years 2000-2003. *Indicates weir count rather than mark-recapture estimate.

Year	Coho Salmon N(hat)	Coho Salmon SD	steelhead trout N(hat)	steelhead trout SD	Chinook Salmon N(hat)	Chinook Salmon SD
2000	177*	-	99	23	154*	-
2001	701*	-	195	43	122*	-
2002	1807	213	153	22	135	32
2003	731	25	432	23	26*	-
2004	974	37	254	17	14*	-
2005	789	128	257	17	22*	-
2006	396	47	235	23	18*	-
2007	262	41	203	29	7*	-
2008	399	71	51	7	2*	-
2009	89	10	61	11	2*	-
2010	455	38	132	32	19*	-
2011	624	148	108	35	1*	-
2012	318	75	149	60	2*	-
2013	155	67	127	54	0*	-
2014	718	68	87	23	8*	-
2015	449	86	106	38	2*	-
2016	466	165	235	77	4*	-
2017	535	86	200	39	9*	-
2018	560	125	236	59	1*	-
2019	298	68	225	70	3*	-
2020	335	72	119	78	2*	-
2021	870	104	48	32	0*	-
2022	643	179	25	13	1*	-
2023	537	182	40	20	0*	-

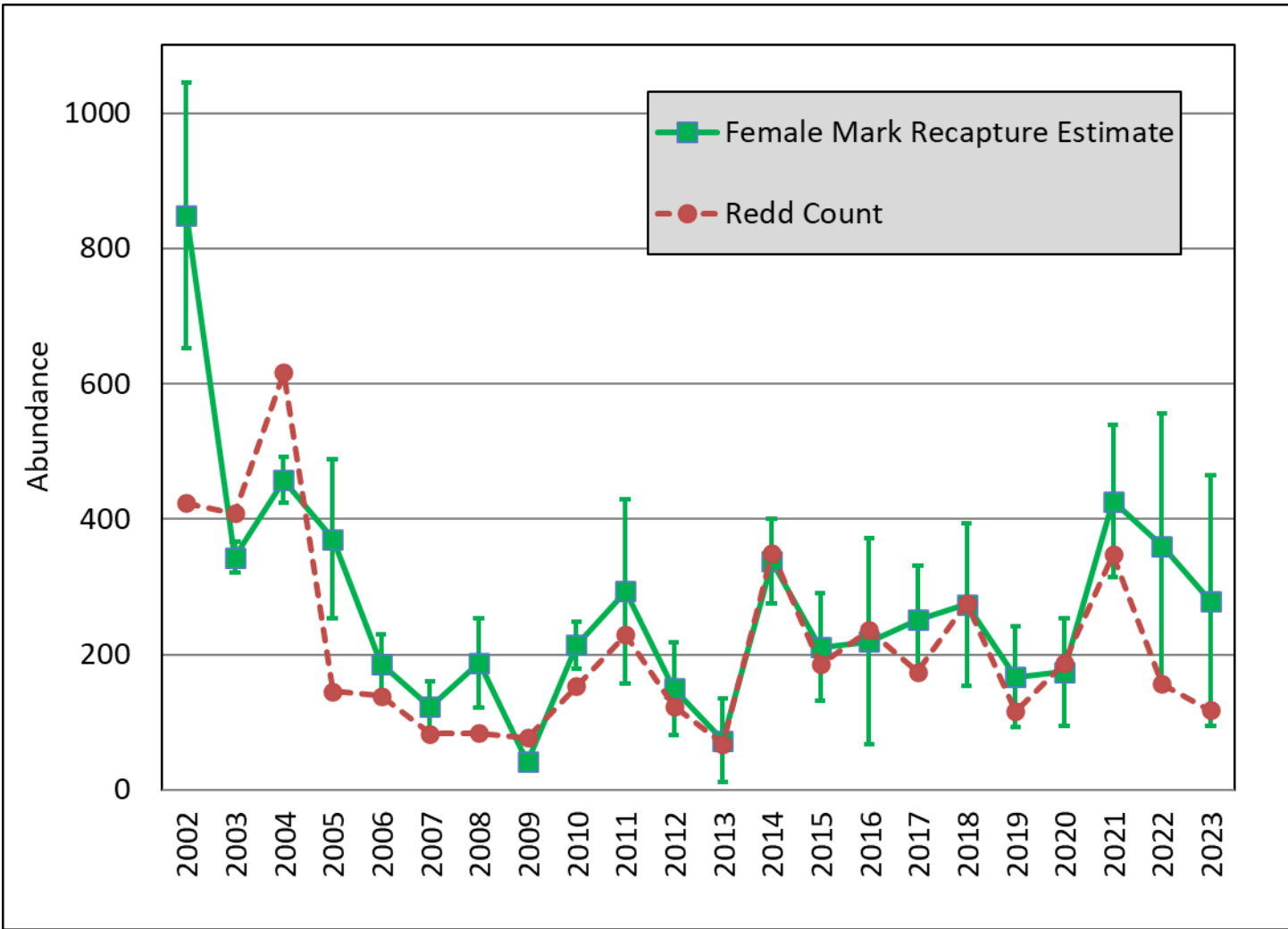


Figure 9. Time series plot of Coho Salmon redd counts and Lincoln-Peterson estimated female adult escapement (\pm 95% confidence intervals), 2002-2023.

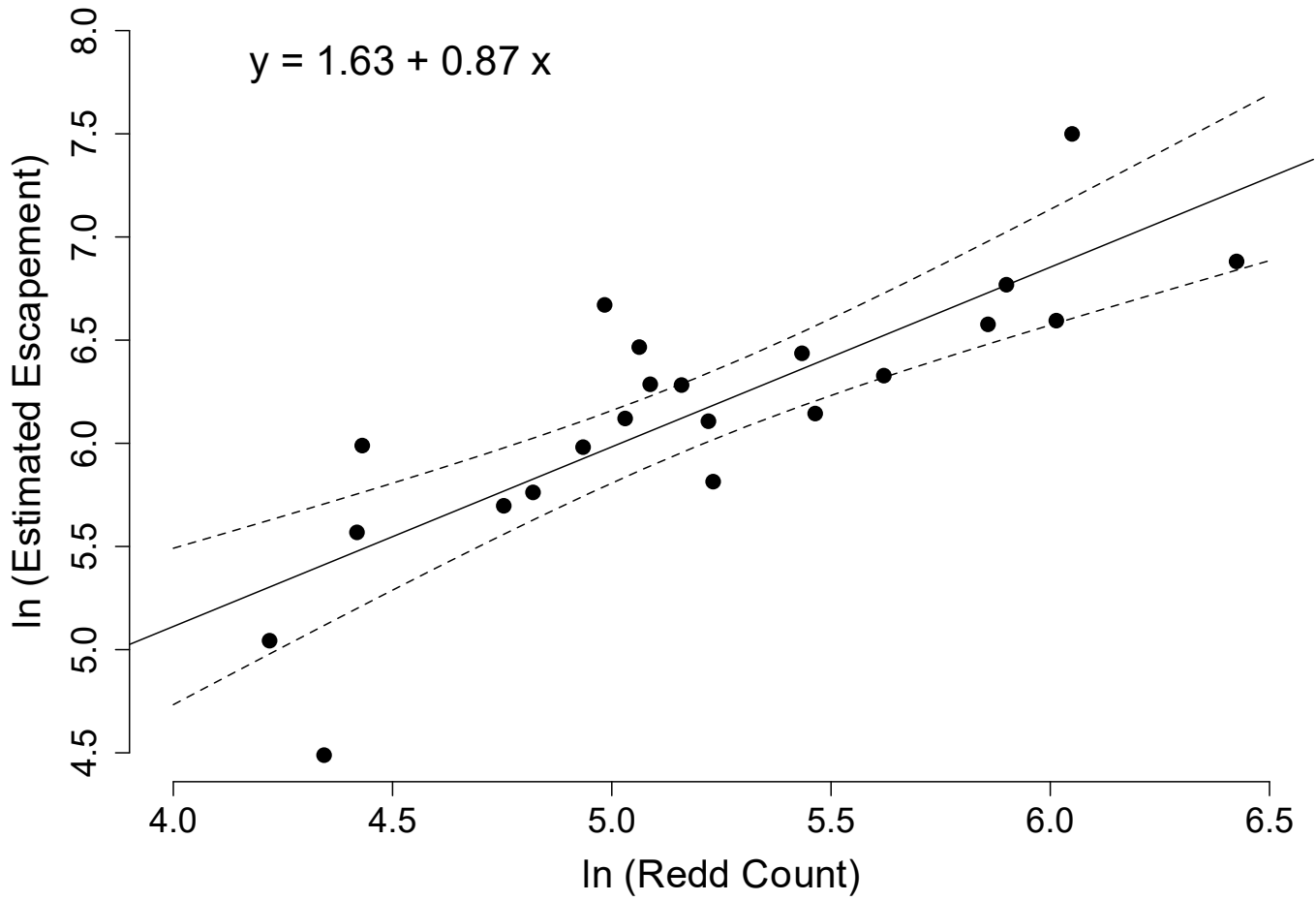


Figure 10. Scatter plot with regression line of natural-log-transformed redd counts vs natural-log-transformed Coho Salmon estimated escapement, 2002-2023. Dotted lines indicate 95% confidence intervals for the fitted regression line.

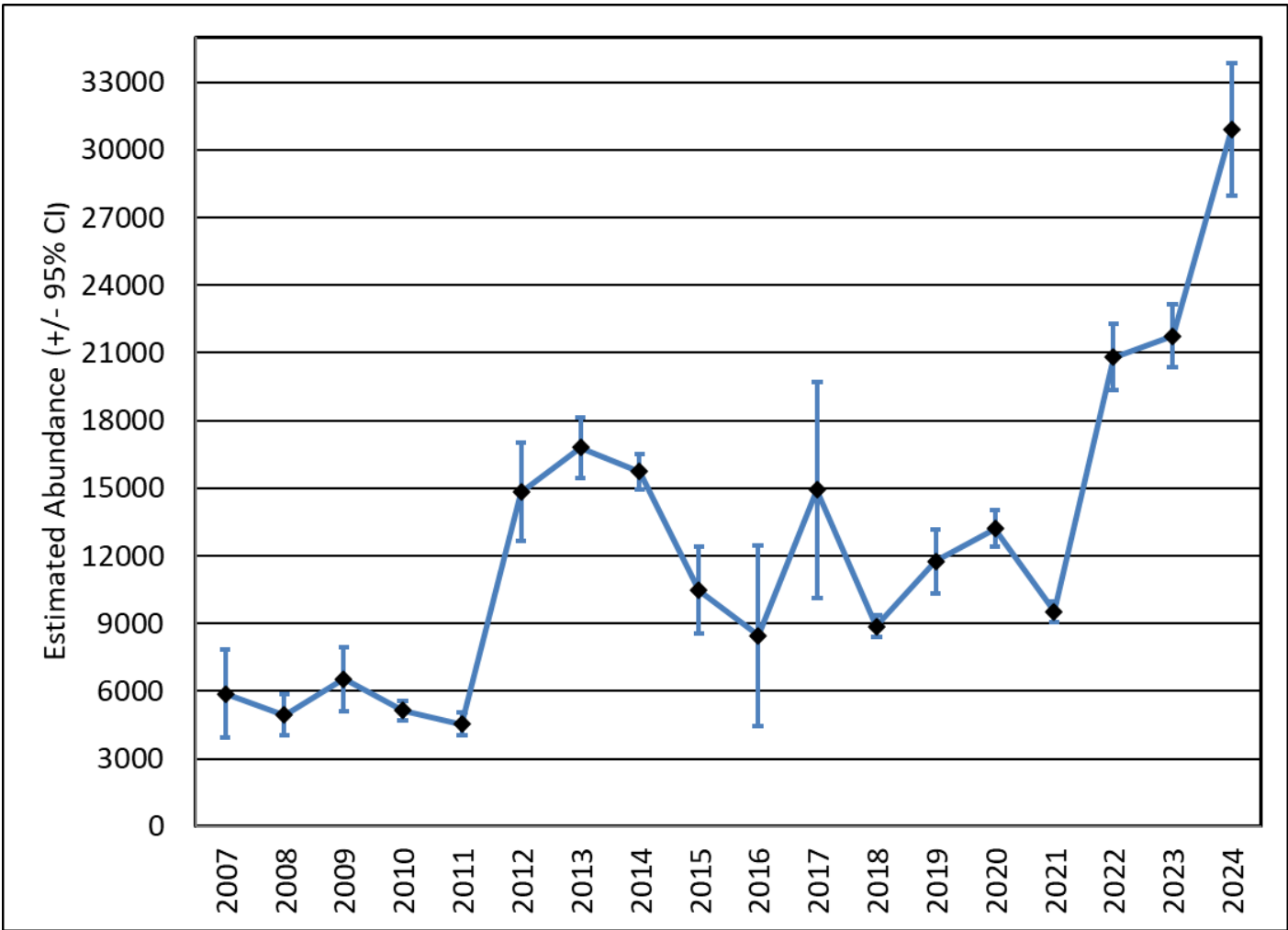


Figure 11. Time series plot of Coho Salmon smolt spring emigration abundance estimates (DARR) for Freshwater Creek, 2007-2024.

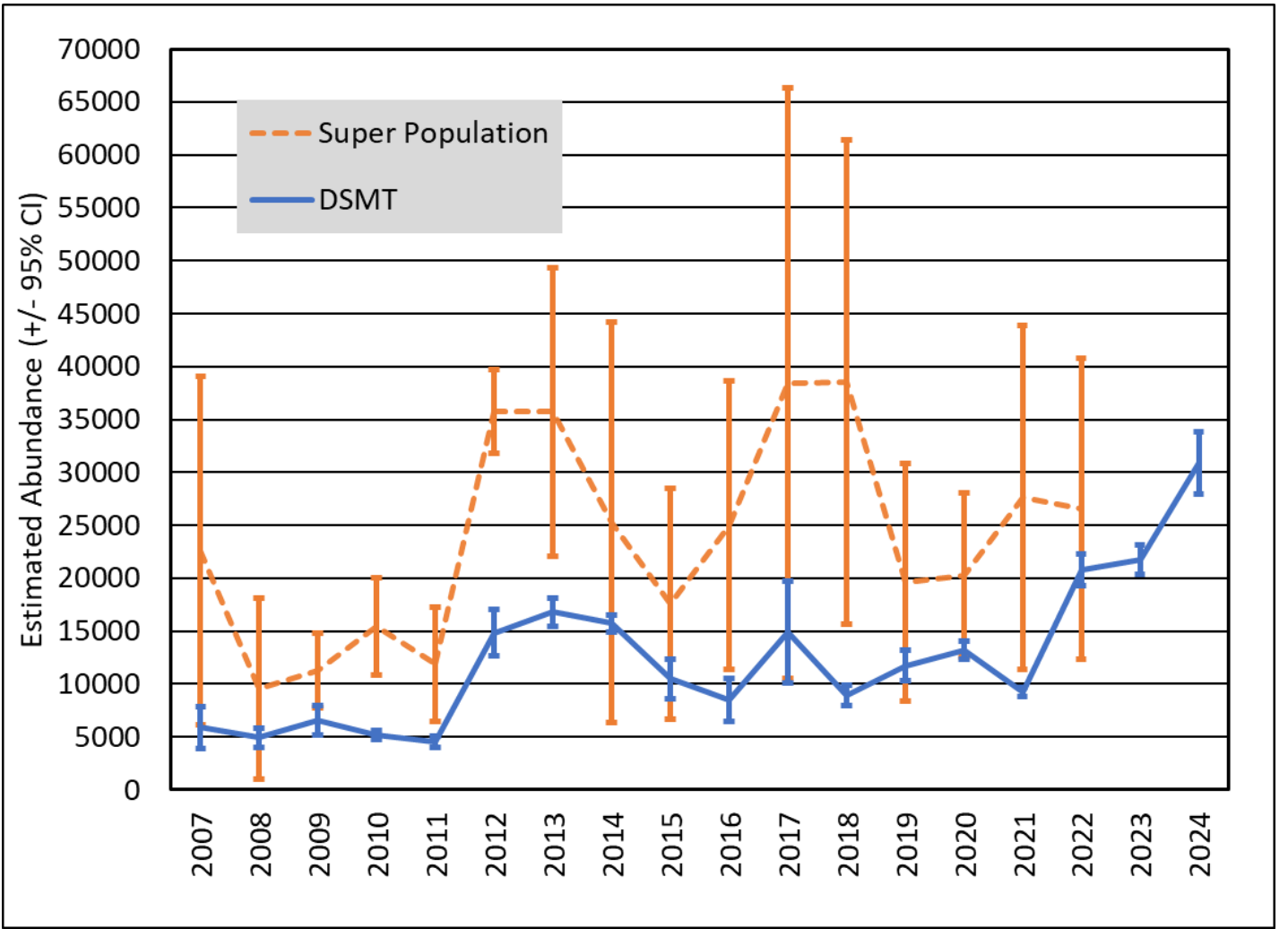


Figure 12. Time series plot of juvenile Coho Salmon spring emigration estimates 2007-2024 and super-population estimates 2007-2022.

Table 6. Emigrant juvenile salmonid catch and abundance estimates (DARR) at the FWW trapping location 2007-2024.

Year	Coho Fry Catch	Coho Smolt N(hat)	Coho Smolt SE	Coho Super N(hat)	Coho Super SE	Steelhead Parr Catch	Steelhead Smolt N(hat)	Steelhead Smolt SE	Chinook Fry Catch	Cutthroat Parr Catch	Cutthroat Smolt Catch	Cutthroat Resident Catch
2007	0	5888	1006	22633	9399	259	1607	312	314*	85	12	2
2008	0	4945	464	9536	4365	146	798	80	253*	68	1	1
2009	0	6543	724	11253	1817	807	1091	101	0	169	7	32
2010	193*	5138	221	15444	2356	168	829	176	104*	114	4	53
2011	150*	4535	256	11862	2755	471	1161	192	2380*	132	9	63
2012	785*	14835	1104	35788	20017	297	1391	454	20*	63	7	160
2013	125*	16795	693	35712	6968	533	1561	89	306*	45	8	336
2014	3*	15724	405	25289	9641	55	456	41	0	22	3	265
2015	11*	10470	980	17577	5559	49	331	36	463*	8	2	206
2016	3*	8467	2046	24970	6969	180	1218	222	62*	59	1	77
2017	1*	14919	2445	38448	14230	40	2111	794	461*	8	1	129
2018	7*	8878	249	38515	11663	203	2063	160	3*	2	0	291
2019	2*	11746	730	19621	5720	102	725	84	0	4	0	165
2020	4*	13215	420	20272	3957	252	2129	99	1*	1	2	249
2021	0	9258	234	27623	8305	34	1064	59	0	0	0	110
2022	120*	20812	754	26562	7272	266	1482	110	0	46	5	113
2023	24*	21754	702	#	#	60	1349	360	0	2	0	71
2024	3*	30890	1499	#	#	44	1048	104	0	0	0	63

*Indicates catches where the DSMT trap was not designed to hold fry > 50mm fork length.

Indicates more years of data needed for estimate.

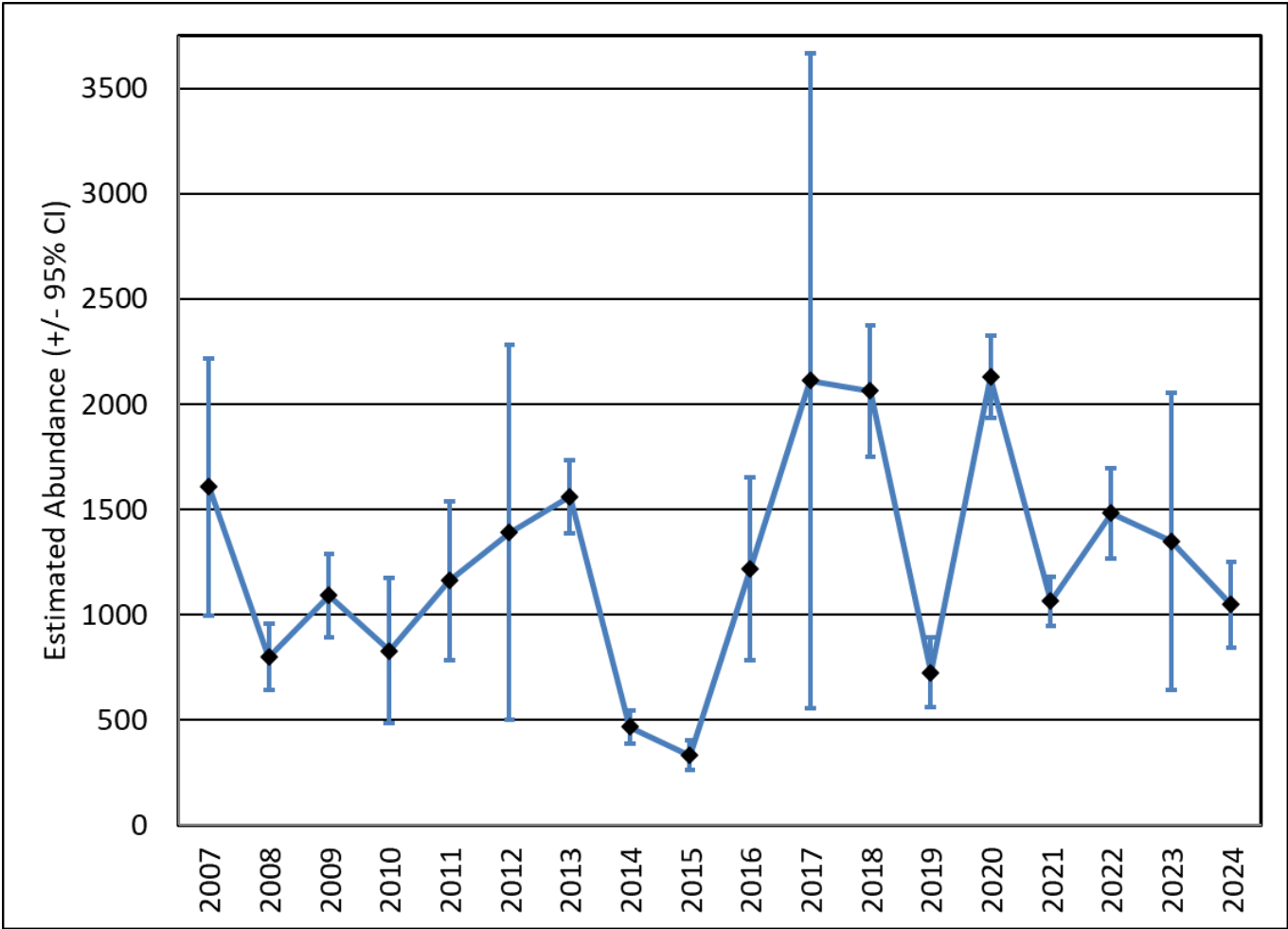


Figure 13. Steelhead trout smolt abundance estimates (DARR) (\pm 95% confidence intervals) in Freshwater Creek for DSMT survey years 2007 through 2024.

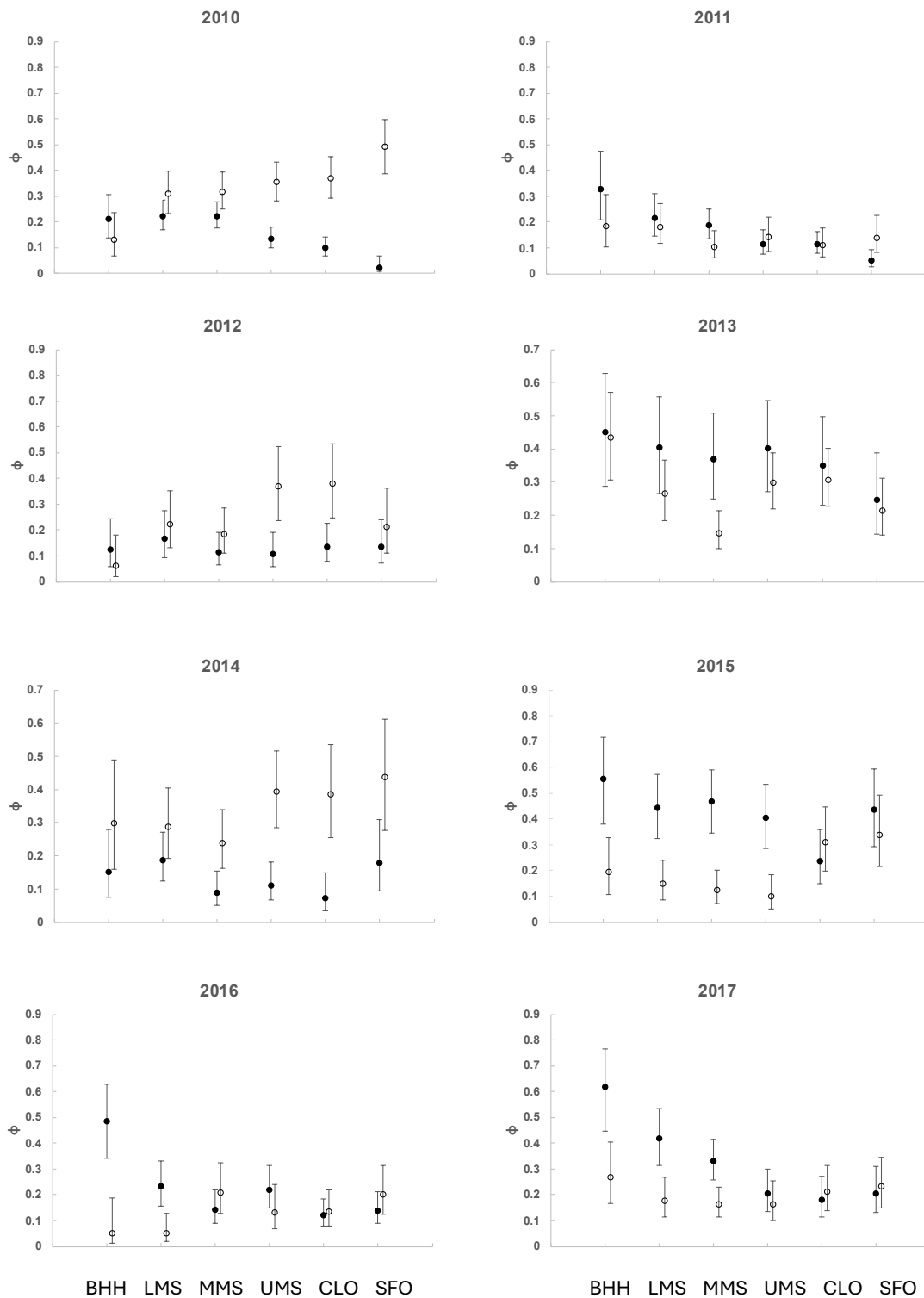


Figure 14. Reach specific probability estimates for fall-tagged Coho Salmon 2010-2017 emigrating early (before the smolt trap was installed, closed points) or during smolt trapping (open points) for each study reach. Refer to Table 1 and Figure 1 for reach locations and details.

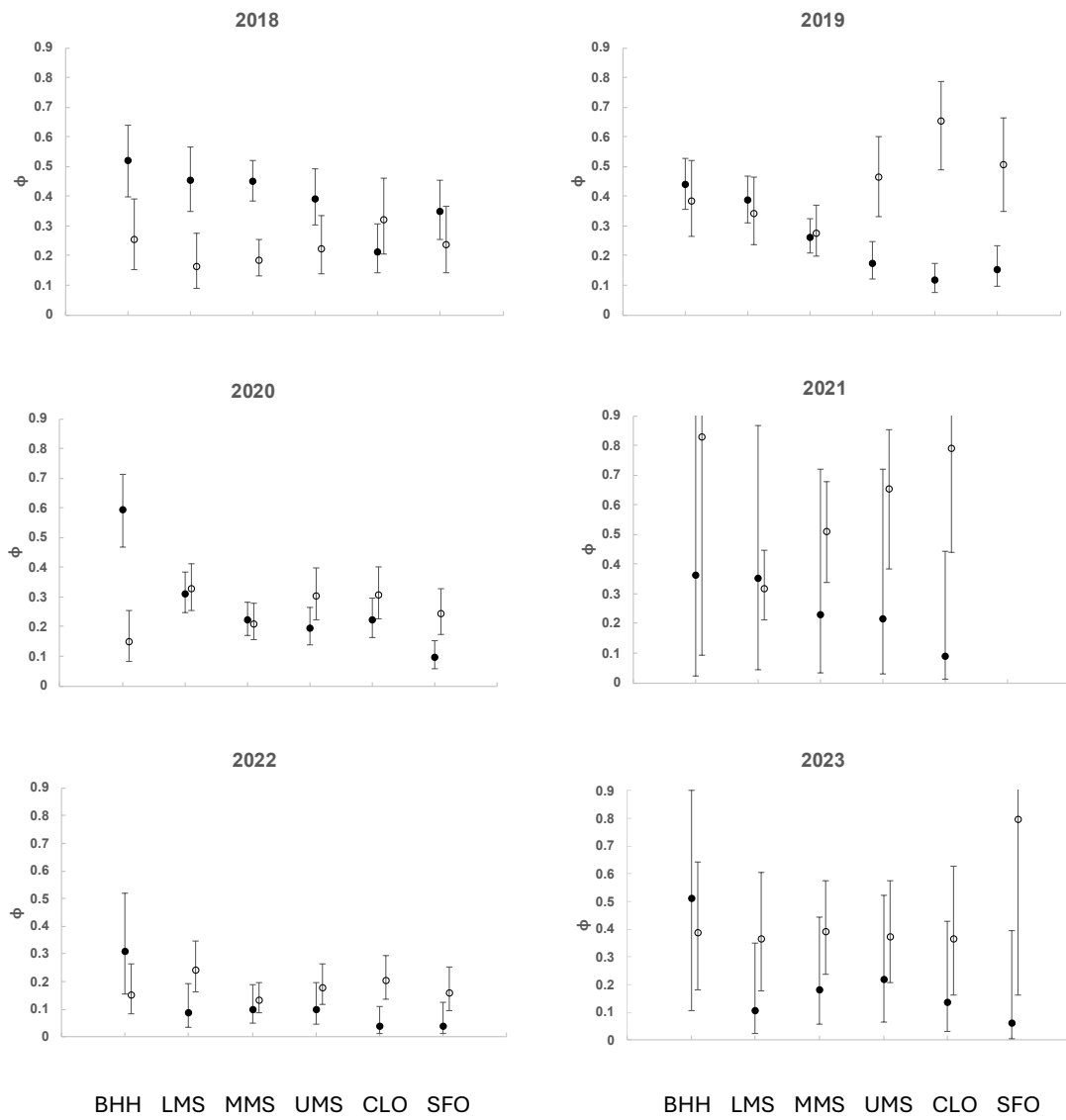


Figure 15. Reach specific probability estimates for fall-tagged Coho Salmon 2018-2023 emigrating early (before the smolt trap was installed, open points) or during smolt trapping (closed points) for each study reach. Refer to Table 1 and Figure 1 for reach locations and details. Insufficient data to estimate probability parameters in SFO for 2021.

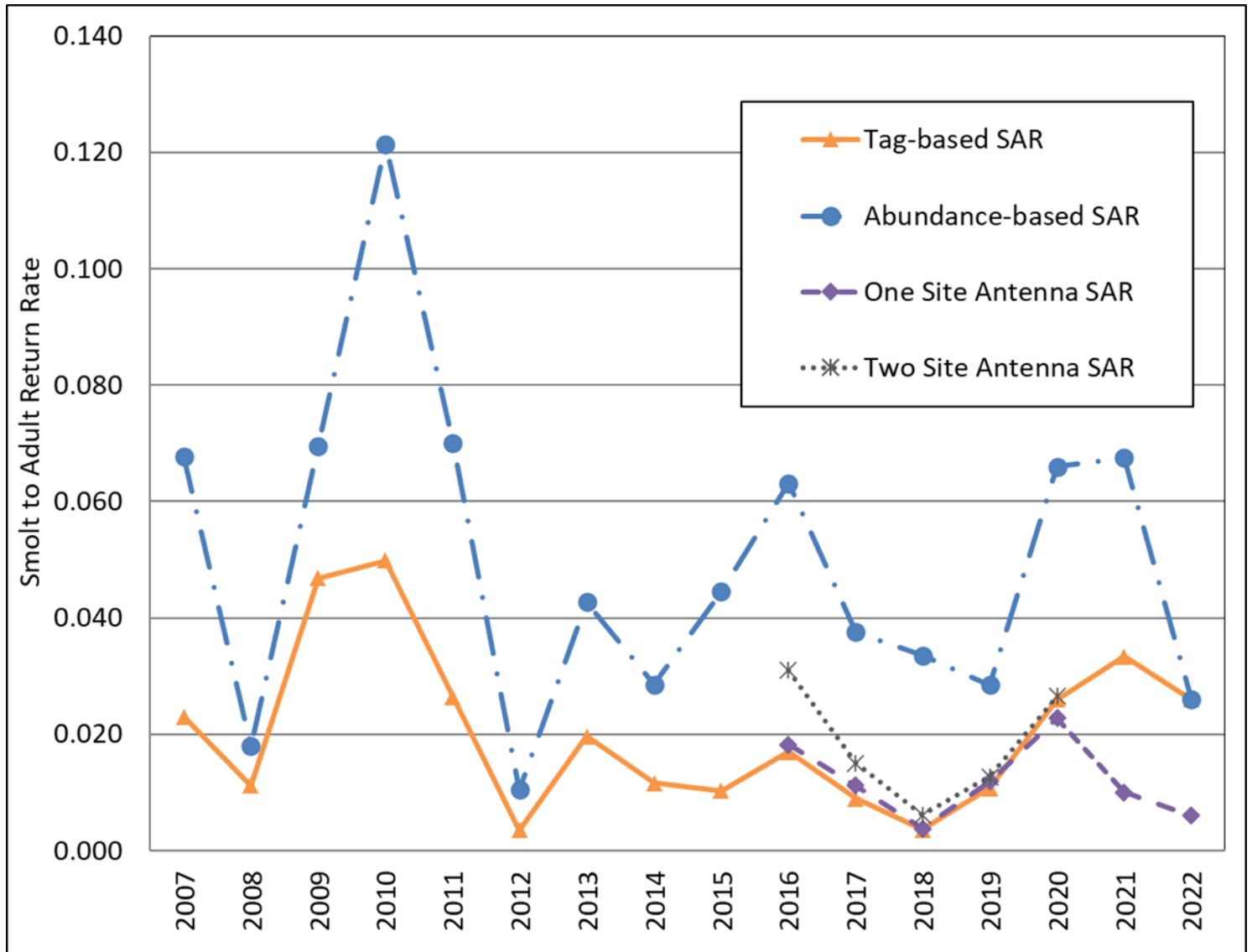


Figure 16. Smolt-to-adult return estimates using four estimation methods for Freshwater Creek Coho Salmon smolts by year of ocean entry 2007-2022.

5 DISCUSSION

5.1 Adult Population Abundance and Trend

Estimated Coho Salmon escapement to Freshwater Creek over the last fourteen years continues to be above the low of 89 animals in 2009 (Table 5). Abundance trajectories of Pacific anadromous salmonids are often characterized by periodic short-term declines and rebounds, driven by annual or decadal variability in climatic conditions that favor or hinder survival, and are likely the cause of the observed fluctuations. The decline in Chinook Salmon weir counts is equally disconcerting. The Chinook Salmon decline is quite dramatic, leading to very few numbers of adult returns and raises concern of compensatory population effects. A small-scale Chinook Salmon hatchery was operated on Freshwater Creek from 1990-2004. Once the augmentation of hatchery-reared Chinook Salmon ceased in 2004, weir captures declined rapidly reaching an all-time low of no returning adults in 2013 and 2021, and there have consistently been below 10 individuals captured since 2011. Steelhead trout returns show no clear trends over the 24-year study. Goode et al. (2005) and Williams et al. (2008) suggest a smoothing of abundance using the geometric mean of the three or four generations, then regressing this response against time. This technique is a conservative method to evaluate trends that requires a minimum of 12 years of data to establish. The three-year log-transformed geometric mean and log-transformed arithmetic mean are very similar and both show a negative decline in the Coho Salmon and steelhead trout populations (Appendix 3) from Freshwater Creek.

5.2 Survival

5.2.1 Smolt-to-Adult Return Rate

One of the goals of LCM monitoring stations is to evaluate if varying adult escapement is due to survival during the freshwater versus marine life stages. In this study we estimate marine survival for a sixteen-year period, using both abundance-based and tag-based methods (Figure 16). Abundance-based SAR estimates tend to estimate marine survival at a higher rate compared to tag-based estimates for all years. This is also documented at other LCM stations (Cochran et al. 2019). Higher SAR from abundance-based estimate when compared to the tag-based estimate may be due to early emigration of smolts during the winter before the trapping at the DSMT starts (Cochran et al. 2019, Rebenack et al. 2015). Abundance-based SAR doesn't account for early emigrants or juveniles rearing below the DSMT that contribute to the "super-population" of smolts. Not accounting for this annually variable fraction of lower basin rearing juveniles would bias the survival higher in years of when this life history is abundant. This study documents the variability in non-natal rearing strategies among cohorts indicating the abundance-based SAR estimator will yield unreliable inference into SAR and should be considered with caution.

Straying of returning adults would bias tag-based SAR estimates. The tag-based SAR model assumption of closure may be violated when tagged adults stray into adjacent watersheds in Humboldt Bay during their spawning run and visa-versa if untagged individuals smolting from other basins returned to Freshwater Creek. Shapovalov and Taft (1954) reported a stray rate, for a Central California wild population of Coho Salmon of 15% from Waddell Creek to Scott Creek. The same study reported Coho Salmon cohorts showing the highest stray rate resulted in the lowest SAR and the lowest stray rate resulting in the highest SAR (Shapovalov and Taft 1954). A previous study (Anderson et al. 2020) found PIT-tagged smolts from Freshwater Creek returning as adults and straying to other Humboldt Bay watersheds. The opposite was also documented with a tagged juvenile Coho Salmon from Jacoby Creek, a nearby Humboldt Bay tributary, returning as an adult to Freshwater Creek.

Tag-based SAR rates of Freshwater Creek Coho Salmon range between 0.4% up to 5%. This variability has contributed to the precipitous short-term declines, and rebounds seen in the time series of adult abundance. Published values of marine survival for wild populations of Coho Salmon range from 0.1% to 37% and average near 10% (Table 7). It should be noted, however, that the largest published values of SAR were generated with a method we perceive would be sensitive to similar biases as the abundance-based estimates in this study, and therefore should be considered with caution. Estimates of Coho Salmon marine survival from Freshwater Creek for 2007 through 2022 smolt cohorts averaged 2.1% for tag-based estimates and 5.0% for the abundance-based estimate and are consistently estimated to be below the published average of 10%. Tag-based marine survival rates of Freshwater Creek Coho Salmon are closer to those reported for wild populations of Coho Salmon by Shapovalov and Taft (1954), which vary from 0.6% to 5.4%, and averaged 2.3%.

Several LCM locations are unable to generate SAR estimates as they are unable to capture adults at a weir or counting station to inspect them for marks or tags and cannot recapture tagged carcasses on the spawning ground surveys. Many of the LCM stations do, however, have several antenna sites that may provide a reasonable, cost effective, SAR estimate using antenna-based methods. Antenna generated estimates of Coho Salmon marine survival from Freshwater Creek for 2016 through 2022 averaged 1.3 % for the one-site antenna method and for 2016 to 2020 for the two-site antenna method 1.7%. Antenna-based SAR estimates are close to tag-based SAR estimates in this study (Figure 16). Antenna-based estimates of SAR in the study are based on a bare minimum of juvenile PIT tag detections at adult return. Antenna efficiency appears to be quite high in most years, and the low number of detections is largely due to poor survivorship.

Historical Freshwater Creek LCM station reports estimated SAR using a tag-based method that incorporated both one salt (jacks) and two salt (adults) life histories. This model proved to be very sensitive to the number of jack returns which are not captured with the same efficiency as 3-year-old adults at the weir or as carcasses on the spawning

grounds. Low capture rates of 2-year-old fish also resulted in sample sizes that were too low for estimating this age class. Because of the potential biases and difficulty in estimating the returning 2-year-old fish, we estimated the tag-based SAR for age 3 adults.

The apparent shift in the difference between the tag-based estimate and antenna-based estimate for the years 2021 and 2022 may be due to the detection efficiency of antennas. Technical difficulties occurred in the last two years, where one antenna was failing during part of the season in 2021, or most of the season in 2022. This failure would require replacement of the pod which is underwater and not accessible. If antenna-based survival estimates are the only method used at a monitoring station it is critical to have properly working equipment during the entire adult migration period.

5.2.2 Juvenile Coho Salmon Overwinter Survival and Pre-Spring Emigration

Overwinter survival has been identified as a critical limiting factor influencing population abundance of Coho Salmon in the Pacific Northwest (Tschaplinski and Hartman 1983, Quinn and Peterson 1996, Huusko et al. 2007, Nickelson et al. 1992, Nickelson and Lawson 1998). Density dependent mechanisms appear to set overwinter habitat capacity for Coho Salmon in coastal streams (Sollazi et al. 2000, Gallagher et al. 2012)

Apparent survival estimates in this study are interpreted as the rate of survival given overwinter fidelity to habitat upstream of FWW. Early emigration is interpreted as the rate at which animals survived a portion of the winter period then left the habitat upstream of the FWW before the commencement of spring trapping, but their full overwinter fate (i.e. survival to spring) remains unknown. The estimated apparent overwinter survival, and early emigration appears variable across both years and reaches above the FWW site in Freshwater Creek (Figure 14 and Figure 15). The large differences in apparent survival between reaches, and life history type, may be due to yearly physical habitat capacity, increased productivity and growth leading to higher survival or a combination of the two (Quinn and Peterson 1996). Low gradient channel morphology is conducive to establishing physical habitat that affords refugia during high discharge winter flow events and leads to higher survival (Bell et al. 2001, Tschaplinski and Hartman 1983, Bustard and Narver 1975).

Apparent overwinter survival of spring migrating smolts in Freshwater Creek ranged from 5% to 79% and varied widely between reaches and years. Published apparent winter survival rates vary from 5-15% in the Twin Rivers, Washington (Roni et al. 2012), to 27% in Rock Creek, Washington (Pess et al. 2011).

Estimating population-specific and habitat-specific demographic rates of Coho Salmon is critical for assessing extinction risk and evaluating responses of populations to habitat degradation and restoration. Estimates of these population parameters are often hampered by a lack of formal methodology to understand with variation in life histories, movement and seasonal habitat use exhibited by juvenile Coho Salmon. We evaluate

potential bias in survival and smolt production estimates associated with a standardized LCM sampling design that incorporates a mark-recapture study extending across sampling periods.

Estimates of smolt production for a Coho Salmon population are an important indicator of population status, an index of overall production from freshwater habitat integrated over the juvenile life stage, and the basis for estimates of key demographic rates for Coho Salmon populations (e.g. overwinter survival of juveniles, SAR survival). In California, smolt abundance is typically measured using downstream migrant traps operated downstream of the primary spawning and rearing habitats in the basin during a 2-4-month period in spring when many smolts migrate to sea (Adams 2011). It has long been recognized that some juvenile Coho Salmon migrate downstream prior to the spring smolt migration (Chapman 1962, Koski 2009, Pess et al. 2011), but the relative abundance of these early emigrants is not known for most populations. This is a critical knowledge gap for at least two reasons: 1) If some early emigrants survive to become smolts and eventually contribute to the returning adult population, then estimating smolt production using only seasonal migrant traps will lead to estimates of SAR that are biased high and juvenile production /overwinter survival estimates that are biased low. 2) If early emigrants are not accounted for in sampling, it is impossible to evaluate the population consequences of habitat loss in the lower-basin and estuarine overwintering areas required by the early emigrant life history.

To begin to address these issues, we used a mark-recapture study to evaluate the patterns of life history expression for juvenile Coho Salmon. For 14 consecutive cohorts, we estimated the probability of emigrating early and the probability of emigrating as smolts. We also identified characteristics of individuals and locations associated with the expression of each life history. In Freshwater Creek, early emigration rates were higher in downstream reaches, reaching as high as 87% for the BHH reach (Figure 14 and Figure 15). Additional sampling and antenna detections in habitat downstream of the smolt trap and in neighboring tributaries show that these early emigrants survive to become smolts at a rate similar to fish that remain in upstream (Ghrist 2019) and that a very small proportion cross Humboldt Bay and spend part of the winter rearing in adjacent tributaries (Halloran 2019, Anderson et al. 2020a). Consistent with recent studies in other regions (Roni 2012, Koski 2009), and within Freshwater Creek (Ghrist 2019, Rebenack et al. 2015), our results continue to highlight the importance of modifying approaches to Coho Salmon population monitoring to account for early emigrants and other juvenile life history variants.

Early pre-smolt emigrating Coho Salmon may be an important life history characteristic expression. These nomadic fish may significantly contribute to the returning adult population (Jones et al. 2021, Roni et al. 2012, Cornwell et al. 2001) in their natal stream. Nomads might colonize other freshwater habitats that do not currently support spawning populations of Coho Salmon (Cornwell et al. 2001). Habitat restoration, including reconnecting freshwater and saltwater ecotones, in Humboldt Bay may

increase survival and habitat capacity for nomadic Coho Salmon. Coho Salmon which rear successfully in these non-natal streams may return as adults and their progeny could re-colonize newly restored habitat.

5.3 Life History

Lifecycle monitoring stations collect data that often leads to novel life history strategies. With individually marked fish and passive recaptures at RFID stations we can describe “new” life histories. Freshwater Creek juvenile Coho Salmon parr have expressed a life history pattern of early emigration and return (EER). Individuals expressing EER move from natal freshwater streams into rearing habitat in the estuary and non-natal habitat during the late fall and early winter. During the early spring these animals remigrate back into their natal freshwater environments before smolting. Rates of EER vary over years and represent 1.8 to 6.5% of the population (Table 8 and Figure 17).

Some similar life history strategies have been documented that are analogous to EER. Faulkner et al. (2017) found EE parr left the Klamath River, migrated through the ocean, and entered Redwood Creek before smolting. Another novel strategy termed “fry-nomad migrants”, described by Jones et al. (2021), is where fry leave their natal freshwater habitat in the spring emigrating to the estuary and return to their natal habitat with early fall rain events.

Table 7. Mean, minimum and maximum Smolt-adult marine survival rates for wild Pacific Coho Salmon populations (*Oncorhynchus kisutch*). Statistical methods vary by population.

Coho Population	Mean	Min	Max	Years	Statistical Method	Source
Auke Creek, AK	20.3%	N/A	N/A	1980-2004	Unknown	Shaul et al 2007
Bemers River, AK	17.6%	N/A	N/A	1990-2004	Unknown	Shaul et al 2007
Hugh Smith Lake, AK	12.9%	N/A	N/A	1984-2004	Unknown	Shaul et al 2007
Taku River, AK	12.0%	N/A	N/A	1992-2004	Unknown	Shaul et al 2007
Lachmach River, BC	10.0%	N/A	N/A	1988-2003	Unknown	Shaul et al 2007
Black Creek, BC	7.1%	N/A	N/A	1986-2004	Unknown	Shaul et al 2007
Salmon River, BC	8.5%	N/A	N/A	1987-2004	Unknown	Shaul et al 2007
NF Scappoose Creek, OR	4.5%	1.7%	9.1%	1997-2010	# Females/ .5 (Smolt Production)	Suring et al 2015
NF Nehalem River, OR	5.9%	1.7%	17.9%	1996-2010	# Females/ .5 (Smolt Production)	Suring et al 2015
EF Trask River, OR	15.5%	6.4%	35.2%	2003-2010	# Females/ .5 (Smolt Production)	Suring et al 2015
Mill Creek (Siletz), OR	3.9%	0.6%	7.4%	1995-2010	# Females/ .5 (Smolt Production)	Suring et al 2015
Mill Creek (Yaquina), OR	13.0%	1.3%	37.9%	1995-2010	# Females/ .5 (Smolt Production)	Suring et al 2015
Cascade Creek, OR	4.3%	0.7%	9.2%	1996-2010	# Females/ .5 (Smolt Production)	Suring et al 2015
WF Smith River, OR	5.7%	1.2%	19.5%	1996-2010	# Females/ .5 (Smolt Production)	Suring et al 2015
Winchester Creek, OR	3.4%	0.1%	8.8%	1998-2009	# Females/ .5 (Smolt Production)	Suring et al 2015
Carnation Creek, BC	13.8%	5.3%	23.4%	1972-1988	Expanded Return/ Smolt #	Holtby et al 90
Carnation Creek, BC	16.6%	7.7%	29.9%	1972-1988	Mark-Recapture escapement, adjusted	Holtby et al 90
Salmon Creek, OR ¹	11%	2%	18%	2007-2011	CJS + Markov chain Monte Carlo	Jones et al 2021
Salmon Creek, OR ²	8%	3%	12%	2007-2011	CJS + Markov chain Monte Carlo	Jones et al 2021
Waddell Creek, CA	2.3%	0.6%	5.4%	1932-1937	% Return of Marked Smolts	Shapovalov & Taft 1954
Freshwater Creek, CA	2.1%	0.4%	5.0%	2007-2022	Tag Based SAR	Anderson et al 2024

¹Parr Migrants or Early Emigrants tagged at age 1.

²Yearling Migrants or Spring Emigrants tagged at age 0 in fall and winter.

Table 8. Life History types of fall pit tagged Coho Salmon juveniles determined by passive RFID recaptures.

Year	# Fall Parr Tagged Recaptures	# Early Emigrants (%)	# Spring Emigrants (%)	# Early Emigrant Returners (%)
2017	555	213 (38.5)	331 (59.7)	10 (1.8)
2018	502	357 (71.1)	133 (26.5)	12 (2.4)
2019	542	268 (49.4)	239 (44.1)	35 (6.5)
2020	341	124 (36.4)	207 (60.7)	10 (2.9)
2021	283	43 (15.2)	235 (83)	5 (1.8)
2022	84	50 (59.5)	32 (38.1)	2 (2.4)
2023	380	76 (20.0)	295 (77.6)	9 (2.4)

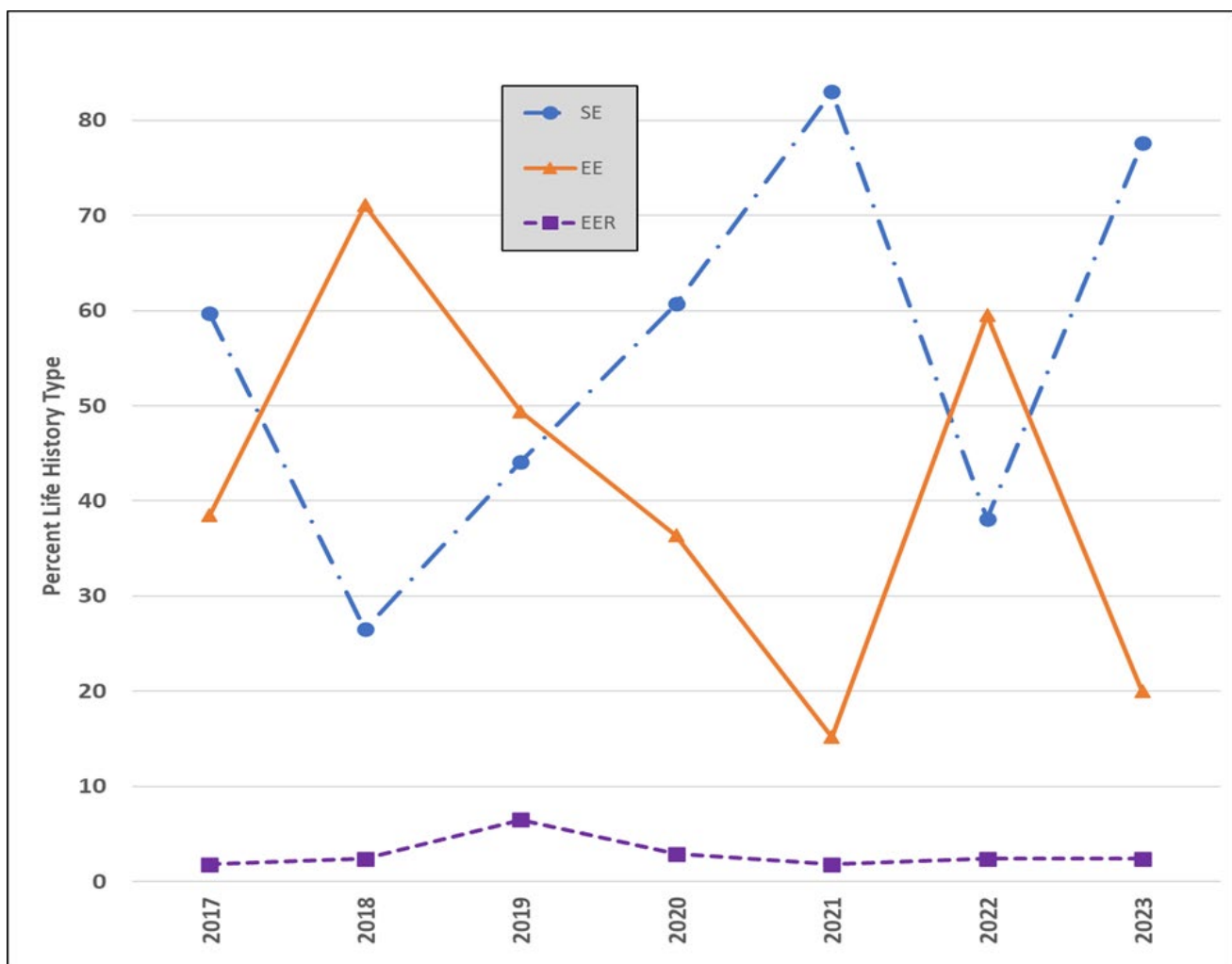


Figure 17. Life history strategies of Freshwater Creek Coho Salmon juveniles in years 2017 through 2023. Percent of juveniles expressing early emigration (EE) before the installation of the dsmt, spring emigration during the operation of the dsmt, and early emigrant returners (EER) which leave the system before the trap is installed and return to be captured in the dsmt in the spring.

6 Trends in Lifecycle Monitoring Stations

The Northern California coast is home to three Coho Salmon LCM watersheds (Mill Creek Basin, Prairie Creek Basin, and Freshwater Creek Basin) where Coho Salmon redd estimates are conducted with similar protocols (Figure 18). This consistency provides an opportunity to compare trend data across populations. Figure 19 presents Coho Salmon redd estimates over several years.

If all the LCM stations in Northern California shared the same freshwater and marine survival you would expect adult estimates to mimic each other over time. Alternate trends in certain years, in these three LCM stations, suggest factors that determine survival are different across space and time. There is no clear relationship in redd estimates and location through the years. For example, Freshwater Creek had the lowest redd estimate in 2013 while Prairie Creek had the highest, with the complete opposite occurring only one year later. The overall resiliency of the SONCC could be stabilized by the portfolio effect. However, when some populations boom, and some bust the group could have less overall variability. Disentangling the environmental drivers of inter-annual variability in Coho Salmon abundance remains a clear goal of Life Cycle Monitoring, and one that can only be achieved with continued monitoring.

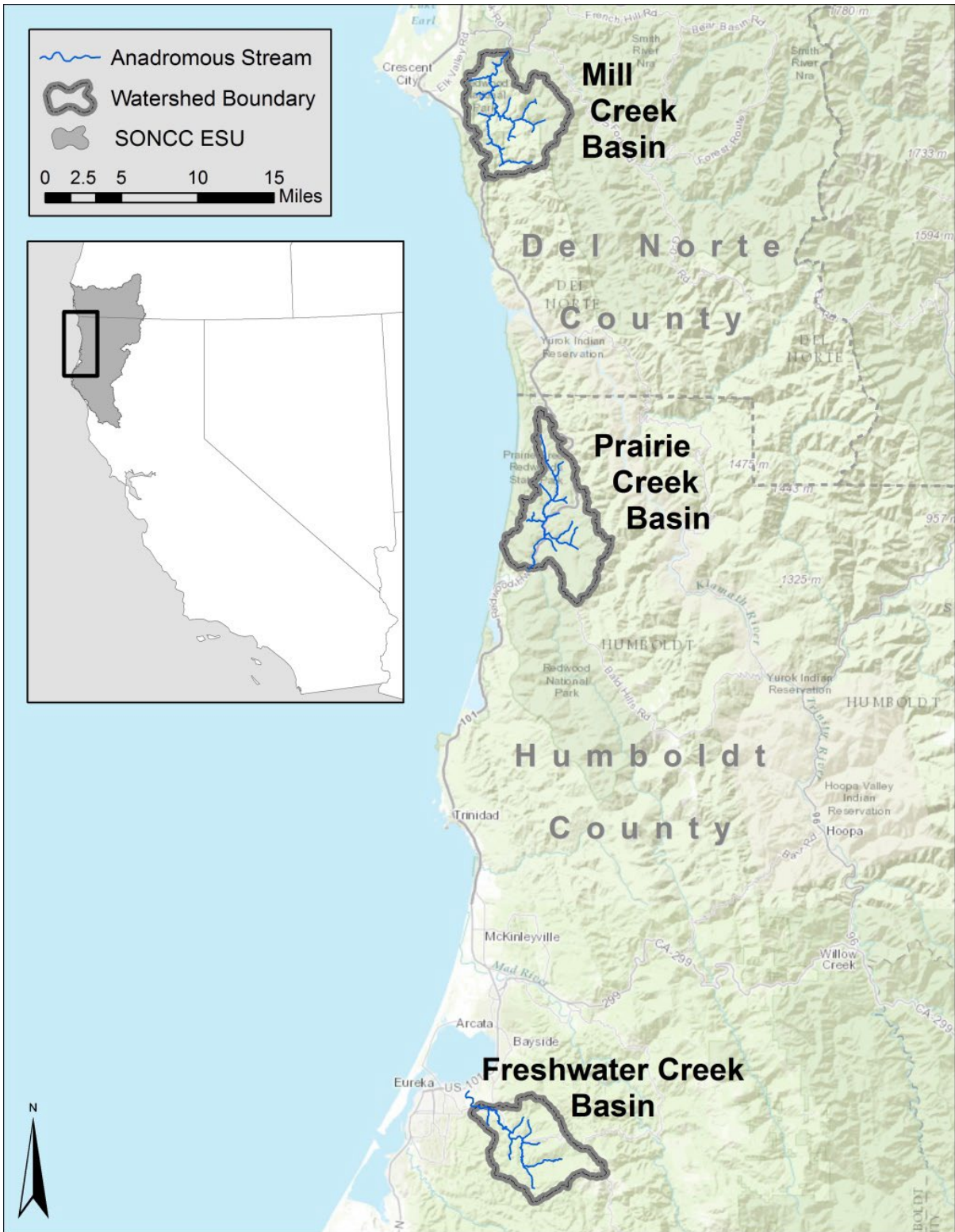


Figure 18. Three LCM stations in Northern California: Mill Creek Basin, Prairie Creek Basin, and Freshwater Creek Basin. (Source: J. Deibner-Hanson).

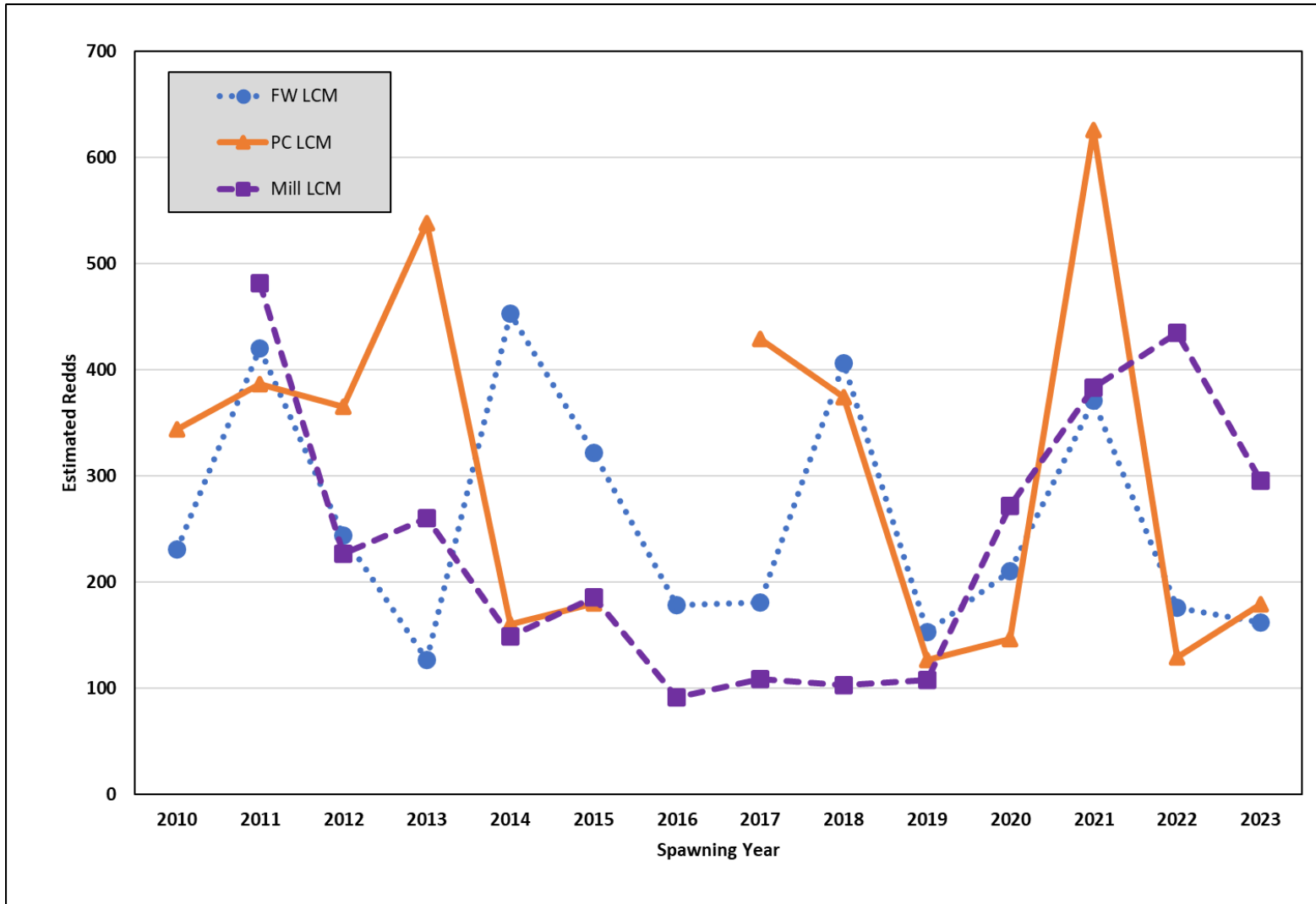


Figure 19. Coho Salmon redd estimates from three North Coast LCM stations (Mill Creek Basin, Prairie Creek Basin, and Freshwater Creek Basin), 2010-2023. Prairie Creek project was not funded for redd counts in 2016.

7 Recommendations

Recent habitat restoration is focused in lower basin, off-channel, or seasonal habitat for enhancing overwinter capacity for juvenile Coho Salmon. The high rates of pre-spring emigration of Coho Salmon in Freshwater Creek to lower basin overwinter habitat supports this approach (Figure 15) and we recommend that these efforts continue to be taken.

In this study we estimate marine survival using tag-based and abundance-based methods and compare those to antenna-based estimates. The abundance-based method generates significantly higher SAR estimates, with a similar pattern to tag-based methods over the years. This is an intuitive outcome given the sizable fraction of early emigrants we estimate that would not be accounted for in the smolt abundance side of the abundance-based SAR. The tag-based and both one- and two-site antenna-based methods yield similar results, however, the antenna models would better incorporate the unmarked fraction of fish that emigrated below the DSMT prior to spring at adult recovery. This result indicates antenna-based methods of SAR estimation may be useful for LCM stations equipped with antenna stations without adult capture facilities.

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10 APPENDICES

Appendix 1. Adult escapement and Smolt Super-Population Equations.

General form of the bias adjusted Lincoln-Petersen estimate of total abundance using a two sample with replacement mark-recapture experiment (Ricker 1975, Chapman 1951). This equation was used for adult escapement (Sec. 2.2.1) and back calculation of super-population of Coho Salmon smolts (Sec. 3.2.3).

$$\hat{N}_i = \frac{(M_i + 1)(C_i + 1)}{R_i + 1} - 1$$

An unbiased estimate of the variance as developed by Seber (1970) is calculated as:

$$V(\hat{N}_i) = \frac{(M_i + 1)^2(C_i + 1)(C_i - R_i)}{(R_i + 1)^2(R_i + 2)}$$

Where:

for adult escapement:

$i = 1$

\hat{N}_1 = Estimated number of returning adults

M_1 = Number of adults given an operculum punch at the weir

C_1 = The number of carcasses checked for an operculum punch

R_1 = The number of carcasses with recovered operculum punch

And,

for Back calculation of super-population of Coho Salmon smolts:

$i = \{2\}$

\hat{N}_2 = Estimated number of downstream migrants

M_2 = Number of fish marked and released downstream during smolt year 1

C_2 = Number of adult fish captured and checked for juvenile marks by return year i

R_2 = Number of juvenile tagged adult fish recaptured at the weir returning from the ocean by cohort i

Appendix 2. Smolt-to-Adult Return (SAR) marine Survival estimators.

Tag-based
$$\widehat{S}_t = \frac{\widehat{T}_A}{T_S}$$

Where:

\widehat{S}_t = smolt-to-adult survival tag-based estimate

\widehat{T}_A = is the estimated number of fish PIT tagged as juveniles returning as adults

T_S = the number of smolts PIT tagged at the downstream migrant trap

And:
$$(\widehat{T}_A) = R_J \left(\frac{C_C}{R_C} \right)$$

Where:

R_J = Number of pit tag adults recaptured at the weir from previous cohort year

C_C = Number of carcasses recovered on the spawning ground surveys inspected for operculum punch.

R_C = Number of carcasses recovered with operculum punch

Abundance-based
$$\widehat{S}_A = \frac{\widehat{N}_A}{\widehat{N}_S}$$

Where:

\widehat{S}_A = smolt-to-adult survival abundance-based estimate

\widehat{N}_A = is the Lincoln-Peterson estimated abundance of returning adults

\widehat{N}_S = DARR estimate of smolts heading to the ocean

And For Lincoln-Peterson estimated abundance:
$$(\widehat{N}_A) = M_W \left(\frac{C_C}{R_C} \right)$$

Where:

M_W = Number of adults receiving an operculum punch at the weir

C_C = Number of carcasses recovered on the spawning ground surveys inspected for operculum punch.

R_C = Number of carcasses recovered with operculum punch

And for DARR estimate \widehat{N}_S See Bjorkstedt 2005

Antenna-based

$$S_{\widehat{Antenna}} = \frac{T_{\widehat{Antenna}}}{T_S}$$

Where:

$S_{\widehat{Antenna}}$ = smolt-adult survival antenna-based estimate

$T_{\widehat{Antenna}}$ = is the estimated number of fish PIT tagged as juveniles returning as adults

T_S = the number of smolts PIT tagged at the downstream migrant trap

And:
$$\left(T_{\widehat{Antenna}}\right) = \frac{\# \text{ Tags detected at antenna \#2 or Site \#2}}{E2}$$

Where: E2 = The efficiency of antenna 2 or site #2

And:
$$E2 = \frac{U \text{ 1 and 2}}{R1}$$

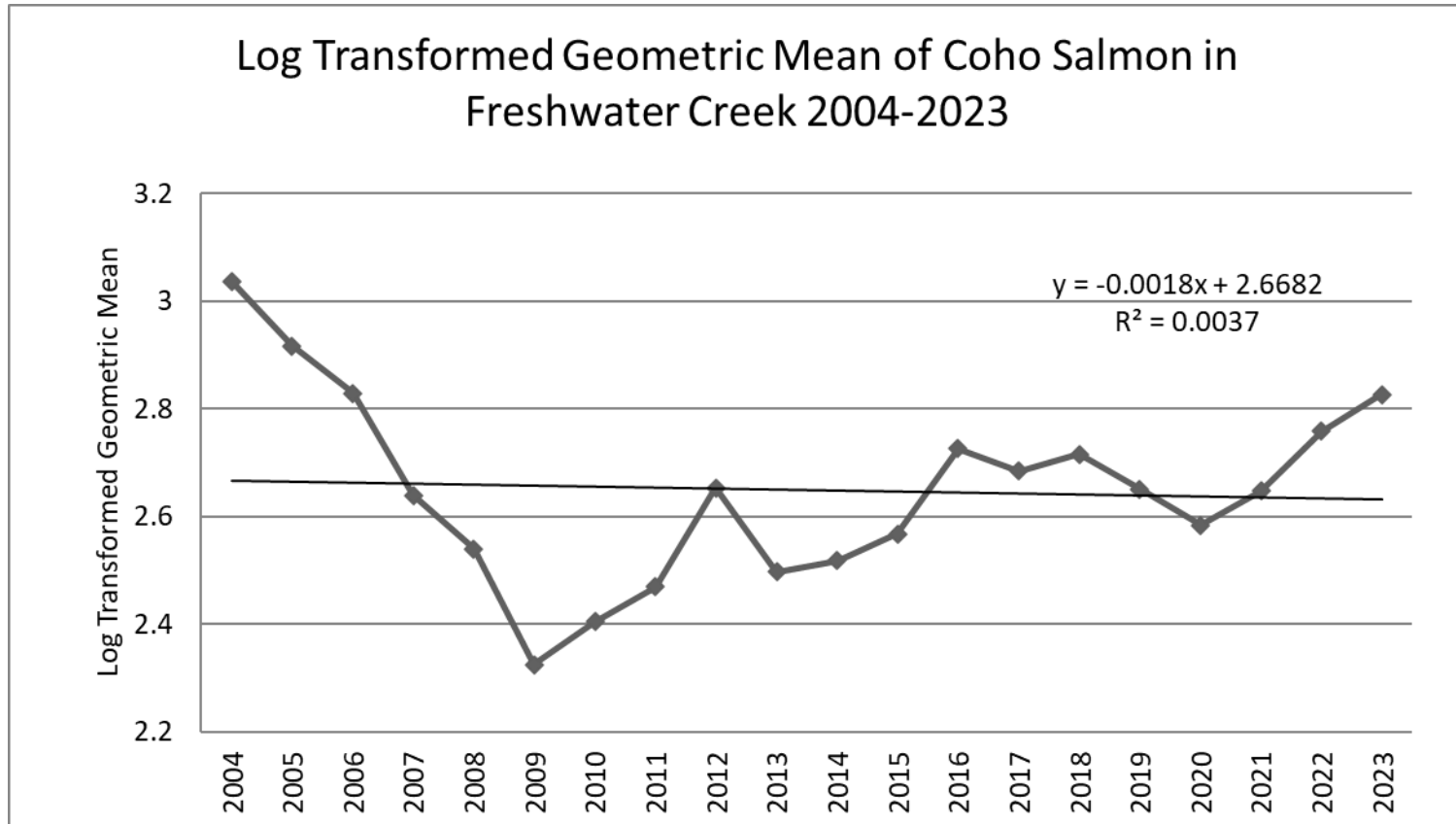
Where:

R1= the number of Pit tags marked as juveniles recaptured at the downstream antenna #1 or site #1.

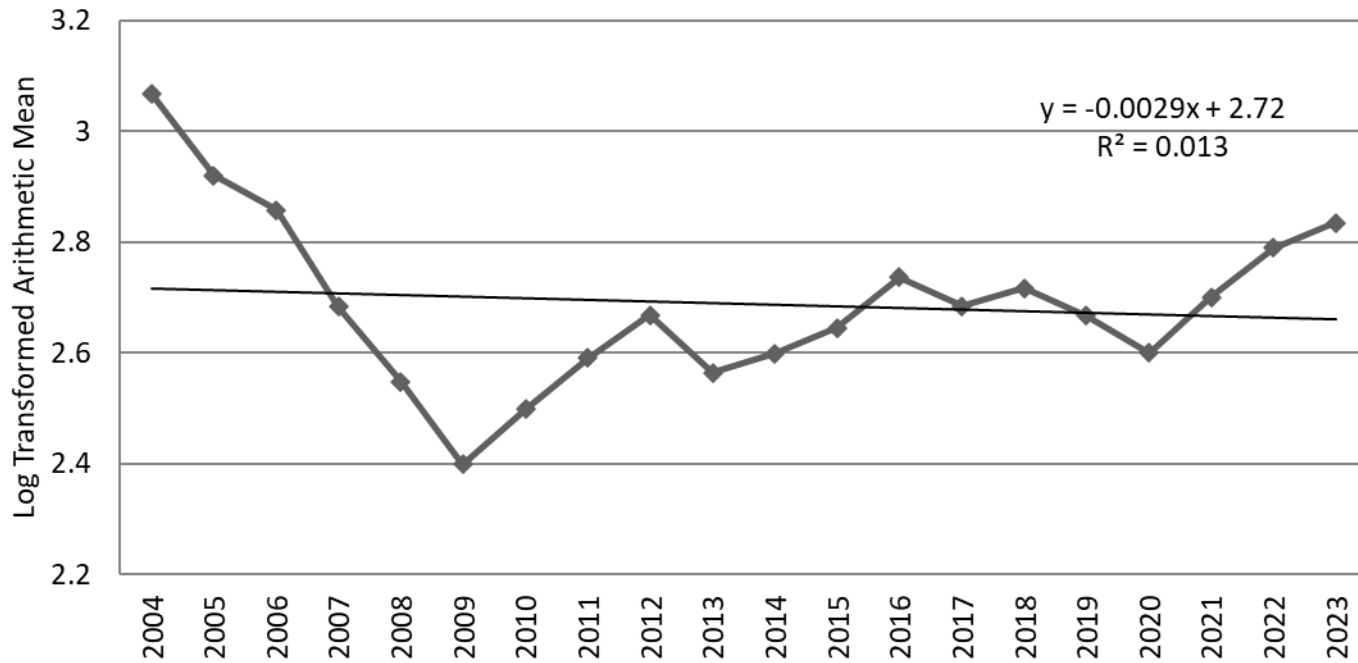
U 1 and 2= the number of pit tags marked as juveniles recaptured at both antennas #1 and #2 or both sites #1 and #2.

Combined Efficiency of both antennas (downstream and upstream) or both antenna sites (FWW and HH) were calculated by adding the unique captures of the downstream antenna #1 or site #1 plus the unique captures for the upstream antenna #2 or site #2 (total number of unique tags detected) and dividing the result by $\left(T_{\widehat{Antenna}}\right)$.

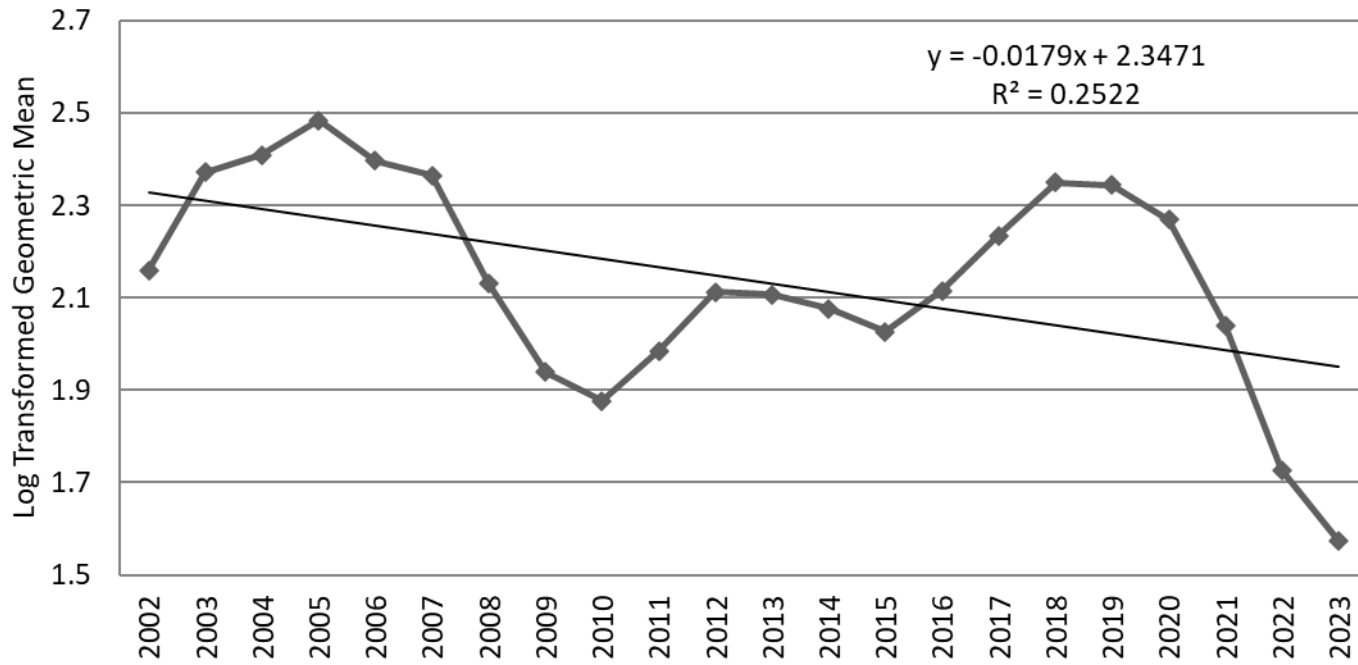
Appendix 3. Log transformed geometric Mean and log transformed Arithmetic means for Coho Salmon (2004-2023) and steelhead trout (2002-2023) in Freshwater Creek.



Log Transformed Arithmetic Mean of Coho Salmon in
Freshwater Creek 2004-2023



Log Transformed Geometric Mean of Steelhead Trout in Freshwater Creek 2002-2023



Log Transformed Arithmetic Mean of Steelhead Trout in Freshwater Creek 2002-2023

