SCIENTIFIC REPORT PREPARED IN PARTIAL FULFILLMENT OF FISHERIES RESTORATION GRANT
Grantee Agreement No: P1210323

Results of Freshwater Creek Salmonid Life Cycle Monitoring Station 2015-2016.

Prepared by

Humboldt State University
Department of Fisheries Biology

Author list

Colin W. Anderson[1]
Darren Ward

---

[1] Author to whom correspondence should be addressed. Humboldt State University.

This report should be cited as: Anderson C. W., Ward D., 2016. Results of Freshwater Creek Salmonid Life Cycle Monitoring Station 2015-2016.

Acknowledgements:

Thanks to the many field technicians, Americorps Watershed Stewards Program members, and California Conservation Corps Veterans Program members who worked on this project. Thanks to Mike Wallace, Terry Roelofs, Seth Ricker, and Dave Hankin for their insights into study design considerations and the ecology of Freshwater Creek salmonids. We would like to thank Mary Kuehner and Todd Newhouse for keeping the machine running. Without access to the watershed none of this would be possible. Thanks to the many landowners in Freshwater Creek especially the Pierson family and Humboldt Redwood Company. The majority of this work was funded by the California Department of Fish and Wildlife's Fisheries Restoration Grants Program.

EXECUTIVE SUMMARY

Introduction

The California Department of Fish and Wildlife (CDFW) and the National Oceanic and Atmospheric Administration ~ Fisheries (NOAA~Fisheries) cooperatively developed the draft Coastal California Salmonid Monitoring Plan (CMP). Two complimentary 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 (LCS) nested within the regional sample frame of the SGS. LCS studies have 4 primary objectives:

- Define the relationship between SGS observations and adult escapement,
- Estimate juvenile and adult abundance, and 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 a LCS with these principal objectives. This report summarizes the results of yearly abundance and survival monitoring efforts from October 2015 to June 2016, as well as 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, and at multiple spatial scales for coho salmon, Chinook salmon, and steelhead trout. 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 mark-recapture experiments

- Coho salmon over-winter survival
- Smolt to Adult Return (SAR) survival

Multiple year comparisons are made for all survey years.

- Relationship between coho salmon redd counts and adult escapement

Results

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

Table A. Adult salmonid escapement for survey years 2000 to 2015. 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.

	Steelhead		Coho		Chinook	
Year	N(hat)	SD	N(hat)	SD	N(hat)	SD
2000	99	23	177*		154*	
2001	195	43	701*		122*	
2002	153	22	1807	213	135	32
2003	432	23	731	25	26*	
2004	254	17	974	37	14*	
2005	257	17	789	128	22*	
2006	235	23	396	47	18*	
2007	203	29	262	41	7*	
2008	51	7	399	71	2*	
2009	61	11	89	10	2*	
2010	132	32	455	38	19*	
2011	108	35	624	148	1*	
2012	149	60	318	75	2*	
2013	127	54	155	67	0*	
2014	87	23	718	68	8*	
2015	106	38	449	86	2*	

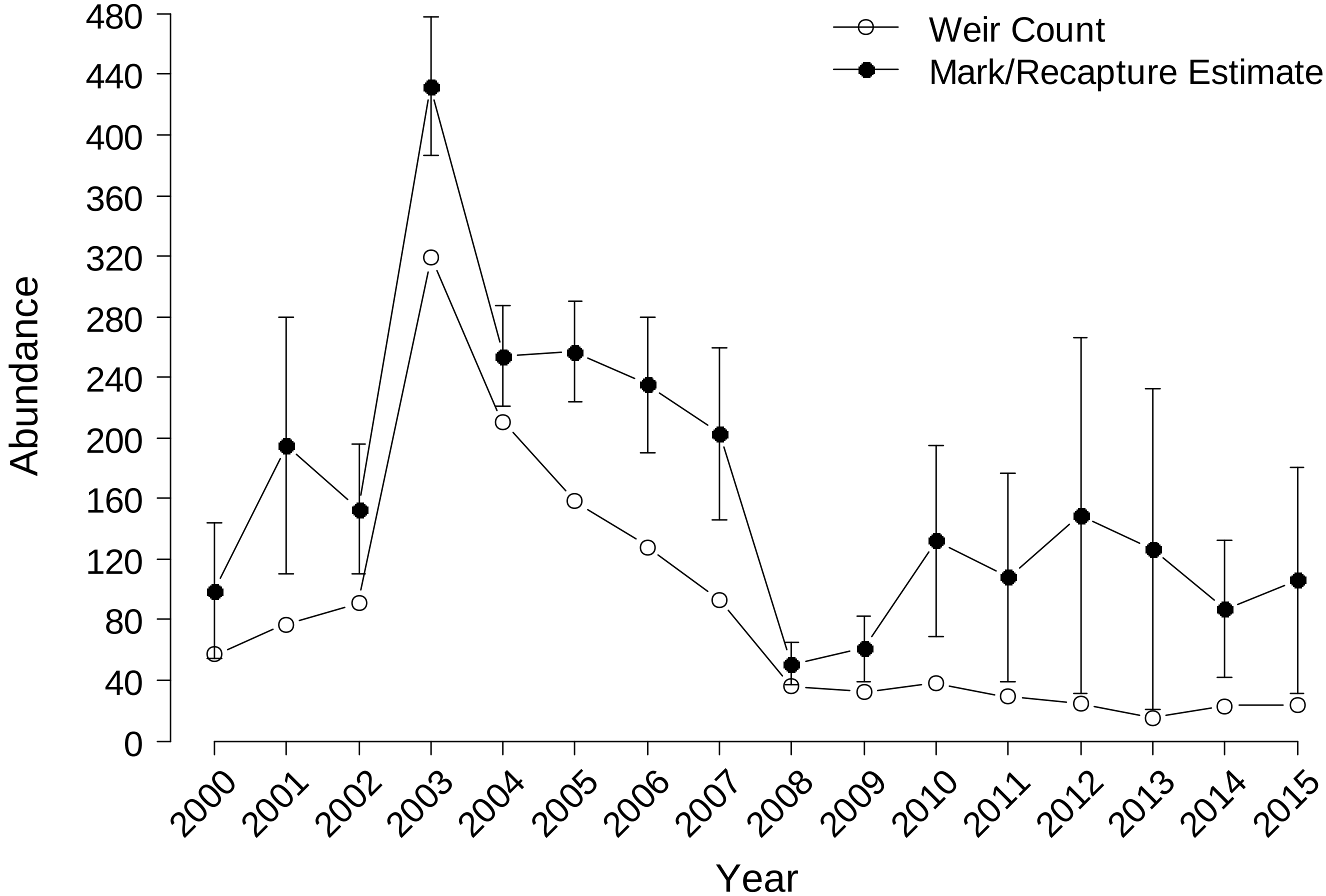


Figure A. Adult steelhead trout weir counts and escapement estimates (± 95% confidence intervals) in Freshwater Creek for survey years 2000 through 2015.

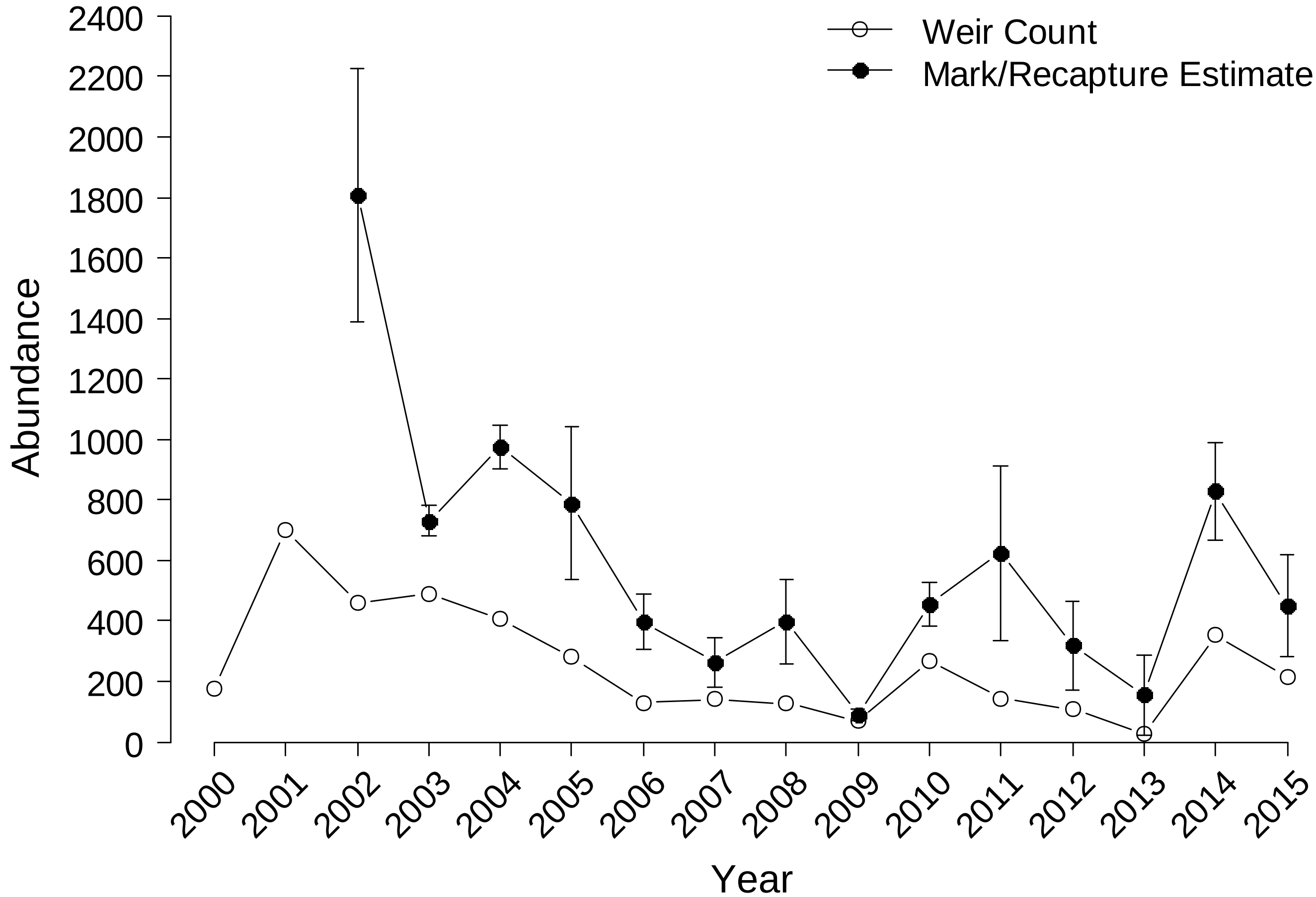


Figure B. Adult coho salmon weir counts and escapement estimates (± 95% confidence intervals) in Freshwater Creek for survey years 2002 through 2015.

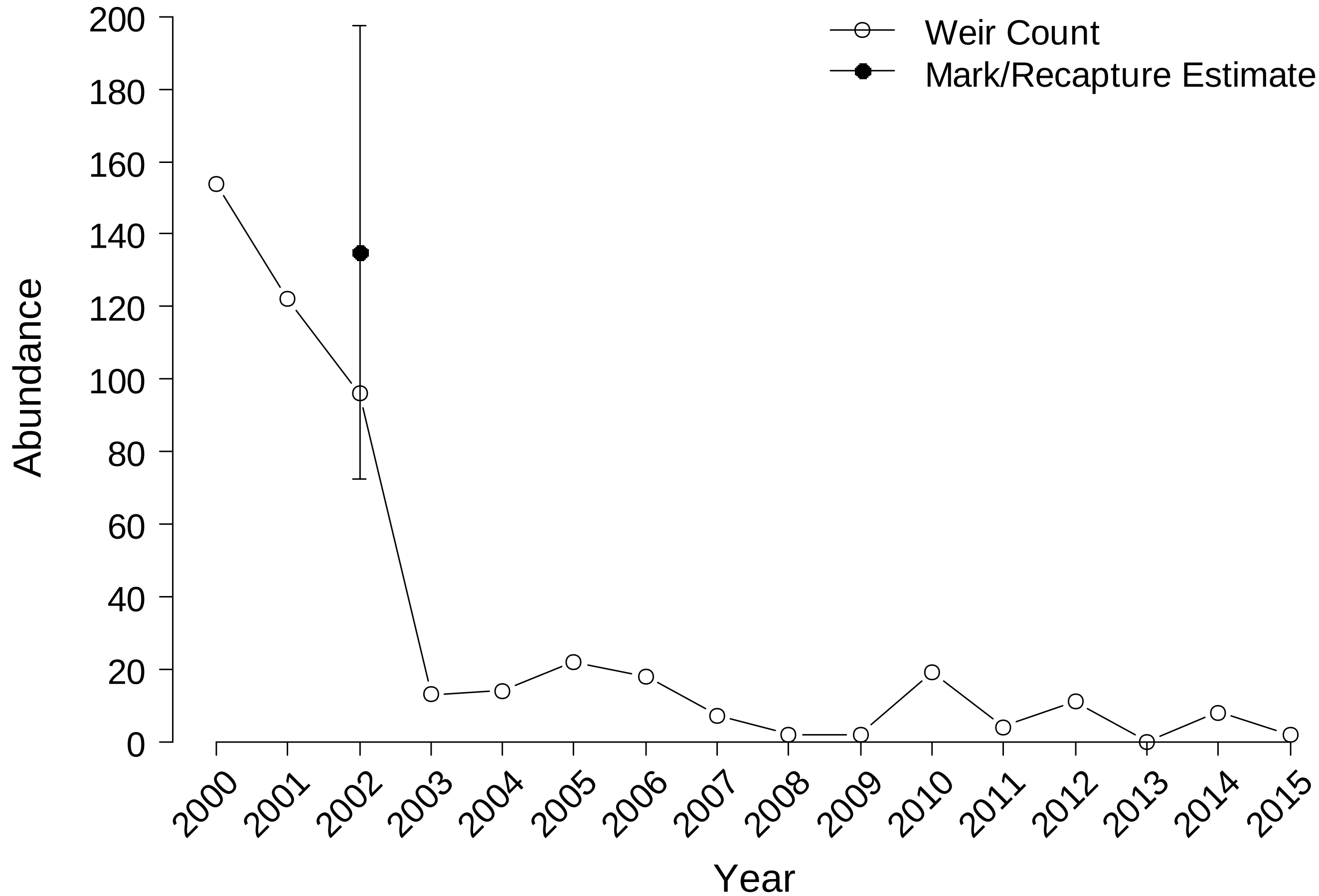


Figure C. Adult Chinook salmon weir counts and escapement estimate (2002; ± 95% confidence intervals) in Freshwater Creek for survey years 2000 through 2015.

Juvenile salmonid spring emigrant trapping: The continuing importance of the lower basin over-winter habitat for coho and steelhead smolts is represented by the increase in overall numbers of smolts when compared to historical estimates from the traps above the Lower Main Stem (LMS) (Figure D. and Table B.). Current trapping occurs lower in the basin at the freshwater saltwater interface at the Humboldt Fish Action Council Weir (HFAC). Year 2006 at the HFAC trap was an experimental effort to explore the potential use of the site and only includes counts from limited trapping days.

Super Population of Smolts: We estimated the hypothetical 'super-population' of smolts that would make up the returning adult run of coho salmon to Freshwater Creek. This estimate includes smolts which emigrated prior to the smolt trap (HFAC) installation (Table B.).

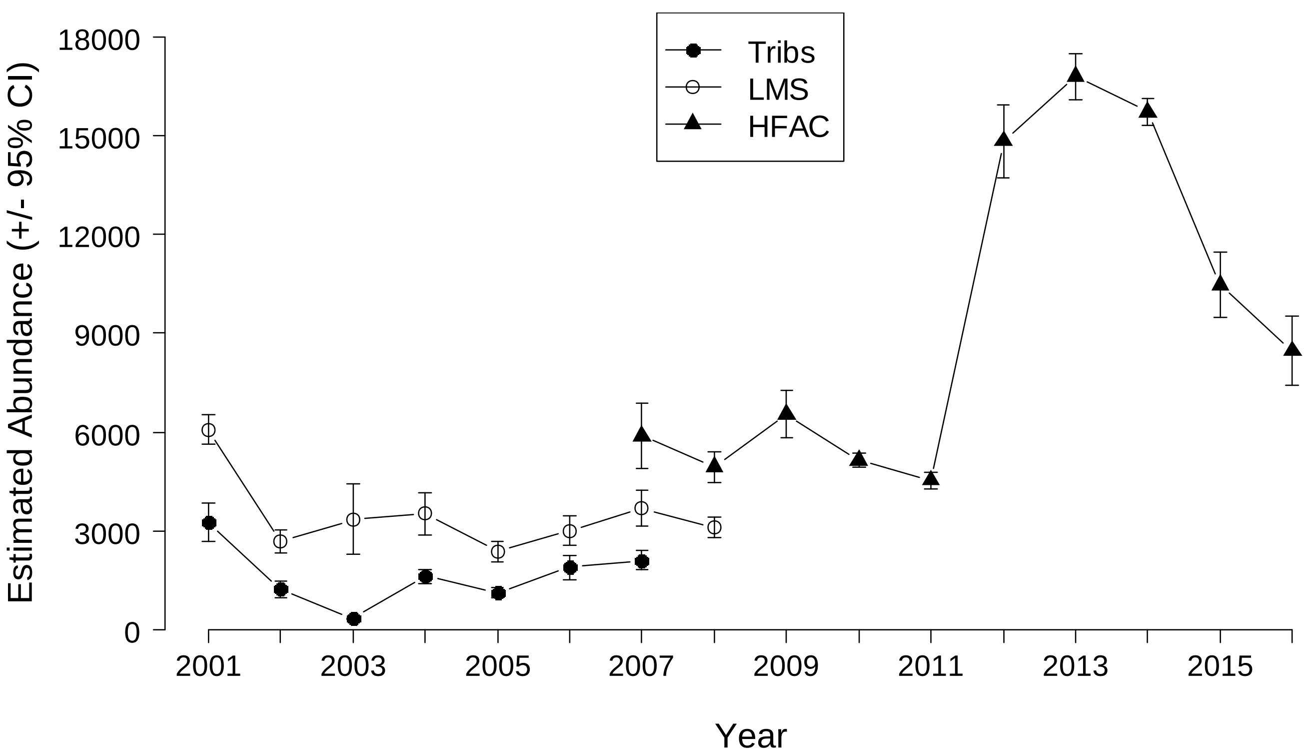


Figure D. Time series plot of juvenile coho salmon spring emigration estimates for all tributary reaches combined (TRIBS), the LMS, and HFAC trapping locations, 2001-2016.

Table B. Emigrant juvenile salmonid catch and abundance estimates for 2006-2016.

Year	Basin	Coho Salmon			Steelhead				Chinook	Cutthroat Trout			
		Age 0+Fry	Age 1+ Smolt		Parr	Pre-Smolt	Smolt		Age 0+Fry-Smolt	Parr	Pre-Smolt	Smolt	Resident
		Catch	N(hat)	95%CI	Catch	Catch	N(hat)	95%CI	Catch	Catch	Catch	Catch	Catch
2006													
	Tribs		1891	365	72	175	39	N/A	493	8	107	10	43
	LMS	4843	3009	432	20	52	22	N/A	913	3	48	2	14
	HFAC		216	N/A	2	3	19	N/A	46*	0	6	3	0
2007													
	Tribs		2111	294	154	280	22	N/A	865	47	150	24	22
	LMS	1752	3685	532	247	284	7	N/A	2298	10	62	11	3
	HFAC		5888	1006	123	136	1607	312	314*	26	59	12	2
	Super Pop		22633	8399									
2008													
	LMS	1777	3096	308	156	124	142	44	988	21	190	0	9
	HFAC		4945	464	57	86	798	80	253*	5	63	1	1
	Super Pop		9536	4365									
2009													
	HFAC		6543	724	424	383	1091	101	0*	61	108	7	32
	Super Pop		11253	1817									
2010													
	HFAC	193*	5138	221	78	90	829	176	104*	15	99	4	53
	Super Pop		15444	2356									
2011													
	HFAC	150*	4535	256	298	173	1161	192	2380*	45	87	9	63
	Super Pop		11862	2755									
2012													
	HFAC	785*	14835	1104	263	34	1391	454	20*	31	32	7	160
	Super Pop		35788	20017									
2013													
	HFAC	125*	16795	693	453	80	1561	89	306*	20	25	8	336
	Super Pop		35712	6968									
2014													
	HFAC	3*	15724	405	10	45	456	41	0	2	20	3	265
	Super Pop		25289	9641									
2015													
	HFAC	11*	10470	980	20	29	331	36	463*	8	16	2	206
2016													
	HFAC	3*	8467	2046	166	14	1218	222	62*	58	1	1	77

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

Smolt to Adult (SAR) marine survival: We estimate that marine survival of the 2014 coho salmon smolt cohort to be 1.4 %. This estimate is slightly below average for Freshwater Creek in 2007 to 2014 (Figure E).

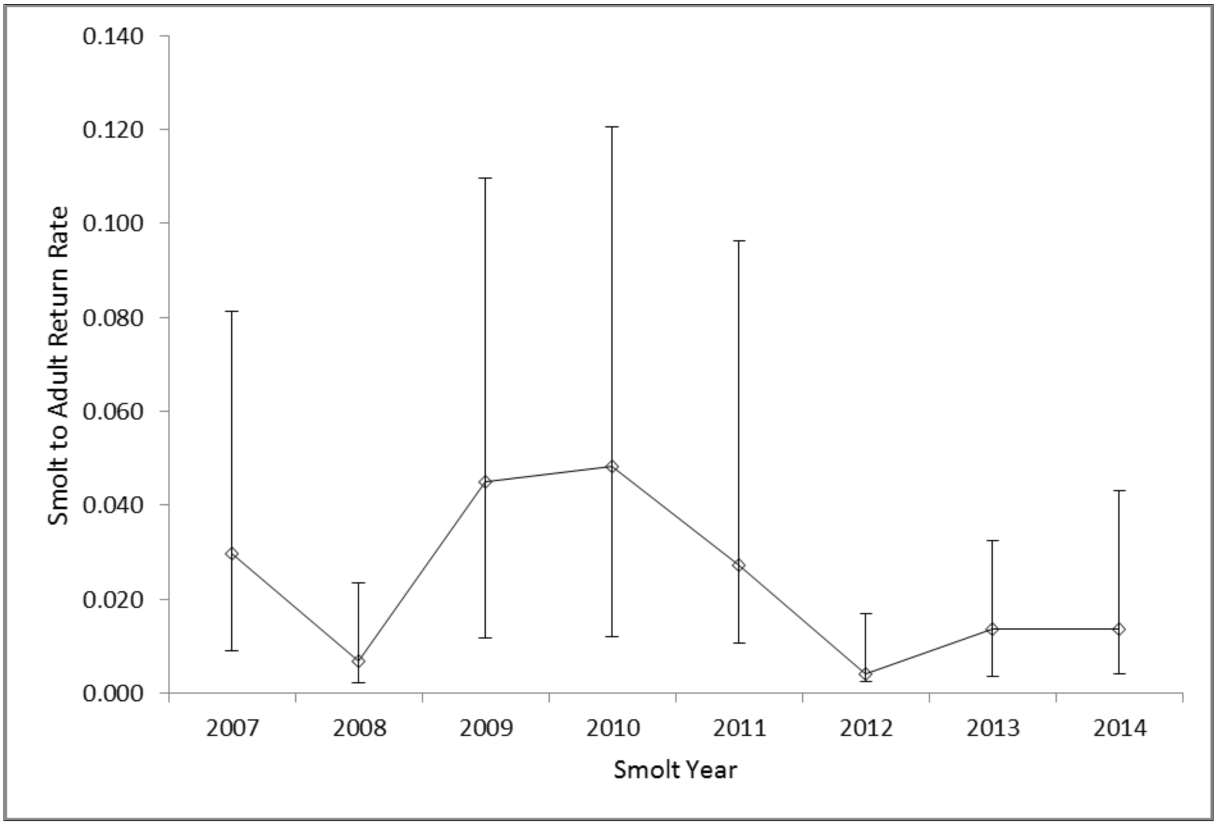


Figure E. Smolt to Adult Return (SAR) rates with 95% confidence bounds for Freshwater Creek coho salmon smolts by year of ocean entry 2007-2014.

Coho salmon redd counts vs. escapement: A significant empirical relationship was found between the 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 ($F=28.18$, $P=0.0002$, $R^2=0.7$)(Figure F.).

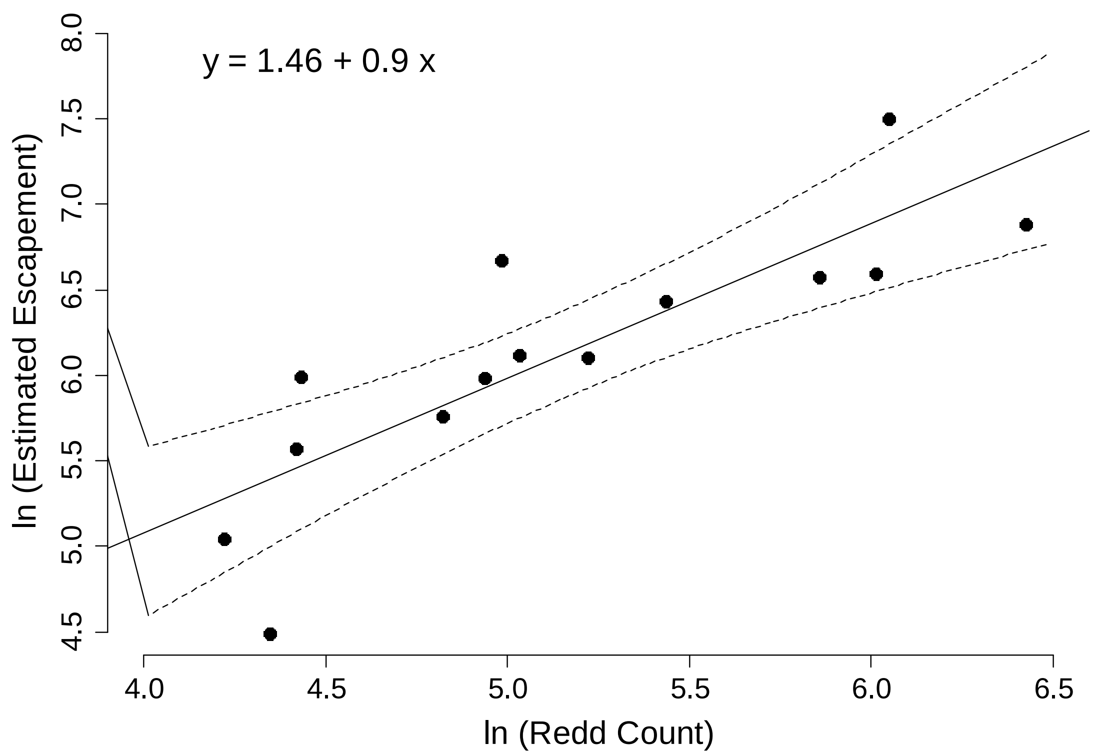


Figure F. Scatter plot with regression line of ln-transformed redd counts vs ln-transformed coho salmon estimated escapement, 2002-2015. Dotted lines indicate 95% confidence intervals for the fitted regression line.

Recommendations: We recommend that future population abundance, survival, and habitat utilization studies in Freshwater Creek take advantage of new development in PIT tag technology to better define what specific habitat attributes contribute to higher survival rates and how juvenile fish utilize, and emigrate to and from these habitats at various life stages. This can be expanded to include nearby streams and seasonal habitat within Humboldt Bay.

Recently, much focus has been placed on restoration of lower basin, off channel or seasonal habitat for enhancing over-winter capacity for juvenile coho salmon. Data presented here justifies this approach and we recommend that these efforts continue to be taken. Attractive restoration sites would be areas where there is the potential to enhance off channel rearing habitat that provides connectivity to the main channel such that fish can find refugia during high discharge events and have the ability to return to the main channel as flows recede.

The development of a population model utilizing stage to stage stock-recruit data requires years (15 years or more is desirable) of data at multiple spatial scales for one population. Therefore, we recommend that all the LCS data collected in coastal California be evaluated for potential use in a single generalized life cycle model that can be used to generate hypothesis of limiting factors and test restoration scenarios to better use LCS data to guide restoration efforts for coho salmon.

CONTENTS

List of Figures

List of Tables

List of Appendices

1 INTRODUCTION

1.1 Background

Pacific Salmon (*Oncorhynchus sp.*) have experienced marked decline in abundance over the last 50 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 (NMFS 2005). 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 (*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, and provides basin by basin threat assessments and attempts to 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 Oceanic and Atmospheric Administration ~ Fisheries 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, the California Department of Fish and Wildlife (CDFW) and the National Oceanic and Atmospheric Administration ~ Fisheries (NOAA~Fisheries) cooperatively developed the draft Coastal California Salmonid Monitoring Plan (CMP) (Adams et al. 2011). Two complimentary 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 (LCS) nested within the regional sample frame of the SGS. LCS studies have 4 primary objectives (not in order of importance) : 1) define the relationship between SGS observations and adult escapement, 2) estimate juvenile and adult abundance, and 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 to be a LCS with these principal objectives.

This report summarizes the results of yearly abundance and survival monitoring efforts from October 2015 to June 2016, 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

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

Levees confine the channel in the lower 6 km and the surrounding land is primarily used for cattle grazing. The stream continues at low gradient from river kilometer (rk) 6 to rk 9.7, of the main-stem and is mainly small parcel residential properties. The remaining 7143 hectares of the watershed encompassing 13 km of anadromous fish habitat, 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 (*Psuedotsuga menziesii*), salmonberry (*Rubus spectasbilis*) and various herbaceous plants in upper sections.

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

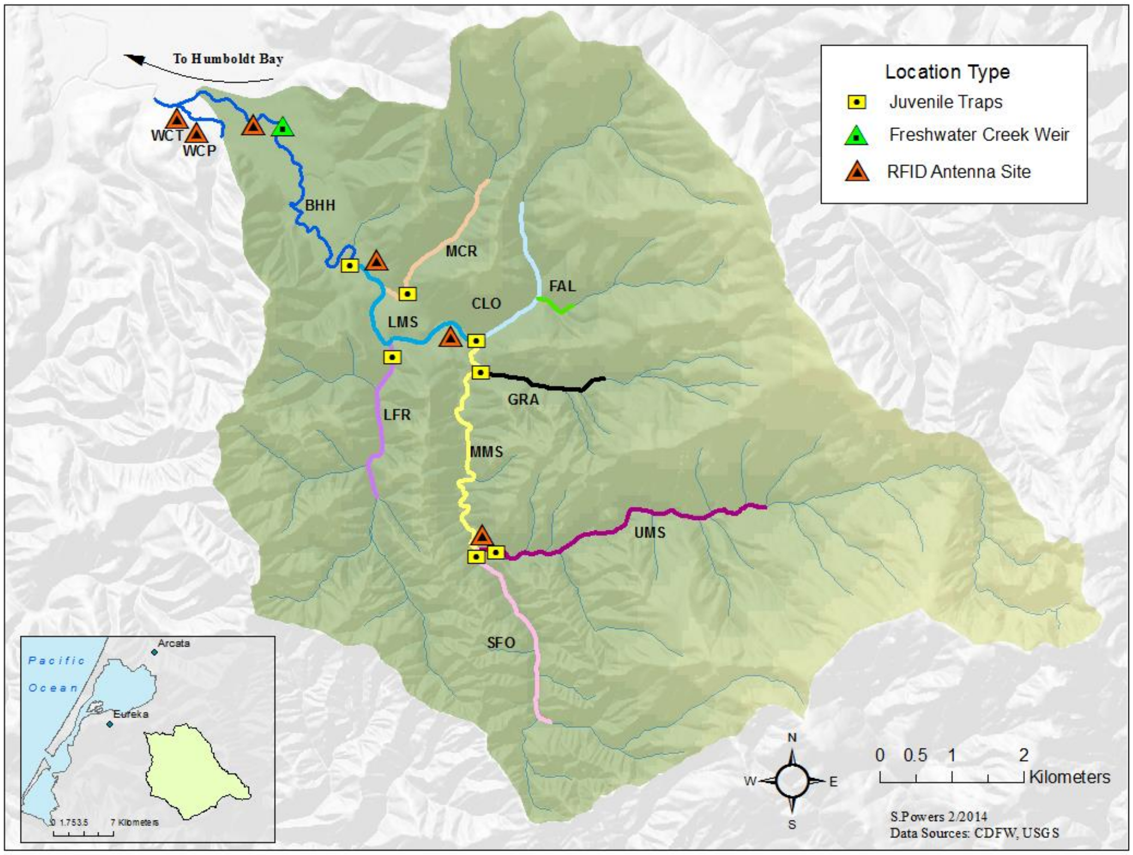


Figure 1. Map of the Freshwater Creek watershed including all sampling reaches (color variations), trap sites, and RFID antenna sites.

Annual rainfall is approximately 150 cm in the headwaters and 100 cm near the mouth, with nearly 90% accumulating between October and April. The remainder of the year offers little precipitation. Stream discharges range from 15 to > 2000 cfs during the rainy season and decline to 2 cfs 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 tridentatus*), Pacific brook lamprey (*Lampetra pacifica*), cutthroat trout (*O. clarki*), prickly and coast range sculpin (*Cottus asper, Cottus aleuticus*) and threespine stickleback (*Gasterosteus aculeatus*).

Amphibians and reptiles present include pacific giant salamanders (*Dicamptodon ensatus*), northern red-legged frogs (*Rana aurora*), foothill yellow-legged frogs (*Rana boylii*), tailed frogs (*Ascaphus truei*) and western pond turtles (*Clemmys marmorata*).

2 METHODS

2.1 Spatial Reach Selection

We partitioned the basin habitat into 8 reaches based upon location within the basin and channel morphology (Figure 1). Each of the five anadromous tributaries and the upper main-stem above the confluence with the South Fork Freshwater Creek are considered the tributaries (Tribs). Main-stem reaches below the South Fork confluence included; the Middle Main-Stem (MMS) extending from the confluence of the South Fork down to the confluence with Cloney Gulch, the lower main-stem (LMS) extending from Cloney Gulch to Howard Heights Bridge crossing and the lowest main-stem reach, and Below Howards Heights (BHH) extending downstream from the Howard Heights bridge crossing into tidally influenced areas of the stream-estuary ecotone ending at the Humboldt Fish Action Council Weir (HFAC Weir).

2.2 Temporal Life Stage Selection

Abundance was measured at two meaningful life stages; 1) adult and 2) age 1+ spring smolts. The periods between each stage are analogous to eggs deposition, emergence, and over-wintering. By extending these abundance indices over multiple years, we are able to add the additional period of the marine phase.

The spatial and temporal extents of the abundance data are not in complete agreement with one another. The adult weir-carcass mark-recapture estimate of escapement includes all fish returning to Freshwater Creek upstream of the HFAC Weir, and does not include any Ryan Creek returns, that likely contribute to the Freshwater Creek populations of fish. Conversely, the back-calculations of the super population of coho salmon smolts includes a hypothetical ‘population’ of smolts that make up the adult spawning population. The ‘true’ spatial extent of this population is unknown and likely includes a component that is ‘stray’ from not only Ryan Creek but also 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.

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

Location Code	Stream/Reach Name	Abundance Spatial Extent					
		Juvenile Salmonid Emigrant Trapping				Adult	
MCR	McCready Gulch	Tribs	LMS	HFAC	Super Population	Spawning survey	Adult abundance
CLO	Cloney Gulch	Tribs	LMS	HFAC	Super Population	Spawning survey	Adult abundance
GRA	Graham Gulch	Tribs	LMS	HFAC	Super Population	Spawning survey	Adult abundance
UMS	Upper Main-stem	Tribs	LMS	HFAC	Super Population	Spawning survey	Adult abundance
SFO	South Fork	Tribs	LMS	HFAC	Super Population	Spawning survey	Adult abundance
LFR	Little Freshwater	Tribs	LMS	HFAC	Super Population	Spawning survey	Adult abundance
MMS	Middle Main-stem		LMS	HFAC	Super Population	Spawning survey	Adult abundance
LMS	Lower Main-stem		LMS	HFAC	Super Population	Spawning survey	Adult abundance
BHH	Below Howard Heights			HFAC	Super Population		Adult abundance
HFAC	HFAC Weir			HFAC	Super Population		Adult abundance
WC	Wood Creek				Super Population		

2.3 Abundance Estimation

2.3.1 Adult escapement

Adult fish migrating upstream were intercepted shortly after entering Freshwater Creek at a permanent weir facility located approximately 8 river kilometers (rk) upstream from the mouth of Freshwater Creek where it enters Humboldt Bay. The trap was operated intermittently from November until early June. The trap was inoperable during low flow periods (<10 cfs) or during periods of high discharge (>500 cfs) when the water over-topped the panels. During these high discharge periods, weir panels were lowered allowing fish to pass unimpeded. Weir counts are incomplete; therefore escapement is estimated with a Petersen mark-recapture experiment.

Captured fish were netted and placed in a tagging cradle for biological sampling. Each fish was identified to species, measured for fork length, 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 and coho salmon received a 12 mm individual identifying PIT (passive integrated transponder) tag. The tag was injected interiorly, just beneath the skin, 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 mark to check for PIT tag loss. If stream discharge was not high, fish were released immediately upstream of the trapping facility. If stream discharge was high, processed fish were held in gated PVC pipe suspended in an aerated flow through recovery tank for a period of up to two hours allowing them to recover before upstream release.

Mark recovery samples for salmon were obtained by inspecting carcasses during surveys of the spawning grounds. During each survey, carcasses were inspected for PIT tags and operculum punches, then given a uniquely numbered jaw tag. Only complete, undegraded carcasses observed for the first time were used in the recovery sample. Recovery sample for steelhead consisted of downstream migrating, post spawn kelts captured at the weir facility. No temporal relationship between marking period and recovery period was apparent for either salmon or steelhead, therefore all marking and recovery periods were combined to form a Petersen estimate of abundance (Appendix 1).

2.3.2 Spawning Ground Surveys

All reaches upstream of and including the LMS were walked by two project personnel approximately once every 10 days or as conditions permitted. On each survey the numbers of live fish were counted, carcasses checked for tags and clips or marks, and newly encountered carcasses were given a uniquely numbered jaw tag. Carcasses were left in their original location.

Each redd encountered was given an individual record number, including date and location within the channel, and categorical age code. Redd dimensions were measured and information was recorded on handheld Ruggedized Digital Assistant devices. These data were recorded on flagging tape and tied to the nearest vegetation above high water. Survey protocol followed that of Gallagher et al. (2007).

Redds were assigned a species by identification of the fish observed guarding or digging. All unoccupied salmonid redds were recorded as unknown.

2.3.3 Juvenile salmonid smolt production

2.3.3.1 Spring down-stream migrant trapping

A single down-stream migrant trap was fished in the Freshwater Creek basin from early March through June, 2016. The emigrant trap was located at the adult trapping weir (HFAC Weir). To operate the weir as a juvenile salmonid downstream migration trap, the center weir panel was retrofit 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 cart 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 cart. This configuration was effective at capturing a portion of the migrating population.

Capture probability and expanded numbers migrants were estimated using a single trap mark-recapture method. Each day, trapped fish were anaesthetized with MS-222, counted, checked for marks. A sample of previously unmarked age 1+ coho were marked by inserting small, individually numbered Passive Integrated Transponder (PIT) tag directly into the body cavity (Prentice 1990, Prentice et al. 1994). Once processed, those fish that were recaptured or did not receive marks were allowed to recover from the anesthetic in flow-through live cars, then released downstream of the trap. Newly marked fish were held in a flow-through live car for up to one hour to check for handling and marking mortalities, and then released one to three pool-riffle sequences upstream of the trap. The marking and recapture data was stratified into weekly time intervals and analyzed Darroch Analysis with Ranked Regression (DARRv2 in R) to produce bounded estimates of abundance (Bjorkstedt 2004).

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), relieid upon, among others, the assumption that all efficiency release fish resume migration past the trap site. Coho and steelhead trout smolts in all but rare cases 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 captures only are reported. Age 0+ fry captures were simply counted, as we did not conduct mark-recaptured 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 hypothetical '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 recaptures occur at the adult life stage after either 1 or 2 salts. 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 over-winter survival and pre-spring emigration

A permanent weir is located in the main stem of Freshwater Creek near the upstream limit of tidal influence (See 2.3.3.1). Downstream of the weir, 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 referred to as Wood Creek encompassing 0.14 km^2 (NRLT, 2010). This marsh has four slough channel networks, totaling just over 1.1 km in length, and a freshwater pond with an area of 401 m^2 (Figure 1). The vegetation in the Wood Creek marsh includes reed canary grass *Phalaris arundinacea*, tufted hairgrass *Deschampsia caespotosa*, salt grass *Distichlis spicata*, Lyngbye's sedge *Carex lyngbyei*, and willows (*Salix* spp.).

We partitioned the Freshwater Creek basin into six study reaches, with reach divisions based on position in the watershed The main stem was composed of four reaches: Upper Main-stem (UMS), Middle Main-stem (MMS), Lower Main-stem (LMS), and Below Howard Heights (BHH). Additional study reaches were in two tributaries: South Fork (SFO) and Cloney Gulch (CLO). Other stream areas in the basin were excluded from this study either because we did not have access for sampling or because no adult coho salmon were detected spawning there.

We marked fish in mid-September to late-October of 2015. We used systematic random sampling within reaches to select pools to seine for juvenile coho salmon. All captured coho salmon were placed in a bucket and seining was repeated until there were enough individuals to mark (4-8 individuals depending on the reach). Individuals were marked (see methods below) and fork length (FL, nearest mm) and wet weight (nearest 0.1 g) was recorded before they were returned to the pool. We attempted to mark approximately 200 individuals per reach.

All juvenile coho salmon selected for marking were first anesthetized with MS-222 (tricaine methanesulfonate). Juvenile coho salmon that were greater than or equal to 60 mm and less than 70 mm were marked with full-duplex PIT tags (Biomark, Inc., Boise, Idaho; full-duplex B, 9.0 mm long, 2.12 mm wide) while juvenile coho salmon greater than or equal to 70 mm were marked with a larger PIT tag (Oregon RFID, Portland, Oregon; half-duplex, 12.0 mm long, 2.12 mm wide). Tags were inserted into the fish body cavity anterior to the pectoral fin using a sterile scalpel. Fish were allowed to recover for 10-30 minutes before returning them to their respective sampling locations.

After tagging, subsequent encounters occurred at antenna arrays or at the migrant trap at the Freshwater Creek weir. Prior to the operation of the migrant trap, early emigrants were detected at three PIT tag antenna arrays located at the Weir, a tide gate at the mouth of Wood Creek (WCT) and the Wood Creek Pond (WCP) (Figure 1). In order for individuals to be detected at Wood Creek they must have moved downstream of the weir and subsequently gone through Freshwater Slough and into Wood Creek. These antennas were 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, smolts were recaptured at a permanent weir. See section 2.3.3.1 for methods.

We used separate Cormack-Jolly-Seber (CJS) analyses to estimate the probability of fall-tagged fish emigrating before spring and the probability of emigrating as spring smolts. A typical CJS model estimates apparent survival (ϕ) of marked individuals between encounters and recapture probability (p) at each encounter after they are marked. Apparent survival is the probability that individuals both survive and are available for detection at the next sampling event. Therefore, in our CJS models, the apparent survival term for the overwinter period is an estimate of the probability of fall-tagged individuals surviving and expressing an early emigrant life history (e.g. they survive and available for detection at the Freshwater Weir and Wood Creek antennas prior to operation of the migrant trap) or a smolt emigrant life history (e.g. they survive and available for detection at the migrant trap) in the respective analyses.

We evaluated overdispersion in the model fits by estimating ĉ for each model. For the smolt emigration model, the estimated ĉ was calculated by dividing the model deviance from the real data by the average model deviance over 1,000 simulations (see Hauer 2013 and Rubenack et al. 2015 for details and R code). This approach was not necessary for the early emigrant model; for the early emigrant model we used the parametric bootstrap algorithm implemented in program MARK (White, 1999). The ĉ for all models was less than 2.

To facilitate comparison with analyses from previous years, we report the parameters for a model fit with a group covariate to produce a separate estimate of apparent survival for fish from each of the six tagging reaches. Model comparison analysis using AICc indicates that it is likely that the apparent survival of smolt emigrants differed across reaches for the 2015/2016 cohort, but apparent survival of early emigrants was similar across reaches.

2.4.2 Smolt to Adult Return (SAR) survival

Juvenile coho salmon smolts were captured at the downstream migrant trap and marked with passively integrated transponder (PIT) tags between early March and mid-June in 2013 (see sec. 2.2.3.1 Downstream migrant trapping). Fish returning to the weir as either grilse (2014) or adults (2015) were captured, checked for PIT tags, and if in good condition, (e.g. no large predator wounds, energetically vigorous) marked with an opercle punch and passed above the weir (see 2.3.1 Adult escapement). The number of adults returning in 2015 were separated into age 2 grilse and age 3 adults, assuming age a knife edge age separation occurs at the nadir in size distribution. Smolt to Adult Return (SAR) survival ($\hat{s}$) was estimated as the estimated number of fish PIT tagged as juveniles returning as grilse and adults ($\sum \hat{N}_i$) divided by the number of juveniles PIT tagged at the downstream migrant trap (M_1) (Appendix 2).

Assessment of statistical bias and construction of confidence bounds was accomplished via non-parametric bootstrap re-sampling. For each sample data set, individual capture histories were re-sampled with replacement a number of times 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). Due to the non-normal distribution of bootstrap SAR estimates, bias corrected accelerated was used for construction of 95% confidence intervals (Manly 1997).

3 RESULTS

3.1 Adult escapement 2015

Fifty-nine spawning surveys were conducted between 19 November and 30 March in Freshwater Creek and it's tributaries to capture the coho salmon spawning season. Two hundred and twenty nine redds were counted. Out of this total, 58 were coho redds, 3 were Chinook redds, 163 were unknown anadromous redds, and 5 were coastal cutthroat redds. (Figure 2).

The adult weir was operated from December through June. The weir was fished 24 hours a day during sufficient flow events. During the low flow periods we removed the weir to allow unimpeded passage of spawning adults, without compromising fish health or exposing them to excessive predation.

3.1.1 Steelhead trout

Twenty-four upstream migrating adult steelhead were captured from 4 December to 6 March. Females (N=10) ranged in size from 500 mm to 710 mm and averaged 626 mm. Males (N=11) ranged in size from 440 mm to 750 mm and averaged 607 mm. Three steelhead of unknown sex ranged from 490 mm to 650 mm.

Out of the 24 upstream migrating steelhead 23 were newly marked and one was recaptured from a previous year. Twenty one steelhead kelts were recaptured moving downstream of which four were identified as having been tagged. The adult steelhead escapement to Freshwater Creek was estimated to be 106 ± 76 (95% C.I.). One live steelhead and zero carcasses were observed during the spawner survey season.

3.1.2 Coho salmon

Two-hundred and twenty-eight upstream migrant adult coho were captured from 3rd December to 15 March. Females (N=112) ranged in size from 350 mm to 690 mm and averaged 607 mm. Males (N=109) ranged in size from 365 mm to 740 mm and averaged 607 mm. Seven coho of unknown sex ranged from 400 mm to 730 mm.

One-hundred and ninety-seven adult coho salmon were newly marked with PIT tags, 19 were recaptured with pit tags, and 216 were marked with opercle punches during 2015. Twelve of the 26 carcasses were identified as having received a mark at the weir. The adult coho salmon escapement into Freshwater Creek was estimated to be 449 ± 173 (95% C.I.). Two-hundred and six live coho and 26 carcasses were observed during the spawner survey season. The majority of coho salmon carcasses were observed in late February.

3.1.3 Chinook Salmon

Three upstream migrating Chinook salmon were captured at the weir in 2015 adult migrant season. Females (N=2) ranged in size from 950 mm to 1000 mm and averaged 975 mm. One Male was captured and was 770 mm. Due to the low abundance of Chinook in Freshwater Creek individuals were counted and passed upstream.

Two live Chinook salmon, and no carcasses were observed during the spawner survey season.

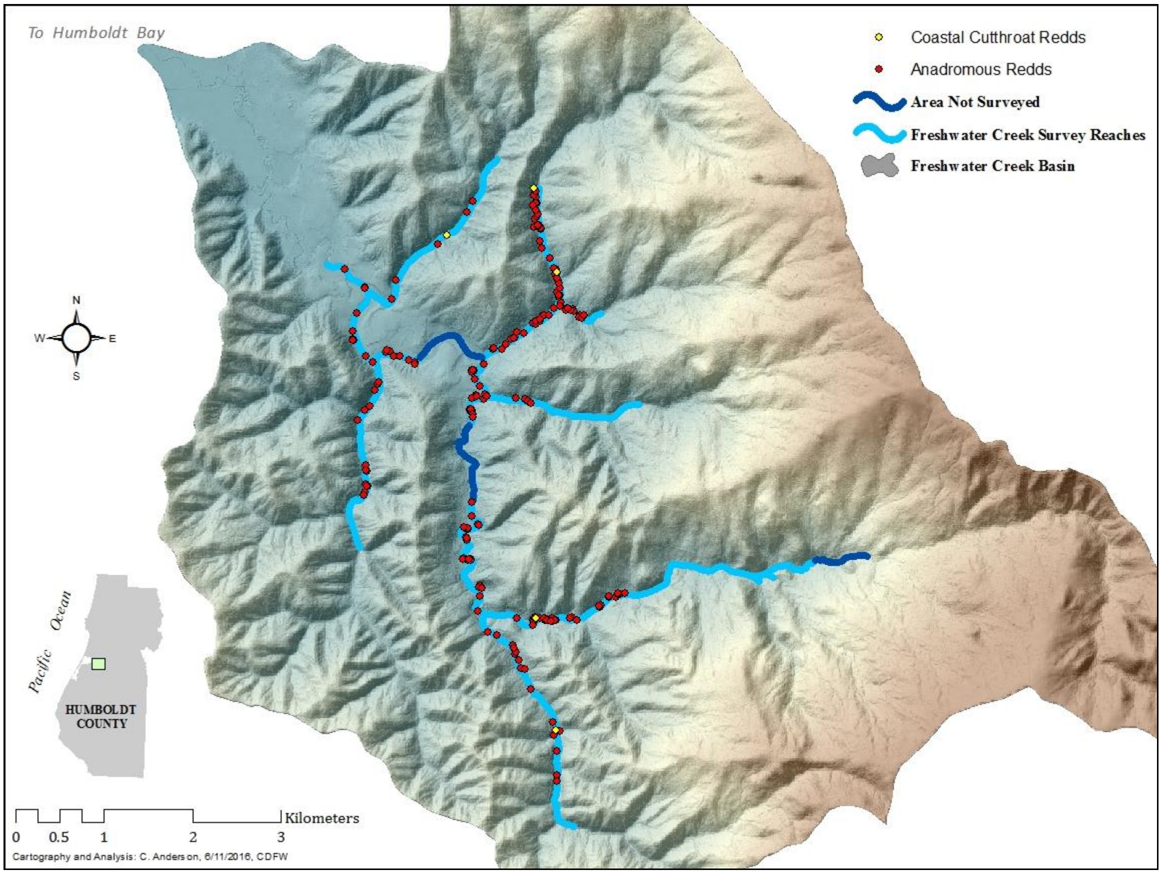


Figure 2. Salmonid redd locations in Freshwater Creek, winter 2015-2016.

3.2 Spring juvenile downstream migrant production 2016

The trap was installed on the first March and ran through 17 June for a total of 108 days. During this time period the trap was partially fishable due to high water events for a total of 12 days.

An estimated 8467 ± 2046 age 1+ coho salmon migrated past HFAC Weir during March through June 2016. An estimated 1218 ± 221 steelhead smolts migrated past the HFAC site March through June 2016. Estimates of coho salmon and steelhead trout smolts, and counts of cutthroat trout age 1+ and 2+, and steelhead parr are presented in Table 2.

Coho salmon fork lengths (N=1224) ranged from 60 mm to 159 mm with a mean of 112 mm at the HFAC Weir (Table 3, Figure 3 and Figure 5). The peak timing of coho captures occurred on 19 May at the HFAC Weir (Figure 7).

Steelhead trout smolt fork lengths (N=283) ranged from 145 mm to 314 mm with a mean of 188 mm at the HFAC Weir (Table 3, Figure 4 and Figure 6). The peak timing of steelhead trout captures occurred on 13 March at the HFAC Weir (Figure 8).

3.2.1 Back calculation of super-population of coho smolts 2014

The back-calculated super population of coho smolts is estimated to be 25,289 ± 9641 (Table 2). This estimate is considered the hypothetical total population of smolts that make up the adult returns to Freshwater Creek as age 2 grilse less than 570 mm in 2014 and as age 3 adults greater than 570mm in 2015.

Table 2. Emigrant juvenile salmonid catch and abundance estimates for 2006-2016.

Year	Basin	Coho Salmon			Steelhead				Chinook	Cutthroat Trout			
		Age 0+Fry	Age 1+ Smolt		Parr	Pre-Smolt	Smolt		Age 0+Fry-Smolt	Parr	Pre-Smolt	Smolt	Resident
		Catch	N(hat)	95%CI	Catch	Catch	N(hat)	95%CI	Catch	Catch	Catch	Catch	Catch
2006													
	Tribs		1891	365	72	175	39	N/A	493	8	107	10	43
	LMS	4843	3009	432	20	52	22	N/A	913	3	48	2	14
	HFAC		216	N/A	2	3	19	N/A	46*	0	6	3	0
2007													
	Tribs		2111	294	154	280	22	N/A	865	47	150	24	22
	LMS	1752	3685	532	247	284	7	N/A	2298	10	62	11	3
	HFAC		5888	1006	123	136	1607	312	314*	26	59	12	2
	Super Pop		22633	8399									
2008													
	LMS	1777	3096	308	156	124	142	44	988	21	190	0	9
	HFAC		4945	464	57	86	798	80	253*	5	63	1	1
	Super Pop		9536	4365									
2009													
	HFAC		6543	724	424	383	1091	101	0*	61	108	7	32
	Super Pop		11253	1817									
2010													
	HFAC	193*	5138	221	78	90	829	176	104*	15	99	4	53
	Super Pop		15444	2356									
2011													
	HFAC	150*	4535	256	298	173	1161	192	2380*	45	87	9	63
	Super Pop		11862	2755									
2012													
	HFAC	785*	14835	1104	263	34	1391	454	20*	31	32	7	160
	Super Pop		35788	20017									
2013													
	HFAC	125*	16795	693	453	80	1561	89	306*	20	25	8	336
	Super Pop		35712	6968									
2014													
	HFAC	3*	15724	405	10	45	456	41	0	2	20	3	265
	Super Pop		25289	9641									
2015													
	HFAC	11*	10470	980	20	29	331	36	463*	8	16	2	206
2016													
	HFAC	3*	8467	2046	166	14	1218	222	62*	58	1	1	77

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

Table 3. Descriptive fork length statistics (mm) for all marked juvenile emigrant coho salmon and steelhead in 2016.

Statistic	Coho Smolts	Steelhead Smolts
Mean	112	188
Standard Error	0.38	1.09
Median	112	187
Standard Deviation	13.32	18.41
Minimum	60	145
Maximum	159	314
N	1224	283
C.I. Mean (95%)	0.74	2.15

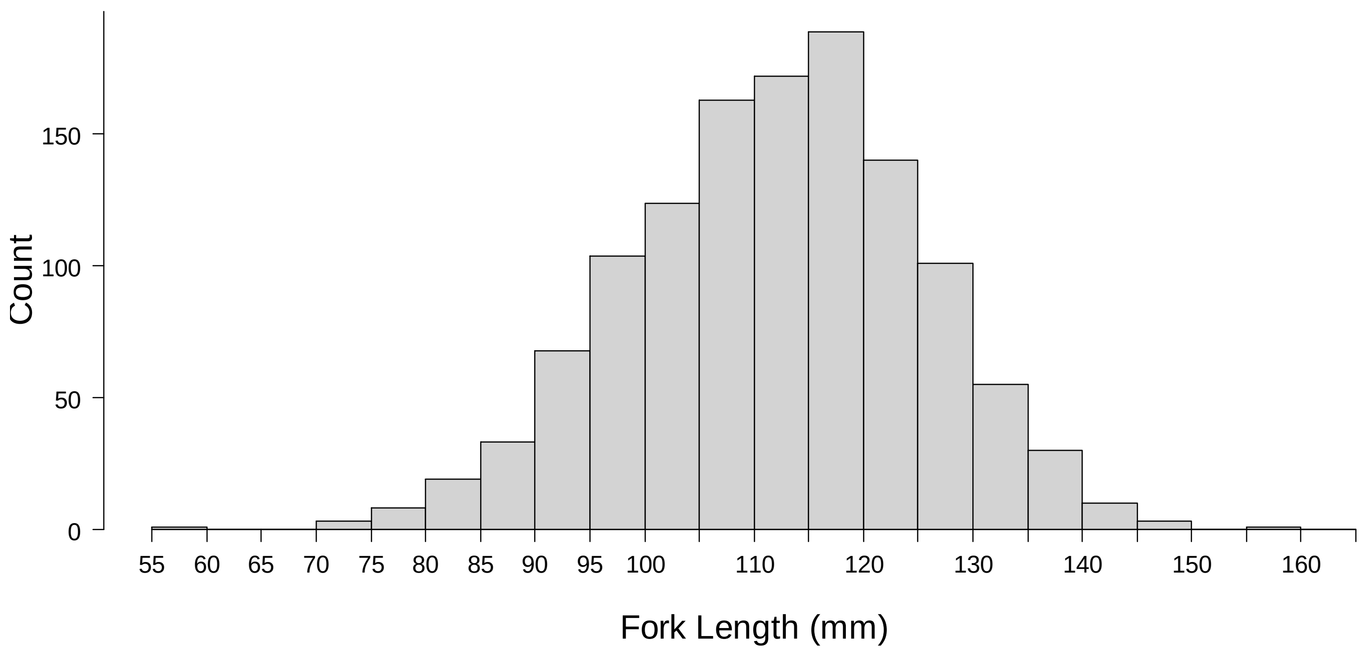


Figure 3. Histogram of emigrant juvenile coho salmon fork lengths (mm) in Freshwater Creek at HFAC, 2016.

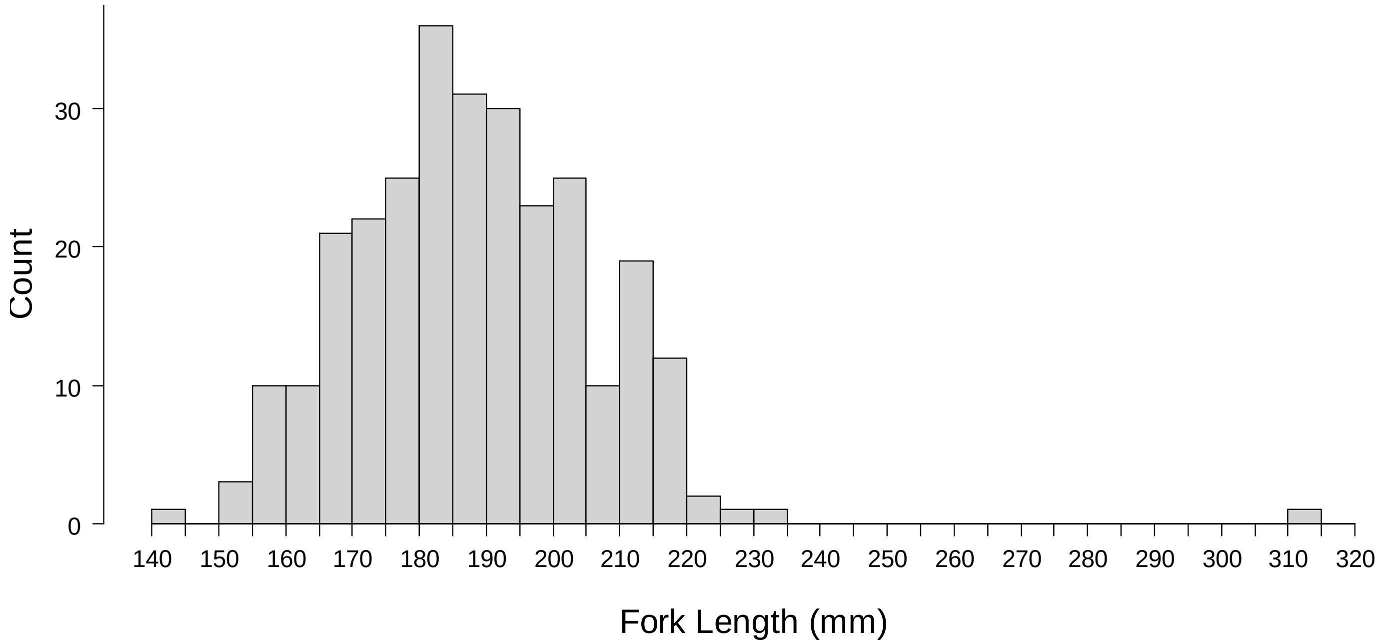


Figure 4. Histogram of emigrant juvenile steelhead trout smolts fork lengths (mm) in Freshwater Creek at HFAC, 2016.

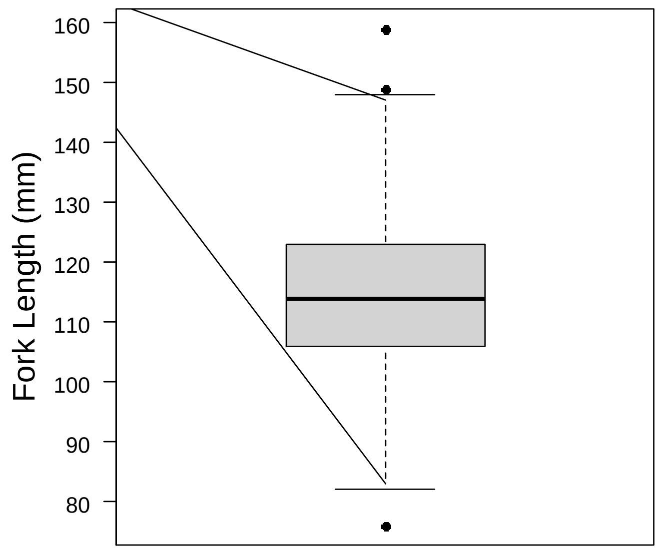


Figure 5. Box plot of emigrant juvenile coho salmon fork lengths (mm). Boxes depict the 25th, 50th and 75th percentiles, whiskers depict 5th and 95th percentiles and points indicate outliers. HFAC trap in Freshwater Creek, 2016.

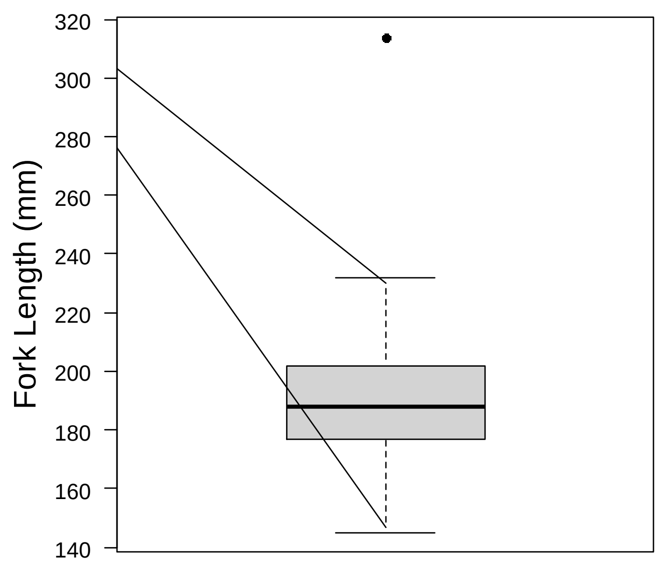


Figure 6. Box plot of emigrant juvenile steelhead trout smolt fork lengths (mm). Boxes depict the 25th, 50th and 75th percentiles, whiskers depict 5th and 95th percentiles and points indicate outliers. HFAC trap in Freshwater Creek, 2016.

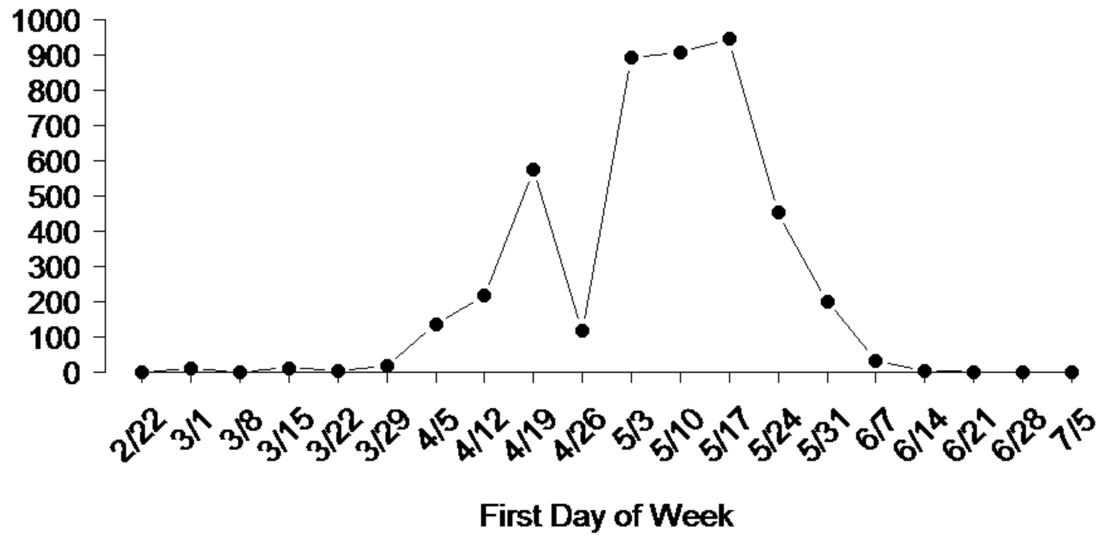


Figure 7. Timing juvenile coho salmon captures by week at the HFAC trap in Freshwater Creek, 2016.

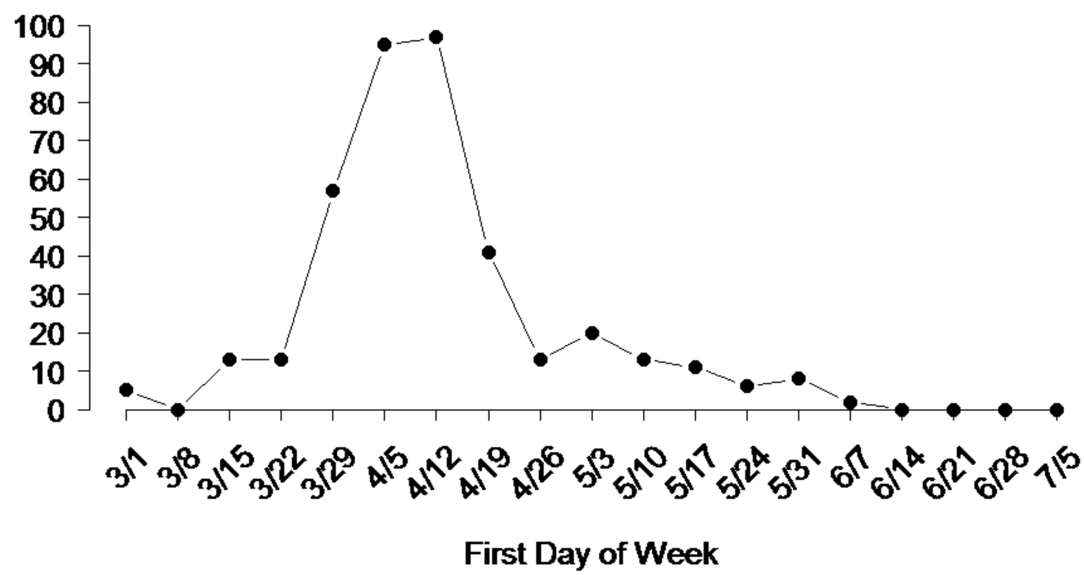


Figure 8. Timing of juvenile emigrant juvenile steelhead trout captures by week at the HFAC trap in Freshwater Creek, 2016.

3.3 Survival Estimation

3.3.1 Juvenile coho salmon over-winter survival and pre-spring emigration

We PIT tagged 1007 fish and recaptured 7 fish during the 2015 fall sampling effort. Within this cohort 679 coho had 8mm tags (fork length 60-69mm) and 328 had 12mm tags (fork length ≥ 70mm). Of these marked fish 100 (9.9%) were detected at the weir DSMT the following spring, of which 53 were 8mm tags and 47 were 12mm tags. Weir efficiency throughout the trapping season was 54.4% (667/1227).

Recaptures of the over-winter survival group occurred throughout the winter and spring on several continuously operating stream-width antenna arrays . Antennas were operated continuously from mid-October through mid-June. Antennas located in the Freshwater Creek main-stem and tributaries only detect the 12mm tags while the Wood Creek tide gate (WCT) and pond (WCP) detectors read 8mm and 12mm tags. During the winter, before the DSMT was operated, 25 (2.5%) of the fall tagged individuals were detected, with antennas, below the weir and are considered early immigrants.

Apparent over-winter survival rates of coho tagged in fall 2015 ranged from 9.9% for smolt immigrants tagged in the upper main-stem (UMS) reach, to 34% for early immigrants tagged in the below Howard Heights (BHH) reach. All parameter estimates were generated with Program MARK, of which parameter estimates for the reach model are shown in Figure 9.

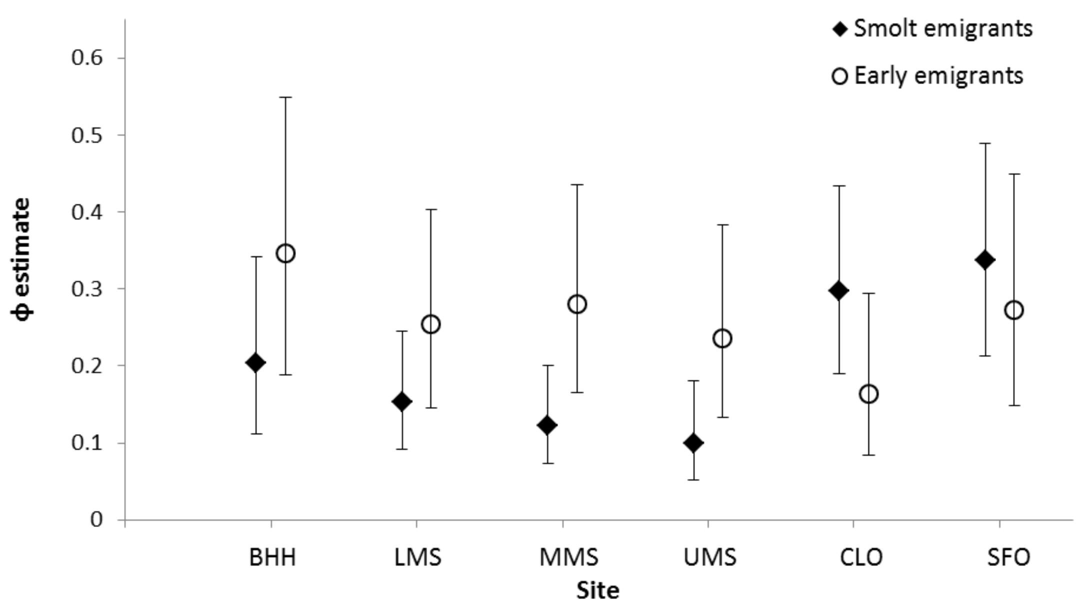


Figure 9. Over-winter survival estimates for individuals for the reach model in 2015.

3.3.2 Smolt to Adult Return survival 2015

During the 2014 spring trapping season 1986 migrating coho smolts were PIT tagged and 428 were recaptured with pit tags from previous marking studies. A total of 2,414 tagged individuals were used for the SAR estimate. Five of these tagged fish were recaptured as age two grilse and 15 were recaptured as age three adults (

Table 4). Weir capture efficiencies were 5.8 % and 37.4% for grilse and three year olds respectively. Bias adjusted Adult SAR for the 2014 smolt cohort is 1.4% with 95% confidence bounds from 0.9% to 3.0%.

Table 4. Mark-recapture data used to generate SAR estimates for the 2014 coho salmon smolt cohorts.

	Year (*i*)	Mw	Cw	Cc	Rc	ê	Rj	$\hat{N}$
Grilse	2014-15	347	305	117	56	0.54	5	9
Adult	2015-16	216	175	26	12	0.57	15	26

Where Mw = Number Marked at the weir, Cw = Number of Fish checked for tags (Grilse < 570mm, Adult > 570mm), Cc = Total marked and unmarked Carcasses, Rc = Carcasses recaptured with Weir marks, ê = Weir Efficiency, Rj = Number of Marked Adults returning to Weir and N(hat)= estimated number of fish PIT tagged as juveniles returning as grilse or adults during year.

3.4 Multiple Year Comparisons

3.4.1 Adult abundance Trends.

Coho escapement in 2015 was estimated at 449 and is slightly below the fourteen year average of 583 (Table 5).

Steelhead escapement in 2015 was estimated at 106 and is below the sixteen year average of 165 (Table 5). This escapement estimate is the fifth lowest in the last sixteen years.

Table 5. Adult salmonid escapement for survey years 2000 to 2015. 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.

	Steelhead		Coho		Chinook	
Year	N(hat)	SD	N(hat)	SD	N(hat)	SD
2000	99	23	177*		154*	
2001	195	43	701*		122*	
2002	153	22	1807	213	135	32
2003	432	23	731	25	26*	
2004	254	17	974	37	14*	
2005	257	17	789	128	22*	
2006	235	23	396	47	18*	
2007	203	29	262	41	7*	
2008	51	7	399	71	2*	
2009	61	11	89	10	2*	
2010	132	32	455	38	19*	
2011	108	35	624	148	1*	
2012	149	60	318	75	2*	
2013	127	54	155	67	0*	
2014	87	23	718	68	8*	
2015	106	38	449	86	2*	

3.4.2 Redd Surveys vs Estimated Adult Coho Salmon Escapement

The relationship of observed redds and estimated coho escapement, by survey year, is shown in Figure 10. There is a significant empirical relationship between the 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 ($F=25.93$, $P=0.0004$, $R^2=0.7$) (Figure 11).

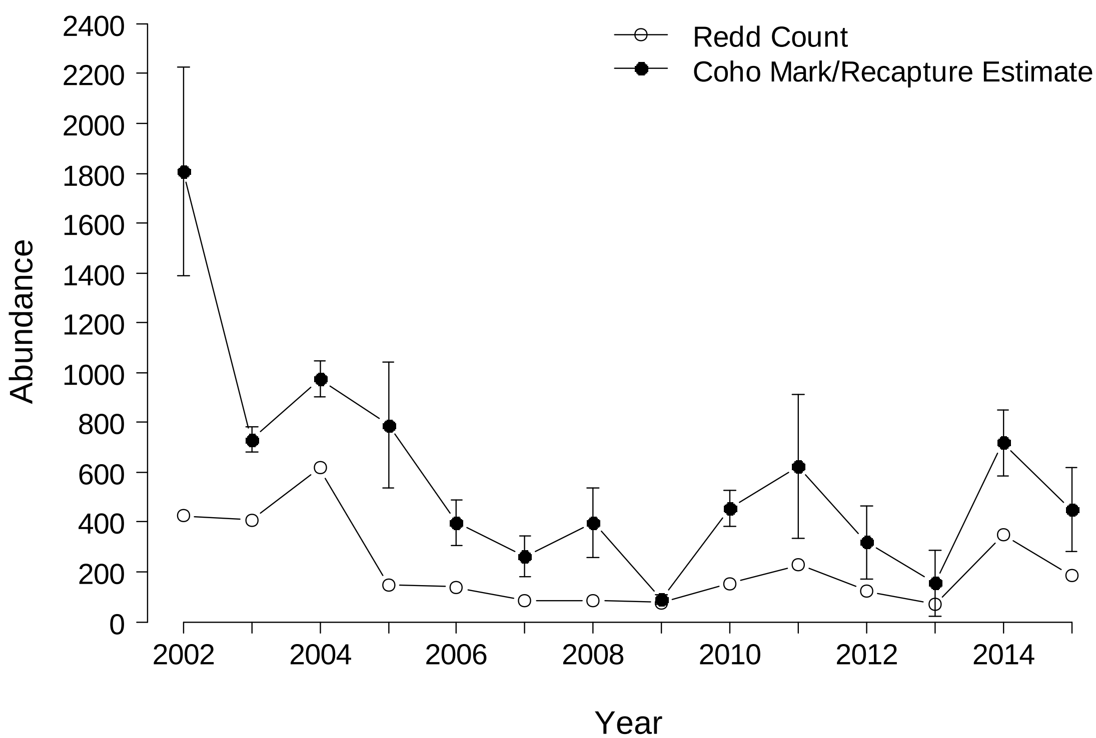


Figure 10. Time series plot of coho salmon redd counts and estimated adult escapement (±95% confidence intervals), 2002-2015.

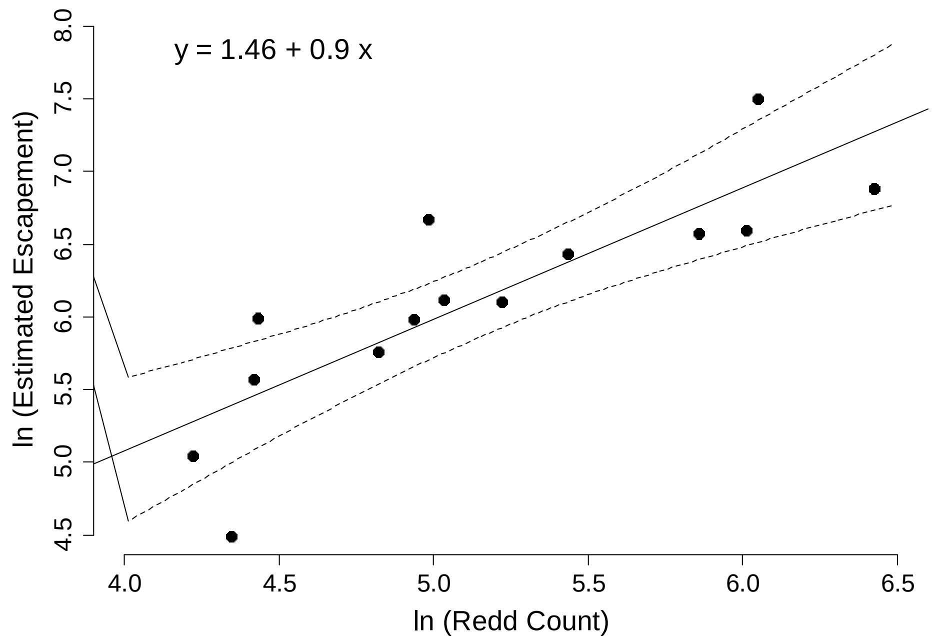


Figure 11. Scatter plot with regression line of ln-transformed redd counts vs ln-transformed coho salmon estimated escapement, 2002-2015. Dotted lines indicate 95% confidence intervals for the fitted regression line.

3.4.3 Spring juvenile down-stream migrant catches and abundance estimates

Spring juvenile salmonid downstream emigrant trapping was conducted over 16 years at multiple spatial scales. From 2001 to 2006 all five major anadromous tributaries and the upper main-stem upstream from the confluence with the South Fork Freshwater Creek were trapped (Tribs). From 2001 to 2008 a main-stem trap was operated (LMS Trap). From 2007 to 2016 the weir at HFAC was utilized as a juvenile downstream emigrant trap (HFAC Weir) (Figure 1).

Coho salmon age 1+ emigrant (smolt) estimates for the Tribs, LMS Trap, and HFAC Weir appear to track one another well, with each down-stream trap estimating a larger fraction of the production (Table 2, Figure 12). In 2007 when all three trap locations were surveyed, 36%, 27% and 37% of Freshwater Creek smolt yield was contributed by the habitat upstream of Tribs traps, between Tribs and the LMS Trap, and between LMS Trap and HFAC Weir respectively (Figure 12). The super population estimate of smolts for the same year is estimated to be 22,633 fish (Figure 13).

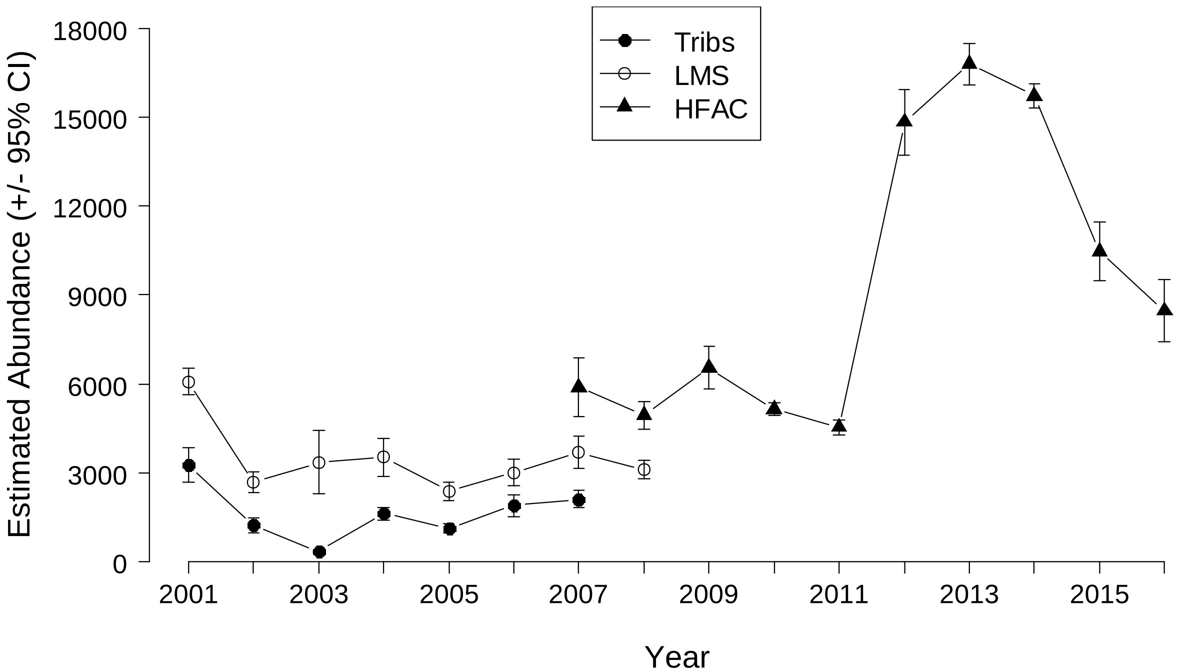


Figure 12. Time series plot of juvenile coho salmon spring emigration estimates for all tributary reaches combined (TRIBS), the LMS, and HFAC trapping locations, 2001-2016.

The super population of coho smolts is estimated with Juvenile to adult tag returns beginning with juveniles tagged in 2006 and provides estimates from 2007 through 2014 (Figure 13). The super population estimate of smolts continues to be higher than the emigrant trap estimate for all years.

Steelhead trout smolt captures were too few for abundance estimates to be made for all years at Tribs and LMS Trap locations. Captures at these sites ranged between 0 to 90 fish. Once the HFAC Weir was utilized as a juvenile emigrant trap, steelhead trout smolt estimates have varied from a high of 1607, in 2007, to a low of 331 in 2015 (Table 2 and Figure 14).

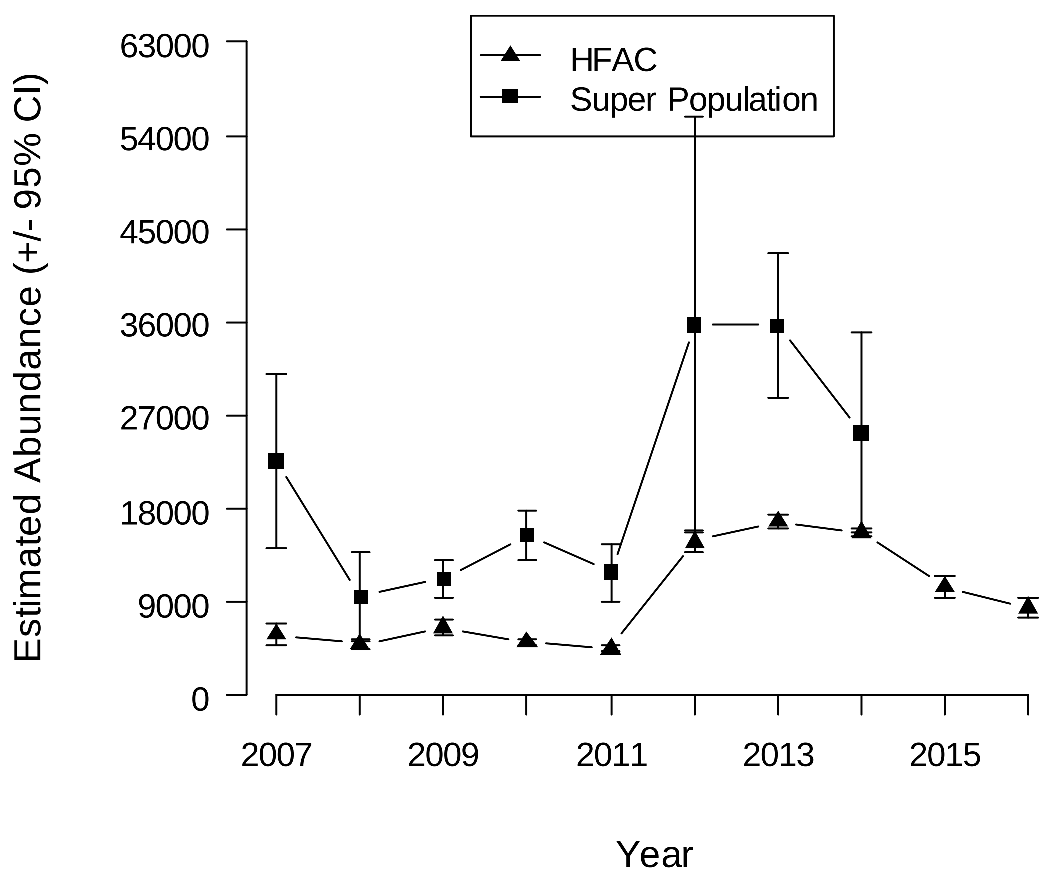


Figure 13. Time series plot of juvenile coho spring emigration estimates (95% confidence intervals) at a migrant trap and super population estimates 2007-2016.

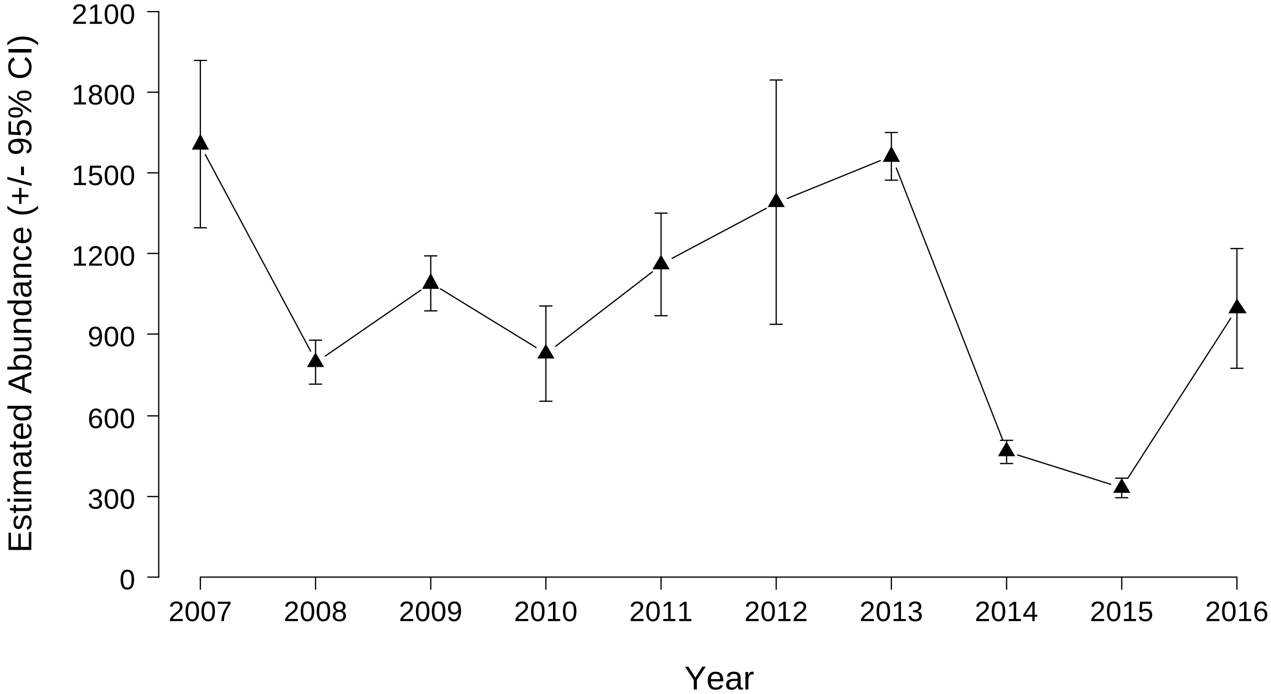


Figure 14. Steelhead Smolt abundance estimates (± 95% confidence intervals) in Freshwater Creek for DSMT survey years 2007 through 2016.

3.4.4 Coho Over-winter Survival Estimates

Over-winter survival of smolts and pre-spring emigration rates vary considerably between reaches and years (
Figure 15). The top model for both the early emigrant and smolt over-winter survival also varied over the 6 year period. In one circumstance, the reach model was the top model for early emigrants in 2010 and in 2011. Both reach or reach type (low gradient main-stem versus higher gradient main-stem and tributaries) are part of the winning models in 4 out of 6 years for both early emigrants and smolts.

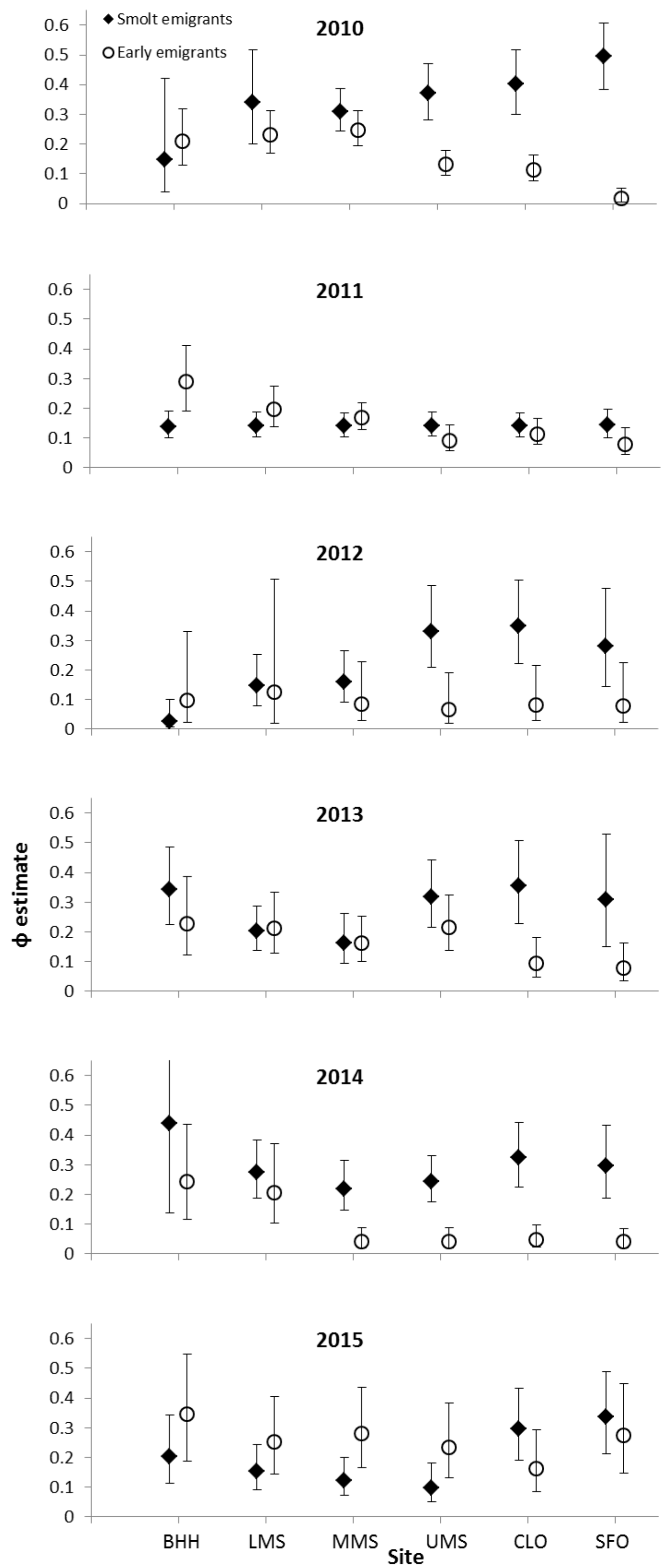


Figure 15. Reach specific parameter estimates for juvenile over-winter survival and pre-spring emigration rates for fall marked coho 2010-2015.

4 DISCUSSION

4.1 Population Abundance and Trend

Estimated Coho salmon escapement to Freshwater Creek has increased over the last six years from a low of 89 animals in 2009. 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 as disconcerting. The Chinook salmon decline is quite dramatic, leading to very few numbers of adult returns and raise concerns over depensatory population effects. 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. Anadromous steelhead trout returns show no clear trends over the 16 year study, but the large single year decline from 2007-2008 to 2008-2009 and continued low abundance in 2009-2010 appear anomalous with regard to the previous eight years of 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, to estimate population abundance, then regressing this response against time. This technique is a conservative method to evaluate trend 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 and steelhead population but may require a few more years of data to provide concrete results (Appendix 3).

4.2 Survival

4.2.1 Smolt to Adult Return survival

One of the goals of LCM monitoring stations is to separate the motives behind varying adult escapement that are due to survival realized during the freshwater versus marine life stages. In this study we estimate marine survival using smolt to adult tag returns (Table 6 and Figure 16) rather than adult abundance estimates divided by juvenile trapping abundance estimates. This method is robust to the spatial scale where smolts can be reliably estimated (e.g. LMS vs. HFAC Weir) and the idea that no smolt trap location or estimate can be made that captures the entire smolt production. However, it is sensitive to the mark recapture assumptions, and realized sample size of juvenile recoveries at the adult stage. Specifically, we make the assumption that 2 year old jack coho salmon are captured at the HFAC Weir and recaptured as carcasses with the same probability as 3 year old coho salmon adults. Our observations at the weir suggest some 2 year old fish swim through the weir bars without being captured. It is unlikely that this bias is large, however, given the relatively small fraction of 2 year olds in the population. Perhaps models using the weir along with Pit Tag detection stations as recapture points would solidify the assumption of equal capture of jacks and adults.

Return rates of emigrating coho salmon range between 0.4% to nearly 5%, and have largely contributed to the short term declines in the time series of adult abundance. The relatively modest (>0.5%-1.4%) increase in SAR for the smolt cohort in 2013 and 2014, however was coupled with a large increase in total smolt production.

Table 6. Bias adjusted Smolt to Adult Return estimates and bias corrected 95% confidence bounds. Freshwater Creek coho salmon smolts by year of ocean entry 2007-2014.

Year	Bias Adjusted SAR	Lower 95% C.I	Upper 95% C.I.
2007	3.0%	2.1%	5.2%
2008	0.7%	0.5%	1.7%
2009	4.5%	3.4%	6.5%
2010	4.8%	3.6%	7.2%
2011	2.7%	1.7%	6.9%
2012	0.4%*	0.1%*	1.3%*
2013	1.4%	1.0%	1.9%
2014	1.4%	0.9%	3.0%

* Calculated non Bias adjusted estimates due to low sample size.

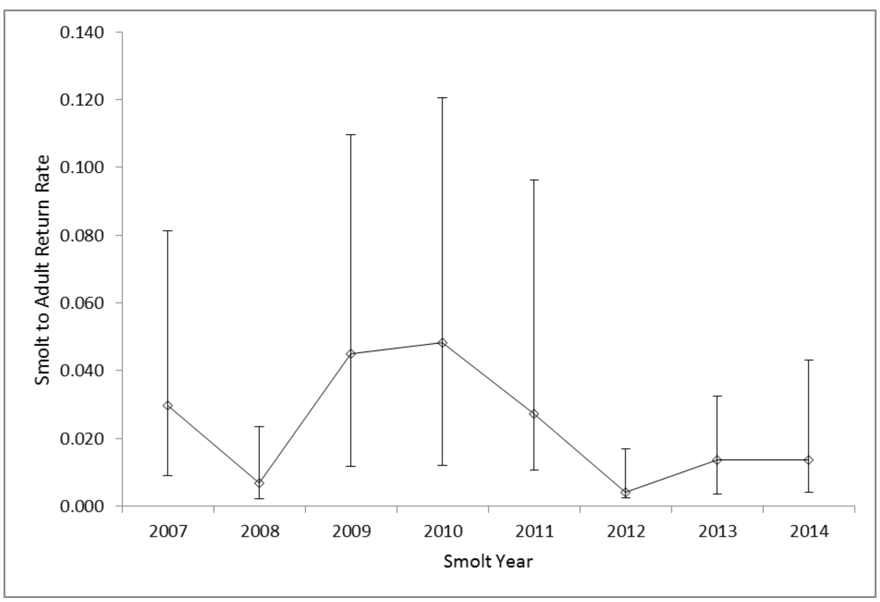


Figure 16. Smolt to Adult Return estimates with 95% confidence bounds. Freshwater Creek coho smolts ocean entry years 2007-2014.

Published values of marine survival for wild populations of coho salmon range from 29% to 0.6% and average near 10% (Table 7). Estimates of coho salmon marine survival from Freshwater Creek for 2007 through 2014 smolt cohorts are consistently estimated to be below this average.

Table 7. Mean, minimum and maximum Smolt-adult survival rates for wild and hatchery Pacific coho salmon populations (Oncorhynchus kisutch).

Coho Population	Type	Mean	Min	Max	Years	No.	Statistical Method	Sources
Auke Creek, AK	W	20.3%			1980-2004	24	unknown	Shaul 07
Berners River, AK	W	17.6%			1990-2004	14	unknown	Shaul 07
Hugh Smith Lake, AK	W	12.9%			1984-2004	20	unknown	Shaul 07
Taku River, AK	W	12.0%			1992-2004	12	unknown	Shaul 07
Lachmach River, B.C. (north)	W	10.0%			1988-2003	25	unknown	Shaul 07
Zolzap Creek, B.C. (north)	W	5.9%			1993-2004	11	unknown	Baxter, Pers. Comm. [1]
Black Creek, B.C. (south)	W	7.1%			1986-2004	18	unknown	Shaul 07
1986-1994	W	10.0%			1986-1994	8	unknown	
1995-2004	W	4.0%			1995-2004	9	unknown	
Salmon River, B.C. (south)	W	8.5%			1987-2004	17	unknown	Shaul 07
1986-1994	W	12.0%			1986-1994	8	unknown	
1995-2004	W	5.0%			1995-2004	9	unknown	
Big Beef Creek, WA (Puget Sound)	W	17.2%			1979-2003	24	unknown	Volkhardt, Pers. Comm. [1]
1992-1999		13.0%			1992-1999	7	unknown	
1978-1989		20.0%			1978-1989	11	unknown	
Deschutes River, WA (Puget Sound)	W	13.1%			1980-2004	24	unknown	Volkhardt, Pers. Comm. [1]
Queets River, WA	W	5.5%	1%	7%	1982-2003	21	unknown	Wang, Pers. Comm. [1]
Bingham Creek, WA	W	4.4%	1%	24%	1983-2004	21	unknown	Volkhardt, Pers. Comm. [1]
Skykomish River, WA	W	11.0%		24%	1992-1999	7	unknown	Lawson. Pers. comm.[1]
	W	16.0%			1978-1989	11	unknown	
Robertson Creek, B.C.	H	5.0%	>0%	10%	1975-2004	19		Shaul 07
Toboggan Creek, B.C. (Skeena River)	H	4%	0.5%		1988-2004	16		Shaul 07
Oregon Production Area	H		2.4%	4.6%	1999-2003	4	(Adult + Jack Returns) / # of smolts released	Daly et al. 09
1975-1991		4.2%			1975-1991	16		Shaul 07
1992-1999		0.5 -1.3%			1992-1999	7		Shaul 07
2000-2004		3.2%			2000-2004	4		Shaul 07
N.F. Scapoose Creek, OR	W		2.8%	9.3%	1997-2004	8	# female spawners / .5(Smolt Production)	Suring et al 09
N.F. Nehalem River, OR	M		1.7%	7.5%	1996-2004	9	# female spawners / .5(Smolt Production)	Suring et al 09
E.F. Trask River	W		6.8%	6.9%	2003-2004	2	# female spawners / .5(Smolt Production)	Suring et al 09
Mill Creek (Siletz River), OR	W		0.6%	7.2%	1995-2004	10	# female spawners / .5(Smolt Production)	Suring et al 09
Mill Creek (Yaquina River), OR	W		1.3%	17.6%	1995-2004	10	# female spawners / .5(Smolt Production)	Suring et al 09
Cascade Creek (Alsea River), OR	W		0.7%	9.2%	1996-2004	9	# female spawners / .5(Smolt Production)	Suring et al 09
W.F. Smith River (Umpqua), OR	M		1.2%	20.9%	1996-2004	9	# female spawners / .5(Smolt Production)	Suring et al 09
Winchester Creek (Coos Bay), OR	M		0.1%	9.9%	1998-2004	7	# female spawners / .5(Smolt Production)	Suring et al 09
Southeast Alaska	M	15.20%			1990-2000	10	CWT Mark-Recapture (Catch + Escapement)	Shaul et al. 2003, NSRAA 2005 [2], PSMFC 2006 [2]
Bear Lake, Alaska	W	19.89%				20	(catch + escapement) / # of Smolts	Vincent-Lang 92 [3]
Black Creek, B.C.	W	4.44%				2	(catch + escapement) / # of Smolts	Clark & Irvine 89 [3,4]
Campbell River, B.C.	W	6.13%				1	(catch + escapement) / # of Smolts	Schubert & Zallen 90 [4]
Chilliwack River, B.C.	W	4.14%				3	(catch + escapement) / # of Smolts	Schubert & Zallen 90 [3]
Qualicum River, B.C.	W	9.68%				15	(catch + escapement) / # of Smolts	Fraser et al. 83 [3,4]
Salwein Creek, B.C.	W	6.29%				1	(catch + escapement) / # of Smolts	Federenko & Cook 82 ; Schubert & Zallen 90 [4]
Salmon River (Langley), B.C.	W	8.30%				6	(catch + escapement) / # of Smolts	Schubert et al. 74; Ricker 81 [4]
Salmon River, B.C.	W	6.69%				3	(catch + escapement) / # of Smolts	Schubert & Kalnin 90 [3,4]
Upper Pitt River, B.C.	W	16.94%				2	(catch + escapement) / # of Smolts	Schubert & Federenko 85 [4]
Birkenhead River, B.C.	W	24.38%				1	(catch + escapement) / # of Smolts	Schubert & Zallen 90 [4]
Southern British Columbia	M		<1%	>30%	1973-1995		CWT Mark-Recapture	Walters & Ward 98
15 Washington Hatchery Stocks	H		<1%	6%	1970-1991		Linear Regression of CWT Mark-Recapture	Ryding & Skalski 99
Carnation Creek, B.C. 1+ Coho	W	13.8%	5.3%	23.4%	1972-1988		Expanded Return / Smolt #	Holtby et al 90
Carnation Creek, B.C. 2+ Coho	W	16.6%	7.7%	29.9%	1972-1988		Mark-recapture escapement, adjusted	
Bingham Creek, WA (Chehalis R.)	W	4.48%	1.0%	7.8%	1980-1983		CWT Mark-Recapture (Catch + Escapement)	Seiler 89
Simpson Hatchery, WA (Chehalis R.)	H	2.45%	1.2%	4.5%	1980-1983		CWT Mark-Recapture (Catch + Escapement)	Seiler 89
Big Creek, OR*	H		1.16%	4.27%	1982		CWT Mark-Recapture (Catch + Escapement)	Mathews & Ishida 89
Coos Bay, OR*	H		0.95%	7.89%	1985		CWT Mark-Recapture (Catch + Escapement)	
Oregon Wild	W	12.06%	4.2%	18.4%	1961-1986		data from McGie; ODFW Records	Emlen et al. 90
Oregon Public Hatchery	H		1.4%	9%	1961-1986		data from McGie; ODFW Records	
Oregon Private Hatchery	H		0.6%	6.3%	1978-1986		data from McGie; ODFW Records	
Oregon Production Area- Weak Upwelli	W	7.0%	4.00%	12.70%	1960-1981	13	escapement + harvest / McGie Smolt #'s	Nickelson 86
Oregon Production Area- Strong Upwell	W	7.4%	4.40%	9.60%	1960-1981	9		
Oregon Production Area- Weak Upwelli	H	3.4%	2.20%	5.00%	1960-1981	13	escapement + harvest / McGie Smolt #'s	Nickelson 86
Oregon Production Area- Strong Upwell	H	8.0%	5.70%	10.50%	1960-1981	9		
Rosewall Creek, Vancouver Island B.C.	W/H		3.13%	45.49%	1976	1	% return of smolts nose tagged with CWT	Bilton et al. 82
			3.13%	11.58%	1976	1		
May Release			12.39%	19.02%	1976	1		
June Release			24.74%	43.34%	1976	1		
July Release			4.82%	20.17%	1976	1		
Washington State Hatcheries	H	7%	0.20%	24.70%	1971-1973	4	% return of smolts nose tagged with CWT	Bilton et al. 82
B.C. Production Hatcheries	H	25%	0.70%	48.30%	1971-1973	4	% return of smolts nose tagged with CWT	Bilton et al. 82
Waddell Creek, CA	W	4.95%	0.98%	7.72%	1933-1937	4	% return of marked smolts (expanded estimate)	Shapovalov & Taft 54
Waddell Creek, CA	W	2.3%	0.60%	5.40%	1932-1937	5	% return of marked smolts (observed)	Shapovalov & Taft 54

* Excluding Jacks

Sources: 1 = Shaul 07; **2 =** Weitkamp 08; **3 =** Bradford 95; **4 =** McGurk 96

Survival (S) is expressed as percentage of smolts to reach maturity and enter Freshwater. Statistical method describes the study specific approach to calculating survival, "No." is the number of brood years used to calculate mean S, and "Years" is the timeframe of study. "Type" indicates whether the stock is wild (W), hatchery (H), mixed (M), or a wild stock reared and released from hatchery (W/H).

4.2.2 Juvenile coho salmon over-winter survival and pre-spring emigration

Over-winter survival of juvenile coho salmon has been suggested as a limiting life stage for coho salmon (Sollazi et al. 2000). In Freshwater Creek over-winter survival appears variable across years and reaches above the HFAC Weir site (Figure 16). The large differences in apparent survival between reaches, and life history type, however, 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, Tchaplinski and Hartman 1983, Bustard and Narver 1975).

Winter Survival of spring migrating smolts in Freshwater Creek ranged from 3% to 49% 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 and abundance of coho salmon is critical for assessing extinction risk and evaluating responses of populations to habitat degradation and restoration. However, these estimates are hampered by a lack of formal methodology to deal with variation in life history traits exhibited by juvenile coho salmon. Here, we address this issue by evaluating a potential bias in survival and smolt production estimates associated with a common sampling design. We accomplished this with a mark-recapture study of six cohorts of juvenile coho salmon in Freshwater Creek.

Estimates of smolt production for a coho 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 populations (e.g. overwinter survival of juveniles, marine 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 migrate downstream prior to the spring smolt migration (Chapman 1962; 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 marine survival 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 six 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. Consistent with recent studies in other regions (Roni 2012; Koski 2009), and within Freshwater Creek (Rubenack 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 may be an important life history characteristic expression. These nomadic fish may significantly contribute to the returning Adult population (Roni et al. 2012, Cornwell et al. 2001) in their natal stream. Another advantage is that nomads might colonize other freshwater habitats that do not currently support spawning populations of coho (Cornwell et al. 2001). Recent habitat restoration, reconnecting freshwater and saltwater ecotones, in Humboldt Bay may increase survival of nomadic coho. Coho which rear successfully in these non natal streams may return as adults and re-colonize newly restored habitat.

5 RECOMMENDATIONS

Much recent focus has been placed on restoration of lower basin, off channel or seasonal habitat for enhancing over-winter capacity for juvenile coho salmon. Data presented here justify this approach and we recommend that these efforts continue to be taken. Specifically, the low gradient areas of lower Freshwater Creek below the LMS trap site in the BHH reach, and lower Ryan Creek should be examined for possible over-winter off channel restoration sites. Attractive restoration sites would presumably be areas where there is the potential to enhance off channel rearing habitat that provides connectivity to the main channel such that fish can find refugia during high discharge events and have the ability to return to the main channel as flows recede. These habitats need not be suitable for year round rearing as winter appears to be when these habitats are important. This type of restoration will only be effective if there are enough fish to seed them. Data presented here imply the importance of lower basin habitats, but also that these areas act as a sink for juveniles once the stream habitat carrying capacity has been reached. Factors leading to increased and sustainable redd emergent success must also be addressed, to fully realize the effects of restored lower basin habitat. The interaction between adult abundance, redd emergent success and over-winter habitat dictates that restoration will be most successful if habitat requirements of multiple life stages are addressed simultaneously.

Stage to stage stock-recruit modeling is a classical technique to develop population models. The development of a realistic population model should be viewed as a tool to inform restoration and test restoration scenarios rather than a scientific end. A realistic quantitative limiting factors life cycle model should be based not only on habitat or reach specific productivity and carrying capacities, but also integrate density and environmental factors influencing life stage specific survival and redistribution of fish. In the context of the recovery process, this type of modeling should be used to identify and test potential restoration actions, as a tool for management. This approach provides a conceptual framework that incorporates scientific understanding of the ecology of salmon and the interaction with their habitat.

The development of a population model utilizing this approach requires many years (i.e. 15 minimum) of data at multiple spatial scales for one population. Therefore, we recommend that all the LCM station data collected in coastal California be evaluated for potential use in a single generalized limiting factors life cycle model. This meta-data analysis may seem to be expensive and unnecessary in light of basic data and information needs, but this is a short-sighted perception. In the long run, research toward and production of a realistic limiting factors life cycle model will reduce monitoring and implementation costs if it is able to quantify limiting factors and the management actions required to address impairments; refine monitoring indicators to increase sensitivity to management actions and biological processes; and reduce, or at least quantify, uncertainty arising from large-scale environmental factors such as climate and ocean productivity change (e.g. Su et al. 2003).

In this study we estimate marine survival using smolt to adult tag returns at the HFAC Weir. We recommend the inclusion of Pit Tag detection stations as recapture points in order to estimate SAR. We would also recommend comparing PIT tag detection only models with weir only models. Several LCM stations have PIT tag stations and no weir and would benefit from this exercise.

Drought conditions which persisted during the years 2013-2015 may change the survival of anadromous fish within Freshwater Creek. Adult run size returning from these drought years may give us a glimpse into what these animals may encounter in a changing ecosystem. Continuing our monitoring efforts is critical to capture the possible effects of drought on coho populations during the next two years of adult data collection.

6 References

Adams, P., L. B. Boydstun, S. P. Gallagher, M. K. Lacy, T. McDonald, and K. E. Shaffer. 2011. *California Coastal Salmonid Population Monitoring: Strategy, Design, and Methods*. *Fish Bulletin* No. 180. California Department of Fish and Wildlife.

Amstrup, S.C., T.L McDonald, and F.J.B. Manly Editors. 2005. Handbook of Capture – Recapture Analysis. Princeton University Press. 313p.

Anderson, D.R., K. Burnham and G.C. White. 1994. AIC Model selection in overdispersed capture-recapture data. Ecology 75: 1780-1793.

Bell, E., Duffy W.G., Roelofs T.D.. (2001) Fidelity and Survival of Juvenile Coho Salmon in Response to a Flood. Transactions of the American Fisheries Society 130:3, 450-458.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Ministry Agirculture, Fisheries and Food, Fisheries Investigation Series 2, No. 19. London, England.

Bjorkstedt, E. (2005). DARR 2.0: updated software for estimating abundance from stratified mar-recapture data. NOAA Tech. Memo. NMFS-SWSC-368. 13 p.

Burnham, K. P., G. C. White, et al. (1995). Model Selection Strategy in the Analysis of Capture-Recapture Data. Biometrics 51(3): 888-898.

Bustard, D. R., and D. W. Narver. 1975b. Preferences of juvenile coho salmon (Oncorhynchus kisutch) and cutthroat trout (Salmo clarki) relative to simulated alteration of winter habitat. Journal of the Fisheries Research Board of Canada 32:681–687.

CDFG (California Department of Fish and Game). 2002. Status review of California coho salmon north of San Francisco. Report to the California Fish and Game Commision, April 2002.

CDFG (California Department of Fish and Game). 2004. Recovery strategy for California coho salmon. Report to the California Fish and Game Commission. 594 pp.

CDFG (California Department of Fish and Game). 2010. Humboldt Bay Juvenile Salmonid Investigations. Annual Performance Report. Federal Aid in Sport Fish Restoration Act. Grant Number F-137-R. Project No. 67.

Cederholm, C.J., Bilby, R.E., Bisson, P.A. Bumstead, T.W., Fransen, B.R., Scarlett,W.J. & Ward, J.W. 1997, Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington steam, NorthAmerican Journal of Fisheries Management, vol. 17,pp. 947–63.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications on Statistics 1:131.

Chapman. D. W. 1962. Aggressive Behavior in Juvenile Coho Salmon as a Cause of Emigration. Journal Fish eries Reasearch Board Canada, 19(6), 1047-1080.

Chesney W.R., Adams C.C., Crombie W.B., Langendorf H.D., Stenhouse S.A., and Kirbey K.M. Shasta River Juvenile Coho Habitat and Migration Study. Prepared for U.S. Bureau of Reclamation, Klamath Area Office by California Department of Fish and Game.

Cooch, E.G. and G.C. White, editors. 2006. Program MARK a gentle introduction, 5th edition. Available: www.phidot.org/software/mark/docs/book/. Accessed 2006 October.

Cormack, R.M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51, 429-438.

Cornwell, T.J., D.L. Botom, and K.K. Jones. 2001. Rearing of juvenile salmon in recovering wetlands of the Salmon River Estuary. Oregon Department of Fish and Wildlife Information reports 2001-2005. Oregon Department of Fish and Wildlife, Portland, Oregon, USA.

Ebersole, J.L., P.J. Wingington, J.P. Baker, M.A. Cairns, M.R. Church, B.P. Hansen, B.A. Miller, H.R. Lavigne, J.E. Compton and S.G. Leibowitz. 2006. Juvenile Coho Salmon Growth and Survival across Stream Network Seasonal Habitats. Transactions of the American Fisheries Society 135:1681-1697.

Efron, B. & Tibshirani, R. 1993, An Introduction to the Bootstrap, Chapman and Hall, London.

Federal Register. 2000. Endangered and threatened species: Threatened status for one steelhead Evolutionarily Significant Unit (ESU) in California. Federal Register, Washington D.C. 61:41514-41612.

Gallagher, S. P. and M. Knechtle (2005). Coastal northern California salmonid spawning survey protocol. 30 p.

Good, T. P., R. S. Waples, and P. Adams. 2005. Updated status of Federally listed ESUs of West Coast salmon and steelhead. U. S.Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-66.

Hauer, J.J. 2013. Overwinter Survival and Growth of Juvenile Coho Salmon, Oncorhynchus Kisutch, in Freshwater Creek, California. Masters Thesis. Humboldt State University. 87pp.

Hankin, D. G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Canadian Journal of Fisheries and Aquatic Sciences 41:1575–1591.

Hankin, D.G., and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45: 834-844.

Hilborn, R. and C. Coronado (1998). Spatial and Temporal Factors Affecting Survival in Coho and Fall Chinook Salmon in the Pacific Northwest. Bulletin of Marine Science 62(2): 409-425.

Horton, G.E., and B.H. Letcher. 2008. Movement patterns and study area boundries: influences on survival estimation in capture- mark- recapture studies. Oikos 117:1131-1142.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52: 225-247.

Koski, K V. 2009. The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. Ecology and Society 14(1): 4.

Lebreton, J.D., K. P. Burnham, et al. (1992). Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62(1): 67-118.

Manly, B. J. F. 1997. Randomization, Bootstrap and Monte Carlo methods in Biology. London: Chapman & Hall.

Miller, B.A., and S. Sadro. 2003. Residence Time and Seasonal Movements of Juvenile Coho Salmon in the Ecotone and Lower Estuary of Winchester Creek, South Slough, Oregon. Transactions of the American Fisheries Society 132:546-559.

McElhany, P., M.H. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Vaible salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-NWFSC-42, 156p.

NMFS (National Marine Fisheries Service). 1997. Endangered and threatened species: threatened status for southern Oregon/northern California coast evolutionarily significant unit (ESU) of coho salmon. Federal Register 62: 24588-24609.

NMFS (National Marine Fisheries Service). 1999. Endangered and Threatened Species: Threatened Status for two Chinook salmon Evolutionarily Significant Units (ESUs) in California; final rule. 50 CFR Part 223. Federal Register 64: 50394-50415.

NMFS (National Marine Fisheries Service). 2005. Endangered and Threatened Species: final listing determinations for 16 ESUs of west coast salmon, and Final 4(d) protective regulations for threatened salmonid ESUs. Federal Register 70: 37160-37204.

NCRLT (North Coast Regional Land Trust). 2010. Restoring Freshwater Farms Reserve. Spring 2010. Pg 3.

Paulik, G. J. 1973. Studies of the possible form of the stock-recruitment curve. Rapports et Proces-Verbaux des Reunions, Conseil International pour L'Exploration de la Mer 164: 302-315.

Pollock, K. H., J. E. Hines, et al. (1985). Goodness-of-fit tests for open capture-recapture models. Biometrics 41(2): 399-410.

Prentice, E.F., T.A. Flagg, C. McCutcheon. 1990. Feasability of using implantable passive integrated transponder (PIT) tags in Salmonids. Fish Marking Techniques. American Fisheries Society Symposium 7. Bethesda Maryland, 879p.

Prentice, E., D. Maynard, et al. (1994). Study to determine the biological feasibility of a new fish tagging system. Portland, Or, Bonneville Power Administration: 250.

Pess G.R., Kiffney P.M., Liermann M.C., Bennett T.R., Anderson, J.H., and Quinn T.P. 2011. The Influences of Body Size, Habitat Quality, and Competition on the Movement of Juvenile Coho Salmon during the Early Stages of Stream Recolinization. Transactions of the American Fisheries Society. Vol. 4, Issue 4. Pgs. 833-897.

Quinn, T. P., and N. P. Peterson. 1996. The influence ofhabitat complexity and fish size on over-winter survivaland growth of individually marked juvenilecoho salmon (Oncorhynchus kisutch) in Big BeefCreek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53:1555–1564.

Ricker, W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin of the Fisheries Research Board of Canada. Bull 191. 382 p.

Ricker, S. J., D. Ward, C. Anderson, and M. Reneski. 2014. Results of Freshwater Creek Salmonid Life Cycle Monitoring Station 2010-2013. California Department of Fish and Game, Anadromous Fisheries Resource Assessment and Monitoring Program, 50 Ericson Ct., Arcata, CA 95521.

Ricker, S. J. (2003). 2002-2003 Annual report results of juvenile salmonid downstream migrant trapping conducted on Freshwater Creek. Arcata, Department of Fish and Game.

Roni P., Bennett T., Holland R., Pess G., Hanson K., Moses R., McHenrey M., Ehinger W., and Walter J. 2012. Factors Affecting Migration Timing , Growth and Survival of Juvenile Coho Salmon in Two Coastal Washington Streams. Transactions of the American Fisheries Society. Vol. 141: 890-906.

Rubenack J.J., Ricker S., Anderson C., Wallace M., and Ward D.M. 2015. Early Emigration of Juvenile Coho Salmon: Implications for Population Monitoring, Transactions of the American Fisheries Society, 144:1, 163-172.

Sarndal, L. C.-E., Swensson, B. & Wretman, J. (1992). Model Assisted Survey Sampling. New York: Springer-Verlag.

Seber, G.A.F. 1965. A note on multiple-recapture census. Biometrica 52: 249-259.

Seiler, D., P. Hanratty, S. Neuhauser, P. Topping, M. Ackley, and L. E. Kishimoto. 1994. Annual performance report October 1992 – September 1993: wild salmon production and survival evaluation. Washington Department of Fish and Wildlife, Olympia.

Shapovalov, L. and A.C. Taft. 1954. The life histories of the steelhead rainbow trout (Salmo gairdneri gairdneri) and silver salmon (Onchorhynchus kisutch) with special reference to Waddell Creek, California, and recommendations regarding their management. California Dept. Fish Game, Fish Bull. 98. 375pp.

Solazzi, M. F., T. E. Nickelson. (2000). Effects of increasing winter rearing habitat on abundance of salmonids in two coastal oregon streams Canadian Journal of Fisheries and Aquatic Sciences(57): 906-914.

Su, Z., R.M. Peterman, and S.L. Haeseker. 2004. Spatial hierarchical Bayesian models for stock-recruitment analysis of pink salmon (Oncorhynchus gorbuscha). Can. J. Fish. Aquat. Sci. 61: 2471-2486.

Tchaplinsky, R. J. and G. F. Hartman, 1983. Winter distributionof juvenile coho salmon (Onchorhynchus kisutch)before and after logging in Carnation Creek, BritishColumbia, and some implications for overwinter survival. Can. J. Fish aquat. Sci. 40:452-461

Volkhardt G.C., S. L. Johnson, B. A. Miller, T. E. Nickelson, and D. E. Seiler. 2007. Rotary Screw Traps and Inclined Plane Screen Traps. In: Salmonid Field Protocols Handbook Techniques for Assessing Status and Trends in Salmonid and Trout Populations. Johnson D. H., B M. Shrier, J S. O'Neal, J. A. Knutzen, X. Augerot, T.A. Oneil, T.N. Pearsons, Editors. American Fisheries Society, Bethesda, MD.

Wallace, M. 2006. Juvenile salmonid use of Freshwater Slough and tidal portion of Freshwater Creek, Humboldt Bay, California. 2003 Annual Report. California Department of Fish and Game, Inland Fisheries Branch Administrative Report No. 2006-04.

Wallace, M. and S. Allen. 2007. Juvenile salmonid use of the tidal portions of selected tributaries to Humboldt Bay, California. Final Report for contracts P0310534 and P0410504 to California Department of Fish and Game Fisheries Restoration Grants Program. June 2007. 14pp.

Wallace, M., and S. Allen. 2009. Juvenile salmonid use of the tidal portions of selected tributaries to Humboldt Bay, California, 2007-2009. Final Report for contract P0610522 to California Department of Fiswh and Game Fishories Restoration Grants Program. August 2009. 32pp.

White, G.C., and K.P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 (suppl.): S120-139.

Williams, T. H., B. C. Spence, W.G, Duffy, D. Hillemeier, G. Kautsky, T.E. Lisle, M. McCain, T.E. Nichelson, E. Mora, and T. Pearson. 2008. Framework for Assessing Viability of the Threatened Coho Salmon in the Southern Oregon/Northern California Coast Evolutionary Significant Unit. NOAA-TM-NMFS-SWFSC-432. Santa Cruz, CA. December 2008. pp 113.

7 APPENDICES

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

General form of the bias adjusted Petersen estimate 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 smolts (Sec. 3.2.3).

$$\hat{N}_1 = \frac{(M_1 + 1)(C_i + 1)}{R_i + 1} - 1$$

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

$$V(\hat{N}_1) = \frac{(M_1 + 1)^2 (C_i + 1)(C_i - R_i)}{(R_i + 1)^2 (R_i + 2)}$$

Where:

for adult escapement:

i= 1
M= The number of captured adults given an opercle punch

C= The number of carcasses checked for an opercle punch

R= The number of carcasses with recovered opercle punch

And,

for Back calculation of super-population of coho smolts:

i= {1,2}
$\hat{N}_1$= Estimated number of downstream migrants

M_1= Number of fish marked and released downstream during smolt year 1

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

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

Appendix 2. Smolt to Adult Return (SAR) marine survival estimator.

$$\hat{s} = \frac{\sum \hat{N}_i}{M_1}$$

where:
$\hat{s}$ = Smolt to Adult Return survival
M_1= Number of juveniles PIT tagged during migration to the ocean

And:

$$\hat{N}_i = Rj_i \hat{e}_i^{-1}$$

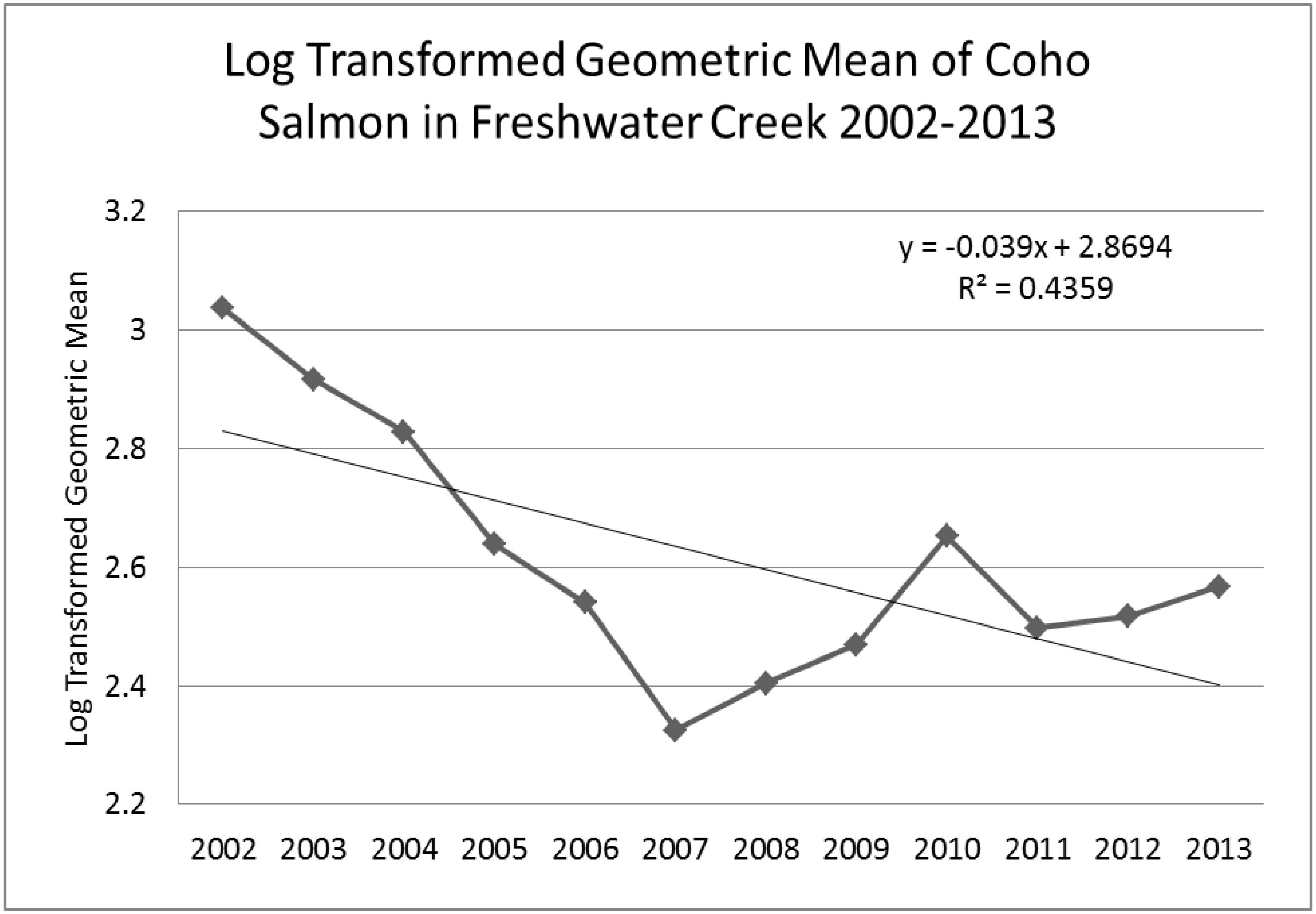
where:
$\hat{N}_i$ = estimated number of fish PIT tagged as juveniles returning as grilse or adults during year *i*
Rj_i= number of fish PIT tagged as juveniles and recovered as adults at the weir during year *i*

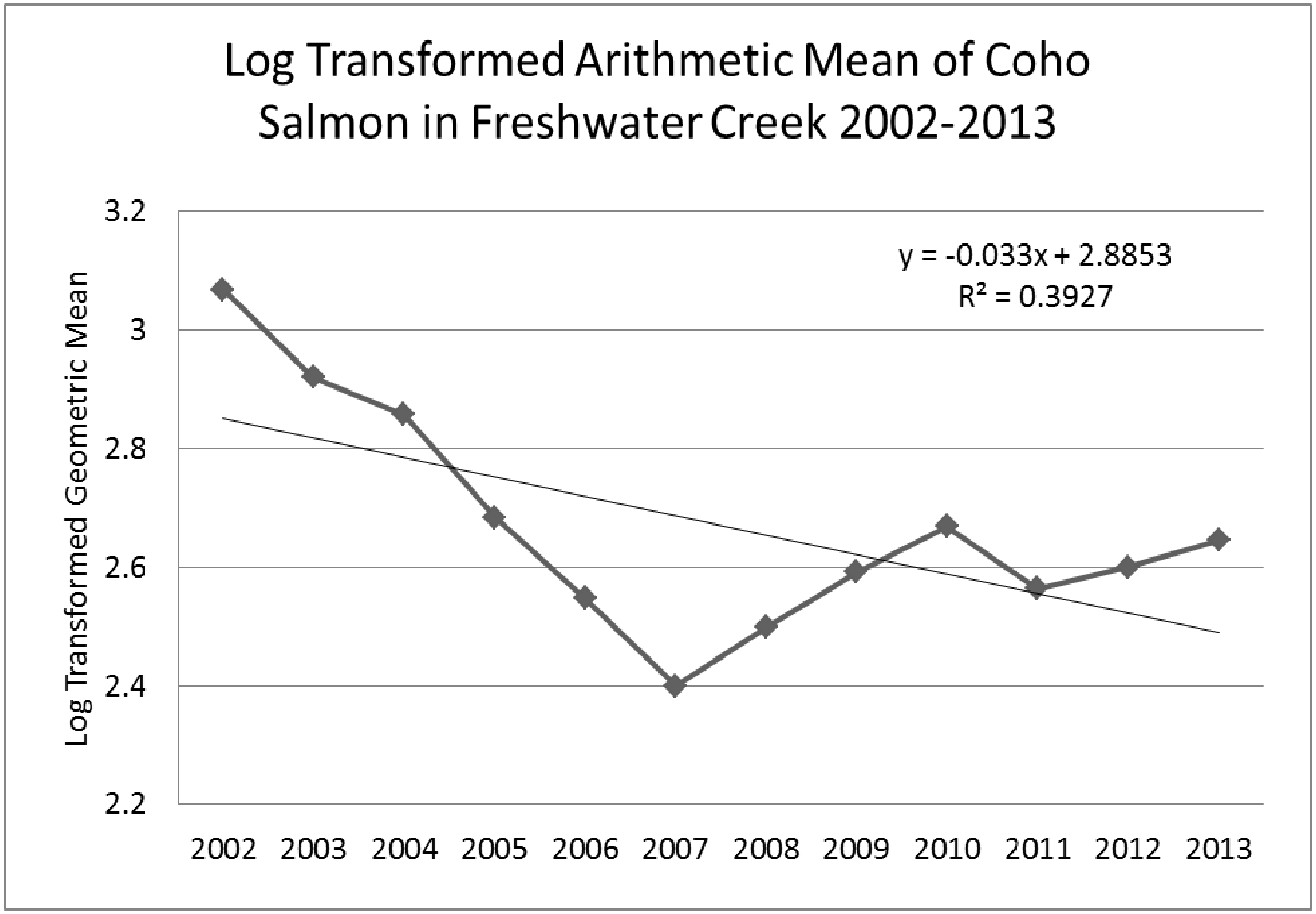
And:

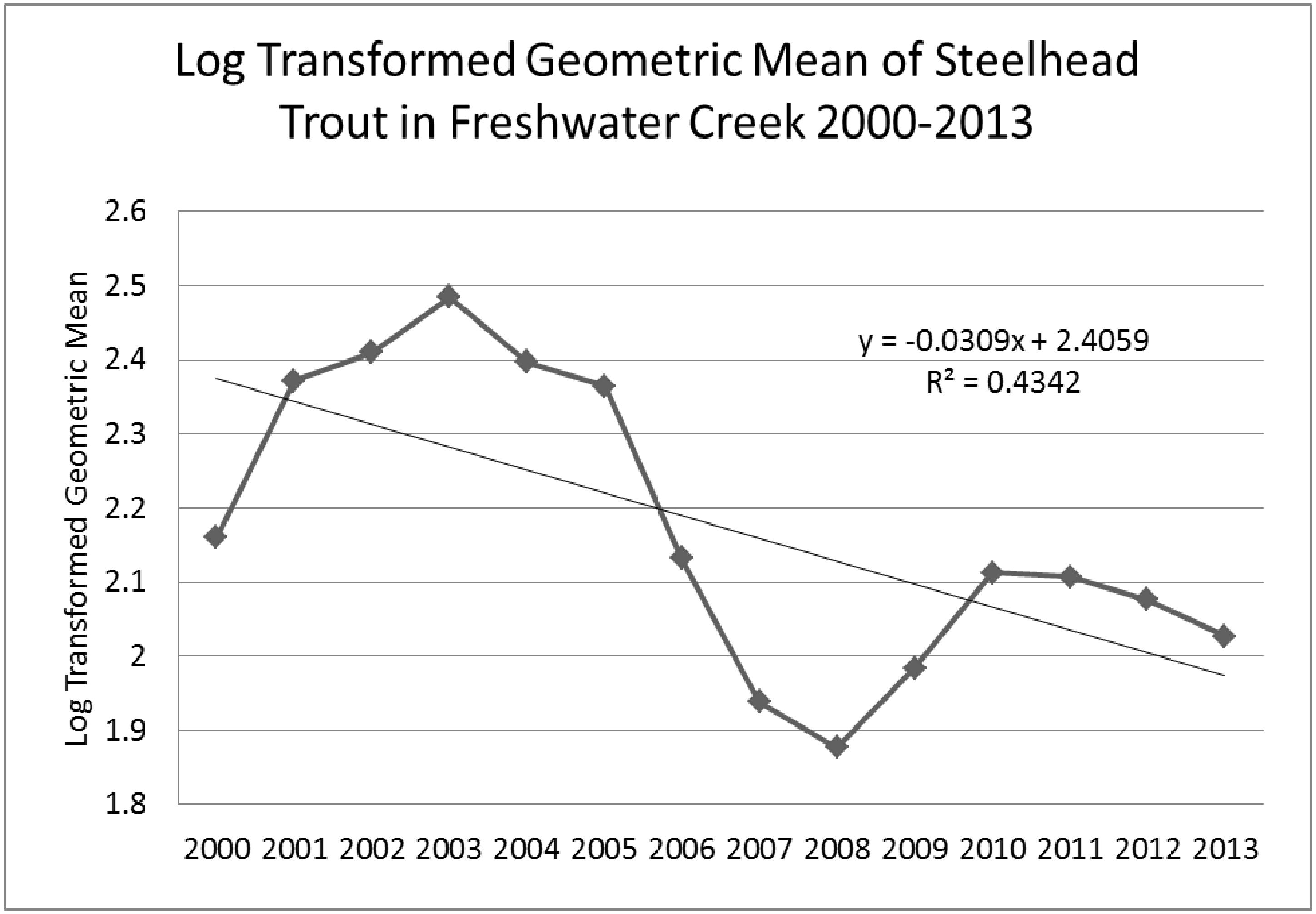
$$\hat{e}_i = (Rc_i Cc_i^{-1}) / (Cw_i Mw_i^{-1})$$

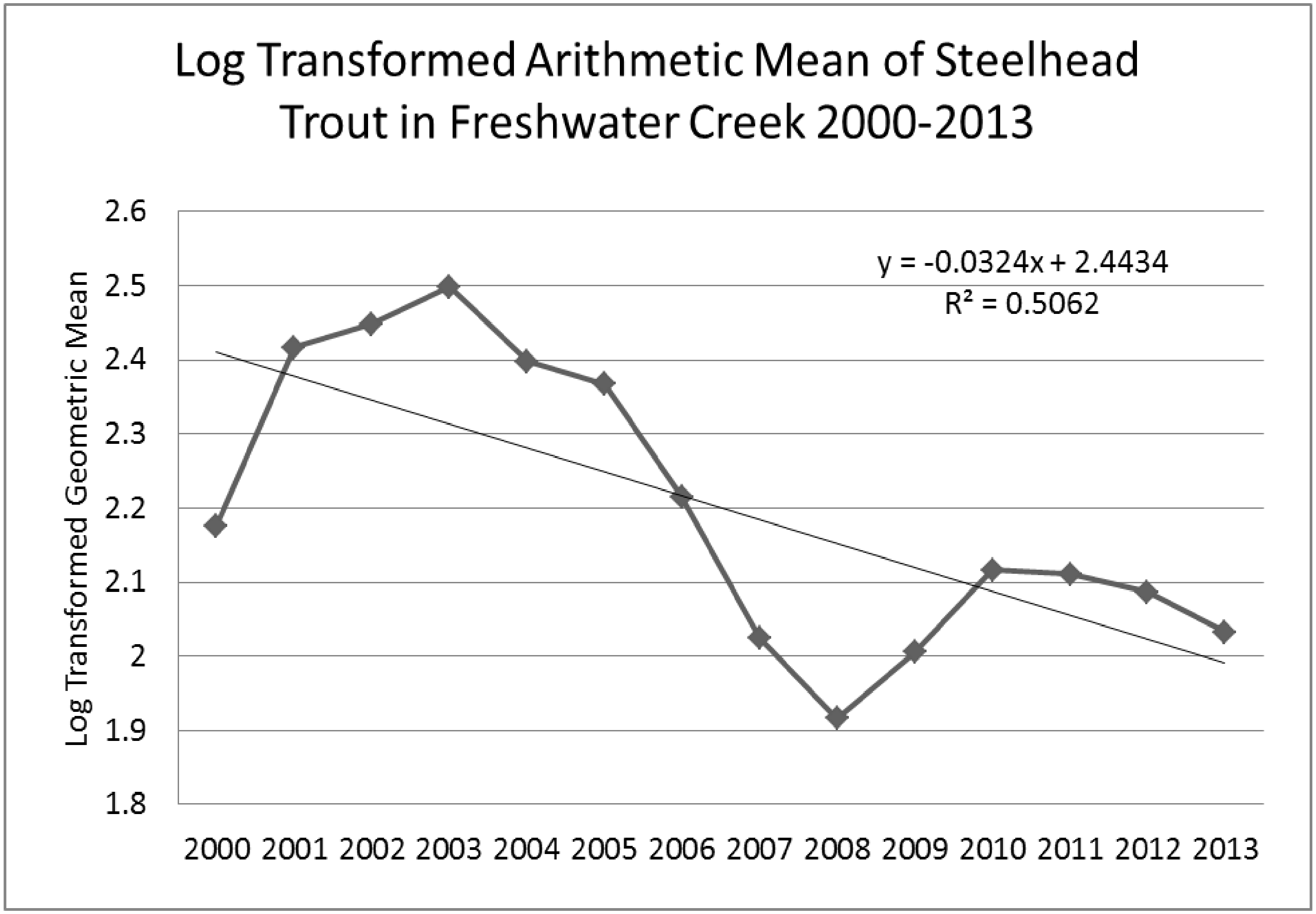
where:
$\hat{e}_i$ = estimated weir trap efficiency during year *i*
Rc_i= Recaptured carcasses having weir opercle punches during year *i*
Cc_i = Total number of carcasses checked for weir opercle punches during year *i*
Cw_i= Number of adult returns to the weir checked for a juvenile PIT tag during year *i*
Mw_i=Number of adult returns to the weir marked with an opercle punch and released above the weir during year *i*

Appendix 3. Log transformed geometric Mean and log transformed Arithmetic means for coho (2002-2013) and steelhead (2000-2013) in Freshwater Creek.




Log Transformed Arithmetic Mean of Coho Salmon in Freshwater Creek 2002-2013
y = -0.033x + 2.8853
R² = 0.3927
Log Transformed Geometric Mean
3.2
3
2.8
2.6
2.4
2.2
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013


Log Transformed Geometric Mean of Steelhead Trout in Freshwater Creek 2000-2013
Log Transformed Geometric Mean
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
y = -0.0309x + 2.4059
R² = 0.4342
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013


Log Transformed Arithmetic Mean of Steelhead Trout in Freshwater Creek 2000-2013
y = -0.0324x + 2.4434
R² = 0.5062
Log Transformed Geometric Mean
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013