Recovery Monitoring of Endangered Coho Salmon in the Russian River: Final Report for Project NA11OAR4170202

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Contents

1 Executive Summary

This report summarizes endangered coho salmon monitoring results collected by University of California Cooperative Extension and CA Sea Grant (UC) in the Russian River watershed from August 2011 through June 2016 in support of the Russian River Coho Salmon Captive Broodstock Program (Broodstock Program). Spawner surveys, downstream migrant trapping, snorkeling surveys, and operation of PIT tag detection systems were used to document abundance, survival, and distribution of coho salmon released from Don Clausen Fish Hatchery into Russian River tributaries. Study streams included Willow, Dutch Bill, Green Valley, and Mill creeks.

Juvenile coho salmon were released annually by the Army Corps of Engineers into the four study tributaries in multiple release groups (age-0 spring and fall, and age-1 smolt). All hatchery-released fish were coded-wire tagged so that origin could later be determined and a fraction were tagged with passive integrative transponder (PIT) tags to evaluate release groups and streams. Using multiple monitoring methods, we tracked hatchery-released fish from the time of release through the adult life stage.

Section 4 describes a smolt abundance and freshwater survival study. From March through June of each year, downstream migrant traps and PIT tag antenna arrays were operated to estimate migration timing, smolt abundance, freshwater survival, winter emigration, size, and growth. Thousands of smolts emigrated from the four monitoring streams each year, with the peak of the migration occurring between mid-April and early-May. On average, stock-to-smolt survival probability was highest for the smolt release group (0.76), intermediate for the fall release group (0.25) and lowest for the spring release group (0.08). Winter emigration probabilities were generally low, but higher in Dutch Bill Creek than in the other three streams. Average smolt size was largest for the smolt release group, the fall release group was intermediate, and the spring release group was the smallest. With the exception of Green Valley Creek, smolt size was larger for hatchery-released fish as compared to natural-origin smolts. Growth rates varied among years and streams, and were highest in Green Valley Creek. The percentage of all smolts captured in the downstream migrant traps that were of natural origin averaged 8% and ranged from 0% to 36%, depending on year and stream.

Section 5 describes an adult abundance and distribution study. From November through April of each year, spawner surveys were conducted and PIT tag antenna arrays were operated in each of the four monitoring streams to estimate the total number, distribution, and migration timing of adult coho salmon returns. Adults were documented returning to each of the four creeks and successfully spawning each year, as evidenced by observations of redds during the winter seasons. Fluctuations in the number of adults returning each year occurred over the study period, but numbers were significantly higher than the near-zero returns during the early 2000s. Adult coho salmon typically entered the mainstem of the river in September or October and then moved into the tributaries to spawn approximately two to three months later when the first significant rain events enabled access. Smolt-to-adult return (SAR) ratios were generally low, averaging 0.7% and ranging from 0% to 1.6% for cohorts 2011-2013 in Willow, Dutch Bill and Mill creeks.

Section 6 describes a juvenile presence and distribution study. From June through October of each year, snorkeling surveys were conducted to document relative abundance and distribution of natural-origin juvenile coho salmon. Natural-origin juveniles were observed in all four creeks in all years that they were expected as a result of spawning activity by returning hatchery-released adults. Relative abundance varied by stream and year but was generally lowest during the summer of 2014, following a winter when the majority of the adults that returned were age-2 and the spawning tributaries were not accessible until February. Distribution of juveniles within streams varied by year.

Overall, the monitoring results described in this report demonstrate that Broodstock Program releases are effectively increasing coho salmon populations within the Russian River watershed. Thousands of smolts are emigrating from Russian River tributaries each year, hundreds of adults are returning, and presence of natural-origin juveniles provide evidence of successful spawning. Despite this success, the Broodstock Program is far from reaching NOAA's recovery target of 10,100 annual adult returns to the Russian River watershed. Through this monitoring work, in combination with other studies we are conducting in the watershed, we have identified low streamflow as a bottleneck to survival for the progeny of hatchery-released fish. Lack of overwinter rearing habitat in Dutch Bill Creek and a partial passage barrier on Mill Creek are other potential limiting factors to long-term recovery.

Another bottleneck for coho salmon recovery in the basin is smolt-to-adult survival (including riverine, estuarine, and marine survival), which appeared low based on the low SAR ratios observed. Little is known about survival of smolts from the point when they leave the tributaries until they enter the ocean, and we recommend supporting studies to better understand this. If there are limiting factors to survival in the mainstem of the river that can be addressed, this will be critical for achieving long-term recovery goals.

Due to unpredictable weather and climate patterns and associated variation in survival among years and streams, we recommend that the Broodstock Program continue its bet-hedging strategy of stocking fish from multiple release groups, primarily the fall and smolt groups. Based on the low stock-to-smolt survival of spring-released fish, and the fact that natural-origin young-of-year are now present in the tributaries, we recommend reducing the spring release stocking to the minimal number of fish that must be stocked due to limited capacity at the hatchery, as well as the relatively small numbers used for oversummer survival studies.

We also recommend continuing the use of streamside tanks as a smolt acclimation strategy. Survival was higher for the tank release groups as compared to the pond release groups in Mill Creek during multiple years of data collection. A new tank site at West Side School on Mill Creek is recommended in place of the pond site.

2 Introduction

In 2004, the Russian River Coho Salmon Captive Broodstock Program (Broodstock Program) began releasing juvenile coho salmon into tributaries of the Russian River with the goal of re-establishing populations that were on the brink of extirpation from the watershed. University of California Cooperative Extension and California Sea Grant (UC) worked with California Department of Fish and Wildlife (CDFW), the US Army Corps of Engineers (ACOE), NOAA's National Marine Fisheries Service (NMFS), and the Sonoma County Water Agency (Water Agency) to design and implement a coho salmon monitoring program to track the survival and abundance of hatchery-released fish. Since the first Broodstock Program releases, UC has been closely monitoring coho populations in four Broodstock Program release streams: Willow, Dutch Bill, Green Valley, and Mill creeks. Operation of PIT tag detection systems, downstream migrant trapping, spawner surveys, and snorkeling surveys are used to estimate smolt abundance, juvenile instream survival, number of returning adults, presence of natural-origin juveniles, and spatial distribution of adults and juveniles in these four watersheds. Data collected from this effort are provided to the Broodstock Program for use in adaptively managing future releases.

In this report, we provide a summary of monitoring activities from 8/1/11 through 6/30/16, funded through NOAA contract NA11OAR4170202 and CDFW contract P133005 (2014 only). Throughout this period, we provided updates of our results to our stakeholders through technical advisory committee meetings, workgroups, presentations, our website, and personal communications with Broodstock Program agency representatives and private landowners. To best accommodate the changing needs of the Broodstock Program, and as a result of our increased technological capacity, we made slight modifications to the methods used during the five-year period. For the purposes of this report, the most recent methods are described. More detailed information and additional reports can be found on our website at http://ca-sgep.ucsd.edu/russianrivercoho.

In 2013, UC, in partnership with the Water Agency and CDFW, began implementation of the California Coastal Monitoring Program (CMP), a statewide effort to document status and trends of anadromous salmonid populations using standardized methods and a centralized statewide database. The CMP monitoring effort expanded the number of coho salmon streams surveyed in the Russian River watershed, complimenting the work described in this report. Results for these additional streams are not included in this report but can be found on our website.

2.1 Study Population: Hatchery Coho Releases

Over the course of the study period, Broodstock Program coho salmon were raised by ACOE personnel at the Don Clausen Fish Hatchery at Warm Springs Dam and released as juveniles into selected Russian River tributaries in three release groups; spring, fall, and smolt. Fish in the spring-release group were stocked as young-of-the-year (yoy) in June, fish from the fall-release group were stocked as yoy in November or December, and fish from the smolt release group were stocked as age-1 smolts in April or May. An additional pre-smolt release occurred in February of 2014 in two streams. Spring, fall and pre-smolt groups were stocked directly into the stream environment. For smolt releases, different acclimation strategies were tested, including retention of fish in streamside acclimation tanks (Dutch Bill and Green Valley creeks) prior to release, retention of fish in a smolt acclimation pond prior to release (Mill Creek), and direct release into the stream environment (Green Valley and Mill creeks).

All hatchery coho salmon received a coded-wire tag (CWT) prior to release so that origin could be determined in the field by scanning fish with a CWT reader. A portion of the juvenile coho salmon released were also implanted with 12.5 mm full duplex (FDX) passive integrated transponder (PIT) tags which allowed for individual tracking of fish through the use of PIT-tag detection systems. Releases into the four monitoring streams over the course of the study period are shown in Table 1.

Table 1. Juvenile coho salmon hatchery releases into four Russian River tributaries, cohorts 2011 through 2015.

Cohort (Hatch Year)	Watershed	Number of Fish Released (Percent PIT-tagged)			
		Spring	Fall	Pre-smolt	Smolt
2011	Willow Creek	0	11,062 (7%)	0	0
	Dutch Bill Creek	1,016 (100%)	9,052 (10%)	0	5,766 (10%)
	Green Valley Creek	1,018 (100%)	12,125 (10%)	0	5,220 (11%)
	Mill Creek	10,131 (19%)	25,014 (10%)	0	5,905 (10%)
2012	Willow Creek	0	22,151 (20%)	0	0
	Dutch Bill Creek	1,045 (100%)	10,038 (20%)	0	6,063 (20%)
	Green Valley Creek	869 (100%)	13,039 (20%)	0	6,082 (20%)
	Mill Creek	8,077 (30%)	16,040 (20%)	0	6,977 (20%)
2013	Willow Creek	0	10,092 (30%)	0	0
	Dutch Bill Creek	1,019 (98%)	12,083 (25%)	0	6,201 (15%)
	Green Valley Creek	210 (100%)	10,187 (34%)	0	6,220 (15%)
	Mill Creek	8,044 (30%)	18,151 (16%)	0	0
2014	Willow Creek	15,393 (15%)	0	15,300 (15%)	0
	Dutch Bill Creek	1,009 (100%)	12,164 (15%)	0	6,152 (15%)
	Green Valley Creek	505 (100%)	15,100 (15%)	15,248 (15%)	6,154 (15%)
	Mill Creek	8,213 (28%)	18,173 (15%)	0	10,512 (15%)
2015	Willow Creek	0	9,032 (30%)	0	0
	Dutch Bill Creek	1,008 (100%)	8,989 (30%)	0	5,018 (30%)
	Green Valley Creek	305 (100%)	8,989 (30%)	0	4,864 (31%)
	Mill Creek	509 (100%)	8,969 (30%)	0	4,775 (31%)

2.2 Study Streams

Willow, Dutch Bill, Green Valley and Mill Creeks were selected by the Broodstock Program as focus monitoring streams where different hatchery release groups of coho salmon could be tracked from the time of release through the adult life stage. In each stream, adult coho salmon spawner surveys were conducted in the winter to estimate the number and distribution of redds, downstream migrant traps were operated in the spring to estimate smolt abundance and instream survival, and summer snorkeling surveys were conducted to document relative abundance and distribution of juveniles. Stationary PIT-tag antenna arrays are also operated year-round in each stream to aid with abundance and survival estimates. Study streams, survey reaches, and monitoring sites are shown in Figure 1.

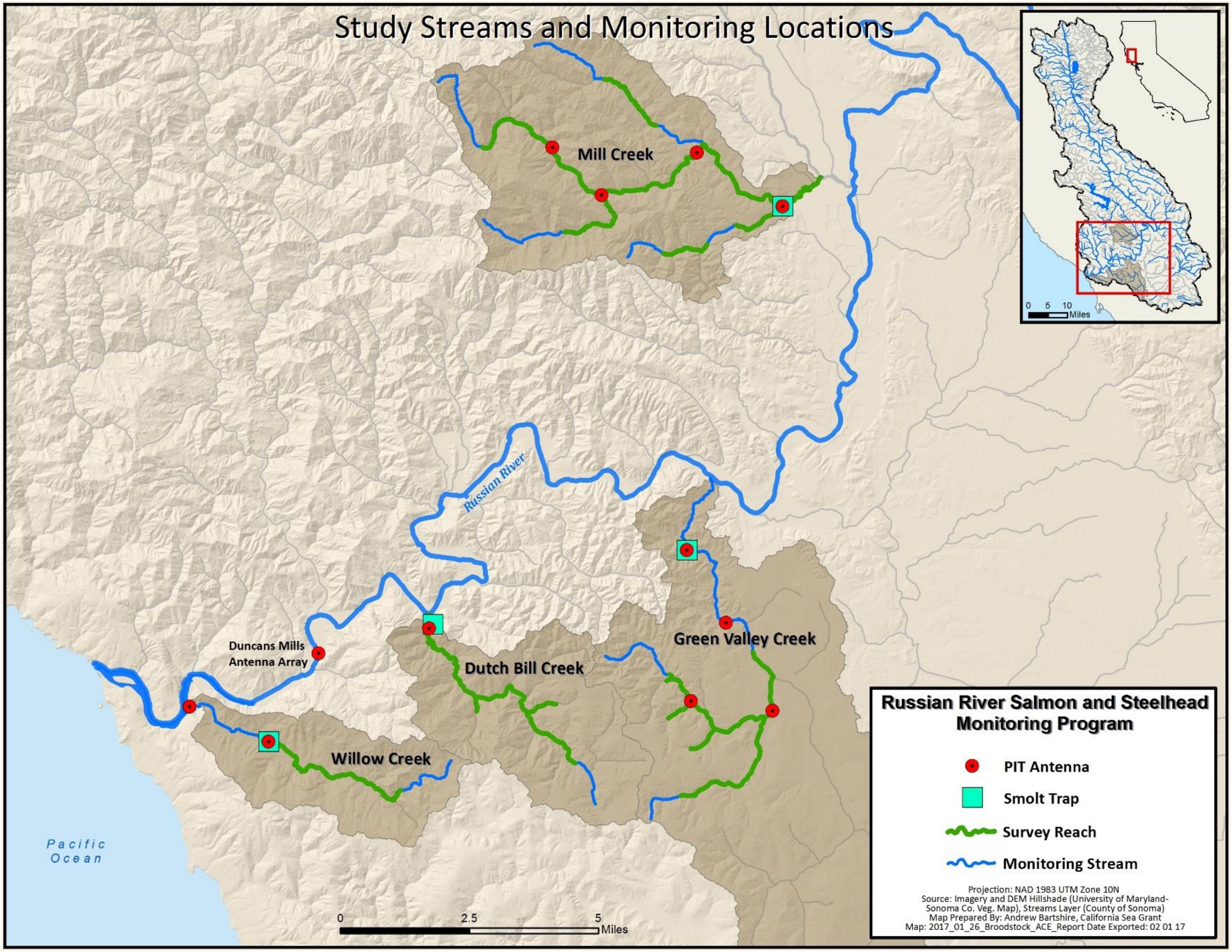

Figure 1. Broodstock Program study streams, survey reaches, and monitoring sites in the Russian River watershed.

2.3 Landowner Access

Because the majority of the study reaches flow through private property representing hundreds of parcels (Figure 2), permission from landowners was required in order to conduct monitoring surveys. As per the request of CDFW, UC assumed management responsibilities of a landowner access database used by Broodstock Program partners including UC, CDFW, ACOE, and the Water Agency. UC staff designed a relational database using Microsoft Access database software in conjunction with ESRI ArcGIS software to manage hundreds of landowner access agreements valid through December 31, 2015. To avoid interruptions in stream access, in May of 2015 a new mailing was sent to approximately 1,000 landowners within the watershed requesting new or renewed access for a five-year period from January 1, 2016 through December 31, 2020. UC staff processed responses to access requests, conducted follow-up calls to non-responders, and corresponded with landowners throughout the study period.

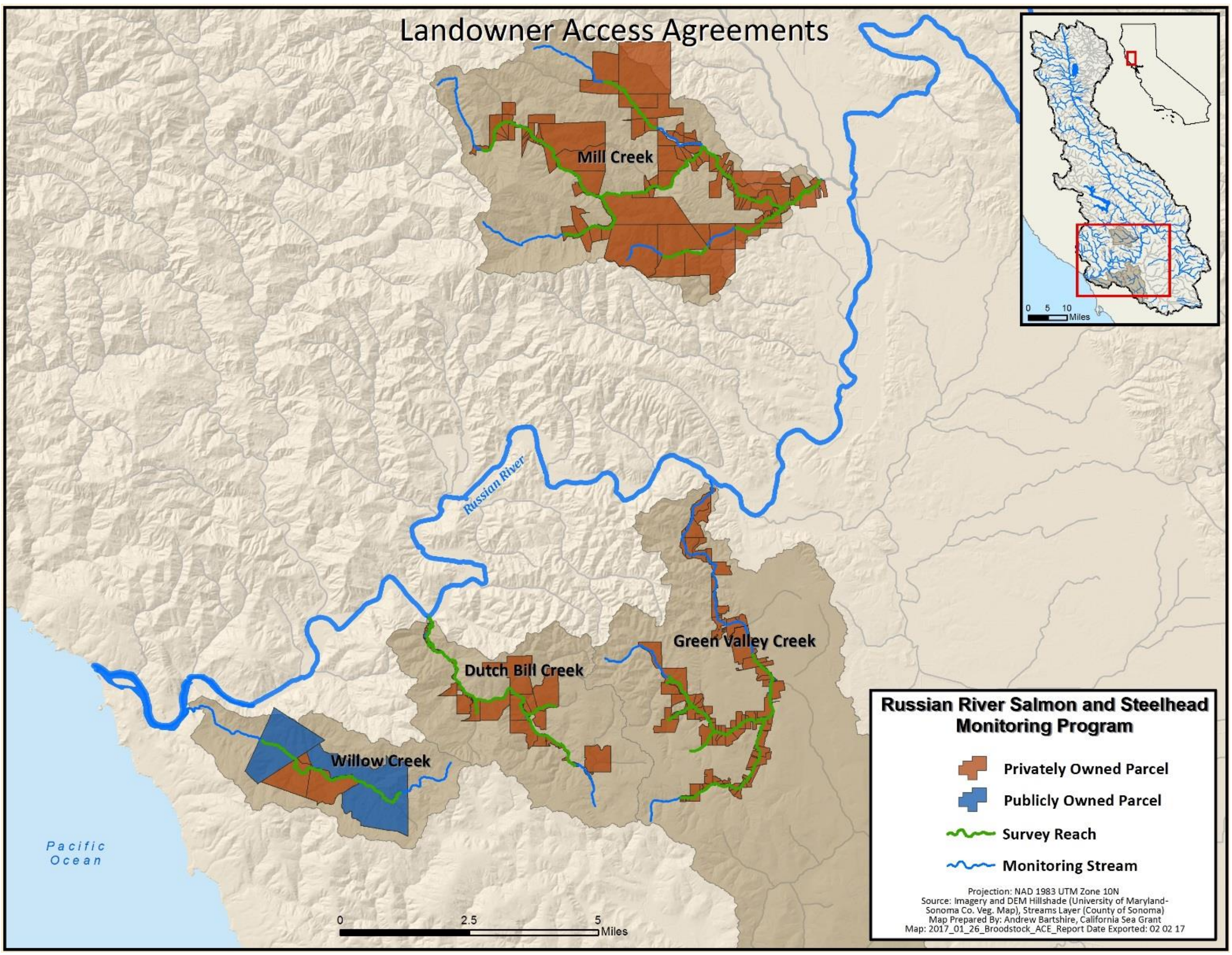

Figure 2. Map showing private and publically-owned parcels adjacent to Broodstock Program monitoring survey reaches.

2.4 Permits

Federal, state, and UC permits were required to conduct the monitoring work described in this report. Monitoring activities were conducted under Section 10(a)1(A) Endangered Species Act permits 10094 (covering take from August 1, 2011 through December 31, 2015) and 18937 (covering take in 2016). Additional permits to perform monitoring over the reporting period included CDFW Scientific Collector's permit # 1034755904, and a UC San Diego Institutional Animal Care and Use Committee permit (Protocol # S12020). All incidental take was reported for each permit as per the requirements of the individual permits.

2.5 Reporting Framework

This report is divided into three general sections that correspond to three life stages of interest to the Broodstock Program, as well as to our different field sampling seasons; 1) smolt abundance and freshwater survival, 2) adult abundance and distribution, and 3) juvenile abundance and distribution. Goals, methods, and results are described in each of the following three sections.

3 Smolt Abundance and Freshwater Survival

The primary goal of this study was to determine whether or not hatchery-released juvenile coho salmon were surviving in the stream environment and migrating out of the tributaries as smolts. A combination of downstream migrant trapping and operation of PIT tag antenna arrays was used to estimate juvenile migration timing, smolt abundance, natural production, freshwater survival, winter emigration, size, and freshwater growth of juvenile coho salmon in Willow, Dutch Bill, Green Valley, and Mill creeks.

3.1 Field Methods

3.1.1 Downstream Migrant Trapping

Downstream migrant (funnel and/or pipe) traps (Figure 3) were operated by UC on Willow and Mill creeks between March and June each year to coincide with coho salmon smolt outmigration. The Green Valley Creek trap was not operated in 2012 through 2014 due to presence of California freshwater shrimp in that creek. After appropriate permitting was secured, UC operated a trap on Green Valley Creek in 2015 and 2016. The Water Agency operated a trap on Dutch Bill Creek during each year from 2011 through 2016 and coho salmon data from this effort were provided to UC for this report. Trapping locations are shown in Figure 1.

Between March and June, downstream migrant traps were tended daily with additional checks during peak outmigration and high flows. During significant storm events, the traps were opened up to prevent injury to fish, avoid loss of equipment, and ensure personnel safety. Each day during the trapping season, captured coho salmon smolts were carefully netted out of the trap box, placed into aerated buckets, and anesthetized using a solution of 0.3 g of tricaine methane-sulphonate (MS-222) per two gallons of water. All fish were then counted, scanned for PIT and CWT tags, and the first 30 coho salmon smolts with a CWT were measured for fork length (mm) and weight (g). Coho salmon smolts with a CWT and no PIT tag beyond the first 30 were tallied, and all PIT-tagged smolts were measured and weighed. Beginning in 2016, a portion of both hatchery and natural-origin coho salmon smolts were PIT-tagged in order to increase sample size for adult return estimates; every fourth non-PIT-tagged hatchery-origin (CWT-only) coho salmon smolt was PIT tagged (25% of all CWT-only smolts), and every second natural-origin (no CWT or PIT tag) coho salmon smolt was PIT tagged (50% of untagged smolts). A genetics sample was collected for each smolt to which a PIT tag was applied by clipping a small corner of the lower caudal fin (1 mm^2) and placing it in an envelope lined with chromatography paper. After workup, biologists waited for fish to thoroughly recover in a separate, aerated bucket before releasing them downstream of the trap. Genetics samples were stored at UC, then sent to NMFS' Southwest Fisheries Science Center for analysis. A proportion of all steelhead and Chinook salmon were measured for fork length (mm) and weight (g), and all other vertebrates and crustaceans were tallied. Data were entered into field computers, downloaded and error-checked upon return to the office, and uploaded into a SQL database.


Figure 3. Mill Creek downstream migrant funnel trap at spring base flows.

3.1.2 PIT Tag Detection Systems

Stationary PIT tag detection systems were operated year-round in stream channels near the mouths of Willow, Dutch Bill, Green Valley and Mill creeks (Figure 1). Multiplexing transceivers, capable of reading FDX PIT tags, were placed in waterproof boxes on the stream bank and powered using AC power with DC conversion systems (Willow, Dutch Bill and Mill creeks) or solar power (Green Valley Creek). Sixteen by two-and-a-half foot antennas, housed in four-inch PVC, were placed flat on top of the streambed and secured with duck bill anchors. The antennas were placed in paired (upstream and downstream), channel-spanning arrays (Figure 4) so that detection efficiency could be estimated and the movement direction of individuals could be determined. Based on test tag trials at the time of installation, read-range in the water column above the antennas ranged from 10” to 20” during baseflow conditions. During storm events, stream depths exceeded 20”, so if PIT-tagged fish were travelling in the water column above that depth they would not be detected on the antennas. The paired arrays were used to estimate antenna efficiency and account for undetected fish. PIT tag detection systems were visited every other week to download data and check antenna status. More frequent visits (approximately daily) were made during storm events. Text files were converted to Microsoft Excel for QAQC procedures and then uploaded to a SQL database.

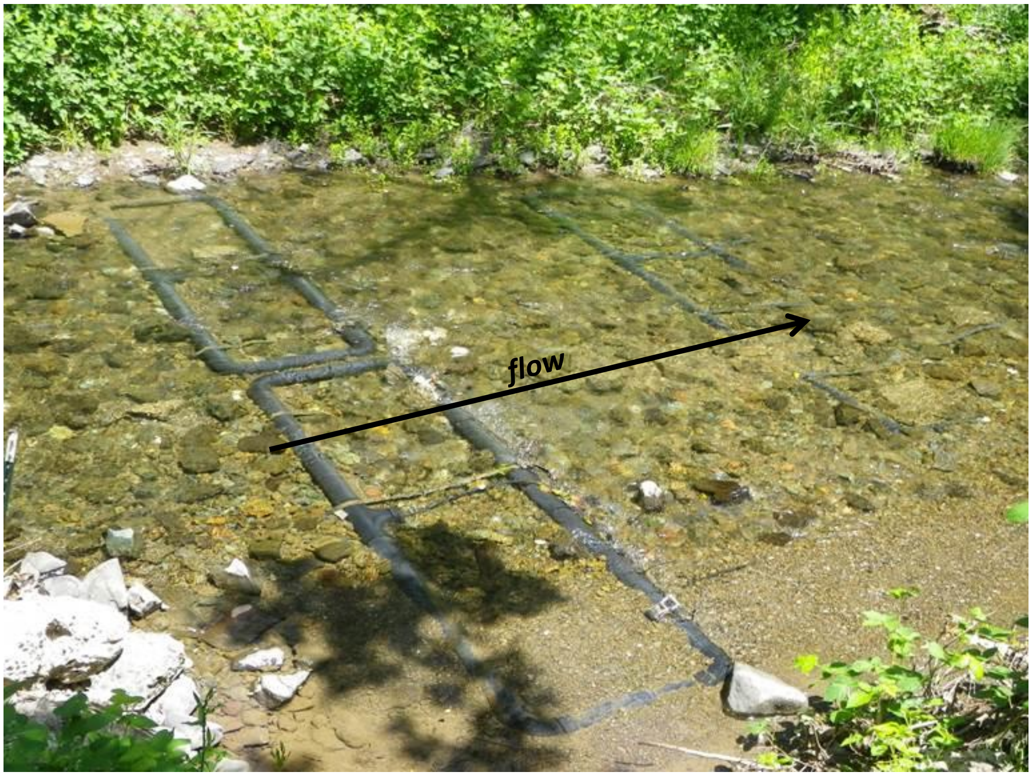

Figure 4. Paired flat-plate PIT tag antenna array on Mill Creek at spring base flows.

3.2 Data Analysis

3.2.1 Smolt Abundance

A two-trap mark recapture design using Program DARR (Bjorkstedt 2005; Bjorkstedt 2010) was used to estimate the total number of coho salmon smolts leaving each creek during the time that each downstream migrant trap was in operation. A PIT tag antenna array located immediately upstream of each trap served as an upstream "trap" where fish were "marked" (marked fish = all PIT tag detections on antenna array), and the smolt trap served as a downstream trap where fish were recaptured. PIT-tagged fish detected at both the antenna array and captured in the trap were considered recaptures, and non-PIT-tagged fish and PIT-tagged fish only detected in the trap (but not the antenna) were considered unmarked fish.

3.2.2 Natural Production

Fish origin (natural or hatchery) was determined for each coho salmon captured in the smolt traps based on the presence of a CWT. Any fish with a CWT present was recorded as a hatchery fish and any fish without a CWT was recorded as a natural-origin fish. These data were used to develop ratios of natural-to-hatchery origin smolts for each stream.

3.2.3 Migration Timing

To document migration timing of hatchery-released juvenile coho salmon past specific antenna and trapping locations (Figure 1), first the minimum detection date following release into the stream was selected for each individually PIT-tagged fish at each site of interest. This dataset of unique detections by site was then used to calculate the total number of individuals detected from each release group (spring, fall or smolt) passing the site each week for each year of data collection. Weekly proportions from October 29 (earliest known date that streams reconnect to Dry Creek or the mainstem of the river) through June 30 were then averaged over all years of data collection and plotted for each stream.

3.2.4 Probability of Survival and Early Winter Emigration

PIT tag detections at antenna and trap sites were used to estimate stock-to-smolt (freshwater) survival and early winter emigration in Willow, Dutch Bill, Green Valley, and Mill creeks. A multistate emigration model (Horton et al. 2011), as implemented in Program MARK (White and Burnham 1999), was used to compare probability of survival and emigration prior to 3/1 for multiple release groups (i.e. spring, fall and smolt) in each of the four monitoring streams.

3.2.5 Size and Growth

All coho salmon smolts measured during downstream migrant trapping operations were used to generate average fork lengths and weights of smolts emigrating from each stream. Measurements of PIT-tagged fish captured in the downstream migrant traps were compared with individual size data collected in the hatchery at the time of tagging to calculate growth rates for individual fish from the time of tagging to the time of capture in the downstream migrant traps. Specific growth rates for length were calculated for individual fish as $(FL_2-FL_1)/(t_2-t_1)$ where FL_1= fork length at hatchery prior to release, FL_2= fork length at the smolt trap, t_1=date measured at hatchery, and t_2= date captured in the smolt trap. Individual growth rates were then averaged by stream and release group.

3.3 Results

3.3.1 Trap Counts and Natural Production

Coho salmon smolts were captured in all years on all streams where downstream migrant traps were operated, with totals by stream and year ranging from 201 to 6,810 (Table 2). Juvenile steelhead (yoy and parr) and smolts were also captured on all streams in nearly all years, though in fewer numbers than coho salmon smolts (Table 2). A small number of Chinook smolts were captured in Dutch Bill and Mill creeks in 2012, 2014, and 2016 (Table 2).

The total number of natural-origin coho salmon smolts captured in all traps each year ranged from 121 in 2013 to 973 in 2015, and percentages of natural-origin fish ranged from 0% to 36% among streams and years (Table 3). The average percentage of natural-origin fish over all years and streams was 8%, with lower multi-year average percentages on Dutch Bill and Mill Creeks (4%) as compared to Willow Creek (12%) and Green Valley Creek (9%).

Table 2. Total number of salmonids captured in downstream migrant traps, years 2012 through 2016. NA indicates that no trap was operated.

Tributary	Species	Life Stage	2012	2013	2014	2015	2016
Willow Creek	Coho Salmon	Smolt	864	3,405	916	707	2,029
		YOY	0	0	0	7	0
	Steelhead	Adult	0	1	0	1	0
		Parr/YOY	26	142	866	462	603
		Smolt	5	25	11	22	8
Dutch Bill Creek	Chinook Salmon	Smolt	13	0	10	0	15
	Coho Salmon	Smolt	2,017	823	1,939	201	2,681
		YOY	2	2	0	0	18
	Steelhead	Adult	0	0	0	0	0
		Parr/YOY	33	79	1,138	13	74
		Smolt	11	18	0	3	8
Green Valley Creek	Coho Salmon	Smolt	NA	NA	NA	6,810	3,573
		YOY	NA	NA	NA	2	0
	Steelhead	Adult	NA	NA	NA	2	1
		Parr/YOY	NA	NA	NA	0	49
		Smolt	NA	NA	NA	3	3
Mill Creek	Chinook Salmon	Smolt	11	0	18	0	0
	Coho Salmon	Smolt	4,802	2,019	1,451	5,715	2,428
		YOY	515	530	0	10	10
	Steelhead	Adult	1	5	1	2	0
		Parr/YOY	859	443	108	29	1,941
		Smolt	41	32	8	17	15

Table 3. Total number of hatchery and natural-origin (no CWT present) coho salmon smolts captured annually in downstream migrant traps, years 2012 through 2016.

Year	Tributary	Hatchery	Natural	Unknown Origin	Total	Percent Natural
2012	Willow Creek	863	0	1	864	0%
	Dutch Bill Creek	1,982	35	0	2,017	2%
	Mill Creek	4,627	154	20	4,801	3%
2013	Willow Creek	3,385	12	8	3,405	0%
	Dutch Bill Creek	717	106	0	823	13%
	Mill Creek	2,011	3	5	2,019	0%
2014	Willow Creek	583	331	2	916	36%
	Dutch Bill Creek	1,311	262	366	1,939	14%
	Mill Creek	1,272	168	8	1,448	12%
2015	Willow Creek	680	20	7	707	3%
	Dutch Bill Creek	179	8	14	201	4%
	Green Valley Creek	5,937	797	76	6,810	12%
	Mill Creek	5,518	148	49	5,715	3%
2016	Willow Creek	1,579	429	22	2,030	21%
	Dutch Bill Creek	2,596	85	0	2,681	3%
	Green Valley Creek	3,335	231	7	3,573	6%
	Mill Creek	2,396	24	8	2,428	1%

3.3.2 Smolt Abundance

Smolt abundance estimates indicate that thousands of smolts emigrated from each of the four Broodstock Program monitoring tributaries each year, with the exception of Dutch Bill Creek in 2015 and Willow Creek in 2012, when the trap was installed in May instead of March (Table 4). Smolt abundance was generally higher in Green Valley and Mill creeks, although patterns can be difficult to discern because different numbers of fish were released into each creek in each year (Figure 5). Abundance was generally lowest in Willow Creek; however, this was to be expected as no smolts were released into this stream.

Table 4. Number of juvenile coho salmon released into Willow, Dutch Bill, Green Valley, and Mill Creeks and estimated number of coho salmon smolts emigrating from each tributary during spring of years 2012 through 2016. Abundance estimates include both hatchery and natural-origin smolts.

Cohort (Hatch Year)	Trap Year	Tributary	Number Released						Estimated Smolt Abundance (95% CI)
			Spring	Fall	Pre-smolt	Smolt	Smolt: River Release [1]	Total	
2011	2012	Willow Creek	0	11,062	0	0	0	11,062	961 (109) [2]
		Dutch Bill Creek	1,016	9,052	0	5,766	0	15,834	6,978 (939)
		Green Valley Creek	1,018	12,125	0	5,220	0	18,363	NA
		Mill Creek	10,131	25,014	0	5,905	0	41,050	15,651 (2,187)
2012	2013	Willow Creek	0	22,151	0	0	0	22,151	4,137 (206)
		Dutch Bill Creek	1,045	10,038	0	3,974	2,089	17,146	1,594 (173)
		Green Valley Creek	869	13,039	0	4,578	1,504	19,990	NA
		Mill Creek	8,077	16,040	0	6,977	0	31,094	7,878 (766)
2013	2014	Willow Creek	0	10,092	0	0	0	10,092	1,522 (298)
		Dutch Bill Creek	1,019	12,083	0	4,190	2,011	19,303	4,024 (435)
		Green Valley Creek	210	10,187	0	4,194	2,026	16,617	NA
		Mill Creek	8,044	18,151	0	0		26,195	6,570 (365)
2014	2015	Willow Creek	15,393	0	15,300	0		30,693	1,018 (140)
		Dutch Bill Creek	1,009	12,164	0	0	6,152	19,325	513 (128)
		Green Valley Creek	505	15,100	15,248	6,154		37,007	17,873 (922)
		Mill Creek	8,213	18,173	0	10,512		36,898	18,207 (1,401)
2015	2016	Willow Creek	0	9,032	0	0		9,032	3,487 (394)
		Dutch Bill Creek	1,008	8,989	0	3,380	1,638	15,015	4,097 (265)
		Green Valley Creek	305	8,989	0	4,864		14,158	9,685 (952)
		Mill Creek	509	8,969	0	4,775		14,253	6,655 (365)

[2] *During trap years 2013 through 2016, a portion of the smolt release groups were imprinted in tanks for approximately two weeks and then released directly into the mainstem of the Russian River due to drought conditions. These fish had no possibility of being detected in the traps and are not included in the abundance estimates.*

[1] *Trap was not installed until May due to permitting issue so only represents partial estimate.*

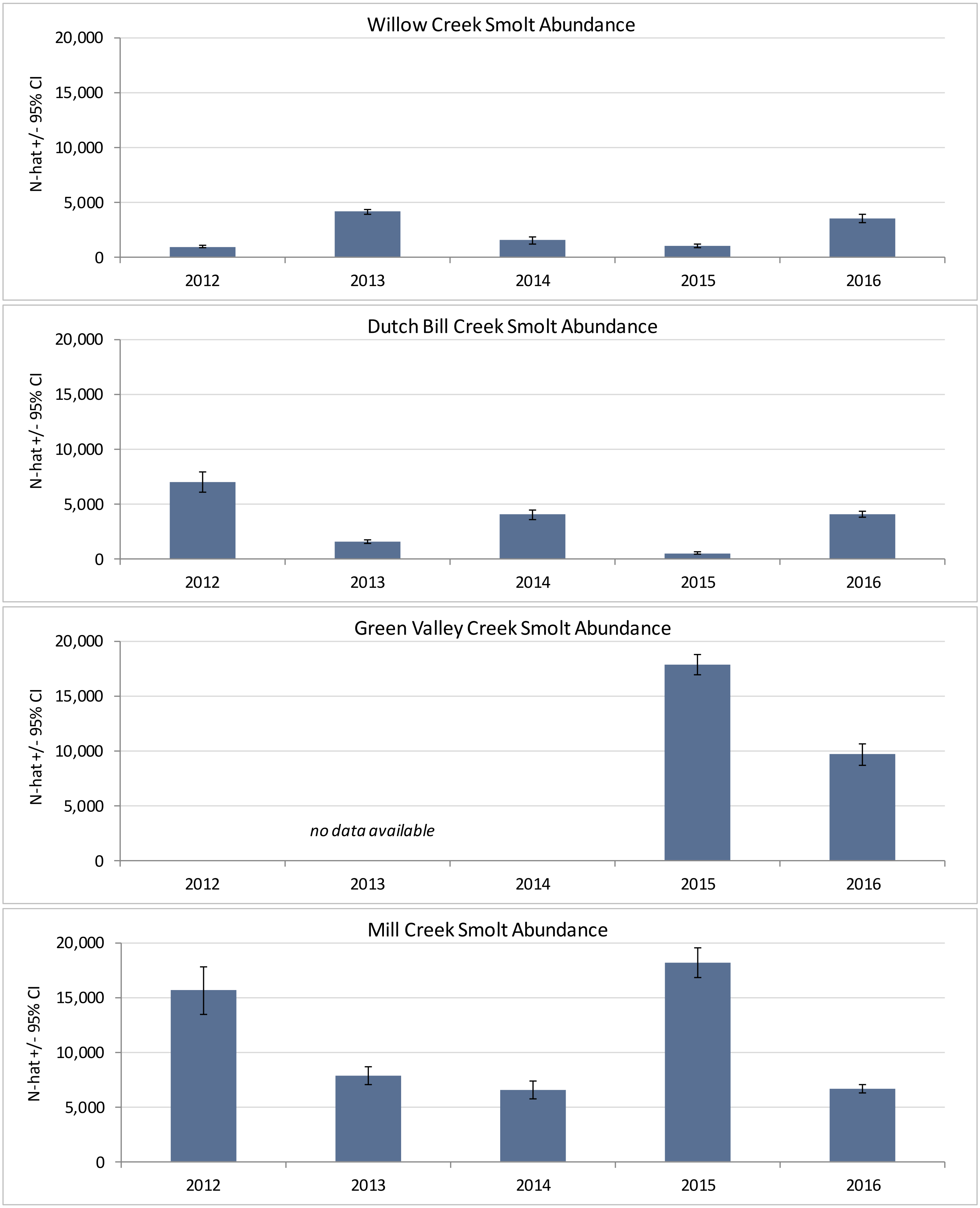

Figure 5. Estimated abundance (N-hat) of smolts emigrating from Willow, Dutch Bill, Green Valley, and Mill creeks during spring of years 2012 through 2016.

3.3.3 Migration Timing

In all four monitoring streams from 2011/12 to 2015/16, the peak of the smolt migration occurred in the spring season, from early April through early May (Figure 6). The average proportion of fish emigrating during the winter season (prior to March 1) varied by stream; Dutch Bill Creek had the highest proportion of winter emigration, Green Valley Creek had the lowest, and Willow and Mill creeks were intermediate (Figure 6).

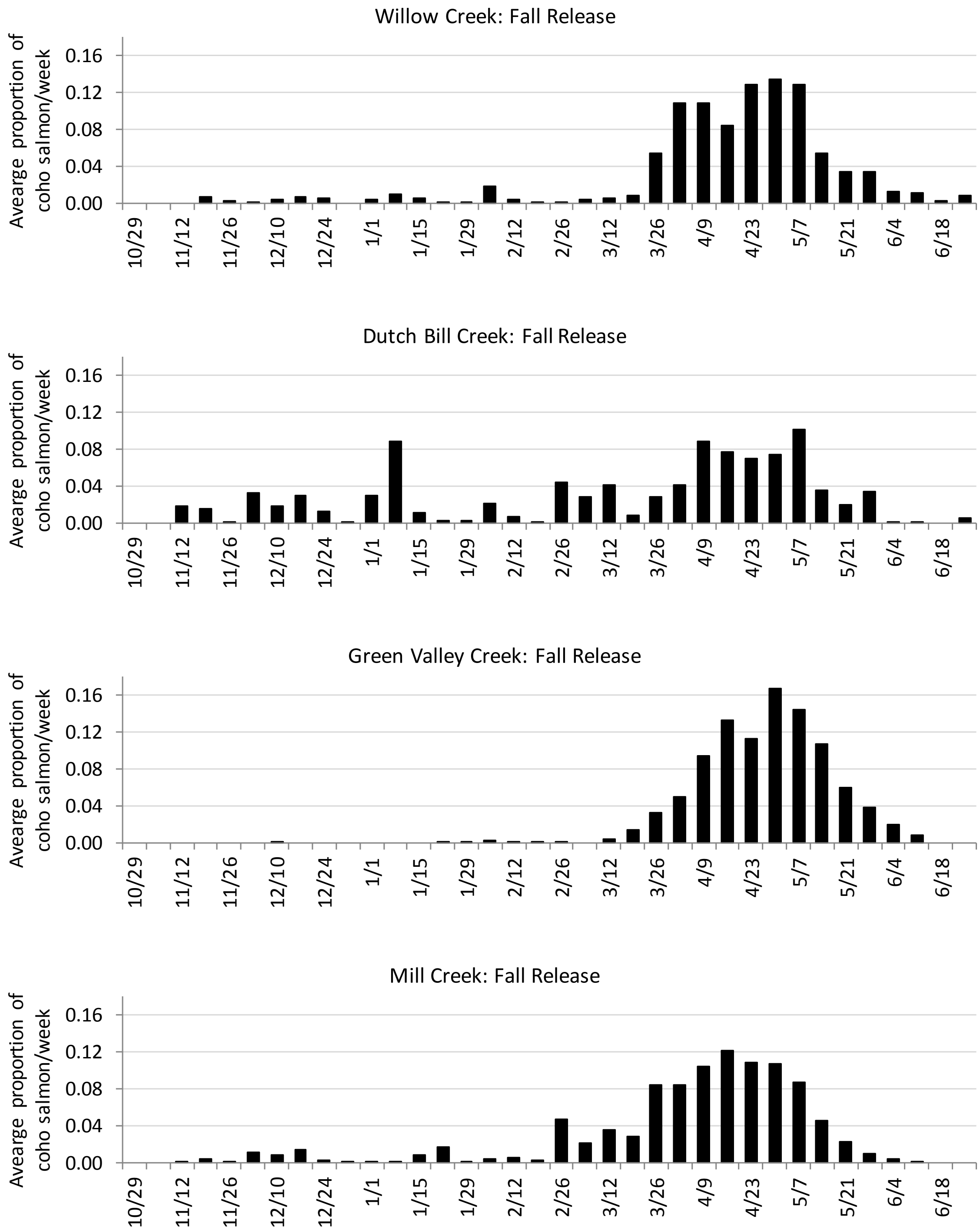

Figure 6. Average proportion of fall-released juvenile coho salmon/week emigrating from Broodstock Program monitoring streams between late October through June of years 2011/12 through 2015/16.

3.3.4 Probability of Survival and Early Winter Emigration

3.3.4.1 Spring and Fall Release Groups

The estimated probability of survival of spring-released juvenile coho salmon from the time of release in mid-June through the end of June the following year (approximately one year later) was generally low, averaging 0.08 across all streams and years and ranging from 0.00 to 0.25 (Table 5). The estimated probability of survival of fall-released juvenile coho from the time of release in late November/early December through the end of June of the following year was higher, averaging 0.25 across all streams and years and ranging from 0.06 to 0.46 (Table 5). In general, overwinter survival of fall-released fish was higher in Green Valley and Mill creeks as compared to Dutch Bill and Willow creeks, and appeared generally higher during the winters of 2011/12, 2013/14, and 2015/16 as compared to 2012/13 and 2014/15 (Figure 7).

Across all streams and years, the estimated probability of spring and fall-released juvenile coho salmon emigrating from their respective release streams prior to March 1 was generally low, averaging 0.03 for the spring release group (range 0.00-0.11) and 0.06 for the fall release group (range 0.00 to 0.33) (Table 6). Emigration probability of fall-released fish was lowest in Green Valley Creek (average 0.00, range 0.00 to 0.01), relatively low in Mill Creek (average 0.07, range 0.01 to 0.11), and higher for Dutch Bill Creek (average 0.12, range 0.08 to 0.16) (Table 6, Figure 8). On Willow Creek, where antennas were operated year-round at the trap site (upstream of 3rd Bridge) and at the mouth (Figure 8), we had the ability to estimate early winter emigration from the release reach (upstream of 3rd Bridge) to both the trap site and the mouth. Interestingly, during the winter of 2015/16, early winter emigration probability past the antennas at the trap site was 0.25, but past the antennas at the mouth was only 0.01, suggesting that fish that moved downstream below the trap site prior to 3/1/16 did not immediately emigrate out of Willow Creek and into the Russian River.

3.3.4.2 Smolt Release Group

The estimated probability of survival of smolt-released fish was generally high, averaging 0.76 but having a broad range from 0.03 to 1.0 (Table 7). When multiple releases occurred in a given year, survival was often lower for the latest release (e.g., see Dutch Bill Creek and Mill Creek releases for cohort 2011) (Table 7). The Mill Creek pond release smolts had lower survival probabilities than the tank or stream releases (Table 7), particularly in low stream flow conditions when we suspected that migrating smolts may have become trapped (UC unpublished data). For cohort 2015, the pond release group had a higher survival probability (0.86); however, the majority of these fish were detected at the Mill Creek smolt trap site within a few days of being released into the pond, suggesting that they were able to escape the pond prior to the date that it was opened to allow for passage.

Table 5. Estimated probability of juvenile coho salmon survival from the date of release through the end of June of the following year. Note that Willow Creek estimates are from the release reach to the mouth unless otherwise footnoted. NA=not applicable (no fish were released or we were not operating antennas).

Cohort (Hatch Year)	Tributary	Spring Release			Fall Release		
		Release Date	Interval Days	Probability of Survival (95%CI)	Release Date	Interval Days	Probability of Survival (95%CI)
2011	Mill Creek	6/13/2011	383	0.25 (0.22-0.28)	11/8/2011	235	0.35 (0.33-0.36)
2012	Willow Creek	NA	NA	NA	11/14/2012	228	0.17 (0.16-0.18) [1]
	Dutch Bill Creek	6/13/2012	382	0.04 (0.03-0.05)	11/13/2012	229	0.12 (0.10-0.15)
	Green Valley Creek	6/13/2012	382	0.07 (0.05-0.08)	11/7/2012	235	0.33 (0.15-0.18)
	Mill Creek	6/19/2012	376	0.14 (0.12-0.16)	10/24/2012	249	0.17 (0.15-0.18)
2013	Willow Creek	NA	NA	NA	11/25/2013	217	0.06 (0.05-0.07)
	Dutch Bill Creek	6/13/2013	382	0.08 (0.07-0.10)	11/11/2013	231	0.29 (0.28-0.31)
	Green Valley Creek	6/13/2013	382	0.07 (0.04-0.11)	12/12/2013	200	0.46 (0.44-0.47)
	Mill Creek	6/12/2013	383	0.16 (0.14-0.18)	11/18/2013	224	0.32 (0.30-0.34)
2014	Willow Creek	6/11/2014	384	0.02 (0.02-0.03)	NA	NA	NA
	Dutch Bill Creek	6/12/2014	383	0.00 (0.00-0.01)	12/4/2014	208	0.06 (0.05-0.07)
	Green Valley Creek	6/12/2014	383	0.06 (0.04-0.08)	12/9/2014	203	0.23 (0.13-0.35)
	Mill Creek	6/13/2014	382	0.03 (0.02-0.04)	12/2/2014	210	0.22 (0.20-0.23)
2015	Willow Creek	NA	NA	NA	12/7/2015	206	0.29 (0.27-0.31)
	Dutch Bill Creek	6/17/2015	379	0.03 (0.02-0.04)	12/10/2015	203	0.18 (0.16-0.20)
	Green Valley Creek	6/18/2015	378	0.00 (0.00-0.02)	12/9/2015	204	0.38 (0.36-0.40)
	Mill Creek	6/18/2015	378	0.10 (0.07-0.12)	11/25/2015	218	0.42 (0.40-0.44)

[1] *Prior to installation of antenna array at the mouth of Willow, so survival probability is from the release reach to the trapsite.*

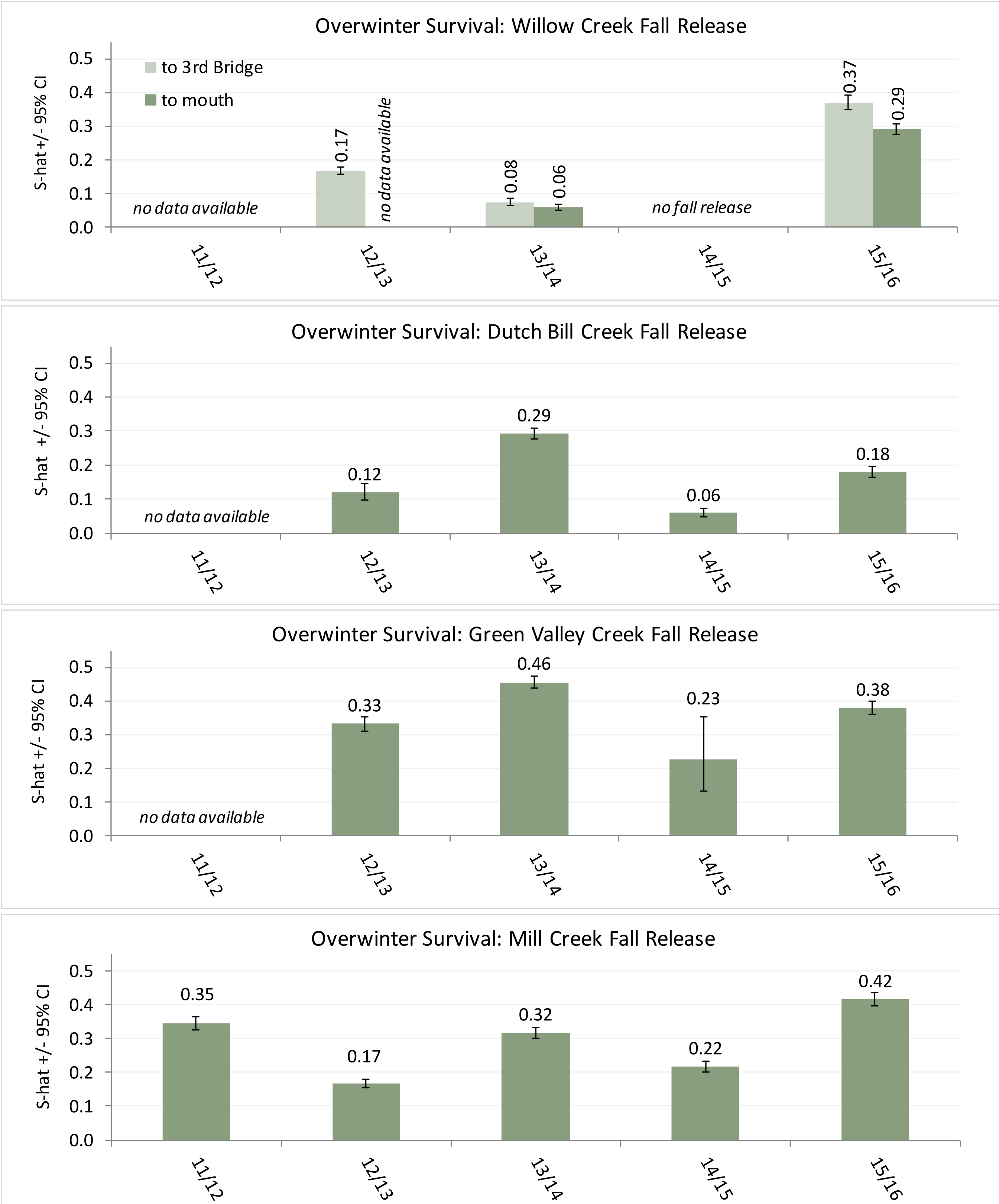

Figure 7. Probability of survival (S-hat) from the time of fall release through detection at the lower antenna/trap sites in spring (3/1 - 6/30) in Willow, Dutch Bill, Green Valley, and Mill creeks, years 2011/12 through 2015/16.

Table 6. Estimated probability of juvenile coho salmon emigrating from each tributary prior to 3/1. Note that Willow Creek estimates represent probability of moving downstream of river km 0.41 (mouth) prior to 3/1, except where footnoted. NA=not applicable (no fish were released or no antennas in operation).

Cohort (Hatch Year)	Tributary	Probability of Emigration prior to 3/1 (95% CI)	
		Spring Release	Fall Release
2011	Mill Creek	0.11 (0.06-0.18)	0.04 (0.03-0.05)
2012	Willow Creek	NA	0.04 (0.03-0.04) [1]
	Dutch Bill Creek	0.01 (0.01-0.02)	0.11 (0.08-0.13)
	Green Valley Creek	0.00 (0.00-0.00)	0.01 (0.00-0.01)
	Mill Creek	0.04 (0.02-0.06)	0.02 (0.02-0.03)
2013	Willow Creek	NA	0.00 (0.00-0.01)
	Dutch Bill Creek	0.06 (0.04-0.07)	0.08 (0.07-0.09)
	Green Valley Creek	0.00 (0.00-0.00)	0.00 (0.00-0.01)
	Mill Creek	0.03 (0.02-0.04)	0.02 (0.01-0.02)
2014	Willow Creek	0.01 (0.00-0.01)	NA
	Dutch Bill Creek	0.07 (0.06-0.09)	0.12 (0.11-0.14)
	Green Valley Creek	0.00 (0.00-0.00)	0.00 (0.00-0.00)
	Mill Creek	0.01 (0.01-0.03)	0.05 (0.04-0.06)
2015	Willow Creek	NA	0.00 (0.00-0.01)
	Dutch Bill Creek	0.04 (0.03-0.05)	0.16 (0.15-0.17)
	Green Valley Creek	0.00 (0.00-0.00)	0.00 (0.00-0.00)
	Mill Creek	0.02 (0.02-0.04)	0.03 (0.03-0.04)

[1] *Prior to installation of antenna array at the mouth of Willow, so emigration probability is from the release reach to the trapsite.*

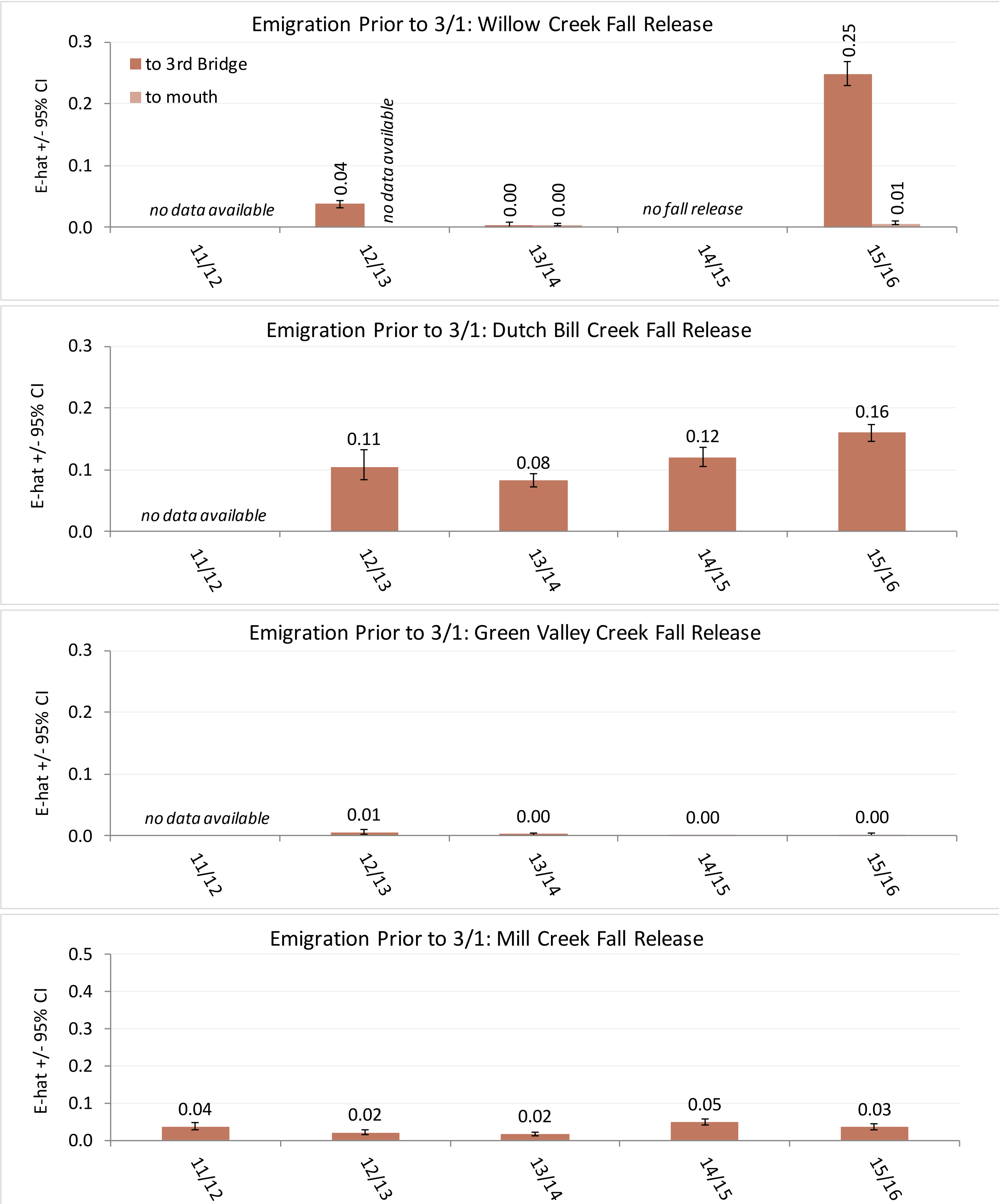

Figure 8. Probability of emigration (E-hat) past antenna sites prior to 3/1 for fall-released fish in Willow, Dutch Bill, Green Valley, and Mill creeks, years 2011/12 through 2015/16.

Table 7. Estimated probability of juvenile coho salmon survival from the date of release through 6/30 for each smolt release group. NA=not applicable (no fish released).

Cohort (Hatch Year)	Tributary	Release Site	River km	Release Type	Release Date	Days Imprinted	Number of PIT Tagged Fish	Probability of Survival (95%CI)
2011	Dutch Bill Creek	Westminster Woods	6.52	tank	4/16/2012	27	196	0.94 (0.88-0.97)
					5/10/2012	24	190	0.92 (0.73-0.98)
					5/29/2012	18	211	0.21 (0.16-0.27)
	Green Valley Creek	Green Valley smolt release tank	16.07	tank	5/2/2012	15	214	0.89 (0.83-0.92)
					5/12/2012	9	153	0.61 (0.53-0.69)
					5/29/2012	12	112	0.80 (0.71-0.87)
		upper Green Valley Rd crossing	13.79	stream	5/17/2012	0	75	0.82 (0.66-0.91)
	Mill Creek	upper smolt release pond	15.54	pond	4/30/2012	26	454	0.42 (0.37-0.46)
					5/29/2012	51	143	0.03 (0.01-0.08)
2012	Dutch Bill Creek	Westminster Woods	6.52	tank	4/11/2013	22	191	1.00 (1.00-1.00)
					4/30/2013	18	495	0.39 (0.34-0.43)
		Monte Rio boat launch	16.5	tank	5/21/2013	20	509	NA
	Green Valley Creek	lower Green Valley Rd crossing	9.32	tank	4/16/2013	14	299	0.85 (0.81-0.89)
					5/1/2013	13	296	0.85 (0.81-0.89)
					5/14/2013	12	298	0.72 (0.67-0.77)
		Steelhead Beach	40.5	tank	5/28/2013	13	295	NA
	Mill Creek	upper smolt release pond	15.54	pond	4/8/2013	21	1396	0.46 (0.44-0.49)
2013	Dutch Bill Creek	Westminster Woods	6.52	tank	4/15/2014	19	299	0.72 (0.67-0.77)
					5/7/2014	20	300	0.55 (0.50-0.61)
		Monte Rio boat launch	16.5	tank	5/28/2014	20	311	NA
	Green Valley Creek	lower Green Valley Rd crossing	9.32	tank	4/24/2014	14	300	0.93 (0.90-0.95)
					5/8/2014	13	302	0.93 (0.89-0.95)
		Monte Rio boat launch	16.5	tank	5/22/2014	13	301	NA
2014	Dutch Bill Creek	Monte Rio boat launch	16.5	tank	4/30/2015	16	315	NA
		Willow/RR confluence	4.01	tank	5/15/2015	14	316	NA
					5/29/2015	11	316	NA
	Green Valley Creek	lower Green Valley Rd crossing	9.32	stream	3/30/2015	0	463	0.93 (0.90-0.95)
					4/20/2015	0	464	0.98 (0.96-0.99)
	Mill Creek	Mill/Palmer confluence	9.98	stream	3/31/2015	0	783	0.85 (0.82-0.87)
					4/20/2015	0	784	0.90 (0.88-0.92)
2015	Dutch Bill Creek	Westminster Woods	6.52	tank	4/18/2016	13	504	0.78 (0.74-0.81)
					5/2/2016	13	505	0.85 (0.82-0.88)
		Monte Rio boat launch	16.5	tank	5/19/2016	13	501	NA
	Green Valley Creek	lower Green Valley Rd crossing	9.32	stream	4/18/2016	0	744	0.96 (0.94-0.98)
					5/2/2016	0	745	0.95 (0.93-0.96)
	Mill Creek	Mill/Palmer confluence	9.98	stream	4/25/2016	0	749	0.86 (0.84-0.89)
		upper smolt release pond	15.54	pond	5/4/2016 [1]	27 (0) [1]	750	0.86 (0.83-0.88)

[1] *Pond-release smolts were placed in the pond on 4/7/16 with the intention of holding them in the pond until 5/4/16; however individuals from this group were detected on the lower Mill antennas beginning on 4/9/16, suggesting that they were able to escape the pond (see movement timing graphs).*

3.3.5 Size

The average fork length and weight of coho salmon smolts captured in the downstream migrant traps over all years, streams, and origins were 111.6 mm and 14.7 g. Across all streams and years, hatchery coho smolts were larger in average size (113.4 mm and 15.3 g) than natural-origin coho smolts (109.6 mm and 14.0 g); however, variation occurred among streams and years (Table 8, Figure 9). On Willow, Dutch Bill, and Mill creeks in most years, natural-origin smolts were smaller in average size than hatchery smolts, but on Green Valley Creek natural-origin smolts were larger in both years of trap operation (Table 8, Figure 9). When comparing among streams, average length and weight of coho salmon smolts was largest on Green Valley Creek (122.0 mm and 18.6 g), smallest on Willow Creek (107.4 mm and 12.9 g), and intermediate on Dutch Bill Creek (112.9 mm and 15.1 g) and Mill Creek (109.8 and 14.3 g). When summarized over all years of data collection, spring-released fish averaged 103.2 mm and 11.9 g, fall-released fish averaged 111.0 mm, and 14.2 g, pre-smolt-released fish averaged 123.5 mm and 19.2 g, and smolt-released fish averaged 129.2 mm and 23.7 g. This pattern occurred in all creeks; the spring release group was the smallest, the fall release group was intermediate, and the presmolt and smolt release groups were the largest (Figure 10).

Table 8. Average fork length (FL) and weight (WT) of natural and hatchery-origin coho salmon smolts captured at downstream migrant traps, years 2012 through 2016. Origin was determined based on the presence of a CWT (hatchery) or lack of a CWT (natural). N= number of fish measured.

Trap Year	Tributary	Hatchery			Natural		
		WT	FL	N	WT	FL	N
2012	Willow Creek	12.9 (±2.5)	108.9 (±6.9)	714	0	0	0
	Dutch Bill Creek	22.3 (±7.7)	127.5 (±13.8)	515	14.1 (±3.3)	110.8 (±7.5)	35
	Mill Creek	13.5 (±5.4)	109.3 (±13)	2,101	12 (±4.2)	103.5 (±13.1)	153
2013	Willow Creek	13.1 (±5.1)	108.4 (±9.2)	2,049	11.4 (±2.9)	104.7 (±10.3)	12
	Dutch Bill Creek	18.2 (±4.4)	120.2 (±9.4)	221	14.3 (±3.1)	110.7 (±8)	106
	Mill Creek	14.8 (±4.9)	112.5 (±11.2)	1,244	8.5 (±2.8)	89.7 (±12.5)	3
2014	Willow Creek	14.6 (±3.3)	112.3 (±8.5)	582	12.3 (±3.4)	103.9 (±10.4)	343
	Dutch Bill Creek	15.5 (±4.3)	114.8 (±10.3)	921	12.2 (±3.5)	105.2 (±10.3)	261
	Mill Creek	13.2 (±3.4)	109.4 (±9.1)	998	12.8 (±3)	106.7 (±9.1)	169
2015	Willow Creek	12.2 (±3.2)	104.4 (±10)	650	14.1 (±4.4)	111.2 (±14)	20
	Dutch Bill Creek	13.4 (±2.4)	110.5 (±7.5)	176	12.8 (±4)	108.3 (±13.2)	7
	Green Valley Creek	17.7 (±4.6)	120.2 (±9.9)	2,182	20.3 (±4.2)	126 (±9)	796
	Mill Creek	18.1 (±5.5)	119.1 (±11.6)	1,676	19.8 (±6.2)	122.9 (±11.8)	143
2016	Willow Creek	12.7 (±3.2)	106.6 (±8.8)	1,430	12.7 (±3.7)	106.5 (±11.2)	405
	Dutch Bill Creek	14.6 (±3.2)	111.9 (±8.4)	1,467	13.3 (±2.6)	108.7 (±7.9)	83
	Green Valley Creek	17.6 (±5.2)	119.1 (±10.2)	2,285	19.3 (±6.5)	122.7 (±12.9)	228
	Mill Creek	15.6 (±4.4)	113.4 (±10.4)	1,722	14.5 (±4)	111.8 (±10.5)	24

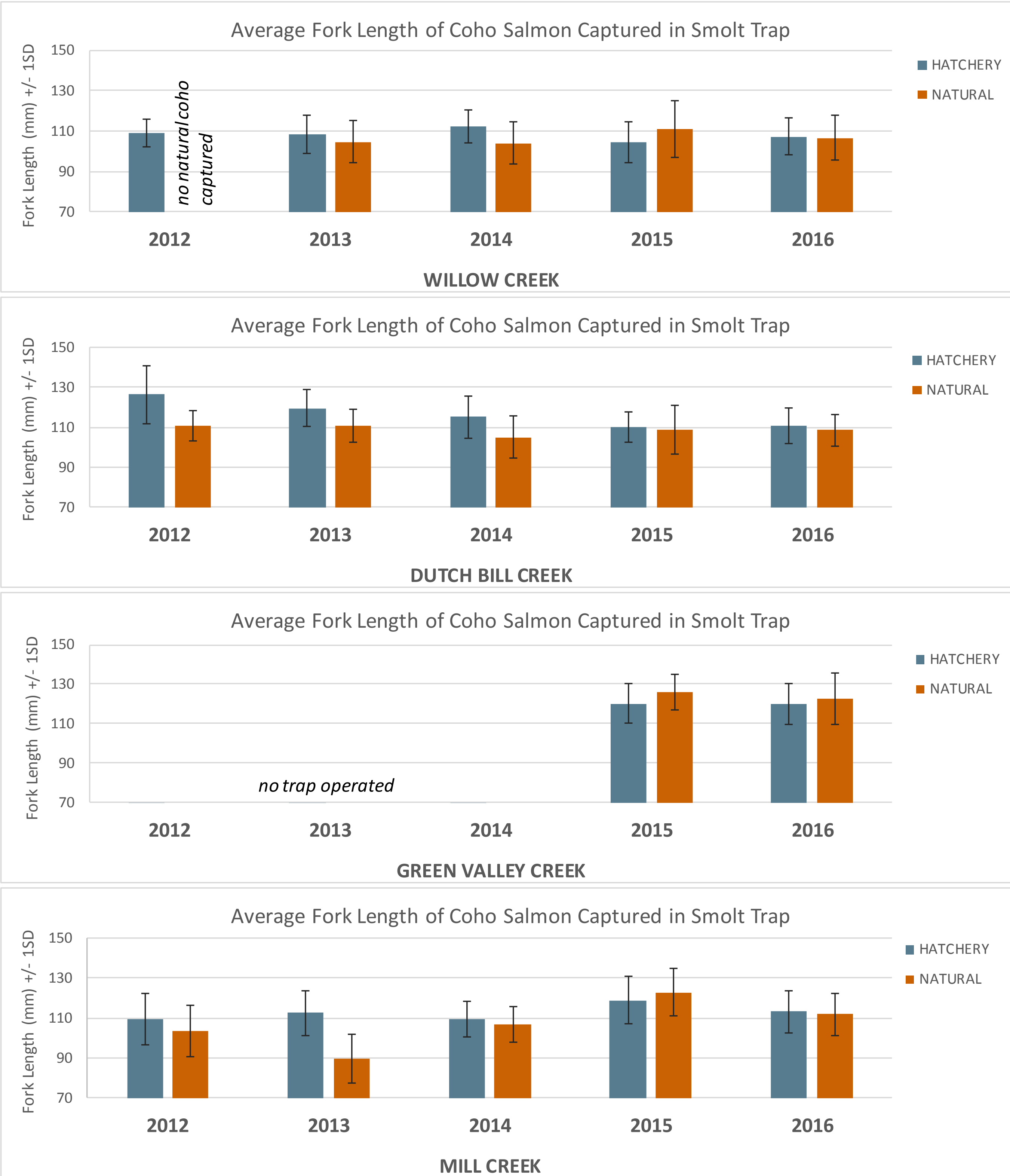

Figure 9. Average fork length (mm) of hatchery and natural-origin coho salmon smolts that were captured at downstream migrant traps by stream and trap year. Note that the y-axis is scaled to the range of 70 mm to 150 mm.

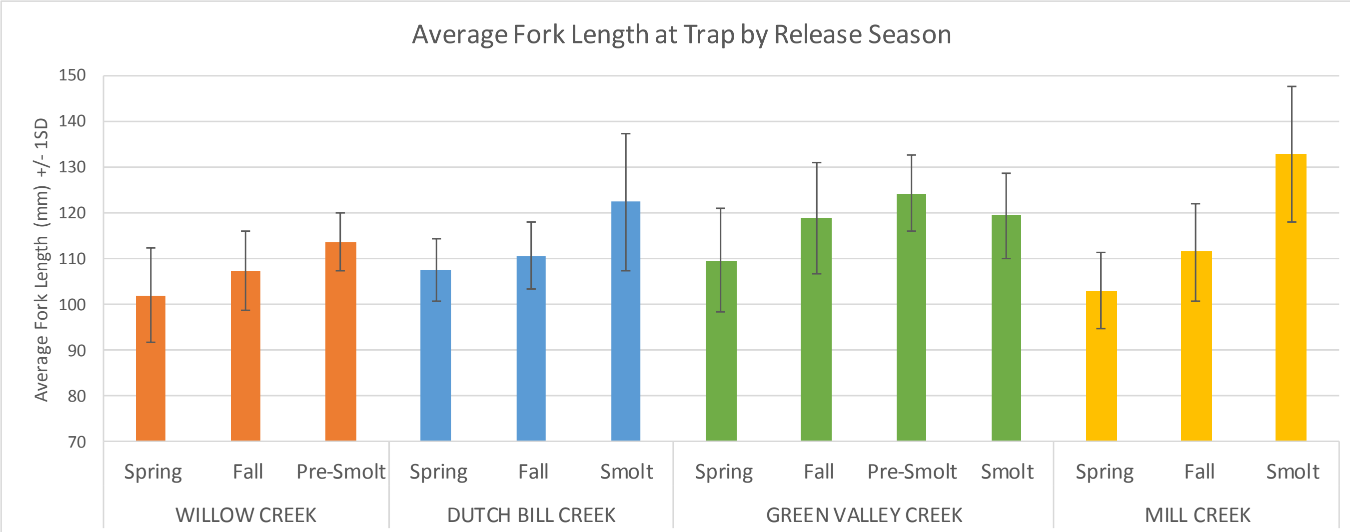

Figure 10. Average fork length (mm) of PIT-tagged coho salmon smolts captured in downstream migrant traps by stream and release season, years 2012 through 2016. Note that the y-axis is scaled to the range of 70 mm to 150 mm.

3.3.6 Growth

As with size comparisons, average daily growth rates of fall-released coho salmon from the time of release through recapture in the downstream migrant traps varied among streams and years (Figure 11). Average growth rates were highest in Green Valley Creek and varied among the other three streams (Figure 11). Average growth rates were lower in all trapped streams during the winter of 2011/12, and remained relatively low in Willow and Mill creeks in 2013 and in Mill Creek in 2014 (Figure 11). Individual variation in growth rate was also observed within streams, as evidenced by the large standard deviations and confirmed by field observations (Figure 11, Figure 12).

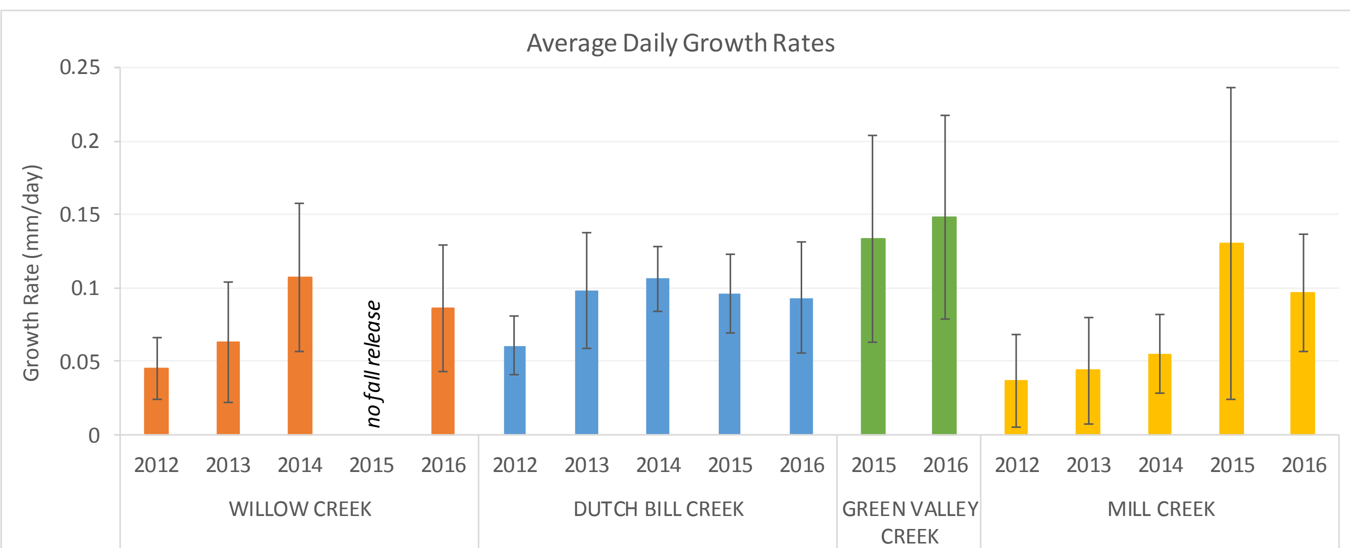

Figure 11. Average daily growth rates in fork length (mm) of PIT-tagged fall-released coho salmon smolts that were recaptured at downstream migrant traps, years 2012 through 2016.

Figure 12. Smolt size variation among coho salmon captured in the Green Valley Creek downstream migrant trap in 2016.

4 Adult Abundance and Distribution

The goal of this study was to document adult migration timing, the number of returning adults, smolt to adult return (SAR) ratios, and spawning distribution in Willow, Dutch Bill, Green Valley, and Mill creeks. PIT tag detection systems were used to document adult hatchery coho salmon return timing, estimate the number of returning hatchery coho salmon adults, and estimate SAR ratios in the four streams, as well as estimated returns to the entire Russian River basin. Spawner surveys were used to document spawning distribution, and to generate estimates of all adult coho salmon and steelhead and redds in the four focus streams.

4.1 Field Methods

4.1.1 PIT Tag Detection Systems

See Section 3.1.1 for a general description of PIT tag detection system methods. To generate estimates of the total number of adults returning to the Russian River basin, additional antenna arrays were operated throughout the watershed by UC and the Water Agency through other sources of funding, including a 12-antenna array located in the mainstem of the Russian River near Duncans Mills, beginning in 2013 (Figure 1).

4.1.2 Spawner Surveys

Survey methodology for documenting spawning salmonids in the Russian River system was adapted from *Coastal Northern California Salmonid Spawning Survey Protocol* (Gallagher and Knechtle 2005) and, beginning in 2013, was coordinated with CMP monitoring in the Russian River watershed (SCWA and UC 2015). Each reach was surveyed at an interval of 10 to 14 days throughout the spawning season. Two-person crews hiked reaches from downstream to upstream looking for adult salmon individuals (live or carcass) and redds. Redds were identified to species based on the presence of identifiable adult fish or from predictions based on redd morphology (Gallagher and Gallagher 2005). Measurements were taken on all redds, including pot length, width, and depth; tailspill length, width, and depth; and substrate size. All observed salmonids were identified to species (coho salmon, Chinook salmon, and steelhead) or classified as unknown salmonids if identification was not possible. Species, certainty of species identification, life stage, sex, certainty of sex, and fork length were recorded for all observed fish. When a carcass was encountered, CWT and PIT-tag scans were performed. A genetics sample, scale sample, and the head (for otolith extraction) were also retrieved from all salmonid carcasses. Geospatial coordinates were recorded for redd and fish observations. Allegro field computers were used for data entry and, upon returning from the field, data files were downloaded, error checked, and transferred into a SQL database.

4.2 Data Analysis

4.2.1 PIT Tag Dataset

First*,* all records of two- and three-year-old PIT-tagged coho salmon detected on antenna arrays between September 15 and March 1 of each year were examined to determine the migratory disposition of detected fish (i.e., returning adults, age-2 outmigrants, or dead individuals) based on the duration and direction of tag movement. Individuals with a net positive upstream movement were categorized as adult returns, which were further evaluated for their return timing relative to stream flow, and to determine minimum and estimated return numbers, as described below. We presumed that two-year olds detected moving in a downstream-only direction were smolts and they were removed from the adult-return dataset. Any tags that were moving very slowly downstream at a given antenna array (approximately greater than one hour between upper and lower arrays) and that were not previously detected leaving as smolts were presumed to be tags from fish that had perished and were removed from the adult-return dataset.

4.2.2 Adult Return Timing Relative to Flow Conditions

The first detection of each returning, PIT-tagged, hatchery adult coho salmon between September 15 and March 1 was plotted with streamflow or stage data from the nearest known gauge. In order to compare timing of entry into the mainstem of the river and entry into the tributaries, plots were created for the Duncans Mills antenna array, as well as for all of the tributary arrays combined.

4.2.3 Adult Return Minimum and Estimated Numbers

Estimates of the number of adult hatchery coho salmon returning to Willow, Dutch Bill, Green Valley and Mill creeks were calculated by 1) counting the number of unique adult PIT-tag detections on the lower antennas of each antenna array (minimum count), 2) dividing the minimum count for each stream by the proportion of PIT-tagged fish released from the hatchery into each respective stream (expanded count per stream), and 3) dividing the expanded count by the estimated efficiency of the lower antennas of paired arrays on each stream (estimated count per stream). The efficiency of the lower antennas of each paired antenna array was estimated by dividing the number of detections on both upstream and downstream antennas by all detections on the upper antennas. Individual data recorded at the time of tagging (age and season of release) was used to estimate the number of returns by release group.

To estimate the total number of hatchery coho salmon adults returning to the Russian River mainstem at Duncans Mills, a similar calculation approach was used; however, efficiency of the Duncans Mills antenna array was estimated by dividing the total number of unique PIT-tag detections of adults at both Duncans Mills and at antenna sites upstream by the total number of PIT-tagged adults detected on arrays upstream of Duncans Mills. Once Duncans Mills antenna efficiency was estimated, we then 1) counted the number of unique adult PIT-tag detections at Duncans Mills (minimum count), 2) divided the minimum count by the proportion of PIT-tagged fish released from the hatchery (expanded count), and 3) divided the expanded count by the estimated efficiency of the Duncans Mills antenna array (estimated count). Because Willow Creek enters the Russian River downstream of Duncans Mills, the Willow Creek estimate was added to the estimate of adults migrating past Duncans Mills. Freezeout and Sheephouse creeks also enter the river downstream of Duncans Mills; however, we did not have a consistent means of estimating adults returning to those streams so any returns to those creeks are not included in the basinwide estimate.

4.2.4 Spring, fall, and smolt release proportions

In order to examine potential benefits of different release strategies (spring, fall, or smolt) on smolt-to-adult survival at a basinwide level, we compared the expected proportions of spring, fall, and smolt release groups emigrating as smolts each year to the proportion of adults returning from each release group. Expected proportions for each release group were estimated for each cohort by multiplying the number of PIT-tagged fish from each release group by the average freshwater survival rate (0.08 for spring, 0.25 for fall, and 0.76 for smolt), and dividing that product by the total estimated number of PIT-tagged smolts from all release groups. Observed proportions were estimated for each cohort by summing the total estimates of returning two- and three-year-old adults for each release group and dividing by the total number of returning adults from all three release groups for that cohort.

4.2.5 Smolt-to-Adult Return (SAR) Ratio

In order to derive the SAR ratio in each of the four focus streams, the sum of the estimated number of two-year-old hatchery adults returning during a given winter and three-year-old hatchery adults returning the following winter was divided by the estimated number of hatchery smolts migrating from each stream between March 1 and June 30 of the year that cohort left as age-1 smolts. The SAR ratio includes the probability of surviving the riverine, estuarine, and ocean environments from when the fish left the tributary as smolts until they returned to the tributaries as adults. In Green Valley Creek, smolt traps were not operated between 2011 and 2013; therefore, SAR ratios could not be estimated for this stream.

4.3 Results

4.3.1 Adult Return Timing

Over the course of this study, returning adult coho salmon were detected on the Duncans Mills antenna array in September or October of each year, approximately two or three months (54 to 104 days) before the first detection on the tributary arrays (Figure 13). Seasonal entry of adults into the mainstem of the river did not appear to be related to flow conditions; however the first detections on the tributary arrays each year are typically correlated with the first significant flow event of the winter (e.g., Figure 14). In most years, the tributaries are disconnected from the mainstem when adult coho salmon begin entering the mainstem of the river and it is not until the first significant rain event that they become accessible to migrating coho salmon (UC unpublished data). The winter of 2013/14 was an unusual year in that the first significant rain event did not occur until the first week of February; therefore, coho salmon adults that were detected on the Duncans Mills array beginning in October did not have access to the tributaries for over three months (Figure 13).

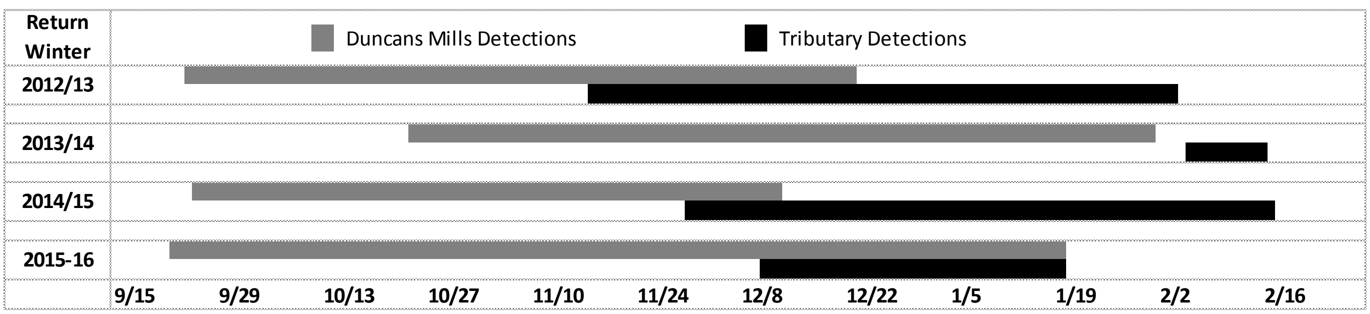

Figure 13. Date ranges of PIT-tagged adult coho salmon detections at the Duncans Mills and tributary antenna arrays.

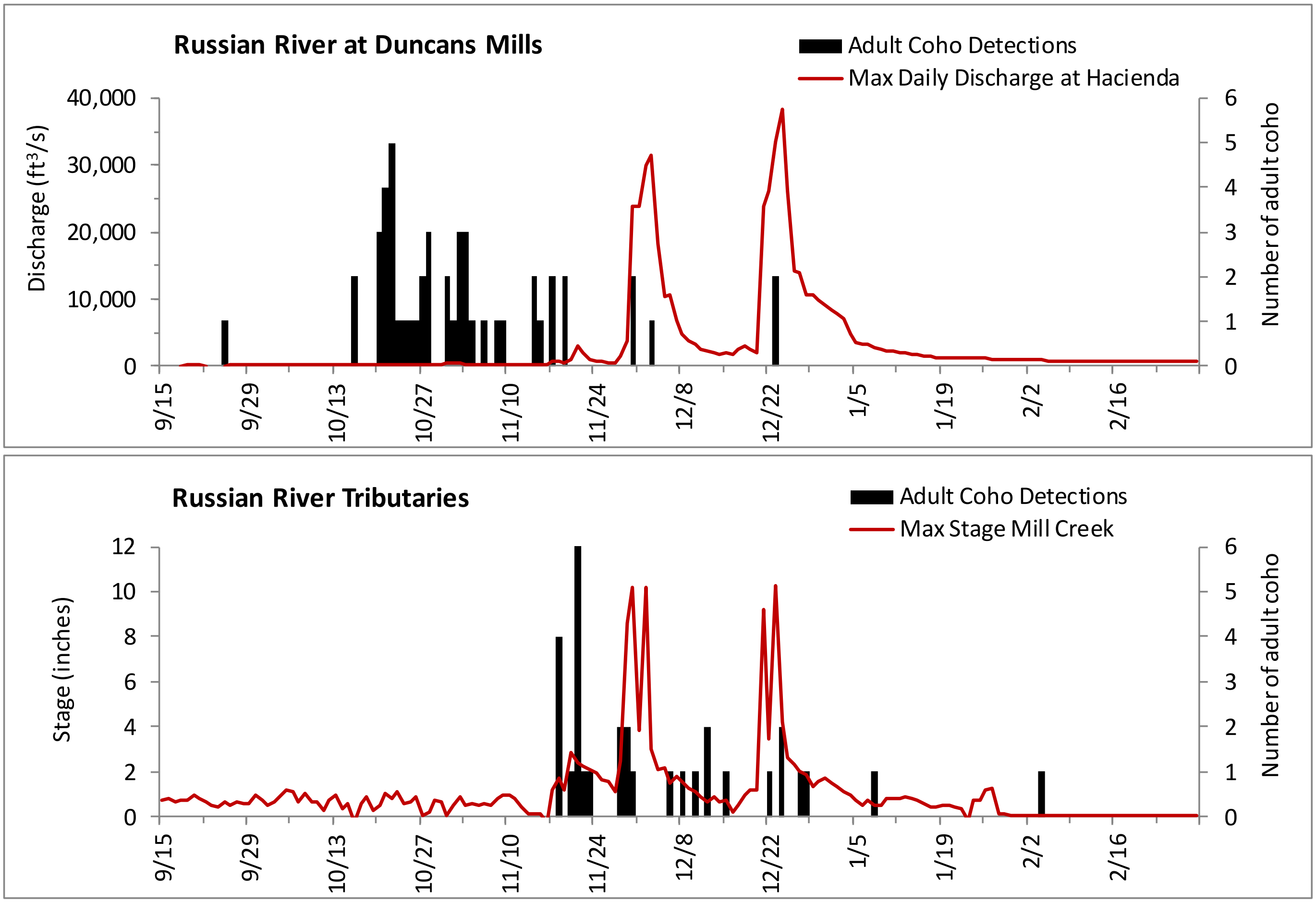

Figure 14. Detections of PIT-tagged coho salmon adults passing upstream of the Duncans Mills (upper) and all tributary antennas combined (lower), September 15, 2012 - March 1, 2013. Hacienda discharge data downloaded from USGS website: http://waterdata.usgs.gov. Mill Creek stage data was collected by UC from a gauge operated by State Water Resources Control Board.

4.3.2 Adult Return Estimates

PIT-tagged adult coho salmon were detected returning in each year that antennas were operated on the four Broodstock Program monitoring streams, with estimates ranging from nine to 32 on Willow Creek, nine to 33 on Dutch Bill Creek, 17 to 74 on Green Valley Creek, and seven to 78 on Mill Creek (Table 9, Figure 15 - Figure 18). Estimated returns to the Russian River watershed ranged from 192 to 536 over the study period, a significant increase from the previous decade when less than 10 adults were known to return to the watershed each year (Figure 19).

Inter-annual patterns in the estimated number of returning hatchery adults varied by stream; in Willow Creek, the highest estimate occurred in the winter of 2013/14 and it was lower in other winters; in Dutch Bill Creek, an increasing trend was observed from 2012/13 through 2015/16; in Green Valley and Mill creeks, returns were relatively higher in the winters of 2011/12 and 2013/14, lower in 2013/14 and 2015/16, and intermediate in 2014/15 (Figure 15 - Figure 18). Annual abundance estimates of hatchery adult coho salmon returning to the Russian River also varied by year, with winter 2012/13 having the highest abundance and winter 2015/16 the lowest (Figure 19).

The proportion of two-year old adults returning was generally high (Table 9), averaging 59% over all streams and years surveyed. Variation occurred among years; no two-year olds returned in any stream except for Willow Creek in 2012/13 and only two-year olds returned in 2013/14 (Table 9, Figure 15 - Figure 18).

Table 9. Estimated annual adult hatchery coho salmon returns to Coho Broodstock Program monitoring tributaries. PIT-tag detection systems were not in place in Willow and Dutch Bill creeks during the winter of 2011/12 so estimates could not be generated for those streams during that winter.

Return Winter	Tributary	Individual PIT Tag Detections	Estimated Adults	Percent Age-2
2011/12	Green Valley Creek	14	49	80%
	Mill Creek	13	68	55%
2012/13	Willow Creek	2	17	79%
	Dutch Bill Creek	2	9	0%
	Green Valley Creek	20	74	0%
	Mill Creek	13	78	1%
2013/14	Willow Creek	6	32	100%
	Dutch Bill Creek	3	15	100%
	Green Valley Creek	3	17	100%
	Mill Creek	1	7	100%
2014/15	Willow Creek	4	16	62%
	Dutch Bill Creek	5	18	42%
	Green Valley Creek	9	44	53%
	Mill Creek	10	52	79%
2015/16	Willow Creek	3	9	73%
	Dutch Bill Creek	6	33	0%
	Green Valley Creek	3	17	58%
	Mill Creek	6	14	85%

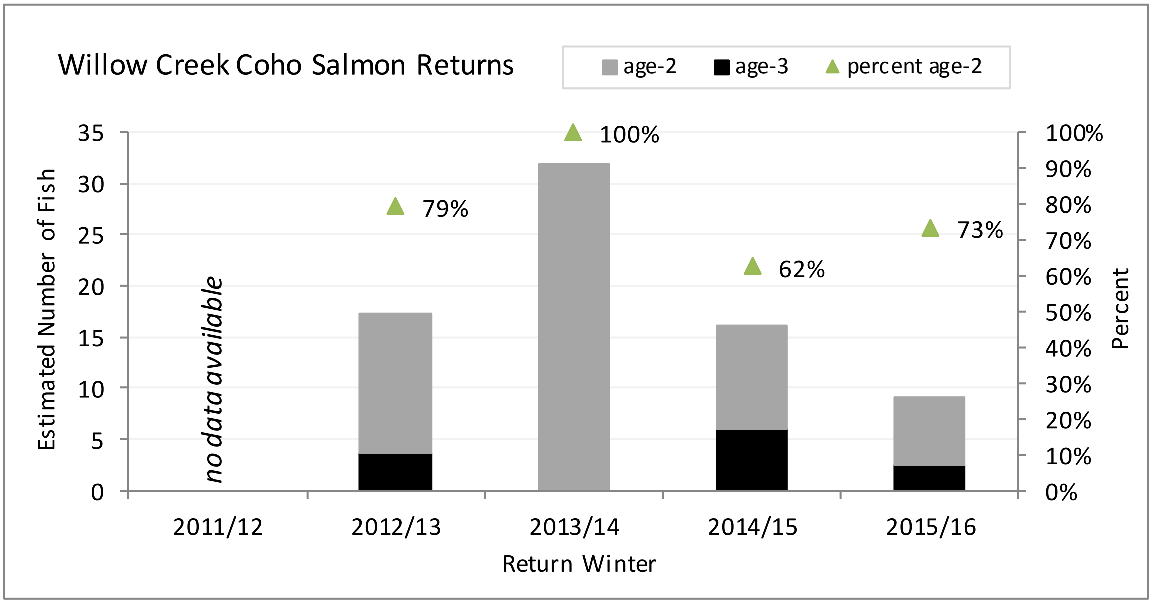

Figure 15. Estimated annual Willow Creek adult hatchery coho salmon returns by age in return seasons 2012/13 through 2015/16.

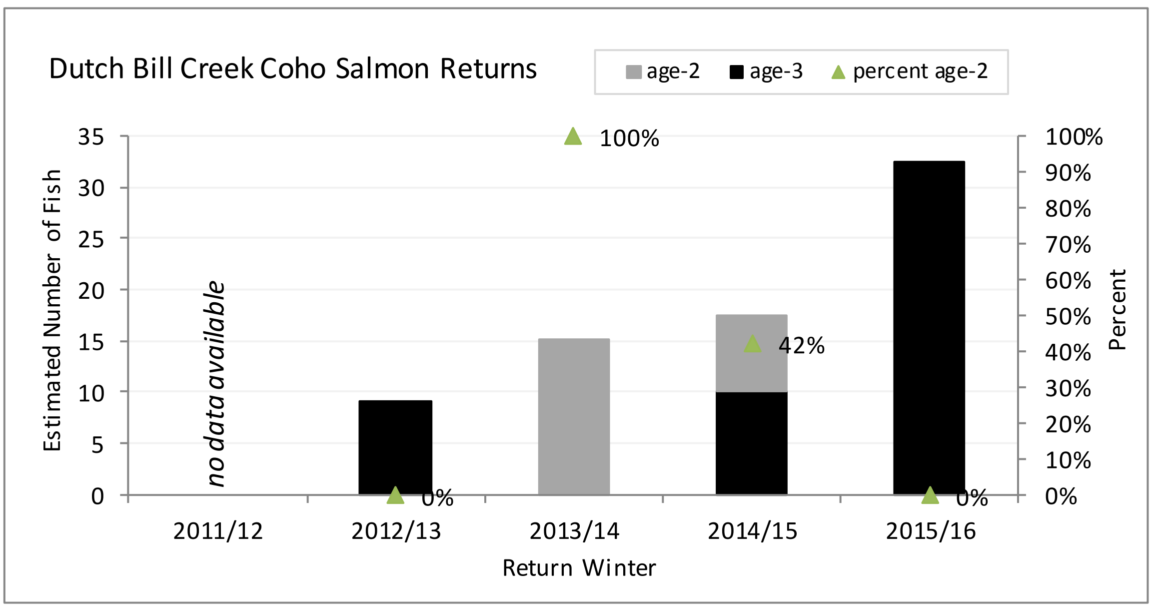

Figure 16. Estimated annual Dutch Bill Creek adult hatchery coho salmon returns by age in return seasons 2012/13 through 2015/16.

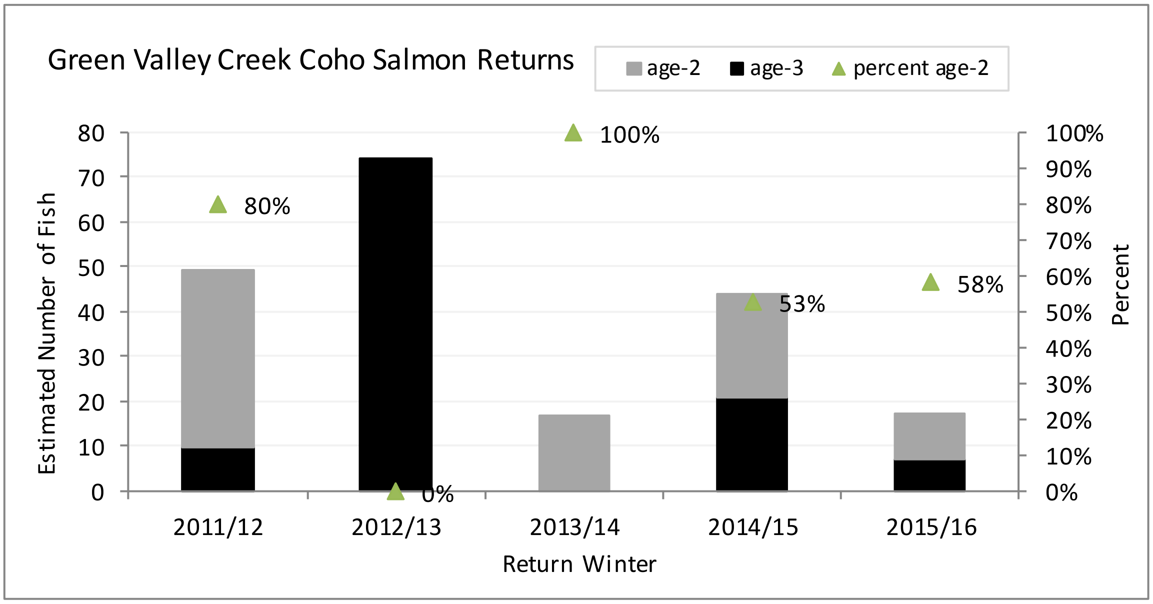

Figure 17. Estimated annual Green Valley Creek adult hatchery coho salmon returns by age in return seasons 2012/13 through 2015/16.

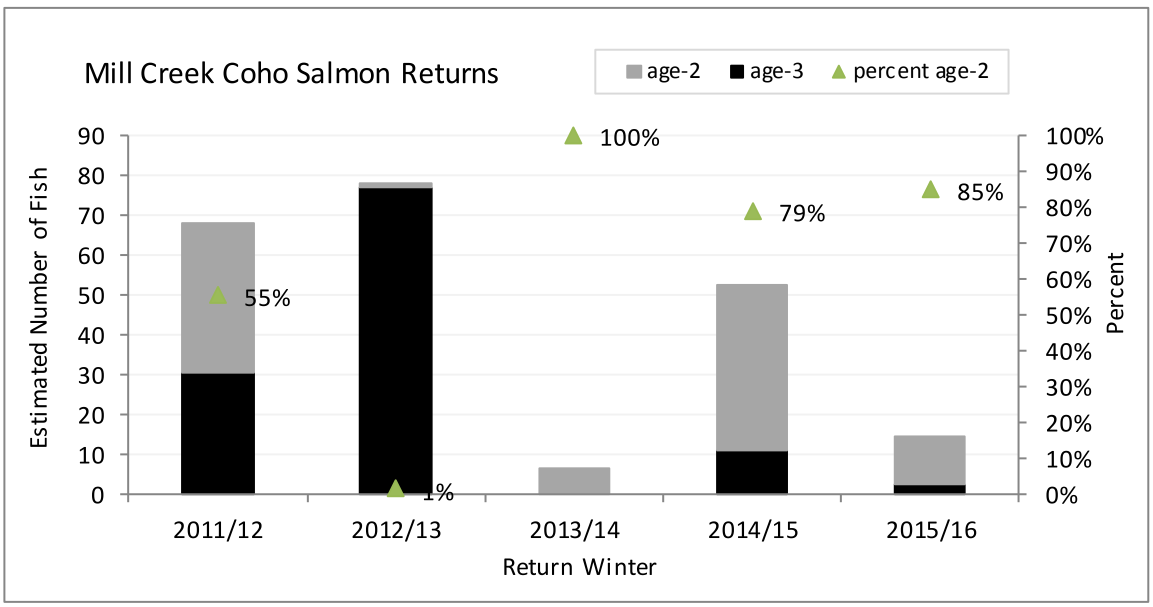

Figure 18. Estimated annual Mill Creek adult hatchery coho salmon returns by age in return seasons 2012/13 through 2015/16.

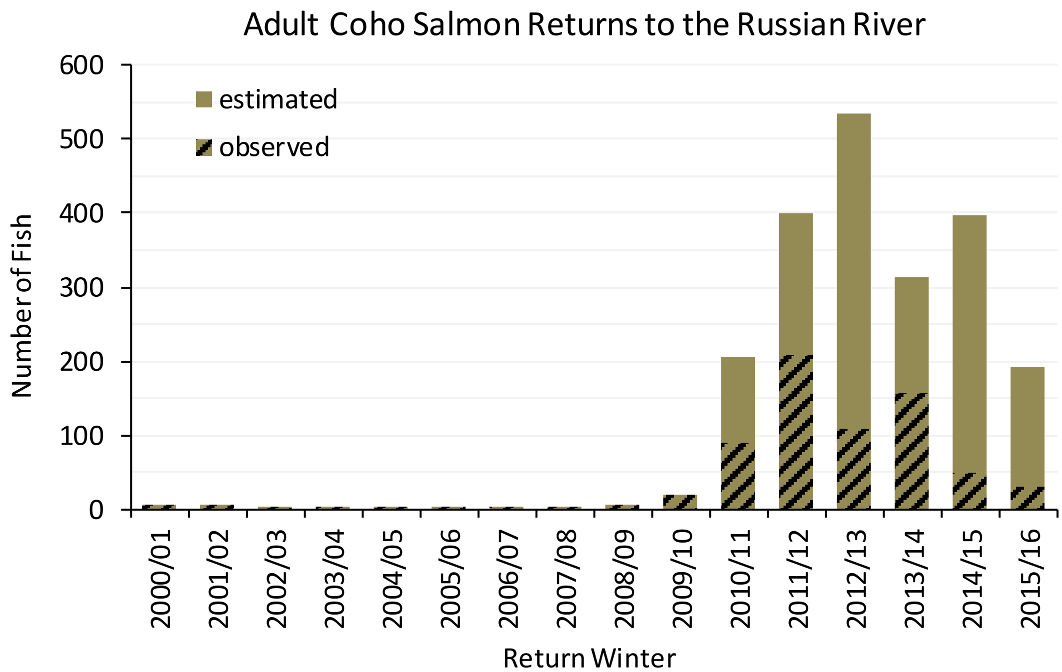

Figure 19. Estimated annual adult hatchery coho salmon returns to the Russian River, return seasons 2000/01 through 2015/16. Note that methods for counting/estimating the number of returning adult coho salmon were not consistent among years; prior to 2009/10, spawner surveys were the primary method, from 2009/10 to 2011/12 methods included spawner surveys, video monitoring, and PIT-tag detection systems and, beginning in 2012/13, with the installation of the Duncans Mills antenna array, PIT-tag detection systems were the primary method used.

4.3.3 Expected v. Observed Proportions by Release Group

The expected verses observed proportions of returning adults by release group were similar in most cohorts for the spring release group, with observed values slightly lower than expected values in three of the four cohorts, suggesting that there was no smolt-to-adult survival advantage for spring release fish over the other release groups (Table 10). For cohorts 2010 and 2011, we observed a higher proportion of fall release adults returning than were expected, as well as a lower proportion of smolt release adults than expected (Table 10). This pattern did not occur for cohorts 2013 and 2014, where observed proportions were similar to expected proportions for all release groups (Table 10).

Table 10. Expected proportions of PIT-tagged spring, fall, and smolt release group fish returning as adults compared to observed proportions returning as adults.

Cohort (Hatch Year)	Spring			Fall			Smolt		
	Expected Proportion	Observed Proportion	Observed-Expected	Expected Proportion	Observed Proportion	Observed-Expected	Expected Proportion	Observed Proportion	Observed-Expected
2010	0.05	0.04	0.00	0.23	0.54	0.32	0.73	0.41	-0.31
2011	0.10	0.07	-0.03	0.29	0.48	0.19	0.61	0.45	-0.16
2012	0.07	0.03	-0.05	0.35	0.36	0.00	0.57	0.61	0.04
2013	0.05	0.04	-0.01	0.43	0.43	0.00	0.52	0.53	0.01

4.3.4 Smolt-to-Adult Return (SAR) Ratios

Overall, SAR ratios were low, ranging from zero to 1.6 percent over all of the streams and years sampled (Figure 20 - Figure 22). In Willow and Dutch Bill creeks, the smolt abundance generally mirrored the trends in adult abundance for cohorts 2012 and 2013; however in Mill Creek, no clear relationship could be discerned (Figure 20 - Figure 22).

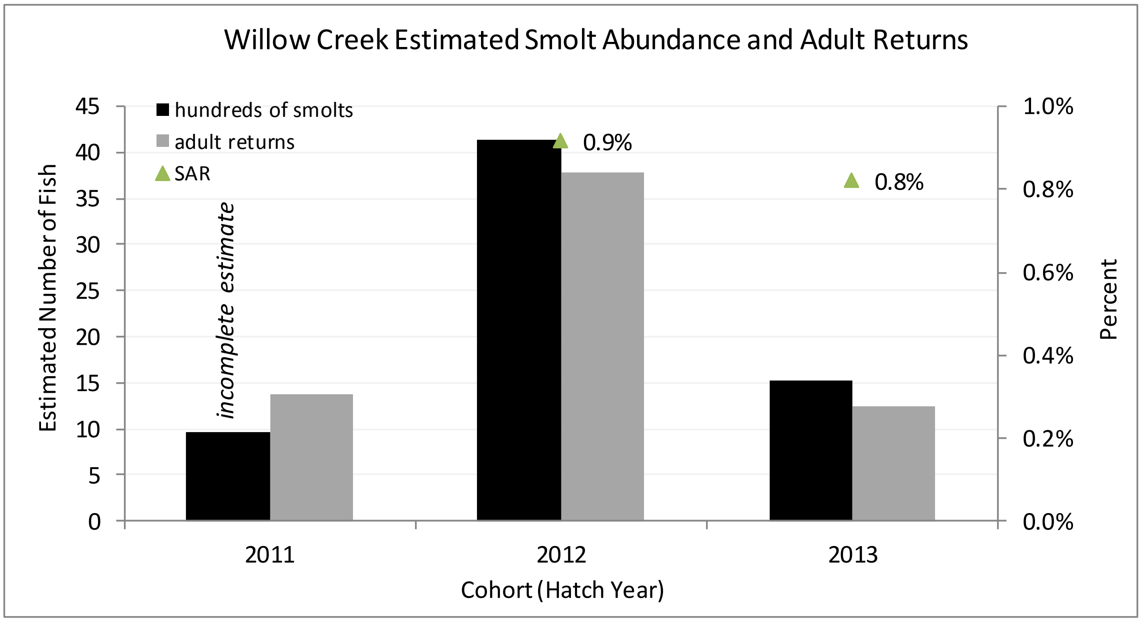

Figure 20. Estimated coho salmon smolt abundance, adult returns, and smolt-to-adult (SAR) survival ratios in Willow Creek, cohorts 2011 through 2013.

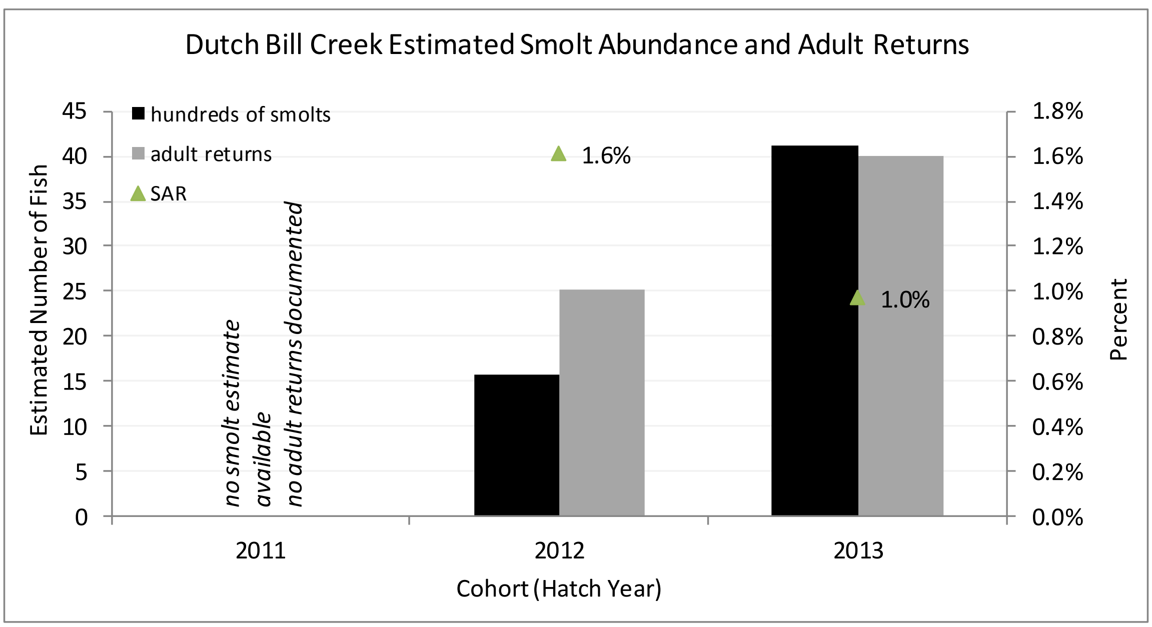

Figure 21. Estimated coho salmon smolt abundance, adult returns, and smolt-to-adult (SAR) survival ratios in Dutch Bill Creek, cohorts 2011 through 2013.

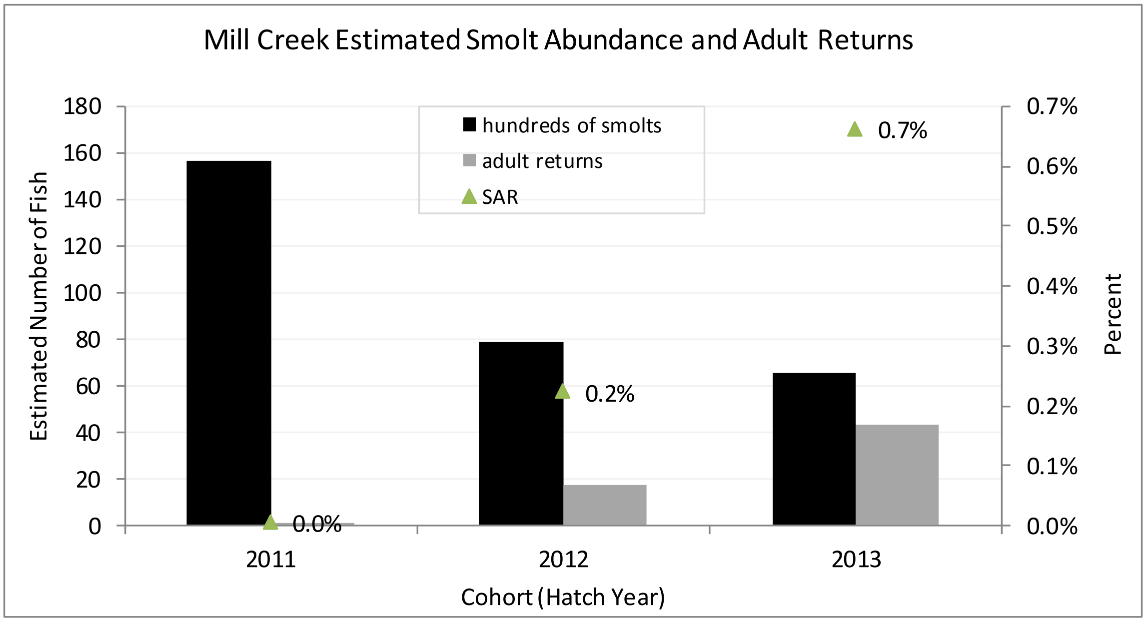

Figure 22. Estimated coho salmon smolt abundance, adult returns, and smolt-to-adult (SAR) survival ratios in Mill Creek, cohorts 2011 through 2013.

4.3.5 Redd Counts and Distribution

Coho salmon redds were documented in each of the four monitoring streams each year (Table 11, Figure 23 - Figure 27), with the exception of Willow Creek in return winters 2011/12 and 2012/13, which was prior to expected returns from hatchery releases. Steelhead redds were also observed in most streams in most years (Table 11). In Mill and Green Valley creeks, the greatest number of redds were observed in 2012/13, which corresponded to the highest adult return estimates in those streams (Table 11, Table 9).

Redd distribution varied by stream and year (Figure 23 - Figure 27). In Willow Creek, no coho redds were observed during the first two survey winters, but they were observed throughout the survey reaches the following three winters, along with steelhead redds. In Dutch Bill Creek, coho salmon redds were generally concentrated in the lower and middle reaches, while steelhead redds were found throughout the stream, including in the upper reaches in some years. In the mainstem of Green Valley Creek, coho salmon redds were more frequently observed in the upstream half of the survey reach, while steelhead redds were observed lower down. Redds from both species were observed in Purrington Creek. In the Mill Creek watershed, the majority of coho salmon redds were observed in the lower reaches of the stream, downstream of the confluence with Wallace Creek, while steelhead redds were distributed throughout the survey reaches. Spatial distribution of redds for other CMP survey reaches can be found on our website: (http://www.cohopartnership.org).

Table 11. Number of coho salmon, steelhead, and unknown salmonid species redds observed in Broodstock Program monitoring streams, winters 2011/12 through 2015/16.

Return Winter	Tributary	Coho Salmon	Steelhead	Unknown Salmonid
2011/12	Willow Creek	0	0	0
	Dutch Bill Creek	4	16	0
	Green Valley Creek	6	29	3
	Mill Creek	15	27	0
2012/13	Willow Creek	0	0	1
	Dutch Bill Creek	6	6	0
	Green Valley Creek	19	28	3
	Mill Creek	27	17	2
2013/14	Willow Creek	7	15	0
	Dutch Bill Creek	8	7	1
	Green Valley Creek	7	18	1
	Mill Creek	2	20	2
2014/15	Willow Creek	5	9	2
	Dutch Bill Creek	1	0	0
	Green Valley Creek	5	15	9
	Mill Creek	9	29	11
2015/16	Willow Creek	11	4	8
	Dutch Bill Creek	3	5	5
	Green Valley Creek	5	11	5
	Mill Creek	12	22	13

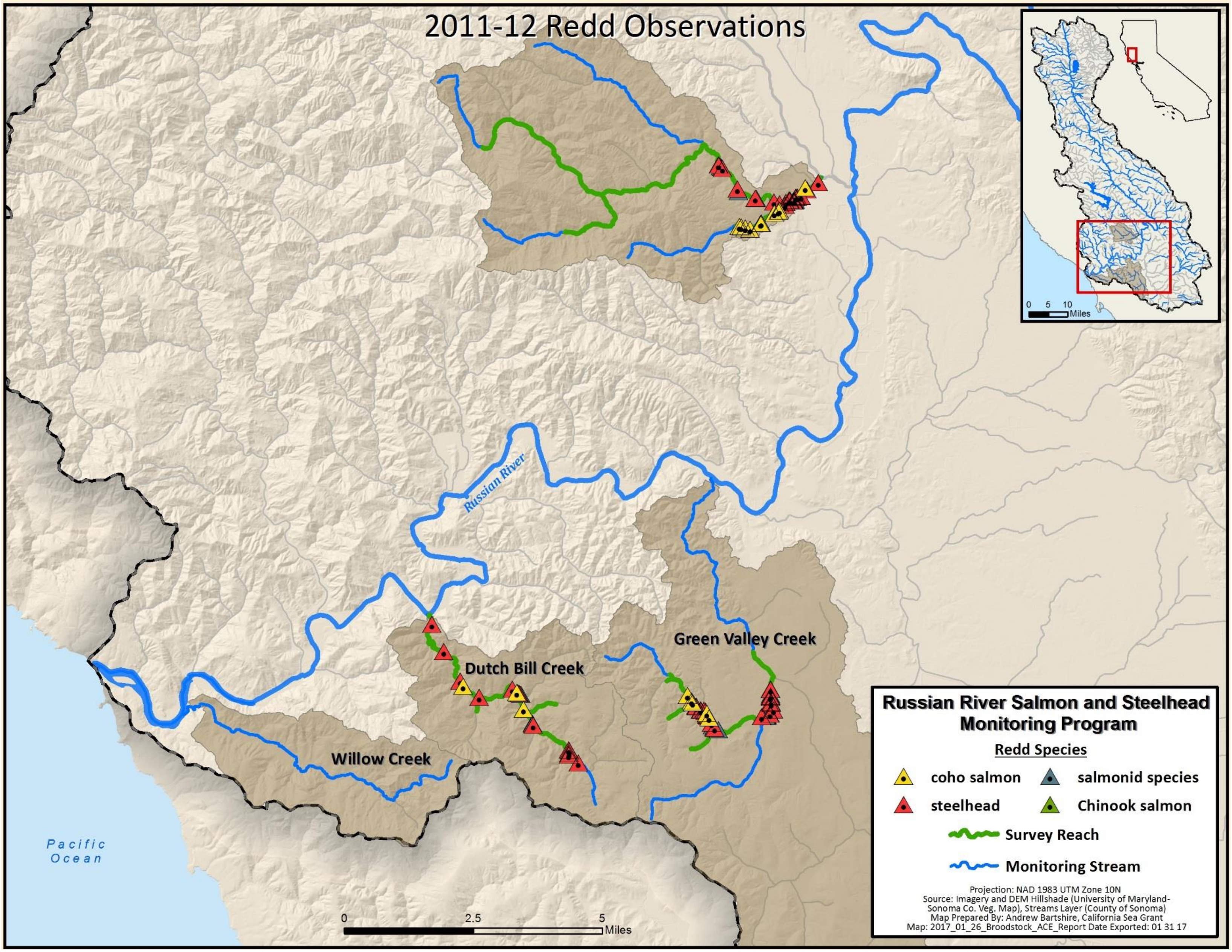

Figure 23. Distribution of observed salmonid redds in Broodstock Program monitoring streams during winter 2011/12.

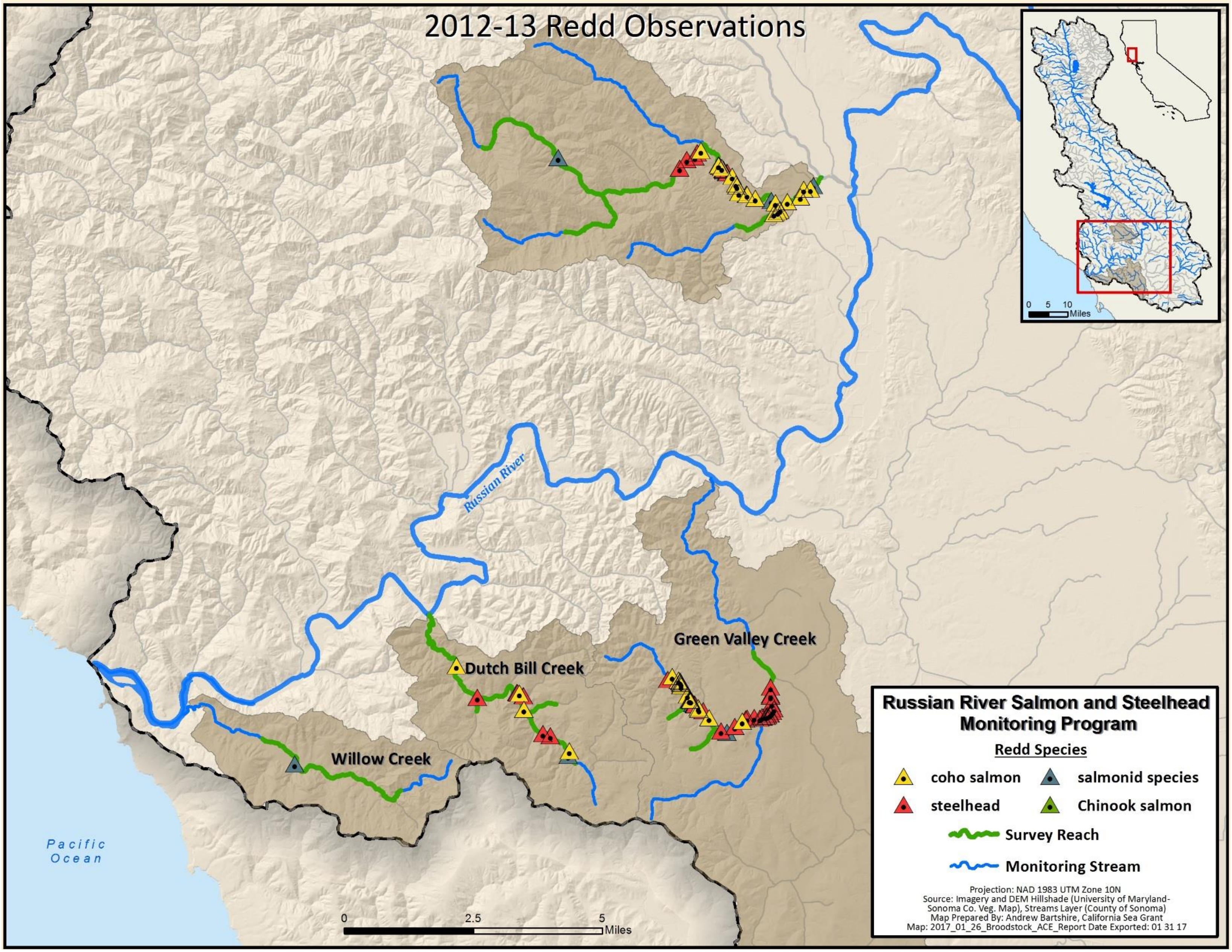

Figure 24. Distribution of observed salmonid redds in Broodstock Program monitoring streams during winter 2012/13.

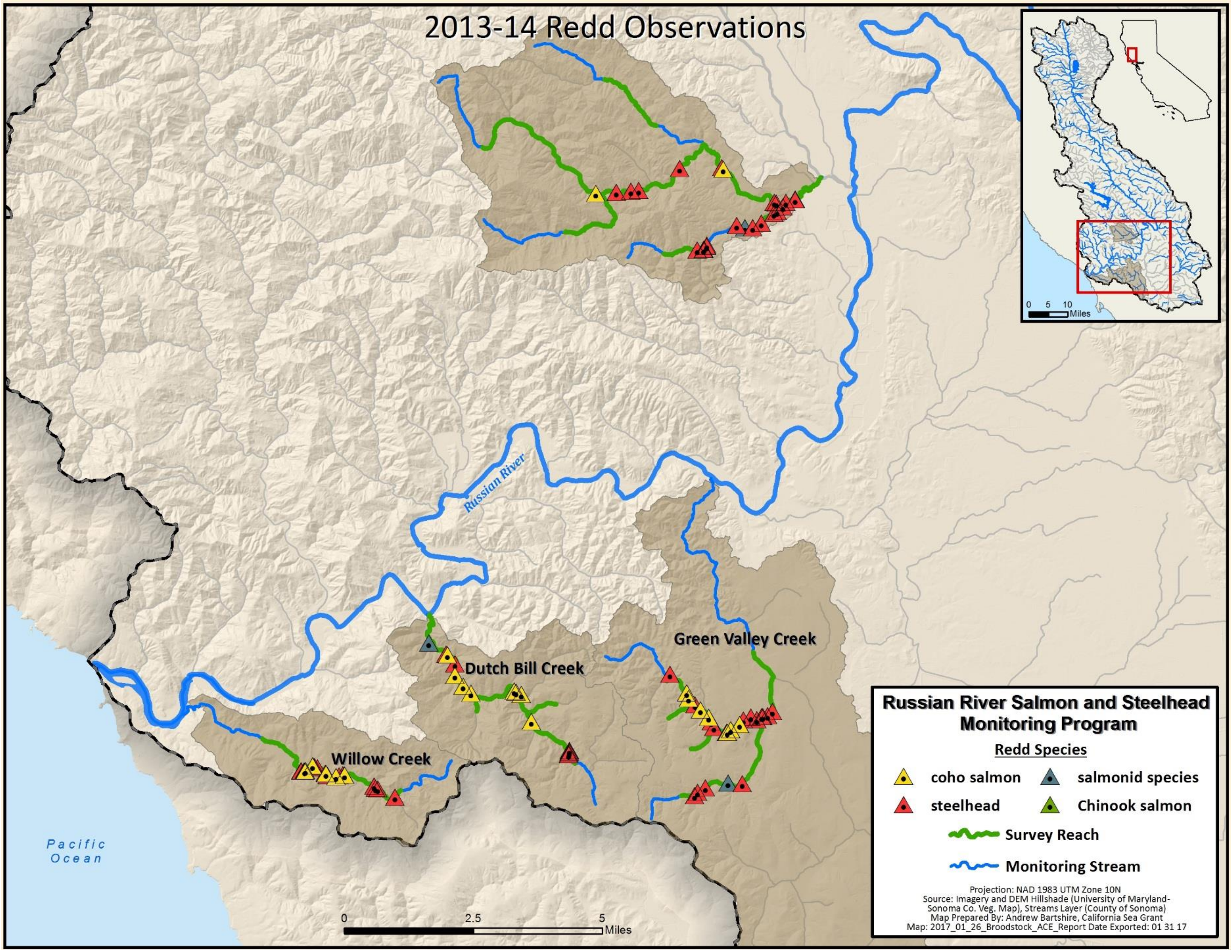

Figure 25. Distribution of observed salmonid redds in Broodstock Program monitoring streams during winter 2013/14.

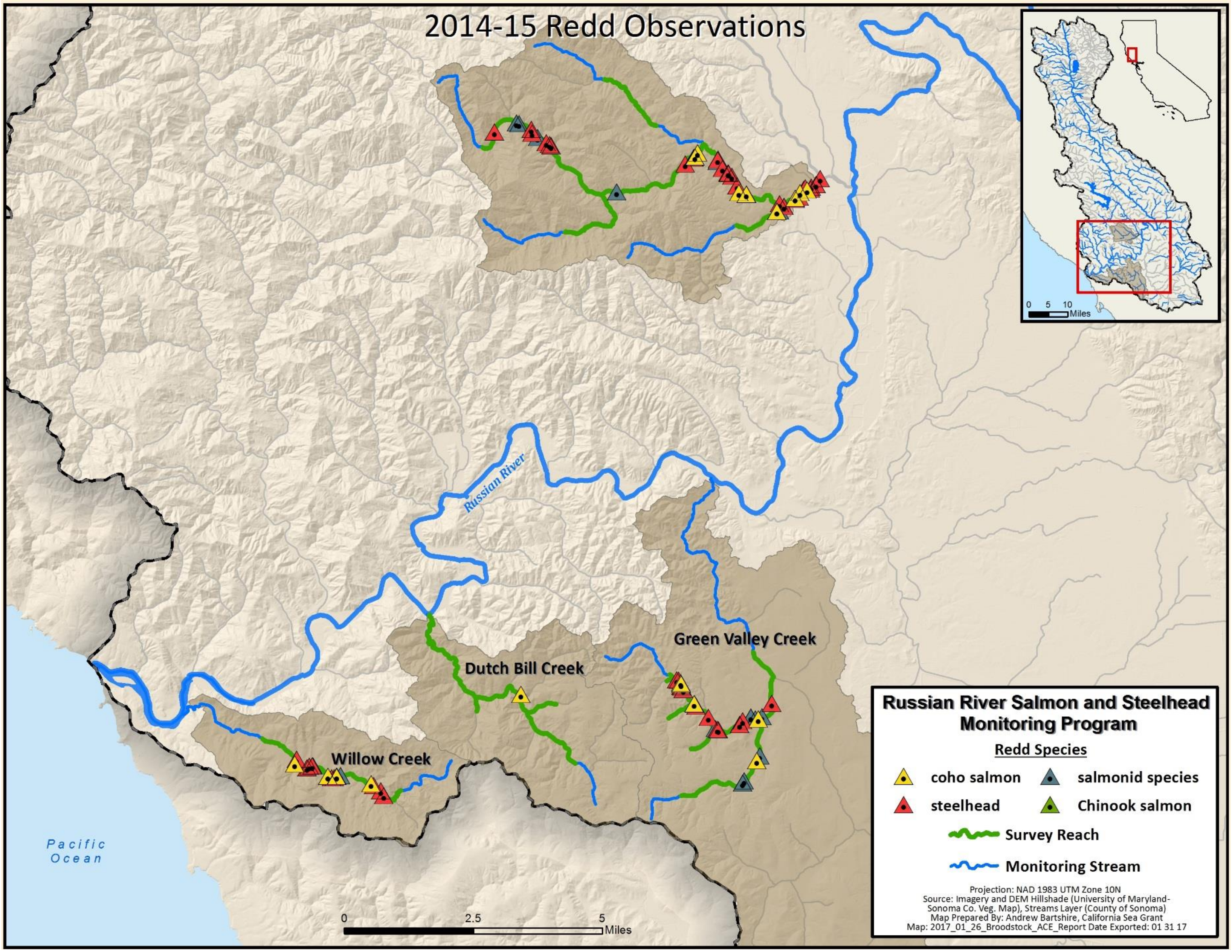

Figure 26. Distribution of observed salmonid redds in Broodstock Program monitoring streams during winter 2014/15.

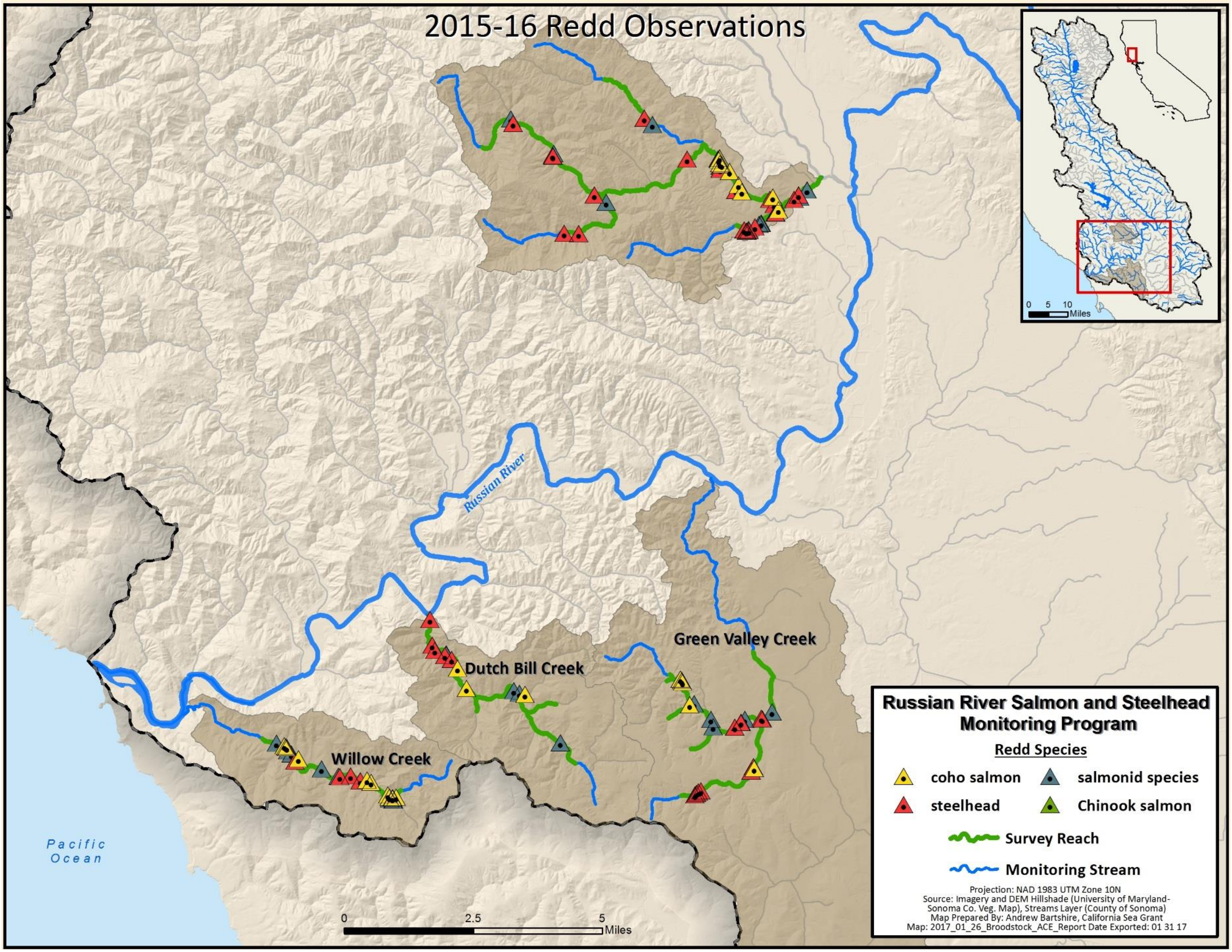

Figure 27. Distribution of observed salmonid redds in Broodstock Program monitoring streams during winter 2015/16.

5 Juvenile Presence and Distribution

Summer snorkeling surveys were conducted in the survey reaches of Willow, Dutch Bill, Green Valley, and Mill creeks (Figure 1) in order to document the spatial distribution and relative abundance of natural-origin juvenile coho salmon. These data were used to determine whether successful spawning occurred each year and to track trends in distribution of natural-origin juvenile coho salmon over time. Beginning in 2013, surveys were coordinated with the CMP monitoring effort; results from additional Russian River tributaries can be found on our website at http://ca-sgep.ucsd.edu/russianrivercoho.

5.1 Field Methods

Snorkeling surveys were based on protocols modified from O'Neal (2007) in which individual pools were snorkeled and juvenile coho salmon and other salmonid species were counted. The frequency of pools snorkeled changed between 2012 and 2016, as sampling strategies were modified in order to be consistent with CMP monitoring approaches. In 2012, all pools in each survey reach were snorkeled (pre-CMP monitoring). In 2013 (first year of CMP), all pools in Mill and Dutch Bill creeks were snorkeled and every second pool in Willow and Green Valley creeks was snorkeled. From 2014 through 2015, once a suitable sampling strategy was established serving the needs of Broodstock Program and CMP monitoring, every second pool was snorkeled in all survey reaches (SCWA and UC 2014).

In each survey reach, fish were counted in either every pool or every other pool, with the first pool (odd or even), determined randomly. In each surveyed pool, snorkeler(s) moved from the downstream end of the pool (pool tail crest) to the upstream end, surveying as much of the pool as water depth allowed (e.g., Figure 28). A zigzag pattern was used by individual snorkelers as they moved through the pool and dive lights were used to inspect shaded and covered areas. In order to minimize disturbance of fish and sediment, snorkelers avoided sudden or loud movements. Double counting was minimized by only counting fish once they were downstream of the observer. In pools requiring two snorkelers, two lanes were agreed upon and each snorkeler moved upstream through the lane at the same time and rate. Final counts for the pool were the sum of both lane counts. All observed salmonids were identified to species (coho salmon, Chinook salmon, steelhead) and age-class (young-of-year (< age-1), parr (≥ age-1)), based on size and physical characteristics (e.g., Figure 29). Beginning in 2014, geospatial data was collected for every snorkeled pool so that maps depicting spatial distribution could be generated. Allegro field computers were used for data entry and, upon returning from the field, data files were downloaded, error checked, and transferred into a SQL database. Spatial data was stored in an ArcGIS geodatabase for map production.

Figure 28. A diver conducts a survey in an isolated pool.

Figure 29. A natural-origin coho salmon yoy observed during snorkeling surveys.

5.2 Results

Natural-origin coho salmon yoy were observed in all four monitoring streams in all survey years, with the exception of Willow Creek in 2012 and Mill Creek in 2014 (Table 12). In Green Valley and Mill creeks, trends in relative abundance of coho salmon yoy generally followed trends in coho salmon redd counts the previous winter; however, in Willow and Dutch Bill creeks, no clear patterns were observed (Figure 30). Very few natural-origin coho salmon yoy were observed in any creek during the summer of 2014, following the winter of 2013/14 when adult coho salmon did not have access to spawning tributaries until February (Figure 30).

Density and spatial distribution of natural-origin coho salmon yoy observed in 2014 and 2015 snorkeling surveys are shown in Figure 31 through Figure 38. In Dutch Bill, Green Valley and Mill creeks, small groups of hatchery coho salmon were released in June of each year into specific reaches for oversummer survival studies. We were not able to distinguish between hatchery and natural-origin fish during snorkeling surveys, so all observations are included. Survival study reaches are distinguished on each map; fish releases prior to snorkeling surveys likely explain the higher densities in those reaches.

In Willow and Dutch Bill creeks, juvenile coho salmon were distributed fairly evenly throughout the survey reaches in both years (excluding the higher numbers in the Dutch Bill Creek stocking reaches), with higher densities in 2015 than in 2014 (Figure 31- Figure 34). In Green Valley Creek, juvenile coho salmon were concentrated upstream of the confluence with Purrington Creek and densities were also higher in 2015 than in 2014 (Figure 35- Figure 36). In Mill Creek in 2014 (if stocking reaches are excluded), juvenile coho salmon densities were highest near the confluence with Dry Creek and in a middle reach located immediately downstream of a Palmer Creek spring release reach (Figure 37- Figure 38). In 2015, densities in Mill Creek were highest upstream of the confluence with Wallace Creek and in the lower reaches of Felta Creek (Figure 37- Figure 38).

Table 12. Minimum count of natural-origin coho salmon yoy observed during summer snorkel surveys, years 2012 through 2015. Note that for 2012, all pools in the survey reaches were snorkeled; in 2013, all pools were snorkeled in Mill and Dutch Bill creeks and every other pool was snorkeled in Willow and Green Valley creeks; and in 2014 and 2015, every other pool was snorkeled in all survey reaches. Relative abundance is the same as the minimum count when all pools were snorkeled and double the minimum count when every other pool was snorkeled.

Year	Tributary	Minimum Number of Natural-Origin Coho Salmon Yoy	Relative Abundance
2012	Willow Creek	0	0
	Dutch Bill Creek	1,960	1,960
	Green Valley Creek	1,504	1,504
	Mill Creek	590	590
2013	Willow Creek	442	884
	Dutch Bill Creek	935	935
	Green Valley Creek	4,290	8,580
	Mill Creek	3,259	3,259
2014	Willow Creek	36	72
	Dutch Bill Creek	28	56
	Green Valley Creek	26	52
	Mill Creek	0	0
2015	Willow Creek	1,139	2,278
	Dutch Bill Creek	292	584
	Green Valley Creek	1,147	2,294
	Mill Creek	297	594

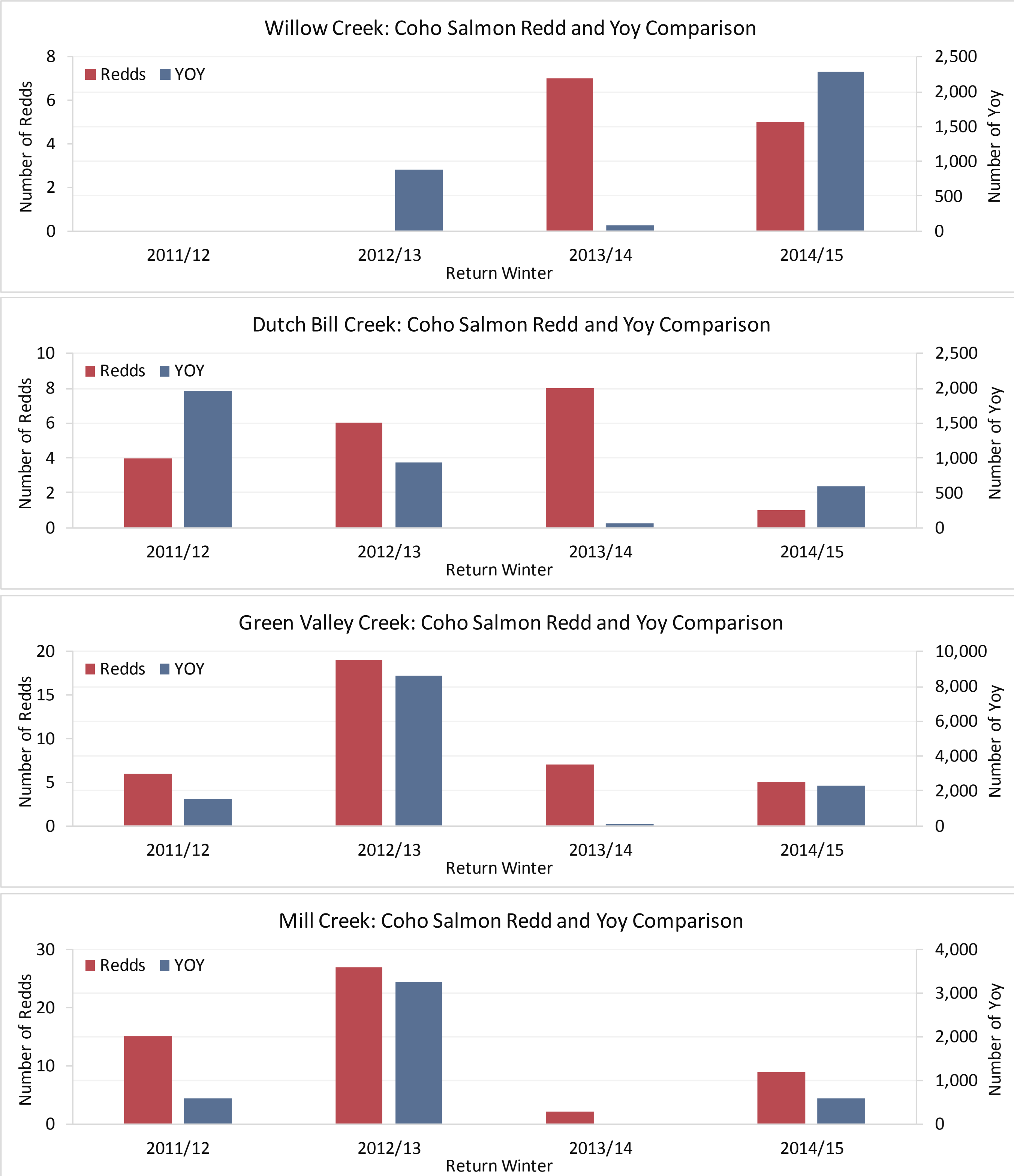

Figure 30. Minimum number of coho salmon redds counted compared to relative abundance of coho salmon yoy the following summer in four Broodstock Program monitoring streams.

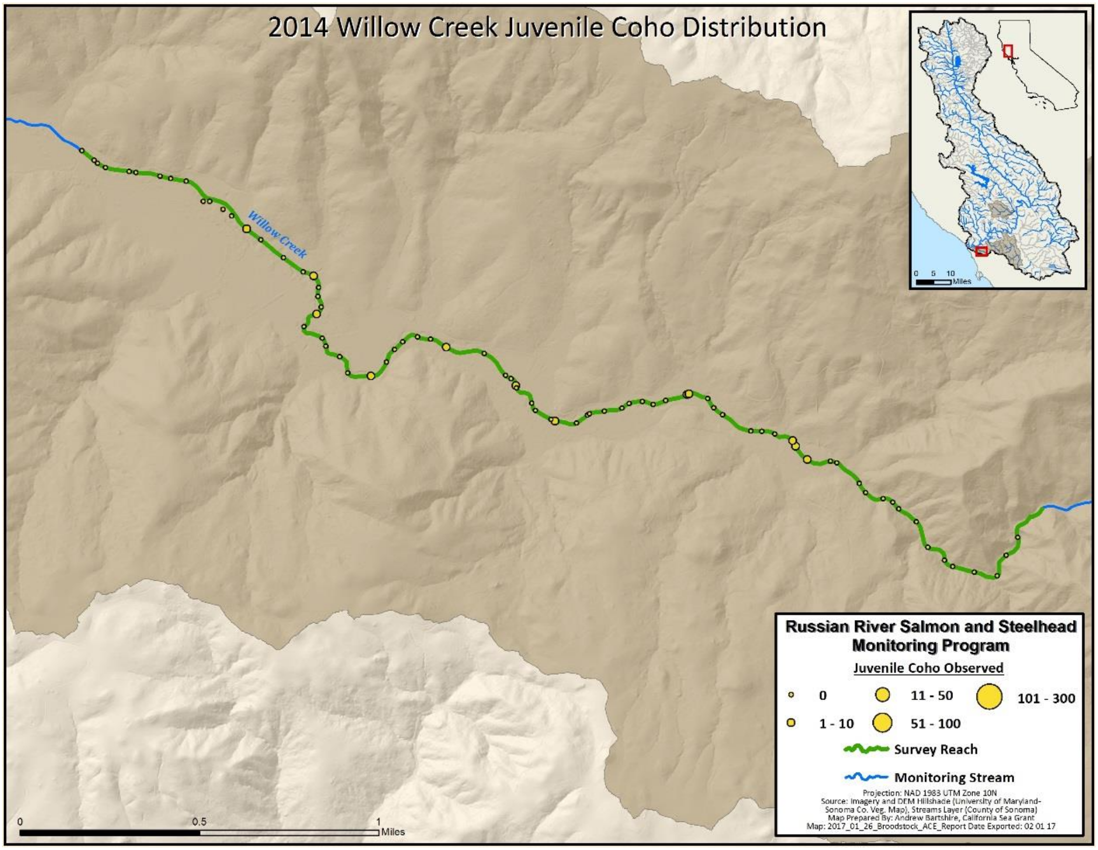

Figure 31. Density and distribution of juvenile coho salmon yoy observed in Willow Creek, 2014.

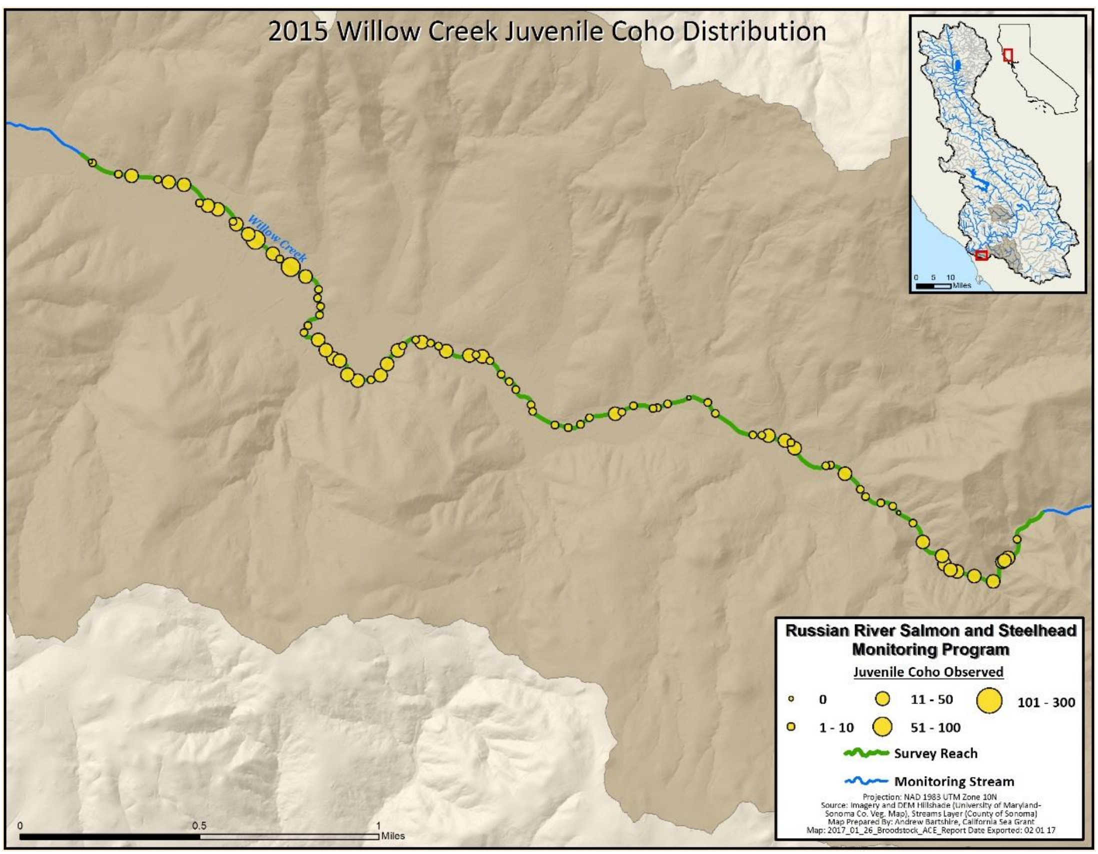

Figure 32. Density and distribution of juvenile coho salmon yoy observed in Willow Creek, 2015.

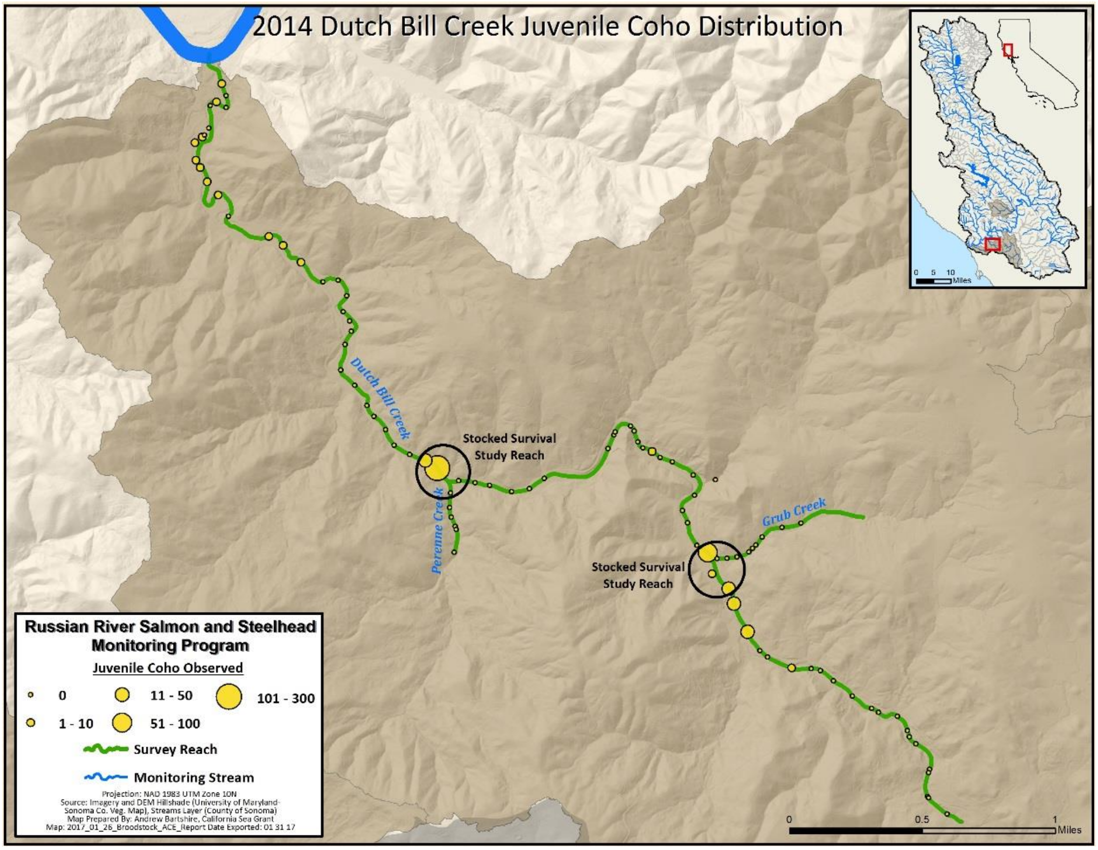

Figure 33. Density and distribution of juvenile coho salmon yoy observed in Dutch Bill Creek, 2014.

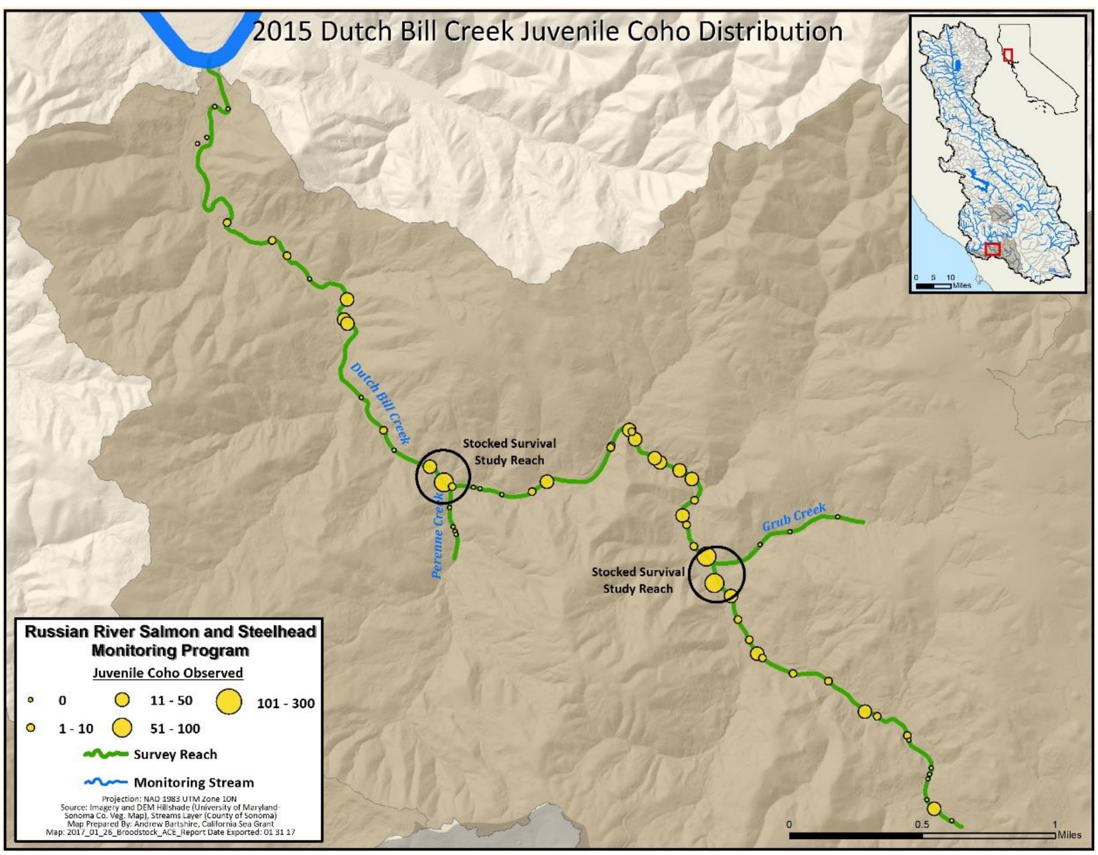

Figure 34. Density and distribution of juvenile coho salmon yoy observed in Dutch Bill Creek, 2015.

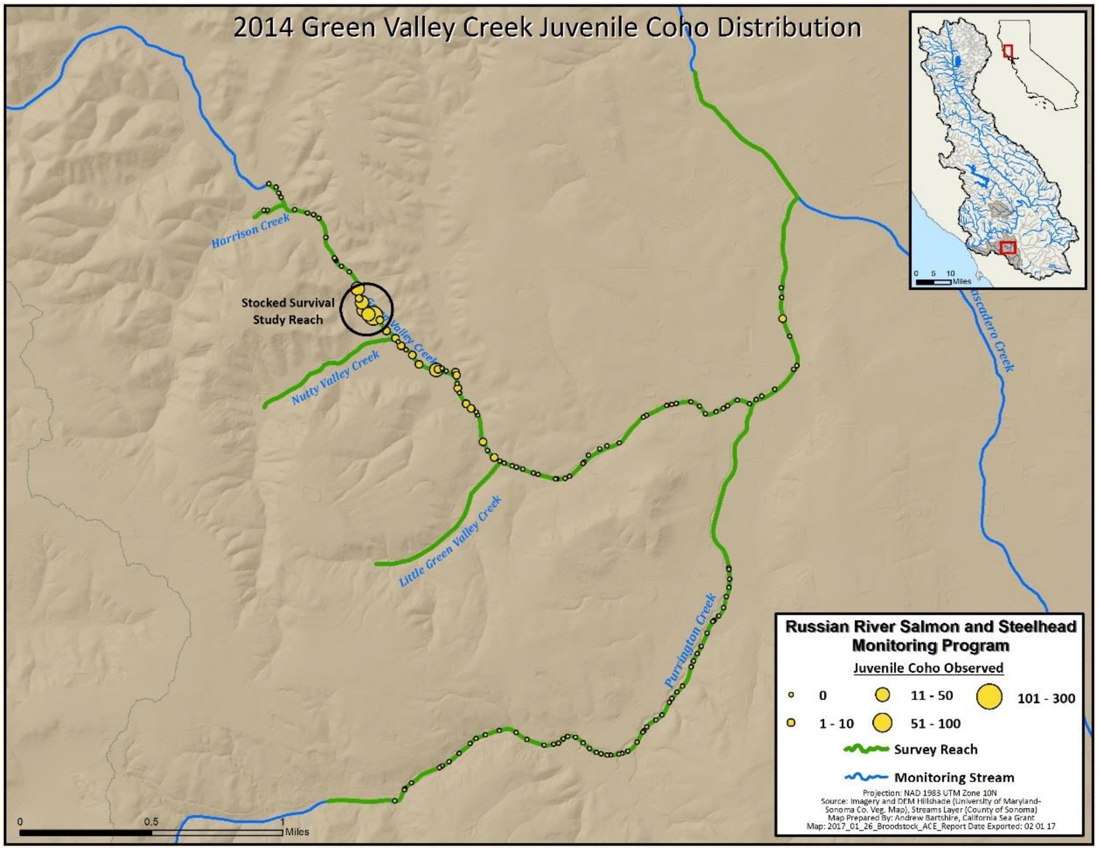

Figure 35. Density and distribution of juvenile coho salmon yoy observed in Green Valley Creek, 2014.

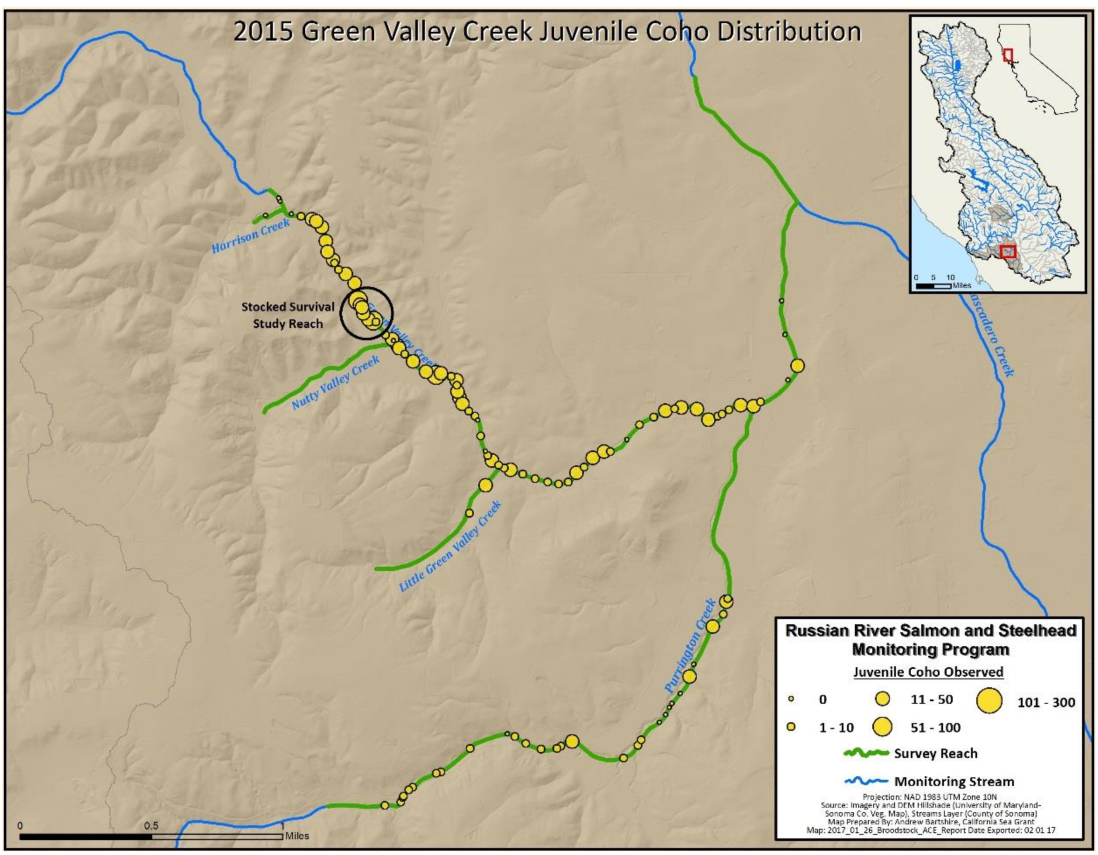

Figure 36. Density and distribution of juvenile coho salmon yoy observed in Green Valley Creek, 2015.

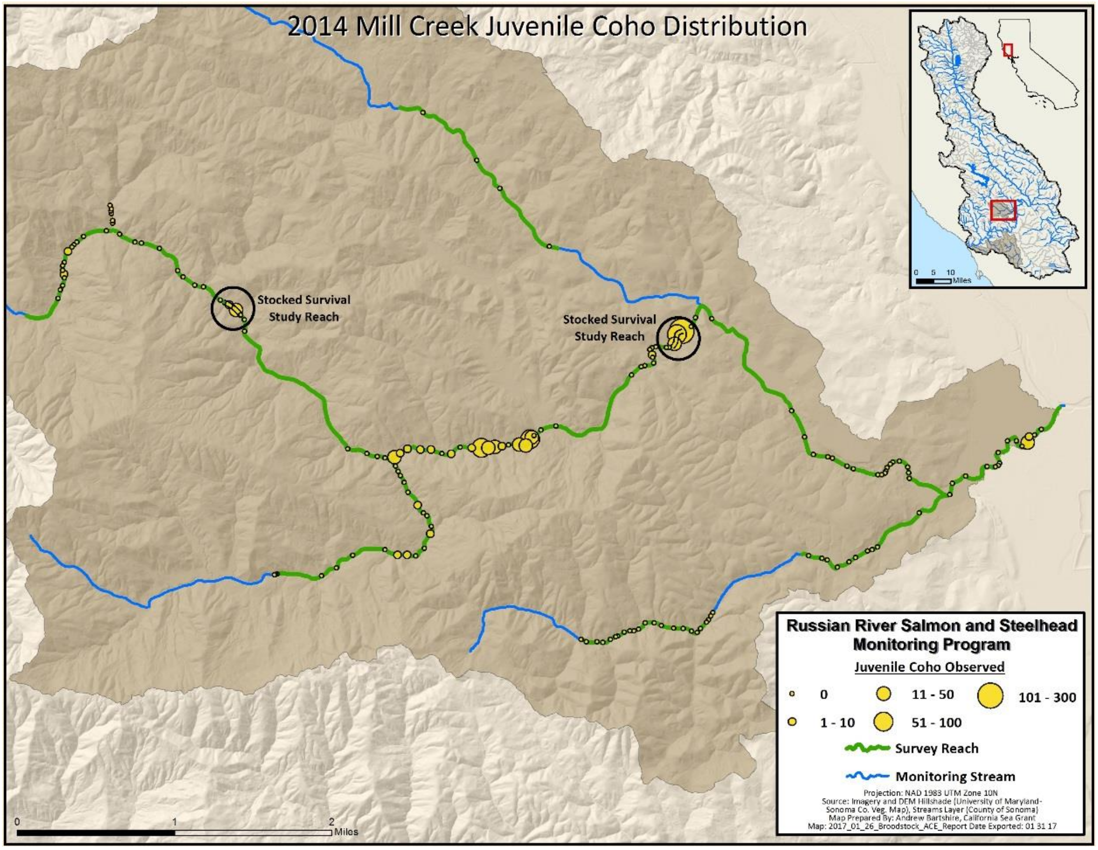

Figure 37. Density and distribution of juvenile coho salmon yoy observed in Mill Creek, 2014.

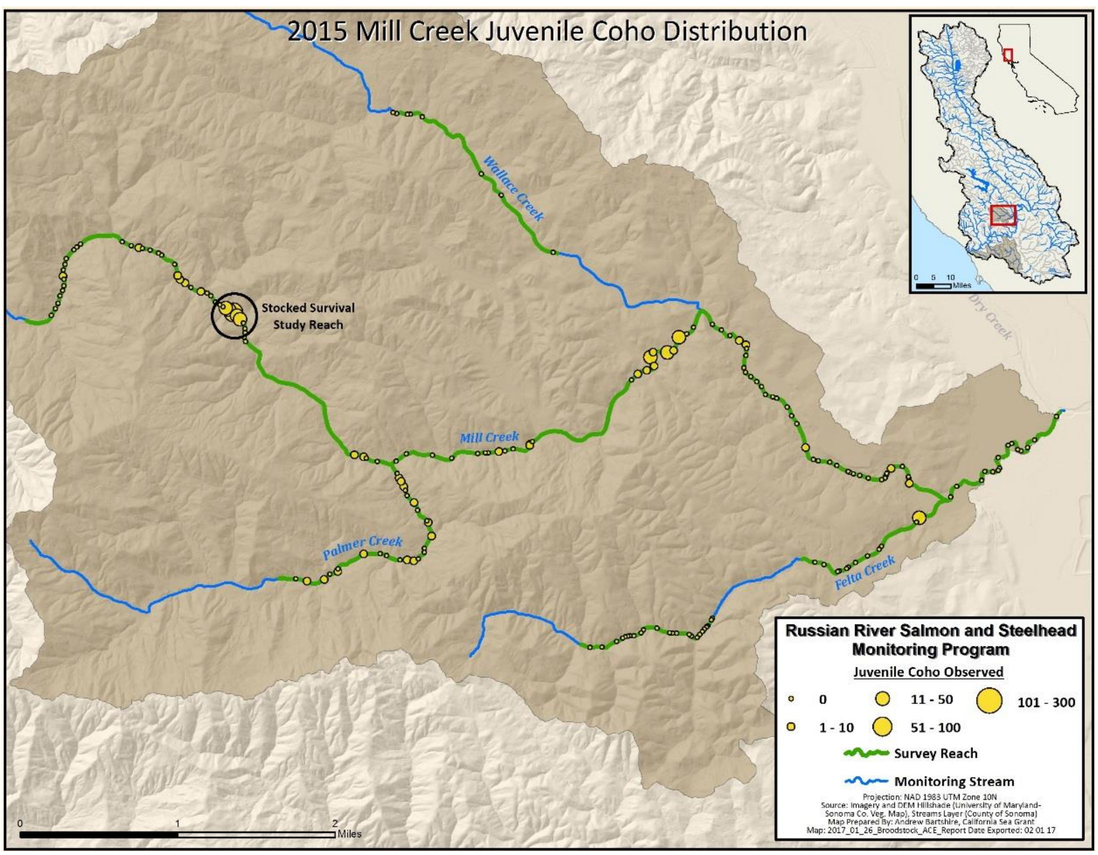

Figure 38. Density and distribution of juvenile coho salmon yoy observed in Mill Creek, 2015.

6 Discussion and Recommendations

Over the five years of this study, we documented the successful outmigration of hatchery-released coho salmon smolts, the return of coho salmon adults, and the production of natural-origin juveniles in Willow, Dutch Bill, Green Valley, and Mill creeks, all indications that the Broodstock Program is effectively increasing coho salmon populations in the Russian River watershed.

6.1 Freshwater Survival and Smolt Abundance

Differences in freshwater survival of hatchery-released juvenile coho salmon were observed among release groups (spring, fall, and smolt). As expected, average stock-to-smolt survival over all years and streams was lowest for the spring release group (0.08), which spends a year in the stream environment, intermediate for the fall release group (0.25), which spends approximately three to six months in the stream environment, and highest for the smolt release group (0.76), which spends only days to weeks within the stream environment. When comparing expected verses observed proportions of adult returns from each release group, we did not detect evidence of a smolt-to-adult survival advantage for the spring release group and, in two of four cohorts evaluated, we observed higher than expected proportions of adults returning from the fall release group and lower than expected proportions for the smolt release group (Table 10). However, sample size for adult returns was small, so it is possible that we did not detect a long-term survival advantage for the spring release group when one was present.

Based on the low stock-to-smolt survival probabilities for the spring release group and the fact that there is no compelling evidence for a smolt-to-adult survival advantage, we recommend reducing the proportion of fish released in the spring season. This would also be advisable given the fact that natural-origin juveniles are now present in the Broodstock Program streams. Stocking hatchery fish in stream reaches where natural-origin fish occur during the spring and summer season when habitat is limited due to low stream flow conditions could have a negative impact on natural-origin fish. The impact of stocking hatchery fish in streams where natural-origin fish are present would be reduced in the fall and winter when streamflow is higher and more habitat is available. We suggest limiting spring releases to occasions when the capacity to rear fish to the fall season at the hatchery is limited, and for use in specialized oversummer survival studies. Because of unpredictable weather and climate patterns and associated variation in survival among years and streams, we also recommend that the Broodstock Program continue its bet-hedging strategy of stocking fish from multiple release groups, primarily the fall, presmolt, and smolt groups.

In a previous study comparing different smolt release strategies, UC found that almost all juvenile coho salmon released as smolts directly into the stream emigrated from the stream within a few days of being released (Obedzinski 2012). To foster imprinting on designated release streams, the Broodstock Program has used two acclimation strategies for the smolt release, where possible; streamside tanks (Dutch Bill and Green Valley creeks) and stocking fish into an instream pond created by a flashboard dam (Mill Creek). Fish placed in the streamside tanks were held in the tanks for a minimum of approximately two weeks and then released into the streams if flow conditions were sufficiently high to allow passage downstream, or into the mainstem of the Russian River if flows were too low.

Survival probability of coho salmon smolts from the time they were removed from the tank and placed in the stream environment until they were detected on the antenna arrays averaged 0.76 over the course of the study (range 0.21 to 1.0). Although the adult return sample size was too small to fully evaluate imprinting success, we observed tank-held smolts returning as adults to Dutch Bill and Green Valley creeks, suggesting that the fish are successfully imprinting.

The survival probability of smolt-released fish placed in the instream pond on Mill Creek for imprinting was lower over the last few years, averaging 0.44 (range 0.03 to 0.0.86). It was higher for the 2015 cohort (0.86) but there was clear evidence that the majority of the fish left the pond immediately because many of them were detected on the antennas near the mouth a day after they were placed into the pond and not subjected to potential mortality associated with being contained in a pond for a month (Obedzinski et al. 2016b). Although adult sample size has been too small to compare return rates of stream-released versus pond-released smolts, we have observed pond-release adults returning to Mill Creek, indicating some measure of imprinting success. However, due to the lower survival probability in previous years and the difficulties of containing fish within an instream pond, we recommend exploring locations where imprinting tanks could be placed and operated on Mill Creek; possibly at Westside School, which would also allow for educational opportunities.

Freshwater growth in Green Valley Creek was notably higher than in the other three Broodstock Program monitoring streams (Figure 11). This was the only stream in which natural-origin coho salmon smolts were larger than hatchery-released smolts (Figure 9). Relatively large smolt size and high growth has been observed in previous years (Obedzinski 2012) and can be explained by the high abundance of benthic macroinvertebrates present in Green Valley Creek, as compared to other Russian River tributaries (Obedzinski 2008).

6.2 Adult Returns

Adult hatchery coho salmon were detected returning to all four Broodstock Program monitoring streams, as well as to the Russian River mainstem. In the majority of streams, return numbers were lower during the winter of 2015/16 than in most recent years, but still far from the near-zero returns observed in these streams prior to the inception of the Broodstock Program. Drought may have played a role in the lower numbers of adults returning from the spring release groups in recent years, as spring-released juveniles spend a full summer season in the tributaries where wetted habitat conditions and juvenile coho salmon oversummer survival have been poor during the last three years (Obedzinski et al. 2016a). Lower returns for fall and smolt release groups (which reside in the hatchery over the summer dry season) suggest that higher mortality is occurring in the mainstem of the Russian River or in the ocean environment. We are uncertain why we are observing an increasing trend in adult returns to Dutch Bill Creek. It is possible that improvements to overwinter habitat by Gold Ridge RCD in recent years, as well as the shorter migration distance to the ocean as compared to Mill and Green Valley creeks, may play a role.

Although we observed lower overall returns of coho salmon to the Russian River during the last three years than in the winter of 2012/13, returns in recent years are still significantly higher than during the early 2000s (Figure 19) and we attribute this general success to Broodstock Program releases, as well as to habitat enhancement work that has been completed in the watershed. Environmental factors outside of our control, such as marine survival and drought, can have a strong influence on the number of adults returning each year and, as in wild populations, we anticipate ongoing cycles in the number of returns.

Low SAR estimates (0 – 1.6%, Figure 20 - Figure 22) pose a challenge to recovering coho salmon populations in tributaries of the Russian River watershed. SAR estimates represent survival from the time that smolts leave a given tributary, migrate downstream through the river and estuarine environments, reside in the ocean, and then migrate back upstream through the estuarine and riverine environments. Given such a variety of conditions experienced during these phases, it would be very informative to be able to separate out riverine, estuarine, and ocean survival to identify whether mortality, particularly of juveniles, is high in the mainstem of the river and/or in the estuary. Estimation of smolt survival through the river has been attempted by operating PIT antennas at Duncans Mills; however, we have been unable to successfully span the entire river channel with antennas, and detection efficiencies of smolts, which travel high in the water column, have been too low to estimate smolt abundance for the entire river. The Water Agency is seeking an additional year-round antenna site further upstream on the mainstem of the Russian River, with the intention of estimating smolt survival through a portion of the river. Radio and/or acoustic tracking of smolts to estimate survival as they travel through the river and estuary would also be a useful method of teasing apart survival in the multiple habitat-types smolts inhabit after they emigrate from the tributaries.

In recent years, low SAR ratios have resulted in a very low sample size of returning adult PIT-tagged fish. This has prohibited our ability to adequately evaluate the success of different release strategies, including whether there are differences in survival of returning adults relative to release season and/or release stream. Current tagging rates have been sufficient for making release group comparisons of freshwater survival; however, we would need to increase tag rates in order to make adequate comparisons of SAR ratios for different release groups. To address this, we suggest that the Broodstock Program Release Workgroup revisit a set of simulations prepared to help decide appropriate tagging rates for the program. Additionally, we propose increasing tag rates by applying tags to coho salmon captured in the smolt traps on Willow, Dutch Bill, Green Valley, and Mill creeks. We began tagging captured smolts in 2016, and think it will be an effective way of increasing the number of PIT-tagged adult returns to the four streams without adding a significant expense. An additional, more costly approach would be to increase tag rates of all fish released from the hatchery.

One component lacking in our monitoring program is the ability to estimate the proportion of natural-origin adults returning to the basin. Although, theoretically, we can estimate this ratio by scanning recovered carcasses for the presence of a CWT, in practice we have never recovered a sufficient number of carcasses to generate this estimate. Through smolt trapping efforts in the spring, we have sufficient sample size to estimate this ratio at the juvenile stage on the four Broodstock Program monitoring streams. The Broodstock Program should discuss the appropriateness of applying these results to adult return data for the entire basin, or adopting alternative methods of estimating this ratio for returning adults.

6.3 The Next Generation

Documentation of natural-origin juveniles in the four Broodstock Program monitoring streams (Table 12), as well as multiple tributaries throughout the Russian River watershed in recent years (Obedzinski et al. 2016a), indicates that adult hatchery returns are successfully reproducing. However, through the course of this and other monitoring efforts, we have identified bottlenecks to survival for the progeny of hatchery-released fish.

By comparing redd and natural-origin juvenile distribution with wetted habitat survey data from additional studies (Obedzinski et al. 2016a), we have documented that low streamflow is a significant bottleneck to long-term coho salmon recovery in many Russian River tributaries. Although adults are returning and successfully spawning in the tributaries as a result of hatchery releases, the majority of their progeny are unable to complete their life cycle due to drying stream conditions during the summer rearing season, particularly in drought years such as 2014 and

2015. Increasing streamflow in Russian River tributaries will be necessary to achieve the Broodstock Program's goal of re-establishing self-sustaining runs of coho salmon.

Another potential bottleneck we have identified is a lack of overwinter rearing habitat for juvenile coho salmon in Dutch Bill Creek, as evidenced by higher winter emigration rates (prior to March 1) in that stream as compared to the other three Broodstock Program monitoring streams (Table 6, Figure 8). Pulses of movement occurring during the winter season appeared to be related to storm events (Obedzinski et al. 2016b), suggesting that in high flows there may be insufficient instream shelter for overwintering juveniles. Smaller winter pulses were observed at the Willow Creek smolt trap site (Obedzinski et al. 2016b); however, fish that moved downstream past the upper Willow antenna site were not detected at the lower antenna site until after March 1, indicating that they overwintered in the lower reaches of Willow Creek during the winter season.

In Mill Creek, a partial passage barrier was discovered through spawner surveys and redd mapping. In most years of the study period, the majority of coho salmon redds observed were downstream of an old flashboard dam below the Wallace Creek confluence, providing evidence that the dam was hindering passage of adult coho salmon. These data were used by Trout Unlimited to seek funds to remediate passage at the flashboard dam site and, during the summer of 2016, modifications to the barrier to allow passage were completed through funding from NOAA, CDFW, and the Water Agency.

Data from this ongoing monitoring work is provided to Broodstock Program agency partners, as well as to the larger salmon and steelhead recovery community, including Resource Conservation Districts, non-profit organizations, and private landowners. By relating this data to results from other studies conducted in the Russian River watershed and making the information publically available, we aim to support the Broodstock Program in making informed decisions about hatchery releases, provide insight into potential bottlenecks to coho salmon recovery, and help evaluate additional long-term recovery actions such as habitat enhancement work and instream flow improvements.

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