Coho Salmon and Steelhead Monitoring Report

Winter 2022/2023

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July 2023, Santa Rosa, CA.

Contents

Suggested reference: California Sea Grant and Sonoma Water. 2023. Coho salmon and steelhead monitoring report: Winter 2022/23. University of California, Santa Rosa, CA.

Funding acknowledgement: Fish monitoring efforts in four Broodstock Program watersheds included in this report were funded by the US Army Corps of Engineers under contract W912P7-21-C-0002. Funding for data collected from additional streams included in this report were provided by California Department of Fish and Wildlife and Sonoma Water as part of the Coastal Monitoring Program.

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1. Background

In 2004, the Russian River Coho Salmon Captive Broodstock Program (Broodstock Program) began releasing juvenile coho salmon (*Oncorhynchus kisutch*) raised at the US Army Corps of Engineer's (USACE) Don Clausen Fish Hatchery into tributaries of the Russian River with the goal of reestablishing populations that were on the brink of extirpation from the watershed. California Sea Grant at University of California (CSG) worked with local, state, and federal biologists 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, CSG has been closely monitoring smolt abundance, adult returns, survival, and spatial distribution of coho salmon populations in four life cycle monitoring (LCM) watersheds: Willow, Dutch Bill, Green Valley, and Mill creeks. Data collected from this effort are provided to the Broodstock Program for use in evaluating the success of hatchery releases and adaptively managing future releases.

Over the last decade, CSG has developed many partnerships in coho salmon and steelhead (*O. mykiss)* recovery, and our program has expanded to include identification of limiting factors to survival, evaluation of habitat enhancement and streamflow improvement projects, and implementation of a statewide salmon and steelhead monitoring program California Coastal Monitoring Program (CMP). In 2010, we began documenting relationships between streamflow and juvenile coho salmon survival as part of the Russian River Coho Water Resources Partnership (Coho Partnership), an effort to improve streamflow and water supply reliability to water-users in flow-impaired Russian River tributaries. In 2013, we partnered with Sonoma Water (SW) and California Department of Fish and Wildlife (CDFW) to begin implementation of the CMP, a statewide effort to document status and trends of anadromous salmonid populations using standardized methods and a centralized statewide database. These new projects, along with others, have led to the expansion of our monitoring, which now includes over 50 Russian River tributaries.

The intention of our monitoring and research is to provide science-based information to stakeholders involved in salmon and steelhead recovery. Our work would not be possible without the support of our partners, including public resource agencies and non-profit organizations, along with hundreds of private landowners who have granted us access to the streams that flow through their properties.

In 2023, CSG began transitioning away from field data collection and subcontracted with SW to conduct field activities associated with Broodstock Program monitoring. During the winter of 2022/2023, field data was collected by both organizations and beginning in spring 2023, will be conducted entirely by SW.

In this seasonal monitoring update, we provide results from our fall and winter field season, including results from coho salmon monitoring at Passive integrated transponder (PIT) tag detection sites located throughout the watershed and from spawning surveys conducted through both Broodstock Program and CMP monitoring efforts. Additional information and previous reports can be found on CSG's website.

2. PIT tag monitoring

2.1. Goals and objectives

PIT tags and PIT detection systems (antennas and transceivers) were used to document the status and trends of Russian River coho salmon populations at both stream-specific and basinwide scales. From September 15, 2022, through March 1, 2023, our goal was to collect PIT tag data at multiple sites to document adult coho salmon return timing, estimate the number of returning coho salmon adults, and estimate coho salmon smolt to adult return (SAR) ratios in four LCM watersheds (Willow, Dutch Bill, Green Valley, and Mill creeks). Except for SAR ratios, we were able to estimate these metrics for the Russian River basin as well. It was not possible to estimate SAR ratios at the basin scale because we do not have the ability to estimate the number of smolts leaving the entire Russian River basin each year.

2.2. Methods

2.2.1. PIT tagging

Beginning in 2007, a portion of juvenile coho salmon released from Don Clausen Fish Hatchery into the Mill Creek watershed were implanted with 12.5 mm full duplex (FDX) PIT tags. Coho salmon destined for tagging were randomly selected from holding tanks, and for all fish ≥ 56 mm and ≥ 2.0 g, a small incision was made on the ventral side of the fish using a scalpel, and a tag was then inserted into the body cavity. Over the next few years, PIT-tagged coho salmon were released into an increasing number of Russian River tributaries (Table 1). In 2013, the Broodstock Program began PIT tagging a percentage of all coho salmon released into the Russian River watershed. Since then, the hatchery has continued to PIT-tag a proportion of all releases each year.

During the winter of 2022/23, we anticipated the return of PIT-tagged adults from cohorts 2020 (age-3 returns) and 2021 (age-2 returns) that had been released as juveniles into multiple streams (Table 2). In addition, we anticipated the return of adults that we had previously tagged as juveniles at our smolt traps. Approximately half of all natural-origin coho salmon smolts captured in downstream migrant traps during the springs of 2021 and 2022 were PIT tagged in Willow, Green Valley, and Mill creeks (California Sea Grant 2021a, 2022). To increase the sample size for estimating smolt to adult return (SAR) ratios, we also PIT-tagged approximately one quarter of all non-PIT-tagged hatchery smolts captured in Mill, Green Valley and Willow creeks during the springs of 2021 and 2022. Another potential source of PIT-tagged adult returns was natural-origin coho salmon tagged as young-of-year in 2020 during CMP electrofishing surveys in Dutch Bill (857), Purrington (14), and Mill (98) creeks and during a summer survival study in Porter Creek in which a total of 166 coho salmon young-of-year were PIT-tagged in 2020.

Other adults present in the Russian River during the winter of 2022/23 originated from a Broodstock Program release of 29 adult coho salmon into a side channel of Dry Creek (Table 2, Figure 1) on February 13, 2023. The adult coho salmon released at this location were marked with an external floy tag (females pink and males green) and 28 of 29 were PIT-tagged.

2.2.2. Field methods

As part of the Broodstock Program monitoring effort, CSG operated stationary PIT tag detection systems in stream channels near the mouths of Willow, Dutch Bill, Green Valley and Mill creeks (Figure 1). Multiplexing transceivers 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 (e.g., Figure 2) 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 24” during base flow conditions. During high water storm events, stream depths likely exceeded maximum read range depths, so if PIT-tagged fish were travelling in the water column above the maximum read range depth, they may not have been detected on the antennas. The paired arrays were used to estimate antenna efficiency in order to account for undetected fish. From September 15, 2022 through March 1, 2023, PIT tag detection systems were visited every other week to download data and check antenna status. More frequent visits were made during storm events. Additional antenna arrays were operated throughout the watershed by CSG and SW, including a 10-antenna array located in the mainstem of the Russian River near Duncans Mills (see EST-10.46, Figure 1).

Table 1. Number and percent of PIT-tagged coho salmon released into Russian River tributaries by cohort.

Cohort (Hatch year)	Tributaries[1] stocked with coho salmon	Tributaries[1] stocked with PIT-tagged coho salmon	Number coho salmon released into Russian River tributaries	Number PIT-tagged coho salmon released	Percent of Russian River releases PIT-tagged
2007	DRY, DUT, GIL, GRA, GRE, MIL, PAL, SHE	MIL, PAL	71,159	7,456	10%
2008	DRY, DUT, GIL, GRA, GRE, MIL, PAL, SHE	MIL, PAL	91,483	11,284	12%
2009	DRY, DUT, GIL, GRA, GRE, MIL, PAL, SHE	MIL, PAL, GRE	81,231	8,819	11%
2010	DEV, DRY, DUT, EAU, FRE, GIL, GRA, GRE, GRP, MIL, PAL, POR, PUR, THO, SHE	DRY, DUT, GRE, GRP, MIL, PAL	155,388	16,767	11%
2011	ANG, BLA, DEV, DRY, DUT, EAU, FRE, GIL, GRA, GRE, GRP, MAR, MIL, PAL, PEN, POR, PUR, THO, SHE, WIL	ANG, BLA, DEV, DRY, DUT, GIL, GRA, GRE, GRP, MIL, PAL, PEN, PUR, THO, WIL	160,397	18,769	12%
2012	BLA, DEV, DRY, DUT, EAU, FRE, GIL, GRA, GRE, GRP, MAR, MIL, PAL, PEN, POR, PUR, THO, SHE, WIL	BLA, DEV, DRY, DUT, GIL, GRA, GRE, GRP, MIL, PAL, PEN, PUR, THO, WIL	182,370	30,934	17%
2013	AUS, BLA, DEV, DRY, DUT, FRE, GIL, GRA, GRE, GRP, MAR, MIL, PAL, PEN, POR, PUR, SHE, THO, WIL	AUS, BLA, DEV, DRY, DUT, FRE, GIL, GRA, GRE, GRP, MAR, MIL, PAL, PEN, POR, PUR, SHE, THO, WIL	171,846	34,536	20%
2014	AUS, BLA, DEV, DRY, DUT, EAU, FRE, GIL, GRA, GRE, GRP, MAR, MIL, PAL, PEN, POR, PUR, SHE, THO, WIL	AUS, BLA, DEV, DRY, DUT, EAU, FRE, GIL, GRA, GRE, GRP, MAR, MIL, PAL, PEN, POR, PUR, SHE, THO, WIL	235,327	39,556	17%
2015	DRY, DUT, GIL, GRA, GRE, MIL, WIL	DRY, DUT, GIL, GRA, GRE, MIL, WIL	70,510	22,620	32%
2016	AUS, DEV, DRY, DUT, FRE, GIL, GRA, GRE, MAR, MIL, PAL, PUR, SHE, THO, WIL	AUS, DEV, DRY, DUT, FRE, GIL, GRA, GRE, MAR, MIL, PAL, PUR, SHE, THO, WIL	158,379	26,546	17%
2017	AUS, DEV, DRY, DUT, FRE, GIL, GRA, GRE, MAI, MIL, PAL, PUR, RCA, SHE, WIL	AUS, DEV, DRY, DUT, FRE, GIL, GRA, GRE, MAI, MIL, PAL, PUR, RCA, SHE, WIL	133,853	31,773	24%
2018	AUS, DEV, DRY, DUT, EAU, FRE, GIL, GRA, GRE, MAR, MAI, MIL, PAL, POR, PUR, RCA, SHE, WIL	AUS, DEV, DRY, DUT, EAU, FRE, GIL, GRA, GRE, MAR, MAI, MIL, PAL, POR, PUR, RCA, SHE, WIL	134,014	27,823	21%
2019	AUS, DEV, DRY, DUT, EAU, GIL, GRA, GRE, MAR, MAI, MIL, PAL, POR, PUR, RCA, WIL	AUS, DEV, DRY, DUT, EAU, GIL, GRA, GRE, MAR, MAI, MIL, PAL, POR, PUR, RCA, WIL	194,277	31,094	16%
2020	AUS, DEV, DRY, DUT, EAU, GIL, GRA, GRE, KID, MAR, MAI, POR, PUR, RCA, WIL, YEL	AUS, DEV, DRY, DUT, EAU, GIL, GRA, GRE, KID, MAR, MAI, POR, PUR, RCA, WIL	196,276	26,805	13%
2021	AUS, DRY, DUT, EAU, FRE, GRA, GRE, MAR, MIL, PAL, POR, PUR, RCA, SHE, WIL, MAI, KID, YEL	AUS, DRY, DUT, EAU, FRE, GRA, GRE, MAR, MIL, PAL, POR, PUR, RCA, SHE, WIL, MAI, KID	215,021	29,729	14%

[1]Stream Codes: ANG: Angel Creek, AUS: Austin Creek, BLA: Black Rock Creek, DEV: Devil Creek, DRY: Dry Creek, DUT: Dutch Bill Creek, EAU: East Austin Creek, FRE: Freezeout Creek, GIL: Gilliam Creek, GRA: Gray Creek, GRE: Green Valley Creek, GRP: Grape Creek, KID: Kidd Creek, MAI: Russian River Mainstem, MAR: Mark West Creek, MIL: Mill Creek, PAL: Palmer Creek, PEN: Pena Creek, POR: Porter Creek, PUR: Purrington Creek, RCA: Redwood Creek (Atascadero), SHE: Sheephouse Creek, THO: Thompson Creek, WIL: Willow Creek, YEL: Yellow Jacket Creek.

Table 2. Number and percent of PIT-tagged juvenile coho salmon released into Russian River tributaries by stream and release group, cohorts 2020 and 2021.

Cohort (Hatch year)	Tributary	Release group	Total coho salmon released	PIT-tagged coho salmon released	Percent PIT-tagged coho salmon released
2020	Russian River	smolt	12,572	1,905	15%
2020	Willow Creek	fall	6,634	1,000	15%
2020	Austin Creek	fall	12,995	1,963	15%
2020	Kidd Creek	fall	2,542	385	15%
2020	East Austin Creek	fall	10,053	1,508	15%
2020	Gilliam Creek	spring	2,047	310	15%
2020	Gray Creek	spring	5,040	760	15%
2020	Devil Creek	spring	2,547	380	15%
2020	Dutch Bill Creek	fall	11,084	1,732	16%
2020	Dutch Bill Creek	smolt	2,543	385	15%
2020	Green Valley Creek	fall	16,150	2,428	15%
2020	Green Valley Creek	presmolt	10,079	1,521	15%
2020	Green Valley Creek	smolt	3,634	549	15%
2020	Redwood Creek (Atascadero)	spring	2,072	310	15%
2020	Redwood Creek (Atascadero)	fall	3,039	460	15%
2020	Purrington Creek	fall	2,537	385	15%
2020	Mark West Creek	fall	13,641	2,052	15%
2020	Mark West Creek	presmolt	10,080	1,520	15%
2020	Porter Creek	spring	497	497	100%
2020	Porter Creek	fall	6,095	920	15%
2020	Dry Creek	spring	10,017	1,515	15%
2020	Dry Creek	fall	30,274	4,516	15%
2020	Dry Creek	smolt	10,156	1,529	15%
2020	Dry Creek	adult	29	28	97%
2020	Yellowjacket Creek	fry	9,947	0	0%
2021	Russian River	smolt	59,152	9,002	15%
2021	Willow Creek	fall	4,033	610	15%
2021	Sheephouse Creek	fall	1,498	230	15%
2021	Freezeout Creek	fall	1,520	230	15%
2021	Austin Creek	fall	8,053	1,215	15%
2021	Kidd Creek	fall	3,003	459	15%
2021	East Austin Creek	fall	11,022	1,679	15%
2021	Gray Creek	fall	3,840	609	16%
2021	Dutch Bill Creek	fall	11,930	1,811	15%
2021	Green Valley Creek	fall	11,467	1,722	15%
2021	Redwood Creek (Atascadero)	fall	2,000	305	15%
2021	Purrington Creek	fall	2,041	302	15%
2021	Mark West Creek	fall	7,991	1,210	15%
2021	Porter Creek	fall	3,045	459	15%
2021	Dry Creek	fall	20,185	3,073	15%
2021	Dry Creek	spring	30,584	4,526	15%
2021	Mill Creek	fall	12,210	1,827	15%
2021	Palmer Creek	fall	3,050	460	15%
2021	Yellowjacket Creek	RSI	18,157	0	0%

Figure 1. Passive integrated transponder (PIT) antenna and adult release location in the Russian River watershed, winter 2022/23. Labels on antennas include a stream code (first three letters of the stream) and the distance in km from the mouth of that stream.

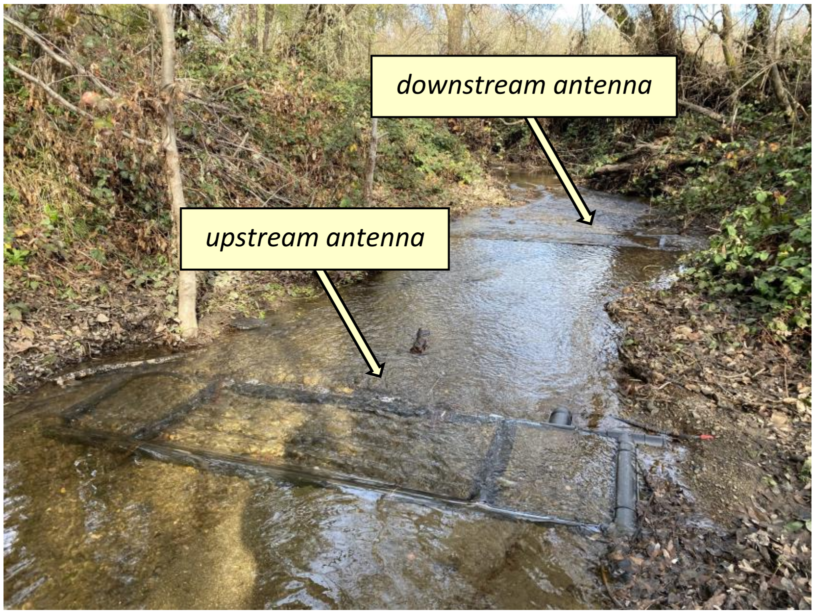

Figure 2. Paired flat-plate antenna array.

2.2.3. Data analysis

First, all records of two- and three-year-old PIT-tagged coho salmon detected on antenna arrays between September 15, 2022 and March 1, 2023 were examined to determine the movement and life history patterns of fish detected on PIT antenna arrays (i.e., returning adults, age-2 outmigrants, or "ghost tags") based on the duration and direction of tag movement. Individuals with a net positive upstream movement during this time frame were categorized as adult returns, which were further evaluated for their return timing relative to flow conditions, and for minimum and estimated return numbers, as described below. We presumed that two-year-olds detected moving in a downstream-only direction were juveniles and they were removed from the adult return dataset. Any tags that were moving very slowly downstream at a given antenna array (approximately one hour or more between upper and lower arrays) and that were not previously detected leaving as smolts, were presumed to be tags from fish that had perished (ghost tags) and these tags were also removed from the adult return dataset.

2.2.3.1. Adult return timing relative to flow conditions

The first detection of each returning PIT-tagged hatchery adult coho salmon between September 15, 2022 and March 1, 2023 was plotted with streamflow or stage data from the nearest available streamflow gage at each antenna site.

2.2.3.2. Adult return minimum and estimated numbers

Estimates of the number of adult coho salmon returning to Willow, Dutch Bill, Green Valley and Mill creeks were calculated by 1) counting the number of unique adult PIT 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 or, in the case of natural-origin fish, the proportion of natural-origin fish PIT-tagged at the smolt trap (expanded count per stream), and 3) dividing the expanded count by the estimated efficiency of the lower antennas of each stream array (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 was used to estimate the number of returns by release group (age and season of release). To avoid the potential for duplication in our expansions of hatchery fish, we did not expand the number of hatchery adults that were previously tagged at the smolt traps unless there were no other hatchery adults detected from that cohort and release stream.

In most winters, 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 as described for the LCM streams; however, the efficiency of the Duncans Mills antenna array was estimated by dividing the total number of unique PIT detections of adults at both Duncans Mills and at antenna arrays upstream of Duncans Mills 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 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, an estimate of adults that entered Willow Creek (but were not detected on or upstream of Duncans Mills) 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 have no means of estimating PIT-tagged adults returning to those streams so returns to those creeks were not included in the basinwide estimate.

During the winters of 2020/21 and 2022/23, low antenna efficiencies at the Duncans Mills antenna array prevented us from using the adult estimation approach used in most years (described above). As an alternative, we first summed the number of unique adult PIT detections on any antenna that was operated in the watershed during the winter of 2020/21 or 2022/23, then divided the number of unique individuals from each release group by the proportion tagged for that release group (Table 2), and finally summed the total expanded counts for each release group. This method did not account for PIT antenna efficiency and therefore may be biased low. However, unlike the Duncans Mills antenna array, antenna efficiencies in the tributaries are generally at or near 100%.

2.2.3.3. Smolt to adult return (SAR) ratios

In each of the four LCM watersheds, the sum of the estimated number of two-year old hatchery adults returning during the winter of 2021/22 and three-year old adults returning during the winter of 2022/23 was divided by the estimated number of smolts migrating from each stream between March 1 and June 30 of 2021 to derive a SAR ratio. 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 tributary as adults. Detections of coho salmon adults from the February 13 adult release were excluded from SAR calculations.

2.3. Results

2.3.1. Adult return timing relative to flow conditions

Total precipitation between October 1, 2022 and March 1, 2023 was slightly above the 20-year average (Figure 3). The first storm event of the year occurred in early-December followed by a high concentration of storm flows between late-December and mid-January (e.g., Austin Creek, Figure 4). To avoid the risk of the transceivers flooding at certain sites, equipment was removed during the first week of January at the Duncans Mills, Dutch Bill, and lower Willow antenna sites. The seasonal antennas operated on the mainstem at Mirabel dam were removed on 12/9/22.

A total of 28 unique PIT-tagged adult coho salmon were detected on PIT antennas in the Russian River watershed during the winter of 2022/23. PIT-tagged adult coho salmon were first detected entering the estuary and mainstem river in November, prior to the first large storm event that increased streamflow (Figure 5, Figure 6) and in the estuary as late as mid-January. Detections in Dry Creek as well as the four LCM streams began in early December and continued through mid-January in some tributaries (Figure 7 - Figure 12). Adult release fish were detected in both Mill Creek and Dry Creek in mid- to late-February, later than detections of fish that were released as juveniles.

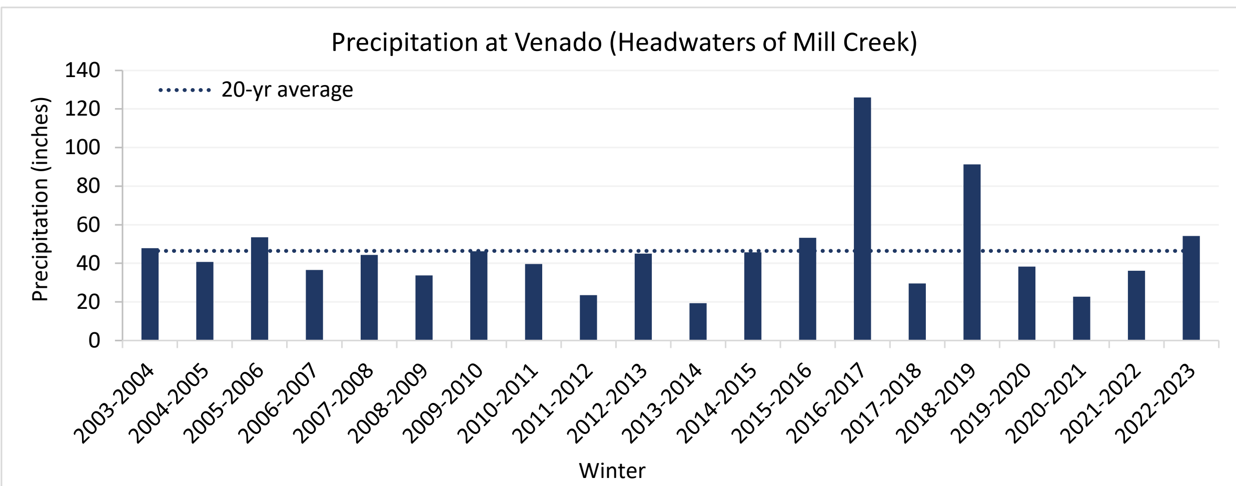

Figure 3. October – February precipitation at Venado gage near Mill Creek headwaters. Data were obtained from the California Data Exchange Center (https://cdec.water.ca.gov).

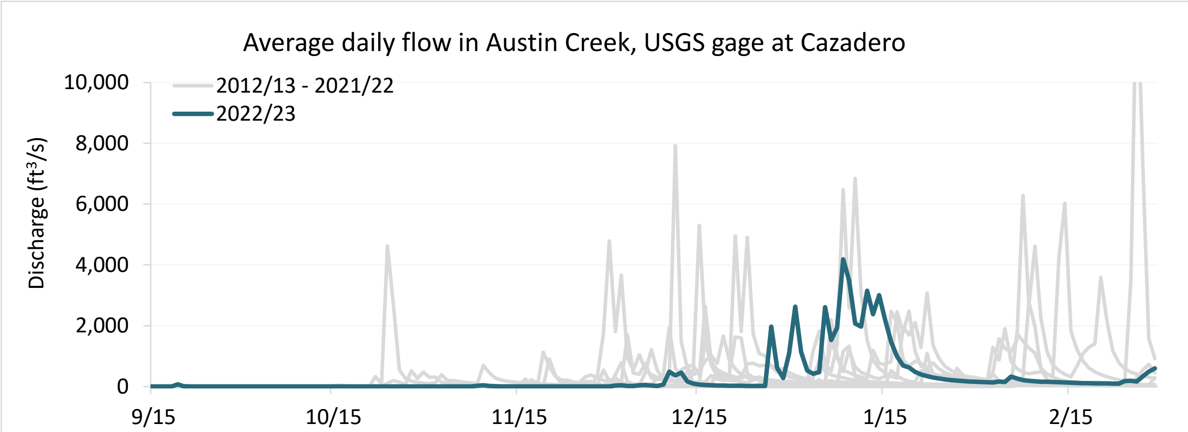

Figure 4. Winter 2022/23 streamflow in Austin Creek near Cazadero as compared to streamflow during the previous 10 winters. Data were obtained from USGS (waterdata.usgs.gov).

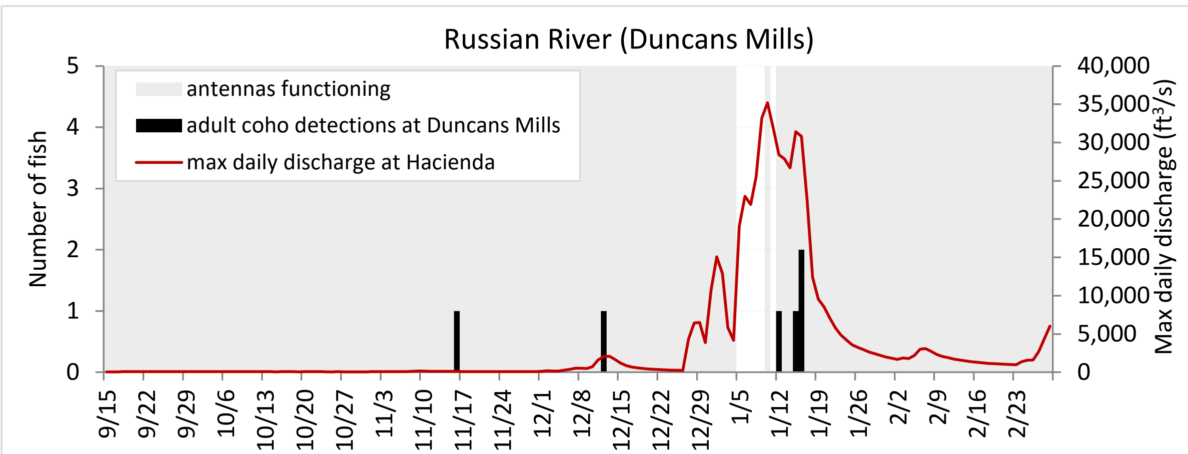

Figure 5. Detections of PIT-tagged coho salmon adults passing upstream of the Russian River antenna array at Duncans Mills (EST-10.46), September 15, 2022 - March 1, 2023. Discharge data were obtained from the USGS gage at Hacienda Bridge (11467000, waterdata.usgs.gov).

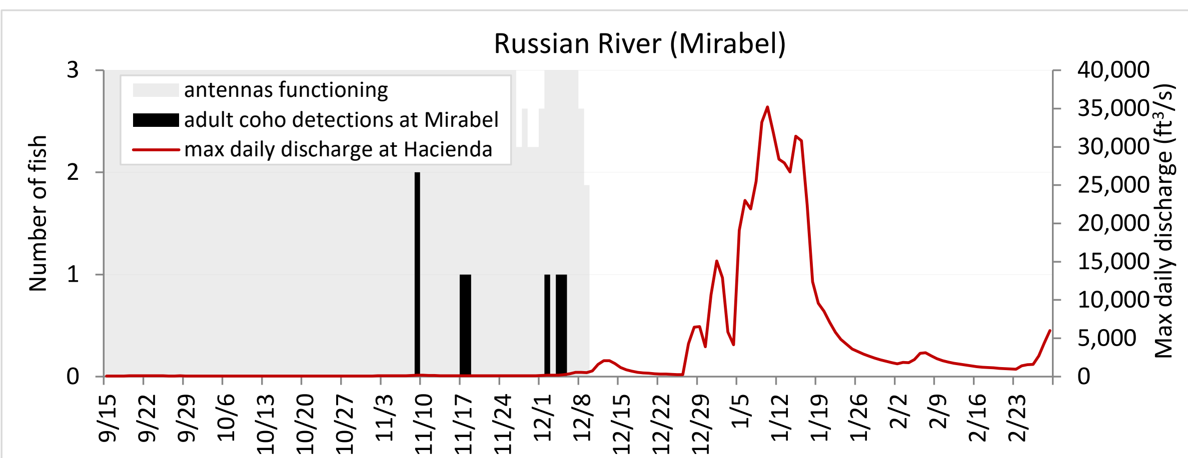

Figure 6. Detections of PIT-tagged coho salmon adults passing upstream of the Russian River antenna array at Mirabel (MAI-28.11), September 15, 2022 - March 1, 2023. Discharge data were obtained from the USGS gage at Hacienda Bridge (11467000, waterdata.usgs.gov). The antennas were removed for the season on 12/9/22.

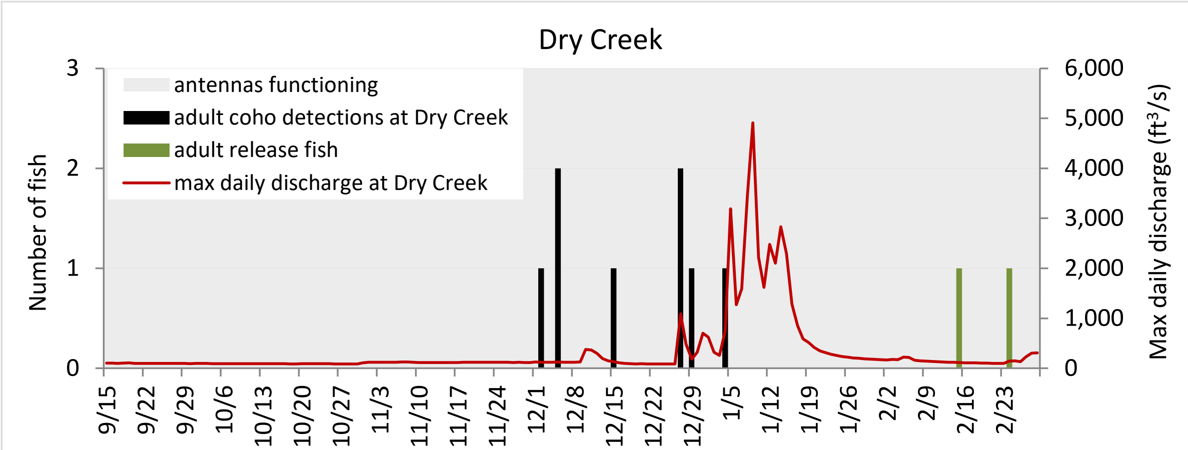

Figure 7. Detections of PIT-tagged coho salmon adults passing upstream of the Dry Creek antenna array (DRY-000.36), September 15, 2022 - March 1, 2023. Discharge data were obtained from the USGS gage at Dry Creek mouth (11465350, waterdata.usgs.gov).

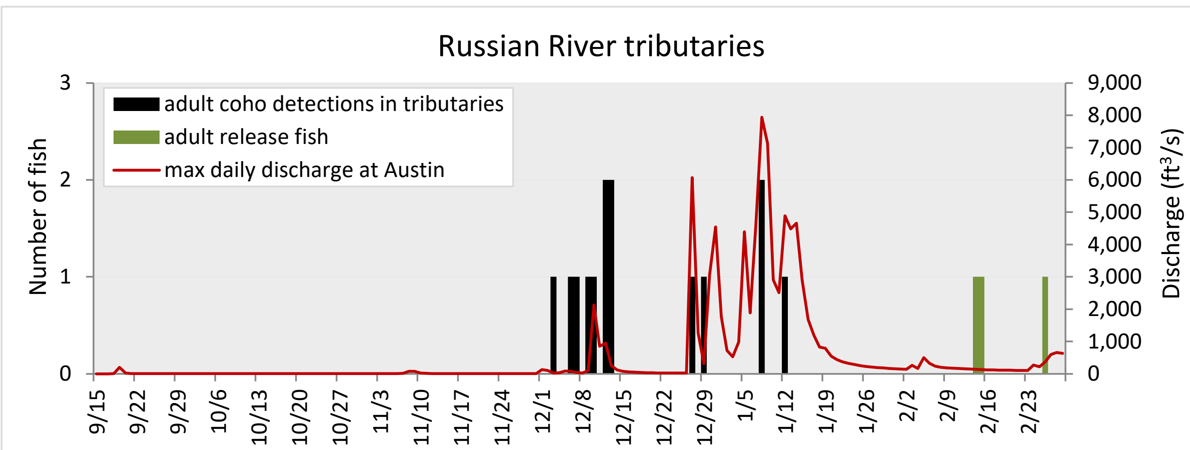

Figure 8. Detections of PIT-tagged coho salmon adults on Willow, Dutch Bill, Green Valley, Mill, Mark West, and/or Porter creek antennas, September 15, 2022 - March 1, 2023. Discharge data were obtained from the USGS gage at Austin Creek (11467200, waterdata.usgs.gov).

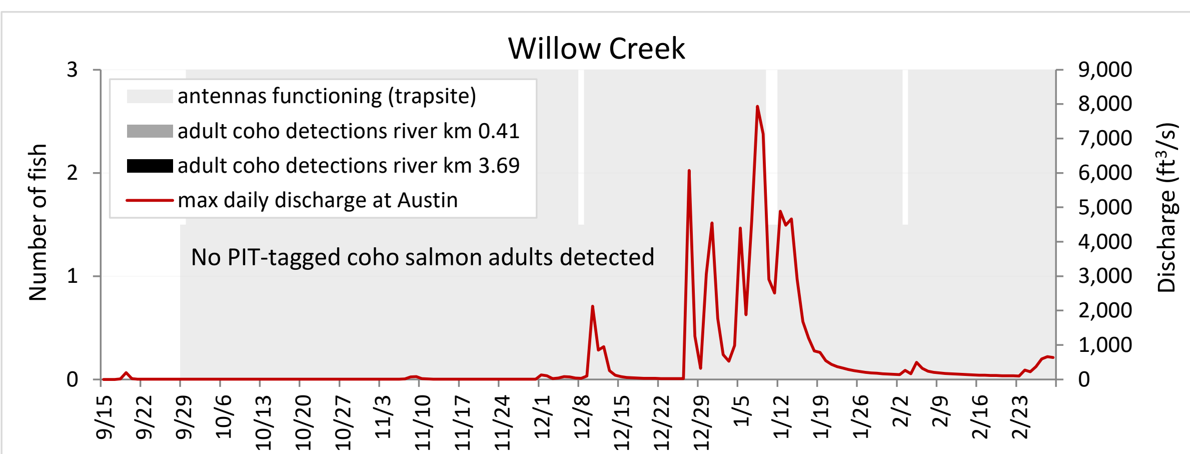

Figure 9. Antenna operation dates on Willow Creek between September 15, 2021 and March 1, 2022. Discharge data were obtained from the USGS gage at Austin Creek (11467200, waterdata.usgs.gov). No adult coho salmon were detected during this period.

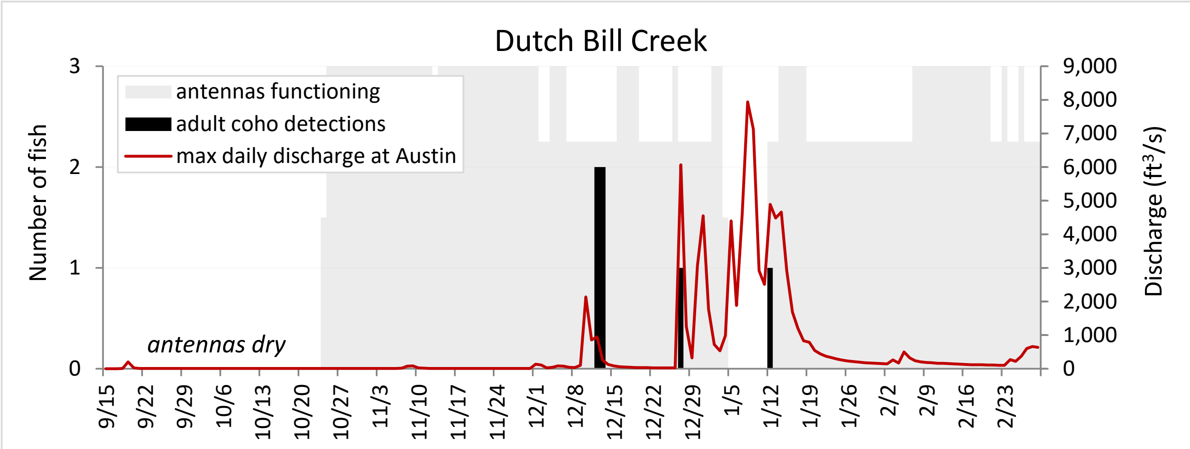

Figure 10. Detections of PIT-tagged coho salmon adults passing upstream of the Dutch Bill Creek antenna array, September 15, 2022 - March 1, 2023. Discharge data were obtained from the USGS gage at Austin Creek (11467200, waterdata.usgs.gov).

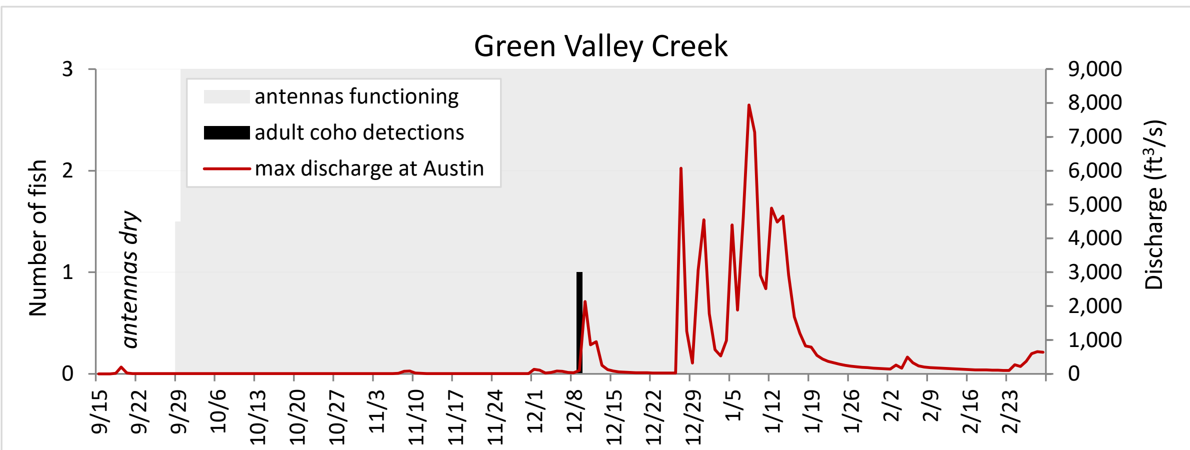

Figure 11. Detections of PIT-tagged coho salmon adults passing upstream of the Green Valley Creek antenna array, September 15, 2022 - March 1, 2023. Discharge data were obtained from the USGS gage at Austin Creek (11467200, waterdata.usgs.gov).

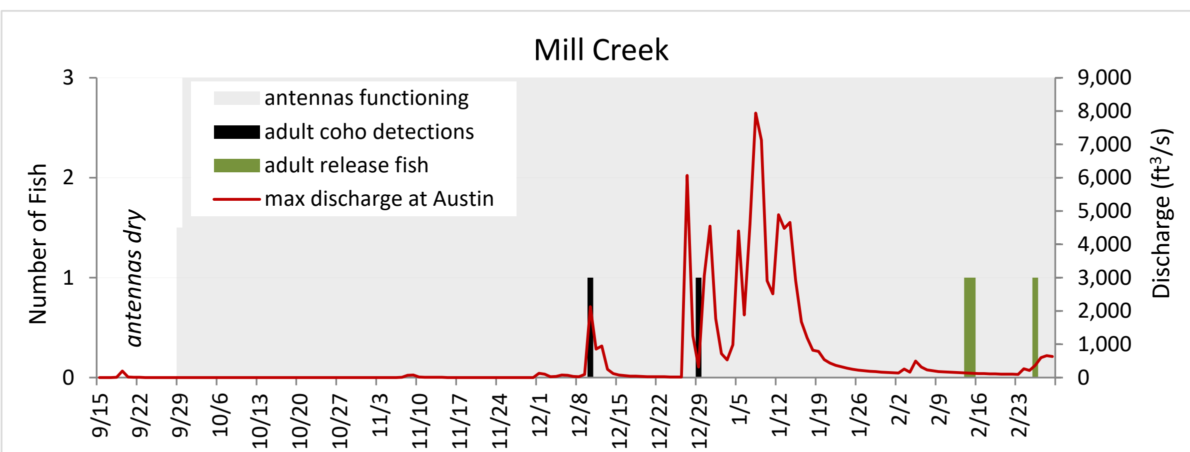

Figure 12. Detections of PIT-tagged coho salmon adults passing upstream of the Mill Creek antenna array, September 15, 2022 - March 1, 2023. Discharge data were obtained from the USGS gage at Austin Creek (11467200, waterdata.usgs.gov).

2.3.2. Adult return estimates

Estimates of adult coho salmon returning to Willow, Dutch Bill, Green Valley, and Mill creeks were 0, 28, 7, and 17, respectively (Table 3 - Table 5), and the estimated number of hatchery coho salmon adults returning to the Russian River Basin was 165 (Table 6). The composition of release groups returning as adults to each watershed varied across watersheds. Despite continuous operation of antenna arrays at the upper antenna site, no PIT-tagged adults were detected entering Willow Creek (Figure 9). In Dutch Bill Creek, all detected adults were age-3 and consisted of hatchery releases from fall and smolt release groups into Dutch Bill, smolt releases into the lower Russian River, and a natural-origin fish that was PIT-tagged during CMP electrofishing surveys (Table 3). Only one PIT-tagged adult coho salmon was detected returning to Green Valley Creek, an age-2 fish from a fall release into Green Valley Creek (Table 4). Mill Creek adult returns originated from a mix of streams and release groups including an age-2 fall release fish into Mill Creek, an age-3 presmolt release fish into Mark West Creek and three adult release fish into Dry Creek (Table 5). Release group composition of adult coho salmon returning to the Russian River watershed included a diversity of streams and age groups with relatively high representation of the lower Russian River smolt release group for both cohorts (32-33%), high representation from Dutch Bill for the age-3 cohort (46%) and high representation of the Mill Creek fall release for the age-2 cohort (32%) (Table 6).

Adult return estimates during the winter of 2022/23 were lower than average compared to previous years, and in the case of Willow and Green Valley creeks, the lowest on record (Figure 13 - Figure 17). The proportion of age-2 returns was highly variable, ranging from 0 – 100%, depending on stream (Figure 13 – Figure 16) and 64% to the Russian River watershed (Figure 17).

Table 3. Minimum, expanded, and estimated counts of adult coho salmon returning to Dutch Bill Creek between September 15, 2022 and March 1, 2023. Minimum count: number unique PIT detections on lower antenna array; expanded count: minimum count/percent PIT-tagged; estimated count: expanded count/estimated antenna efficiency.

Age	Release tributary	Origin	Release group	Minimum count	Percent PIT-tagged	Expanded count	Estimated antenna efficiency	Estimated count
3	Dutch Bill Creek	hatchery	fall	1	16%	6	96%	6.7
	Dutch Bill Creek	hatchery	smolt	1	15%	7	96%	6.9
	Russian River	hatchery	smolt	2	15%	13	96%	13.7
	Dutch Bill Creek	natural	tagged electrofishing	1	95%	1	96%	1.1
							Estimated hatchery adult returns (age-3):	27.3
							Estimated natural-origin adult returns (age-3):	1.1
							Total estimated adult returns:	**28**

Table 4. Minimum, expanded, and estimated counts of adult coho salmon returning to Green Valley Creek between September 15, 2022 and March 1, 2023. Minimum count: number unique PIT detections on upper antenna array; expanded count: minimum count/percent PIT-tagged. The one PIT-tagged fish was detected on only one antenna so antenna efficiency could not be calculated.

Age	Release tributary	Origin	Release group	Minimum count	Percent PIT-tagged	Expanded count	Estimated antenna efficiency	Estimated count
2	Green Valley Creek	hatchery	fall	1	15%	6.7	unknown	6.7
							Estimated hatchery adult returns (age-3):	0.0
							Estimated hatchery adult returns (age-2):	6.7
							Total estimated adult returns:	**7**

Table 5. Minimum, expanded, and estimated counts of adult coho salmon returning to Mill Creek between September 15, 2022 and March 1, 2023. Minimum count: number unique PIT detections on upper antenna array; expanded count: minimum count/percent PIT-tagged; estimated count: expanded count/estimated antenna efficiency.

Age	Release tributary	Origin	Release group	Minimum count	Percent PIT-tagged	Expanded count	Estimated antenna efficiency	Estimated count
3	Mark West Ceek	hatchery	presmolt	1	15%	6.6	100%	6.6
	Dry Creek	hatchery	adult	3	93%	3.2	100%	3.2
2	Mill Creek	hatchery	fall	1	15%	6.7	100%	6.7

Estimated hatchery adult returns (age-3):	6.6
Estimated hatchery adult returns (age-2):	6.7
Estimated adult release fish (age 3):	3.2
Total estimated adult returns (without adult release fish):	**13**
Total estimated adult returns (including adult release fish):	**17**

Table 6. Minimum and expanded counts of hatchery adult coho salmon returning to any Russian River antenna site between September 15, 2022 and March 1, 2023. Minimum count= number unique PIT detections on any Russian River watershed antenna array; expanded count= minimum count/percent PIT-tagged.

Age	Release tributary	Release group	Minimum count	Percent PIT-tagged	Expanded count
3	Dry Creek	fall	1	15%	6.7
	Dutch Bill Creek	fall	2	16%	12.8
	Dutch Bill Creek	smolt	1	15%	6.6
	Mark West Creek	presmolt	1	15%	6.6
	Porter Creek	fall	1	15%	6.6
	Russian River	smolt	3	15%	19.8
	Dutch Bill Creek	natural-origin tagged electrofishing in 2020 [1]	1	95%	1.1
2	Green Valley Creek	fall	1	15%	6.7
	Kidd Creek	fall	1	15%	6.5
	Mark West Creek	fall	2	15%	13.2
	Mill Creek	fall	5	15%	33.4
	Porter Creek	fall	2	15%	13.3
	Russian River	smolt	5	15%	32.9
	Mill Creek	hatchery fish already counted through expansion [2]	2	36%	5.6

Total minimum count:	28.0
Expanded hatchery adult returns (age-3):	*59.2*
Expanded hatchery adult returns (age-2):	*105.9*
Total estimated hatchery adult returns:	***165***

[1] Natural-origin fish were tagged as juveniles and were excluded from the total estimated returns for consistency with previous years' estimates.

[2] Expansions were not made due to potential for duplication (see *Data Analysis* section).

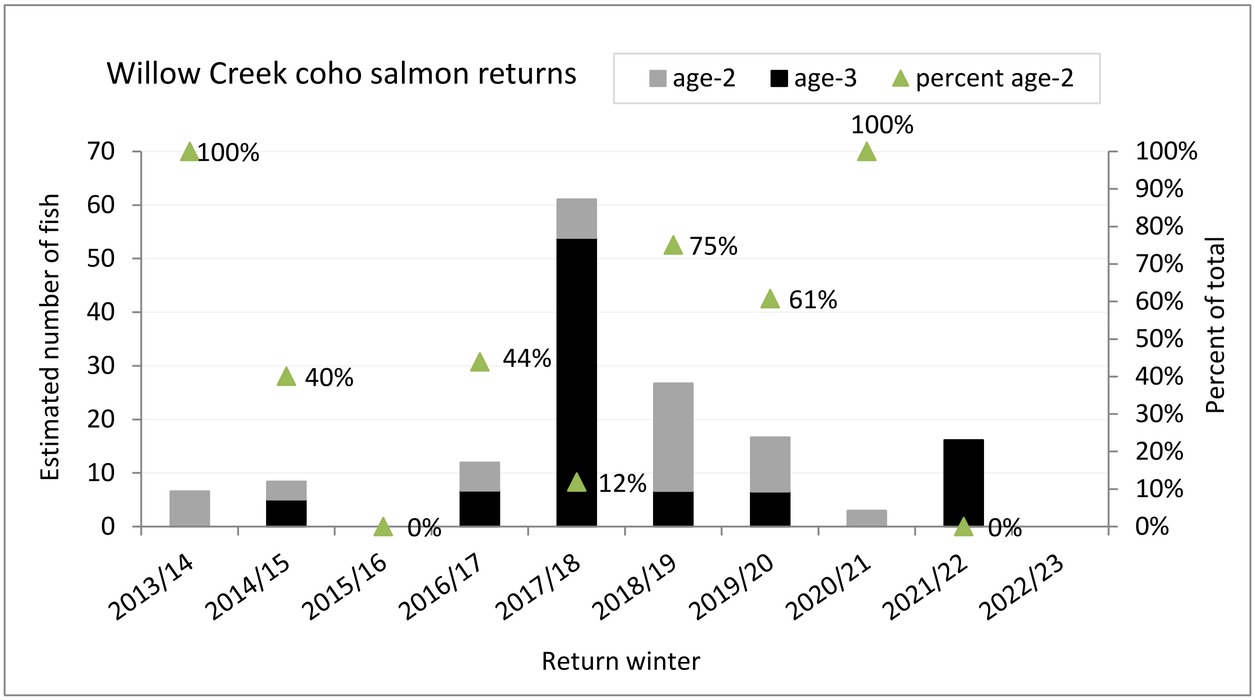

Figure 13. Estimated annual adult coho salmon returns to Willow Creek by age, return seasons 2013/14 – 2022/23. Note that estimates are based on returns to the upper antennas at river km 3.70. No adults were detected in 2022/23.

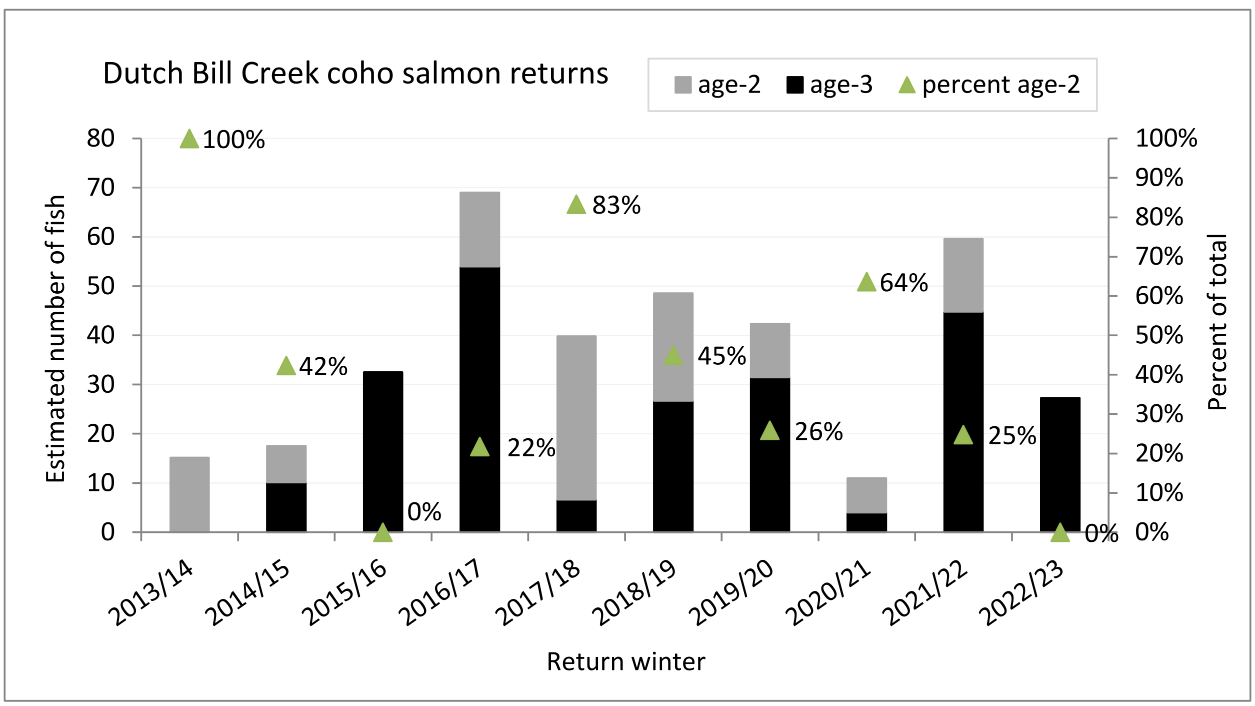

Figure 14. Estimated annual adult coho salmon returns to Dutch Bill Creek by age, return seasons 2013/14 – 2022/23.

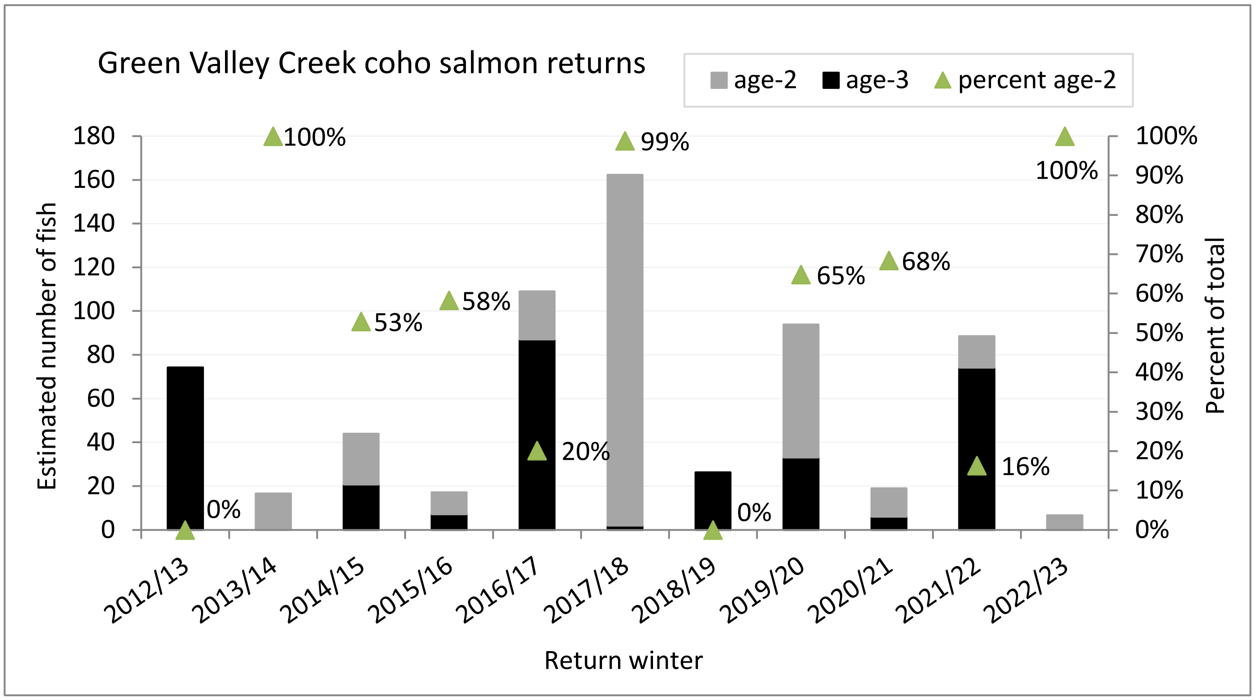

Figure 15. Estimated annual adult coho salmon returns to Green Valley Creek by age, return seasons 2012/13 – 2022/23.

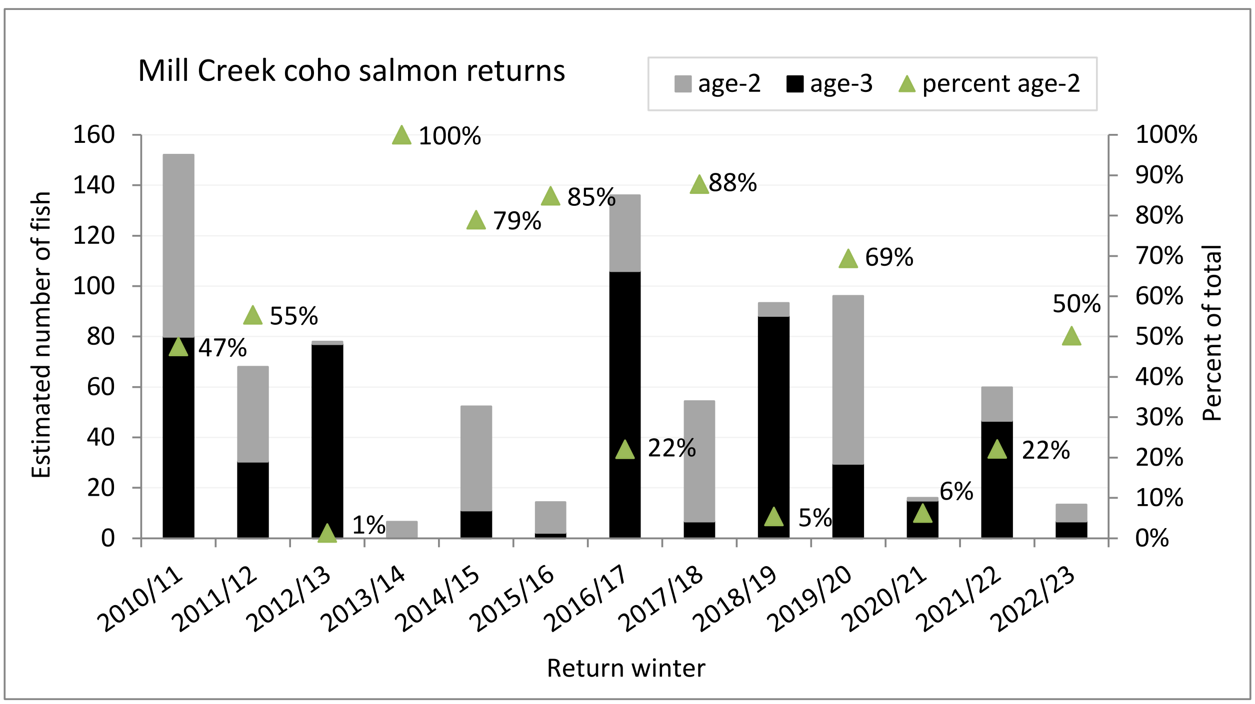

Figure 16. Estimated annual adult coho salmon returns to Mill Creek by age, return seasons 2010/11 – 2022/23.

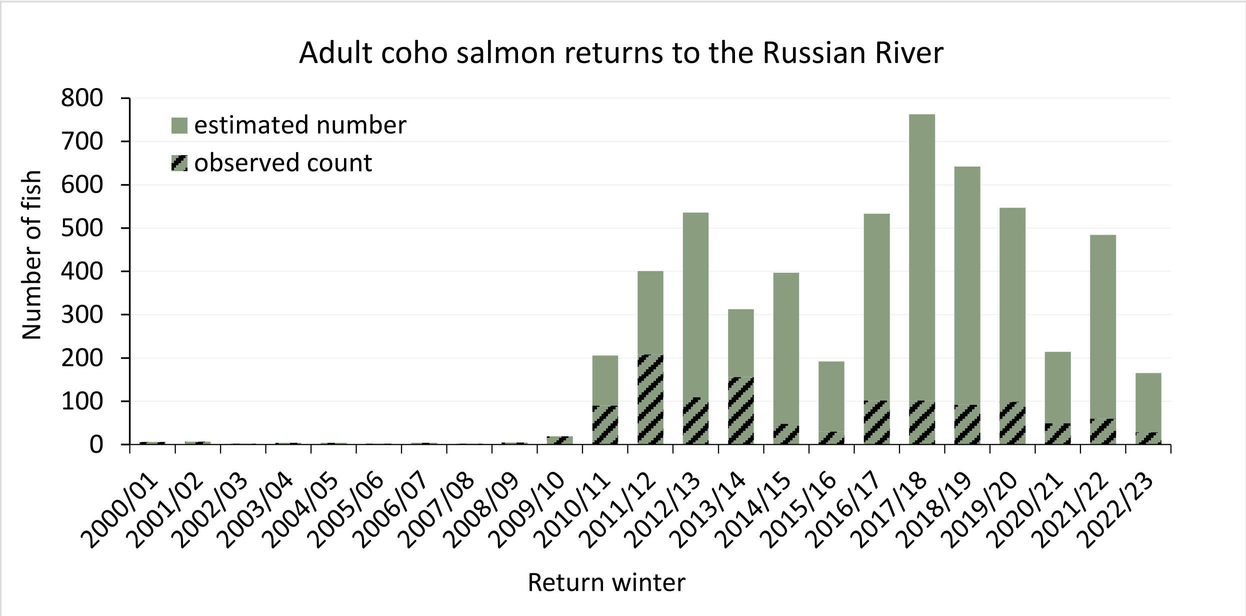

Figure 17. Estimated annual adult hatchery coho salmon returns to the Russian River, return winters 2000/01 through 2022/23. Note that methods for counting/estimating the number of returning adult coho salmon were not consistent among years; prior to 2009/10, spawner surveys were the primary method, from 2009/10 – 2011/12 methods included spawner surveys, video monitoring and PIT detection systems, and beginning in 2012/13, with the installation of the Duncans Mills antenna array, PIT detection systems were the primary method used.

Figure 18. Estimated annual adult hatchery coho salmon returns to the Russian River by age, return seasons 2012/13-2022/23. Note that this figure includes only fish that we were able to age; therefore, totals will be less than adult return estimates shown in Figure 17.

2.3.3. Smolt to adult return (SAR) ratios

Estimated SAR ratios were 0 for Willow Creek, 1.1% for Dutch Bill Creek, 0.2% for Green Valley Creek and 2.9% for Mill Creek (Figure 19 - Figure 22, Table 7). These rates were higher than average in Dutch Bill and Mill creeks and lower than average in Willow and Green Valley creeks (Table 7).

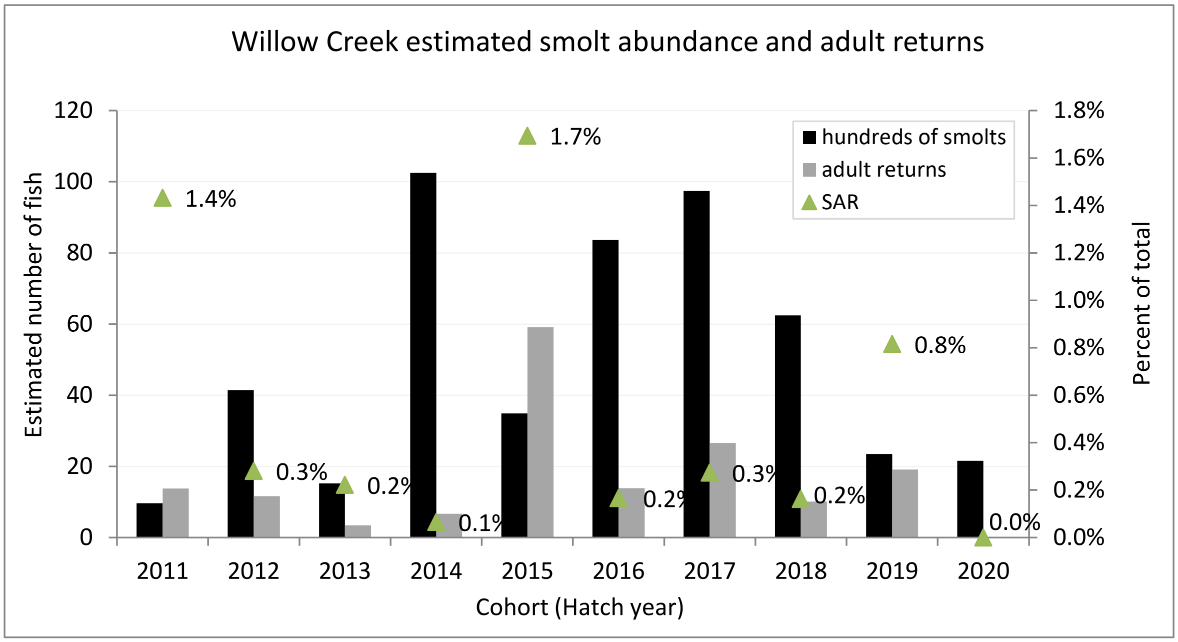

Figure 19. Estimated coho salmon smolt abundance (in hundreds), adult returns, and smolt to adult return (SAR) ratios in Willow Creek, cohorts 2011-2020. Note that estimates are based on returns to the upper antennas at river km 3.69.

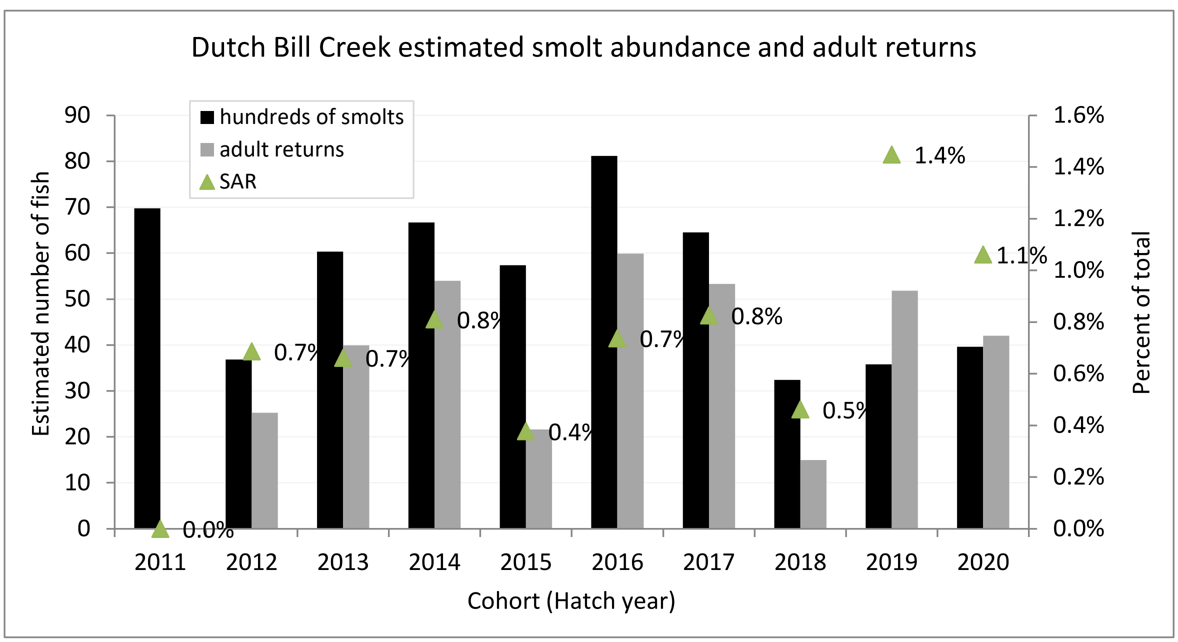

Figure 20. Estimated coho salmon smolt abundance (in hundreds), adult returns, and smolt to adult return (SAR) ratios in Dutch Bill Creek, cohorts 2011-2020.

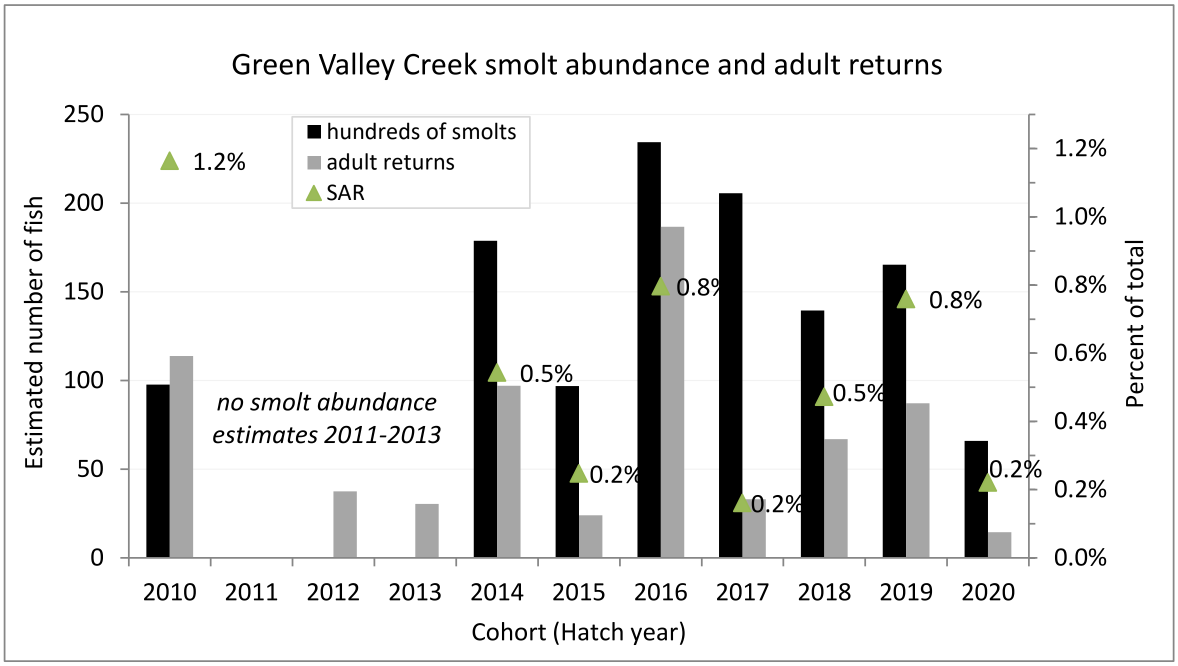

Figure 21. Estimated coho salmon smolt abundance (in hundreds), adult returns, and smolt to adult return (SAR) ratios in Green Valley Creek, cohorts 2010-2020.

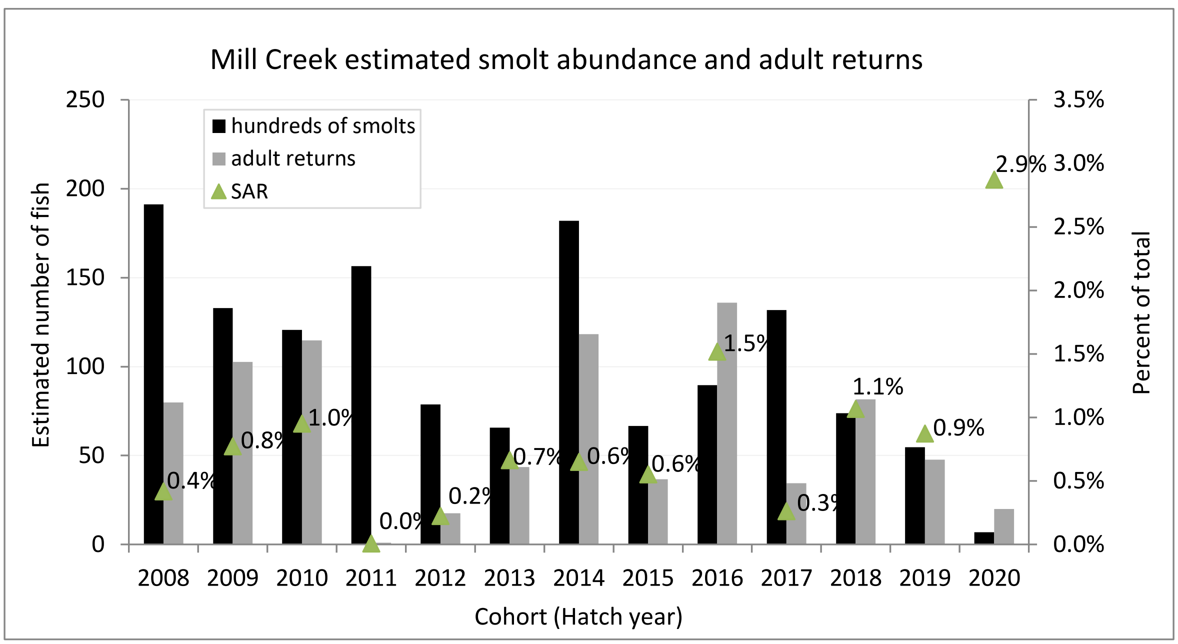

Figure 22. Estimated coho salmon smolt abundance (in hundreds), adult returns, and smolt to adult return (SAR) ratios in Mill Creek, cohorts 2008-2020. Note that adult release fish returning to Mill Creek were excluded from SAR calculations.

Table 7. Smolt to adult return (SAR) ratios estimated for Willow, Dutch Bill, Green Valley, and Mill creeks, cohorts 2008 through 2020.

Cohort (Hatch year)	Age-3 return winter	Willow (River km 3.69)	Dutch Bill (River km 0.68)	Green Valley (River km 6.13)	Mill (River km 2.01)
2008	2010/11	*NA*	*NA*	*NA*	0.4%
2009	2011/12	*NA*	*NA*	*NA*	0.8%
2010	2012/13	*NA*	0.2%	1.2%	1.0%
2011	2013/14	1.4%	0.0%	*NA*	0.0%
2012	2014/15	0.3%	0.7%	*NA*	0.2%
2013	2015/16	0.2%	0.7%	*NA*	0.7%
2014	2016/17	0.1%	0.8%	0.5%	0.6%
2015	2017/18	1.7%	0.4%	0.2%	0.6%
2016	2018/19	0.2%	0.7%	0.8%	1.5%
2017	2019/20	0.3%	0.8%	0.2%	0.3%
2018	2020/21	0.2%	0.5%	0.5%	1.1%
2019	2021/22	0.8%	1.4%	0.8%	0.9%
2020	2022/23	0.0%	1.1%	0.2%	2.9%
	Average	**0.5%**	**0.7%**	**0.5%**	**0.8%**

3. Spawning surveys

3.1. Goals and objectives

Broodstock Program objectives were to estimate the spatial distribution and number of coho salmon redds in LCM watersheds (Willow, Dutch Bill, Green Valley, and Mill). CMP objectives included estimation of the spatial distribution and abundance of coho salmon, steelhead, and Chinook salmon (*O. tshawytscha*) redds in LCM watersheds and in a random, spatially-balanced sample of streams in the Russian River watershed containing salmonid habitat (hereafter basinwide monitoring). Surveys were conducted using standardized CMP methods (Adams et al. 2011; Sonoma County Water Agency and California Sea Grant 2015) and in close coordination with SW to ensure that efficiencies in sampling could be realized while also ensuring that the funding was used for the intended project.

3.2. Methods

3.2.1. Sampling framework and survey reaches

For stream-specific estimates of redd abundance, we surveyed all accessible adult salmonid spawning reaches of Willow, Dutch Bill, Green Valley, and Mill creeks (LCMs). For basinwide estimates, we used a generalized random tessellation stratified (GRTS) approach with soft stratification to survey a random, spatially-balanced selection of reaches that contain *coho salmon* habitat (Figure 23) within the Russian River sample frame (a sample frame of stream reaches identified by the Russian River CMP Technical Advisory Committee[1] as having coho salmon, steelhead, and/or Chinook salmon habitat). Although one of the goals of CMP basinwide monitoring is to survey a sample of reaches that represents the full

[1] A body of fisheries experts, including members of the Statewide CMP Technical Team, tasked with providing guidance and technical advice related to CMP implementation in the Russian River.

extent of steelhead habitat throughout the Russian River watershed (including streams in the upper basin that do not contain coho salmon habitat), sampling in most winters (including 2022/23) was confined to reaches that contain both coho salmon and steelhead habitat (i.e., the lower part of the basin; e.g., Figure 23). Resulting basinwide steelhead redd estimates in this report therefore reflect trends in steelhead abundance only in the part of the watershed that contains coho salmon habitat.

3.2.2. Field methods

Survey methodology for collecting information on spawning salmonids in the Russian River watershed was adapted from the Coastal Northern California Salmonid Spawning Survey Protocol (Gallagher and Knechtle 2005). We attempted to survey each reach at an interval of 10-14 days throughout the spawning season. Two person crews hiked reaches in a downstream to upstream direction looking for adult salmon (live or carcasses) and redds (Figure 24). Redds were identified to species based on presence of identifiable adult fish or from observed redd morphology. Measurements were taken on all redds, including pot length, width and depth; tailspill length, width and depth; and substrate size. In response to widespread stream drying observed in the 2020/21 and 2021/22 seasons, we began categorically documenting the surface flow condition over observed redds. Surface flow condition over redds was categorized as fully wet, partially dry or fully dry. All observed salmonids were identified to species (coho salmon, Chinook salmon, and steelhead), or 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, scans for coded wire tags (CWT) and PIT tags 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 all redd and fish observations. Presence of non-salmonid species was also documented at the reach scale. Trimble TDC600 tablets were used for data entry and, upon returning from the field, data files were downloaded, error checked, and transferred into a SQL database.

3.2.3. Redd and adult return estimates

For redds of unknown species or redds with low certainty of identification, redd measurement data was used to estimate redd species following Gallagher and Gallagher's redd species determination method (Gallagher and Gallagher 2005) with nonparametric K-nearest neighbor algorithm (KNN) used in instances where redd measurements were not available (Ricker et al. 2014a). The estimated number of unique redds was then summed for each surveyed reach. To account for redds missed by observers due to survey timing, the number of redds observed within each reach was expanded based upon the average observational "life span" of redds observed in that same reach (Ricker et al. 2014b). For LCM watershed estimates, where census surveys were conducted, redd estimates from all tributaries and subreaches within each watershed were summed. In the Mill Creek watershed, the redd estimate was expanded to account for sections of stream that we were unable to sample due to lack of landowner access. This expansion was made by calculating an average redd per stream length in surveyed reaches of Mill Creek and multiplying that ratio by the length of stream that was not surveyed. This total was then added to the sum of redds in the surveyed reaches of Mill Creek. For basinwide estimates, we calculated an average redd density per reach and multiplied that density by the total number of adult coho salmon reaches within the Russian River sample frame.

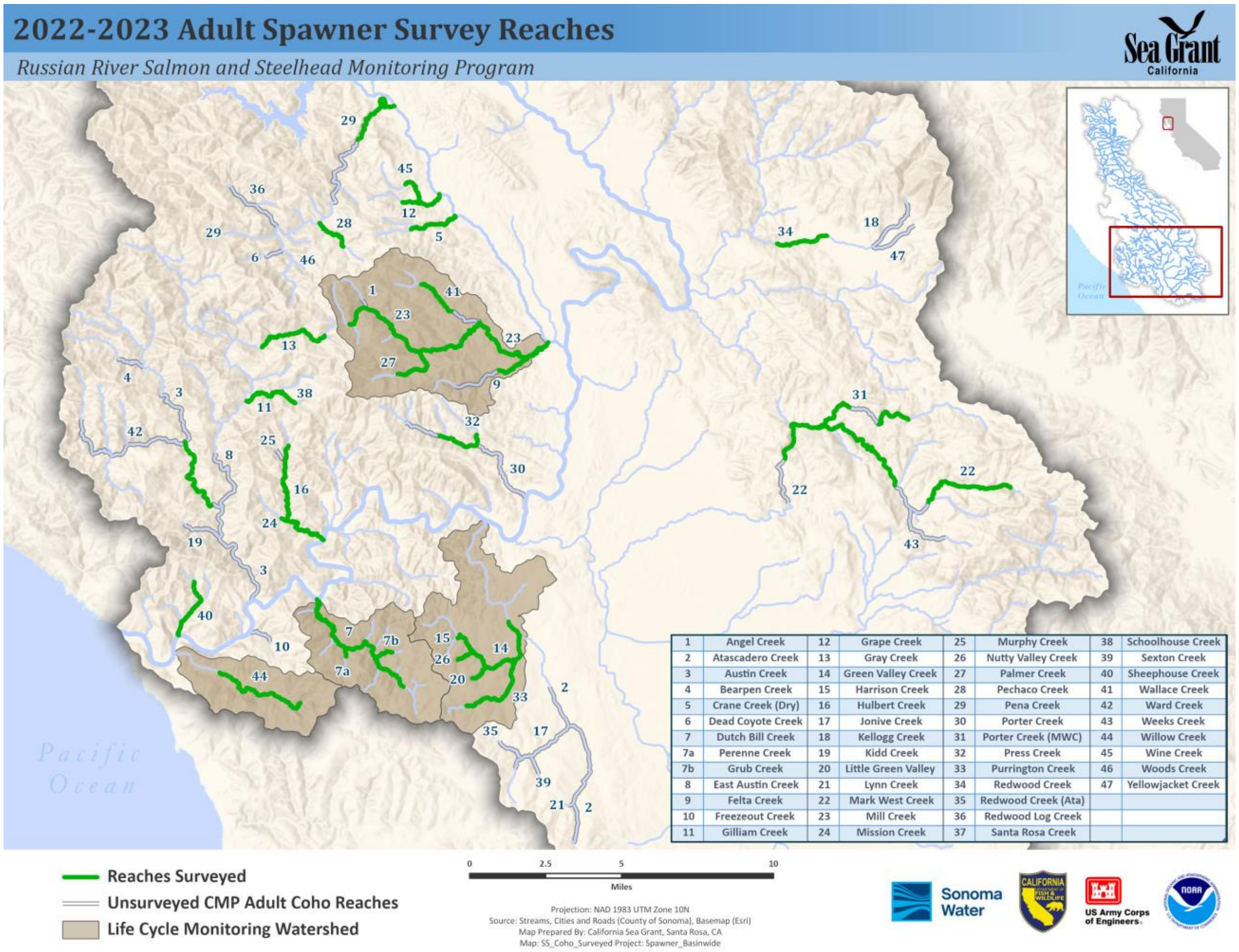

Figure 23. Intensively monitored life cycle monitoring (LCM) watersheds and 2022/2023 spawner survey reaches sampled in the Russian River watershed that contain spawning habitat for both coho salmon and steelhead.

Figure 24. Field biologist standing next to a salmonid redd in a Russian River tributary, winter 2022/23.

3.3. Results

3.3.1. Redd estimates and spawning distribution

We began surveys on December 12, 2022, following the first rain event of the season, and continued surveying through the end of April 2023. Due to persistently high and turbid flow conditions during the winter of 2022/23, we were unable to maintain our goal of conducting surveys within each reach on a 10-14 day cycle, and this resulted in fewer surveys than in previous years (60 survey days as compared to a nine year average of 77 survey days). Overall, we conducted a total of 379 salmonid spawning surveys on 46 reaches in 31 streams within the Russian River basin. A total of 79 salmonid redds were observed: 21 coho salmon redds, 37 steelhead redds, 0 Chinook salmon redds, and 21 redds of unknown salmonid species origin (Table 8). Coho salmon redds and/or adults were observed in eight of the 31 streams surveyed (26%), and steelhead redds and/or adults were observed in nine of the 31 streams surveyed (29%) (Table 8, Figure 25, Figure 26).

Coho salmon redd observations began in early-December and extended into March, peaking in mid-December (Figure 27). Coho salmon spawn timing appeared to peak earlier compared to the average timing, though redds may have been missed during a gap in surveys during the first half of January. Steelhead redd observations began in mid-January and extended into early April, peaking in mid-February, similar to average timing across previous years (Figure 28). However, it is possible that steelhead spawning began in early January but we were unable to document it due to the gap in surveys.

Coho salmon redd estimates in LCM watersheds ranged from 0 in Willow Creek to 24 in Mill Creek, and steelhead redd estimates ranged from 0 in Willow Creek to 20 in Mill Creek (Table 9). When compared with previous years, coho salmon and steelhead redd estimates were extremely low in Willow, Dutch Bill, and Green Valley creeks, and similar (coho) or low (steelhead) in Mill Creek (Figure 29, Figure 30). At the basinwide scale, redd estimates for coho salmon and steelhead were lowest on record since basinwide surveys began during the 2014/15 season (Figure 31).

In the four Broodstock Program watersheds, only two coho salmon carcasses were recovered during the winter of 2022/23; one in Green Valley Creek and one in Mill Creek. The carcass from Green Valley Creek contained a CWT tag and we were unable to CWT scan the Mill Creek carcass due to a missing head. Because the sample size was so low, we were unable to calculate the proportion of natural-origin returns using carcass data.

The distribution of salmonid redds in the four LCM watersheds varied by stream (Figure 32 - Figure 35). No salmonid redds were observed in the Willow Creek survey reaches (Figure 32). In Dutch Bill Creek, three coho salmon redds were observed in the lower reaches, and one unknown salmonid redd was observed near the confluence with Grub Creek (Figure 33). In the Green Valley Creek watershed, we observed three redds in the middle reaches, downstream of the confluence with Little Green Valley Creek and one redd in the upper reach (Figure 34). In the Mill Creek watershed, coho salmon and steelhead redd densities were highest in the lower part of the watershed and in Felta Creek, with a smaller number of steelhead redds in the middle reach and unknown salmonid redds further upstream (Figure 35).

Table 8. Salmonid redds observed by species during winter 2022/23 in Russian River tributaries.

Tributary	Length surveyed (km)	Coho salmon	Steelhead	Chinook salmon	Unknown salmonid	Total
Austin Creek	5.0	0	0	0	1	1
Crane Creek (Dry)	3.2	0	0	0	0	0
Dutch Bill Creek	11.4	3	0	0	1	4
Felta Creek	2.0	1	1	0	2	4
Gilliam Creek	2.6	2	0	0	1	3
Grape Creek	2.6	0	4	0	1	5
Gray Creek	6.3	0	1	0	0	1
Green Valley Creek	7.0	1	2	0	1	4
Grub Creek	1.1	0	0	0	0	0
Harrison Creek	0.2	0	0	0	0	0
Hulbert Creek	8.2	0	0	0	0	0
Little Green Valley Creek	1.2	0	0	0	0	0
Mark West Creek	16.2	2	2	0	2	6
Mill Creek	16.6	7	10	0	5	22
Mission Creek	0.4	0	0	0	0	0
Nutty Valley Creek	1.2	0	0	0	0	0
Palmer Creek	2.9	0	0	0	0	0
Pechaco Creek	2.3	0	0	0	0	0
Pena Creek [1]	12.4	5	15	0	7	27
Perenne Creek	0.5	0	0	0	0	0
Porter Creek	2.3	0	0	0	0	0
Porter Creek (MWC)	5.1	0	0	0	0	0
Press Creek	0.6	0	0	0	0	0
Purrington Creek	4.8	0	0	0	0	0
Redwood Creek	4.8	0	1	0	0	1
Schoolhouse Creek	1.1	0	0	0	0	0
Sheephouse Creek	3.7	0	0	0	0	0
Wallace Creek	2.5	0	0	0	0	0
Willow Creek	6.0	0	0	0	0	0
Wine Creek	1.8	0	0	0	0	0
Woods Creek [1]	4.1	0	1	0	0	1
Total	**140.1**	**21**	**37**	**0**	**21**	**79**

[1] *Only a single spawner survey was completed on upper Pena and Woods creeks. These reaches were not part of the GRTS draw for 2022/23.*

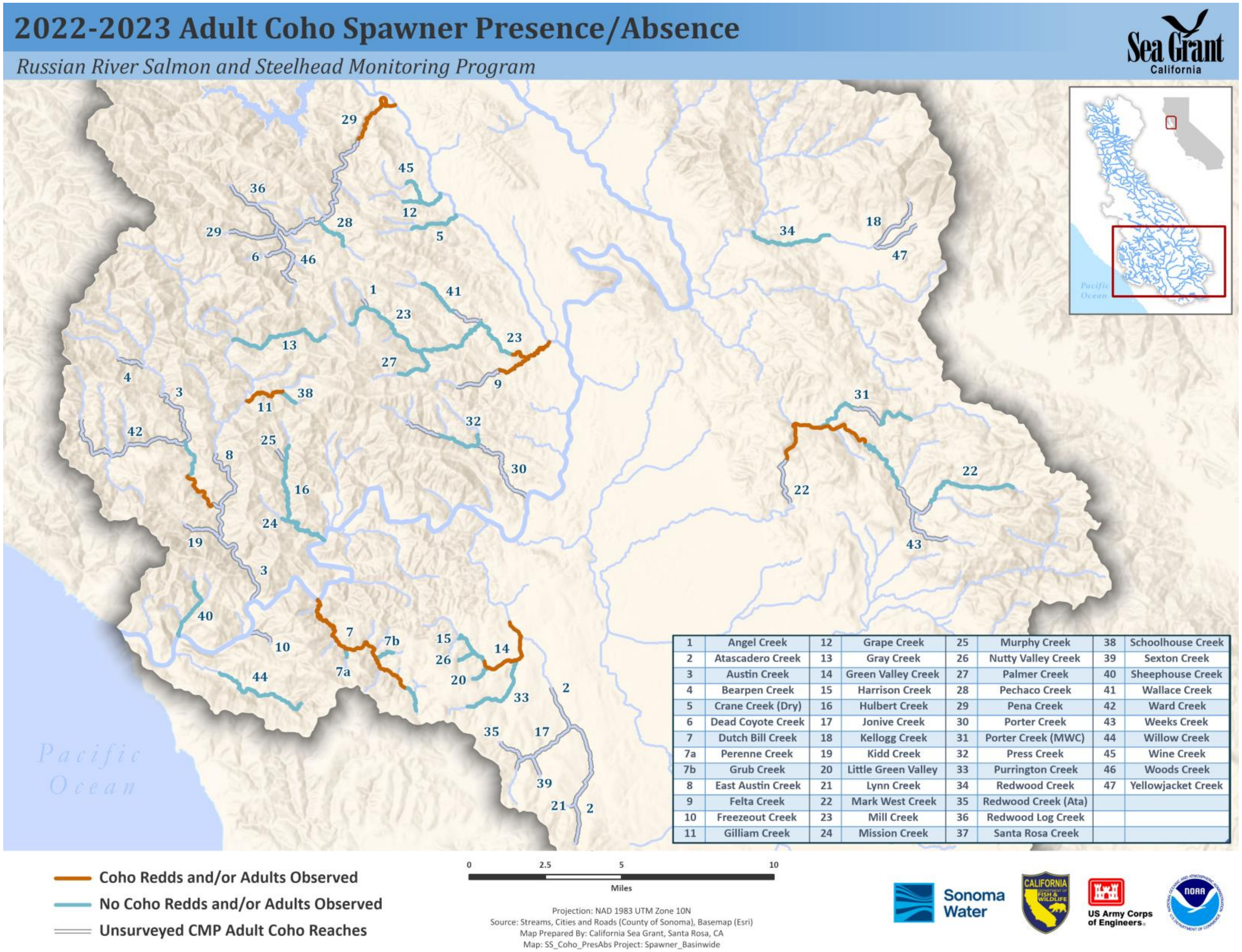

Figure 25. Coho salmon redd and/or adult presence or absence, winter 2022/23.

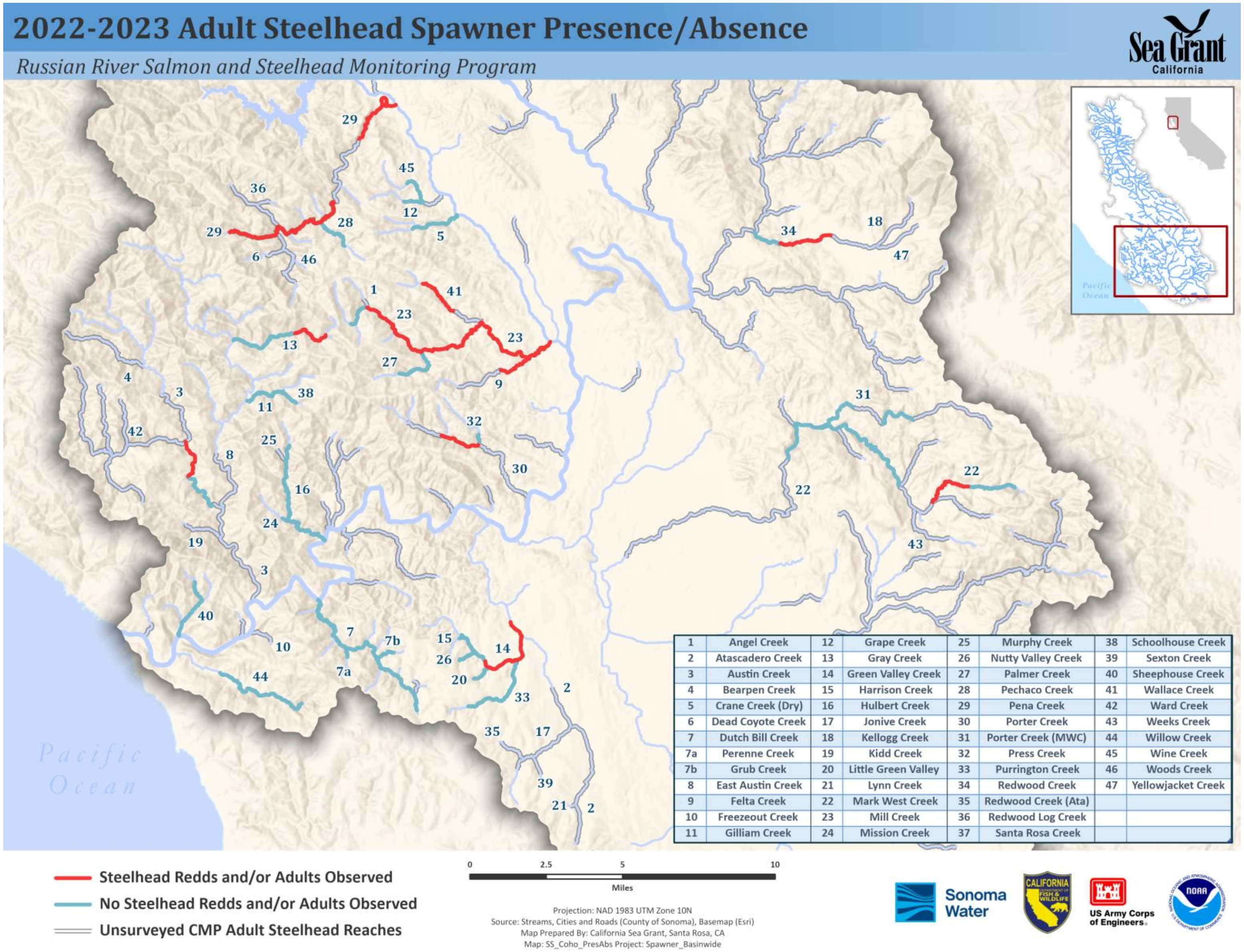

Figure 26. Steelhead redd and/or adult presence or absence, winter 2022/23.

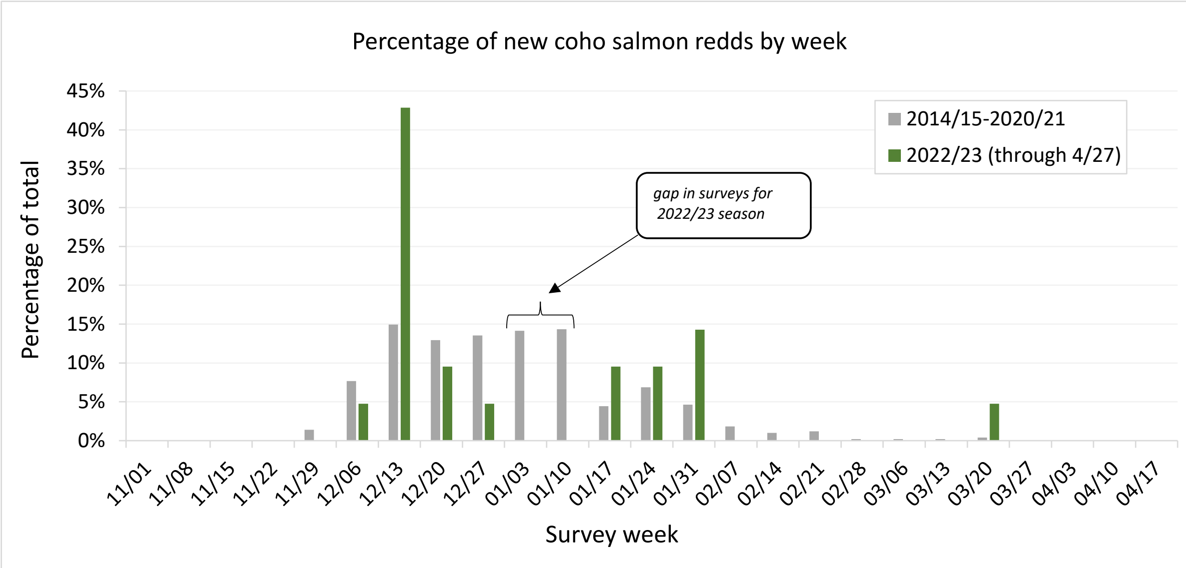

Figure 27. Number of new coho salmon redds observed each week in Russian River Coastal Monitoring Program survey streams, winter 2022/23 in comparison to long term average.

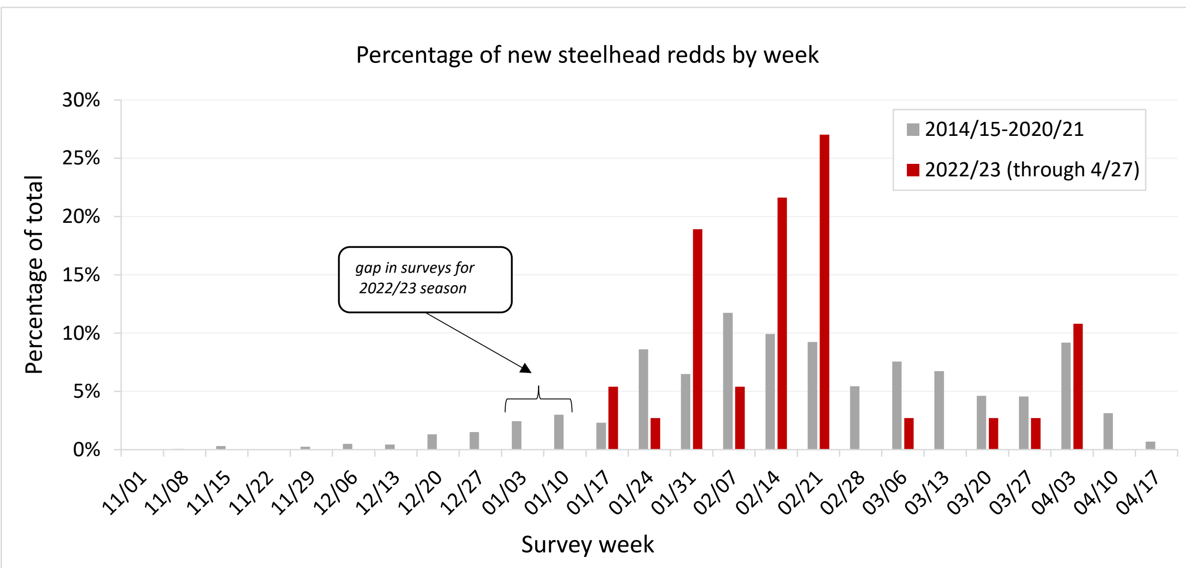

Figure 28. Number of new steelhead redds observed each week in Russian River Coastal Monitoring Program survey streams, winter 2022/23 in comparison to long term average.

Table 9. Estimated coho salmon and steelhead redds and adults in four Russian River watersheds, winter 2022/23.

Tributary	Coho salmon	Steelhead
Dutch Bill Creek	3	1
Green Valley Creek	1	3
Mill Creek	24	20
Willow Creek	0	0

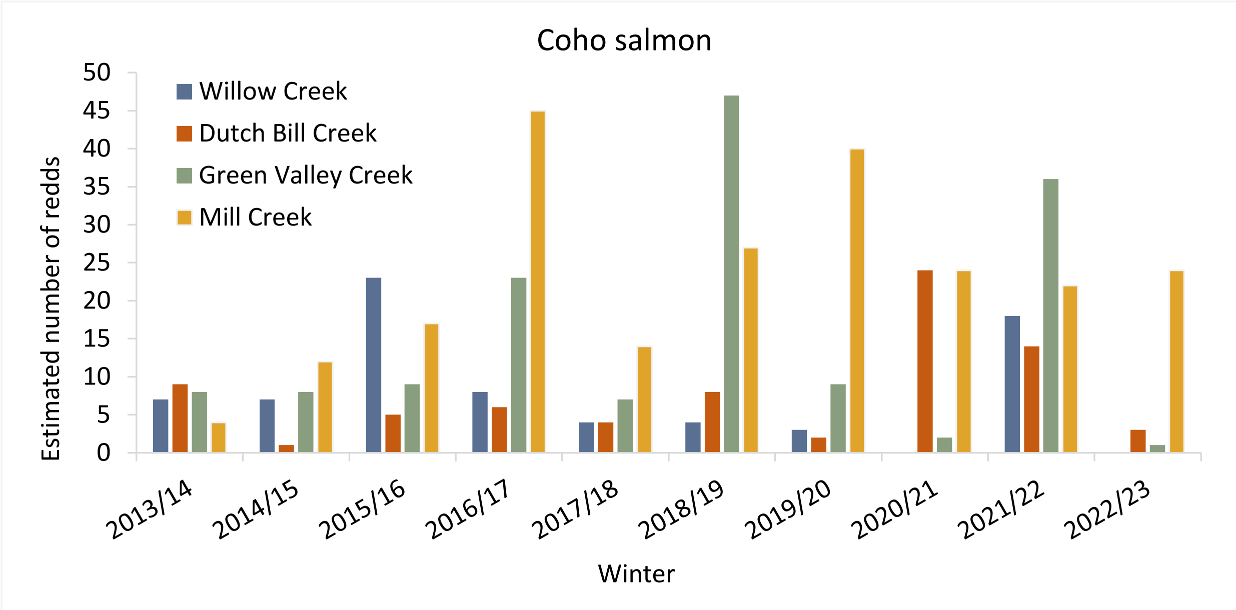

Figure 29. Estimated coho salmon redds in LCM watersheds, return winters 2013/14 through 2022/23.

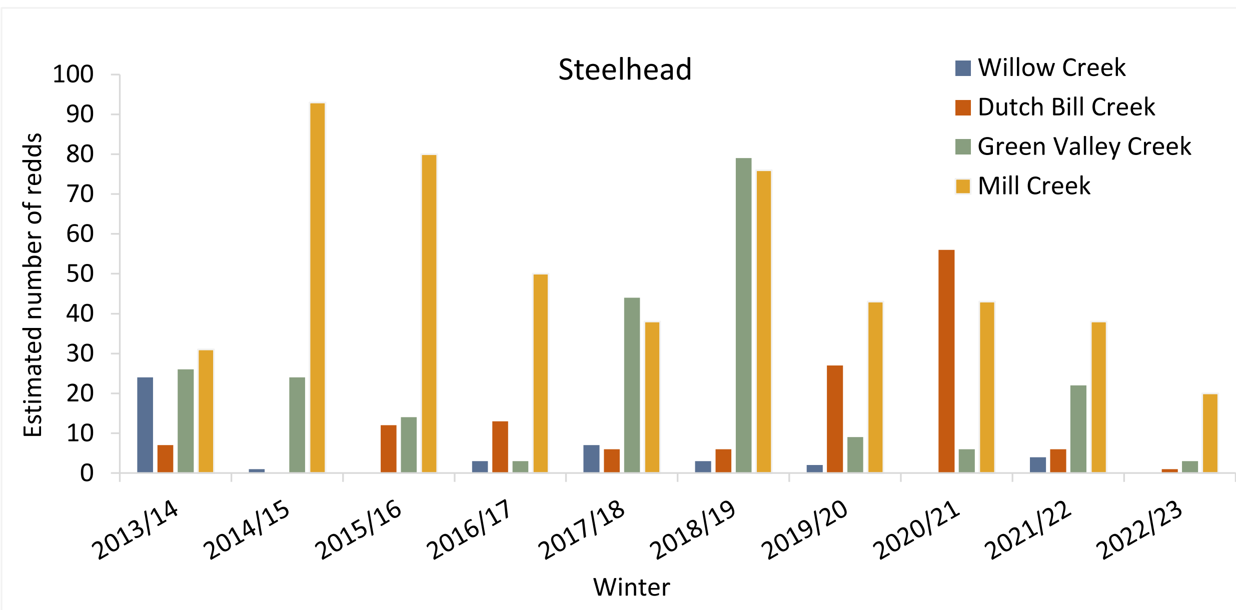

Figure 30. Estimated steelhead redds in LCM watersheds, return winters 2013/14 – 2021/22.

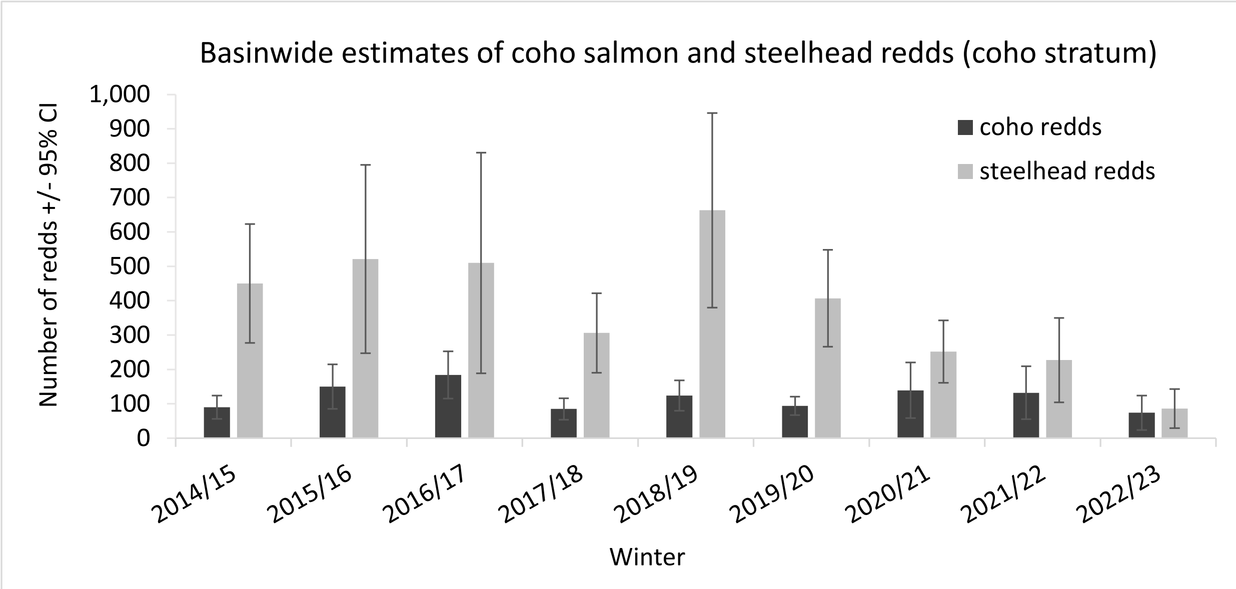

Figure 31. Basinwide estimates of coho salmon and steelhead redds in the Russian River watershed (coho stratum only), return winters 2014/15 through 2022/23.

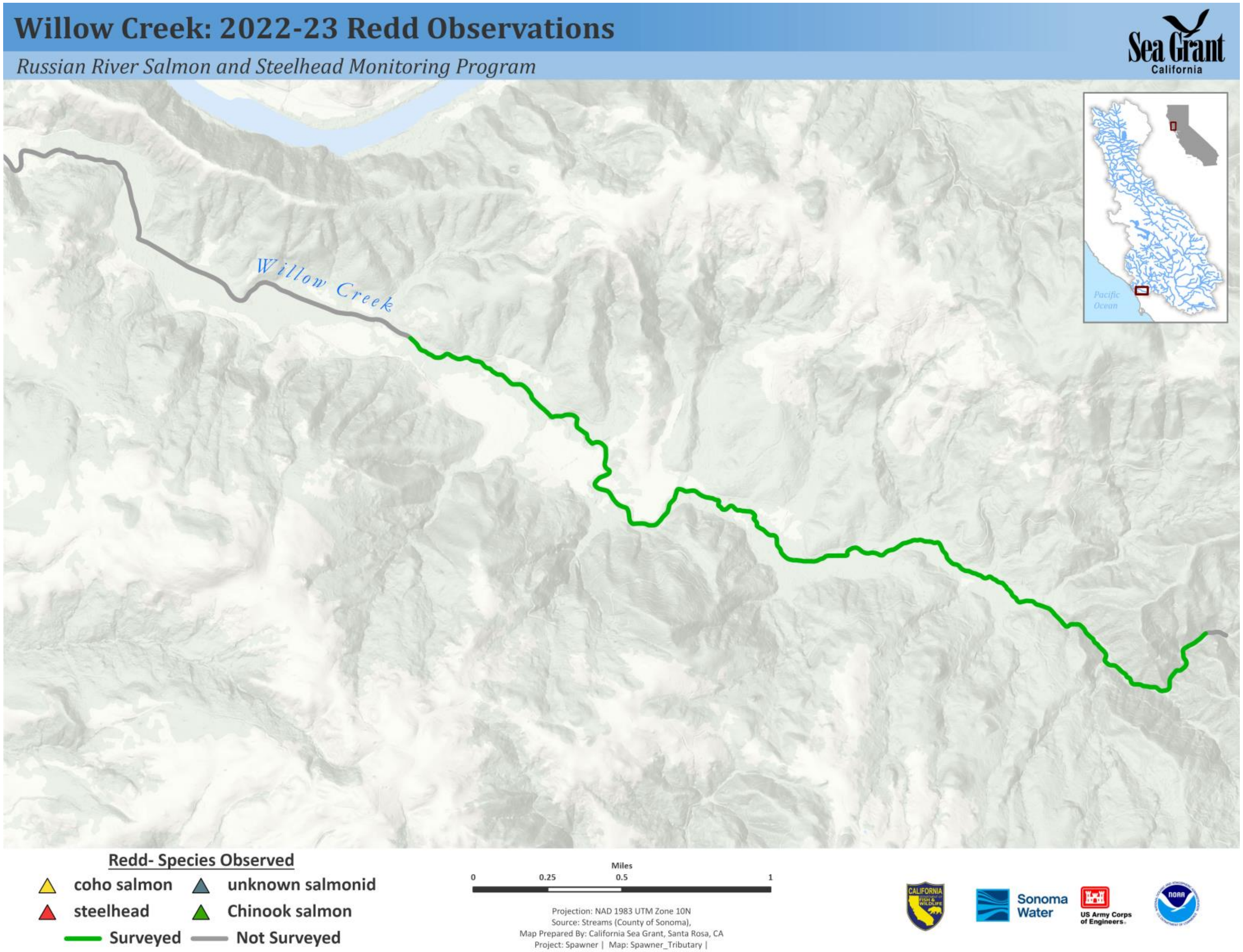

Figure 32. Distribution of salmonid redds observed in Willow Creek during winter 2022/23 (no redds were observed in Willow Creek).

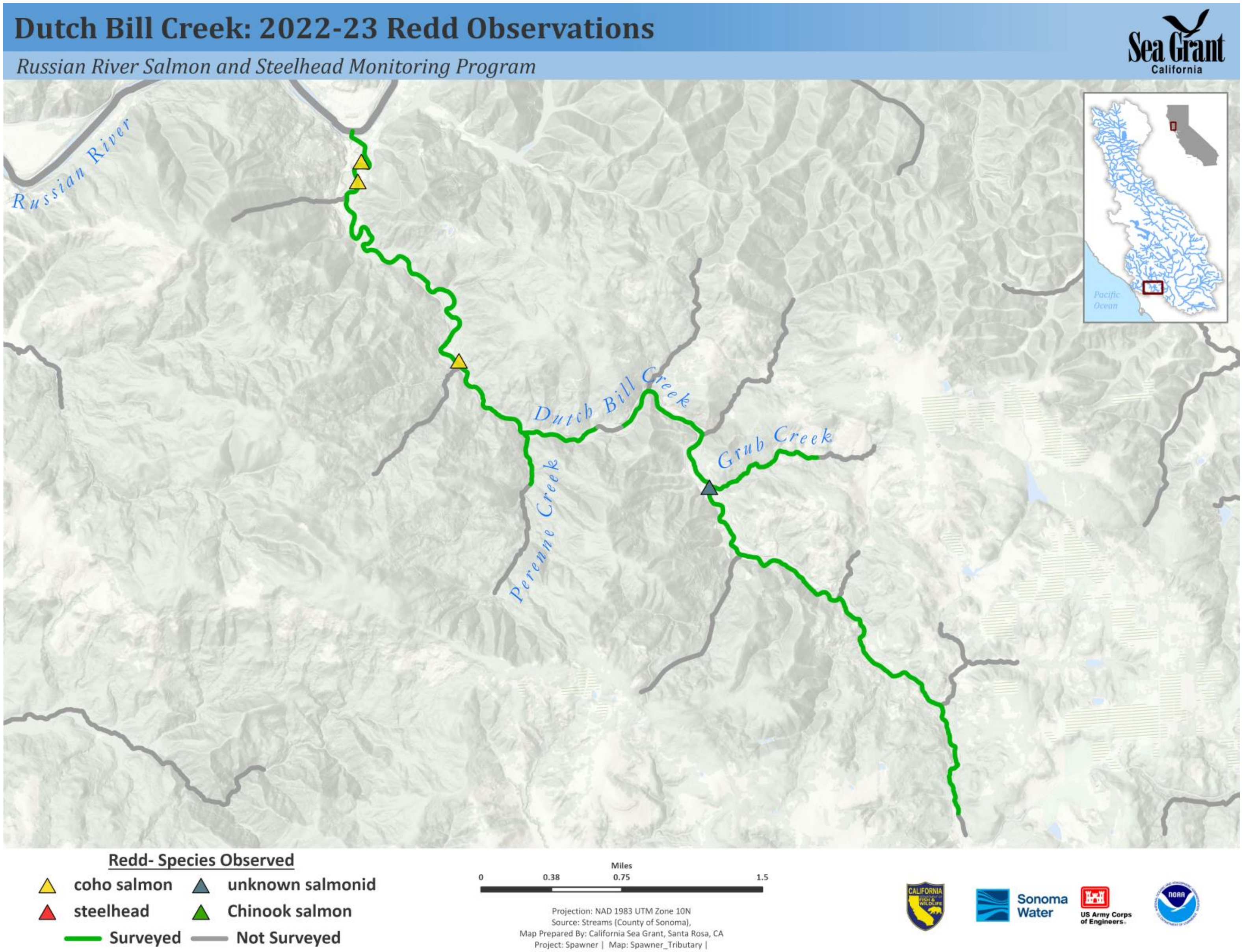

Figure 33. Distribution of salmonid redds observed in Dutch Bill Creek during winter 2022/23.

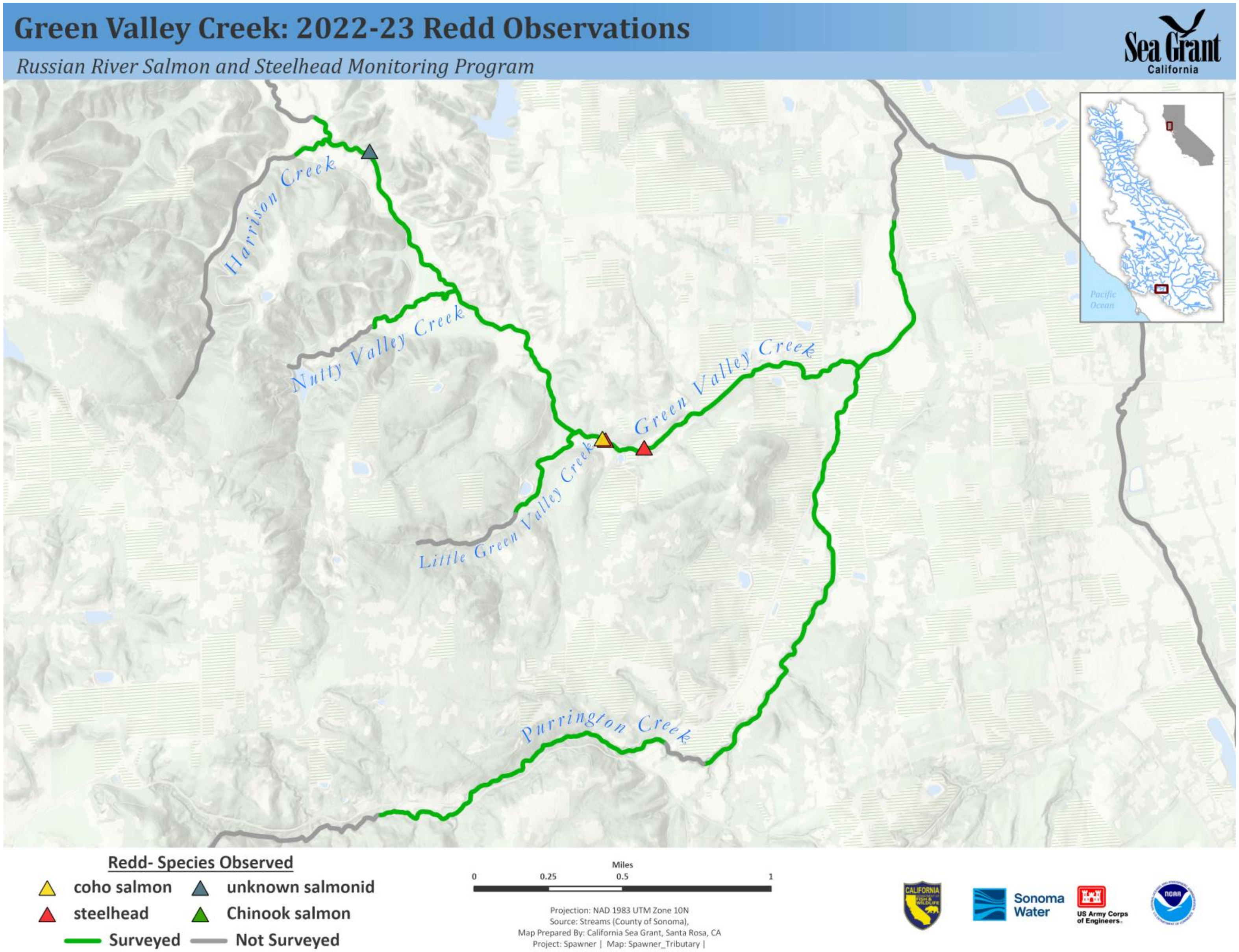

Figure 34. Distribution of salmonid redds observed in the Green Valley Creek watershed during winter 2022/23.

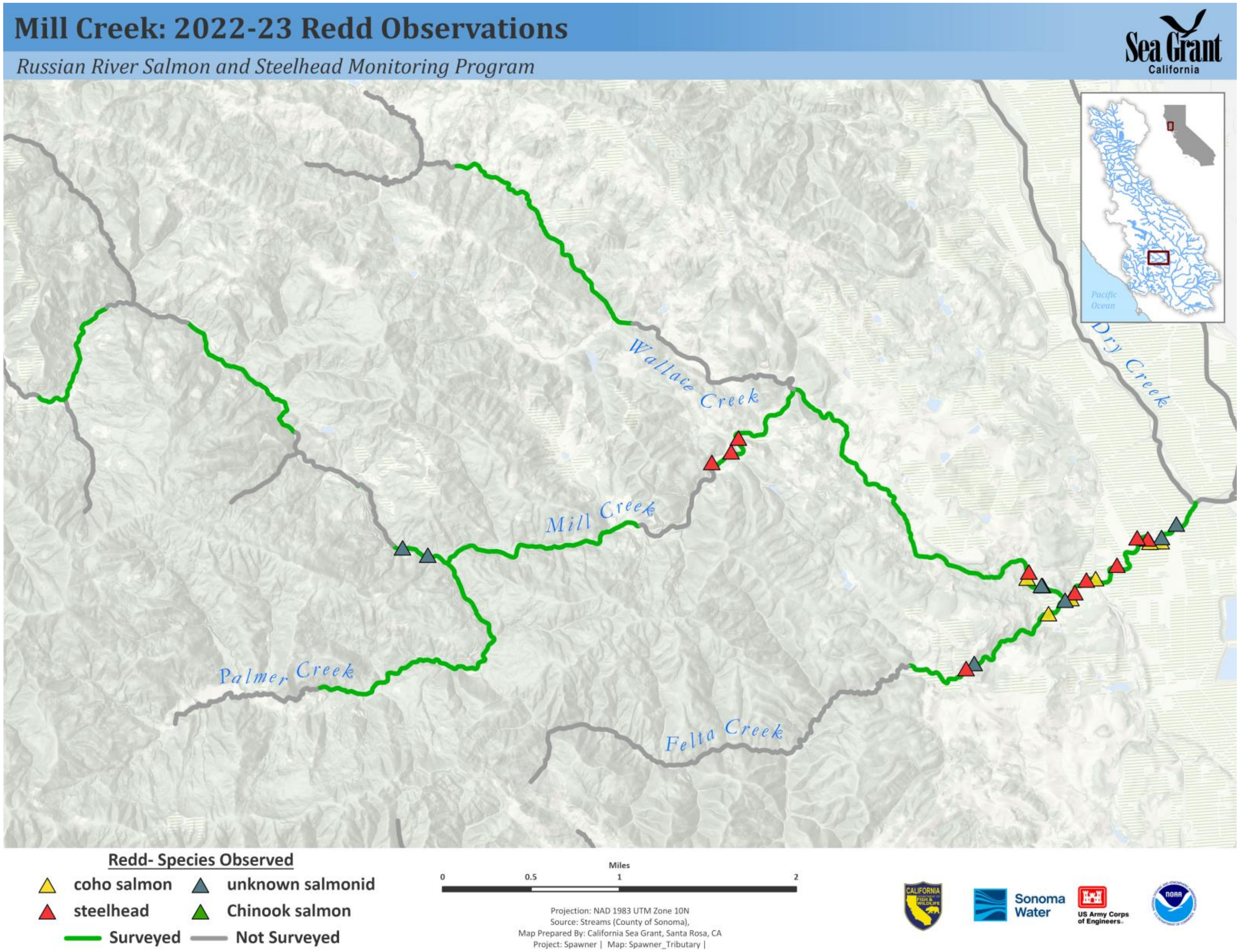

Figure 35. Distribution of salmonid redds observed in the Mill Creek watershed during winter 2022/23.

4. Discussion and recommendations

4.1. Low adult returns

Estimates of coho salmon adult returns to the four LCM streams, as well as to the Russian River basin overall, were low during the winter of 2022/23 as compared to previous years (Figure 13 - Figure 17). Similarly, estimates of coho salmon and steelhead redds were lower in the LCM streams (with the exception of coho salmon redds in Mill) as well as basinwide (Figure 29 - Figure 31). Spatial distribution of coho salmon and steelhead was also reduced compared to recent years. For example, we observed redds and/or adult coho salmon in 26% of streams surveyed, and redds and/or adult steelhead in 29% of streams surveyed during the winter of 2022/23. For both species, these percentages were less than half of averages calculated over the previous seven years (52% for coho salmon and 62% for steelhead).

It is possible that gaps in data collection due to high flows (fewer days of spawner surveys and a short gap in PIT data collection on some streams in January when equipment was preventatively removed) contributed to the lower than usual estimates. However, in monitoring streams where PIT antennas operated consistently throughout the winter season, adult returns were also low. Results from initial snorkeling surveys through June 2023 are indicating low numbers of natural-origin young-of-year (YOY), further evidence of a low adult return year.

Rather than the limited ability to fully conduct surveys, we attribute the estimated low number of adult returns to the drought conditions experienced by this cohort when juveniles were rearing as YOY in the streams in 2020 and migrating to the ocean during the spring of 2021. Although expanded snorkel counts of YOY were relatively high during the summer of 2020 (coho salmon 16,606; steelhead 25,550), widespread drying occurred in the tributaries over the summer and likely led to extensive juvenile mortality (California Sea Grant 2021b). Additionally, smolt outmigration throughout the Russian River watershed in the spring of 2021 was impaired by low streamflow, with stream disconnection observed on all four LCM streams during the March-June smolt migration. Overwinter survival for 2020 fall-release fish in LCM streams was the lowest our program has observed (ranging from 4-6%), likely due to low flow impediments to migration (California Sea Grant 2021a). Furthermore, Sonoma Water estimated that survival of hatchery coho salmon traveling from the upper reaches of Dry Creek to the estuary during the spring of 2021 was 0.18 (Horton et al. 2021), suggesting that even if smolts successfully emigrated from the tributaries, they likely experienced high mortality through the mainstem Russian River that year, with very few fish actually reaching the ocean. Lastly, Mill Creek did not receive a fall release of fish in 2020 due to the Walbridge fire that encompassed the upper half of the Mill Creek watershed, which likely reduced the number of adult returns to that stream system.

Given the stressful conditions experienced by the 2022/23 adult return cohort when they were juveniles, it is not surprising that adult return estimates were low. In response to the 2020 and 2021 drought, the Broodstock Program modified some of the hatchery releases to increase the probability of survival. The 2020 spring release group was stocked entirely into Dry Creek which has higher summer flows than smaller tributaries that have a high probability of drying up during drought. Additionally, the 2021 smolt release group was stocked at staggered dates in spring into the lower river, rather than into smaller tributaries that were becoming disconnected. While we did not detect any of the Dry Creek spring release group returning as adults, there was high representation of the lower river smolt release group. We therefore recommend continuing the strategy of releasing smolts into the lower river during drought years. Interestingly, Dutch Bill Creek also had relatively high representation for the age-3 adult returns. Upper Dutch Bill Creek is the site of an artificial flow augmentation that has been shown to increase streamflow and connectivity during the dry season. This, and the fact that Dutch Bill Creek enters the river relatively low in the watershed (shorter length of the mainstem to migrate through), may have contributed to the relatively higher proportion of returns to Dutch Bill Creek.

Smolt to adult return (SAR) ratios were higher than average in both Dutch Bill and Mill creeks for the 2020 cohort that emigrated as smolts during the spring of 2021 (Table 7). In Dutch Bill Creek, this reflects a higher number of adult returns that originated from Dutch Bill Creek. However, in Mill Creek, adult returns from the 2020 cohort (age-2 fish returning in 2021/22 and age-3 fish returning in 2022/23) all originated from other streams (Green Valley, Dry, Mark West, Russian River). Because of this, the SAR ratio is somewhat misleading as the adult returns did not originate from the smolts that emigrated from Mill Creek in 2021. Nonetheless, SAR generally remains low (<1%) for all LCM streams (Table 7).

4.2. Natural-origin return ratios

To compare the proportion of natural-origin (NOR) to hatchery-origin (HOR) coho salmon adult returns, we compiled annual adult return data for each LCM watershed since year-round PIT monitoring began during the winter of 2012/13 (Table 10). Although there is evidence of NOR returns to all four LCM streams in at least two of 11 years, the numbers and proportions of NOR returns are extremely low (Table 10, Figure 36).

Another means of evaluating natural production of coho salmon is comparing the number of spawners in a given generation (*g*) to the number of NOR spawners in the next generation (*g+1*). We calculated such spawner-spawner ratios by dividing spawner_{g+1} by spawner_g in each of the four LCM watersheds for each generation in which we had data (Table 11, Figure 37). Spawner_g was calculated by summing the estimated number of NOR and HOR returns for each return winter (generation *g*) and spawner_{g+1} was calculated as the number of NOR returns in the next generation (generation *g+1*). To account for different ages at return for spawner_{g+1} (i.e., age-2 and age-3), we summed the number of NOR returns that resulted from spawner_g two and three years later. Ideally, we would observe spawner-spawner ratios of at least 1.0 (i.e., replacement) and an increasing trend over time; however, spawner-spawner ratios have not reached 1.0 in any stream or year, the overall average across streams and cohorts is extremely low (0.05, Table 11), and it is not increasing over time (Figure 37). A potential issue with calculating spawner_{g+1} / spawner_g at the stream scale as we did here, is that it does not account for the fact that individuals can spawn in tributaries other than their stream of origin (where origin is defined as the tributary they were released into or produced from). Based on several years of PIT antenna monitoring in the watershed, adults are often detected in tributaries other than their tributary of origin (e.g., California Sea Grant 2021c). Given our adult monitoring approach (i.e., we do not operate antennas on every tributary in the watershed), there is no ready way of fully accounting for such among-tributary movement. We therefore assumed that inter-tributary movement rates were similar among streams, which is not necessarily true. Regardless, this analysis does provide some perspective on the degree to which the Russian River coho salmon population are unable to complete their life cycle.

The observation of minimal natural production suggests that the Russian River coho salmon population continues to rely almost entirely on hatchery augmentation and that very few individuals are able to independently complete their life cycle in the natural environment. As described in previous reports and other studies, there is evidence that low streamflow is limiting survival and production of NOR fish at multiple life stages. Extensive stream drying during the summer season contributes to mortality of rearing juveniles (Obedzinski et al. 2018; Vander Vorste et al. 2020; Moidu et al. 2021), low spring flow can shorten the migration window of smolts (Kastl et al. 2022) and contribute to lower overwinter survival (California Sea Grant 2021a), and low winter flows can limit access to spawning habitat, alter migration timing, strand fish, and cause redd desiccation (California Sea Grant 2021c). While numerous efforts are underway to increase streamflow in Russian River tributaries (e.g., see Coho Partnership website), the watershed-level changes that are needed to overcome these issues could take decades. Given the increased frequency and intensity of low flow extremes, we anticipate the continued need for hatchery supplementation if coho salmon are to persist in the Russian River watershed.

Table 10. Estimated natural-origin (NOR) and hatchery-origin (HOR) coho salmon adult returns by stream and return winter.

Return winter	Willow		Dutch Bill		Green Valley		Mill	
	NOR	HOR	NOR	HOR	NOR	HOR	NOR	HOR
2012/13	0	14	0	9	0	74	0	78
2013/14	0	7	0	15	0	17	0	7
2014/15	0	8	0	18	0	44	0	52
2015/16	0	0	0	33	0	17	1	13
2016/17	2	10	2	67	2	107	4	132
2017/18	3	58	0	40	2	160	0	54
2018/19	0	27	0	49	0	26	0	93
2019/20	0	17	0	42	0	94	3	93
2020/21	0	3	0	11	0	19	2	14
2021/22	1	15	0	60	0	89	0	60
2022/23	0	0	1	26	0	7	0	13

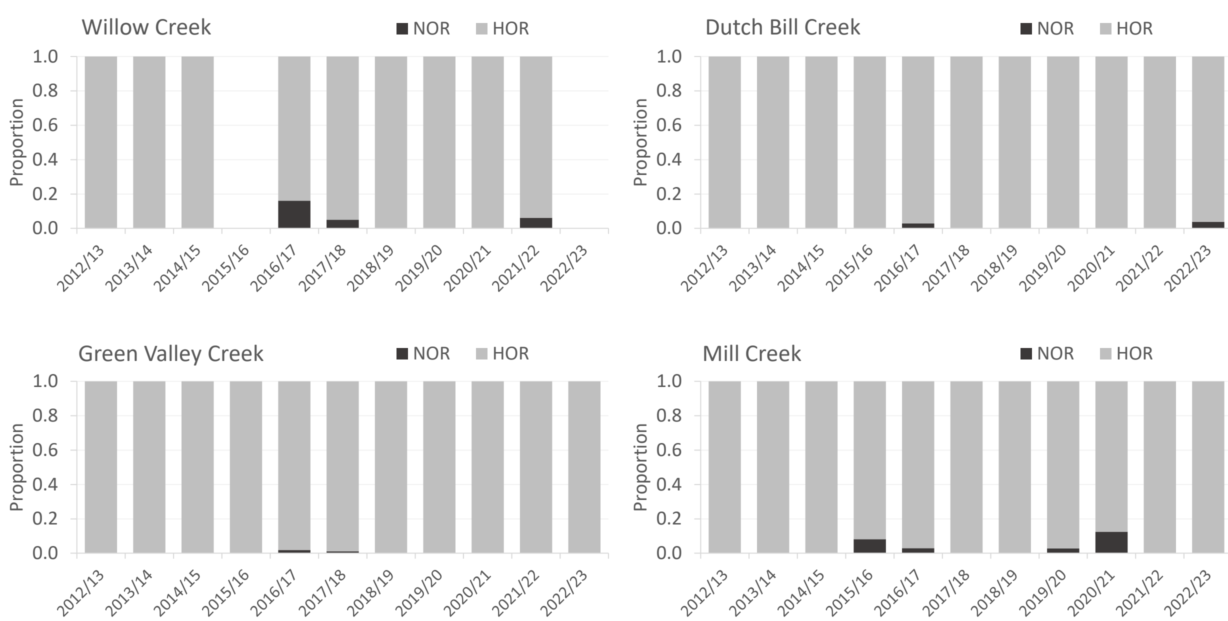

Figure 36. Annual proportion of natural-origin (NOR) and hatchery-origin (HOR) adult returns to four LCM streams, winters 2012/13 – 2022/23.

Table 11. Coho salmon spawner-spawner ratios for LCM monitoring streams in the Russian River watershed. NOR = natural-origin, HOR = hatchery-origin.

LCM watershed	Return winter	Estimated adult returns (NOR + HOR)	Estimated NOR returns in next generation	Spawner-spawner ratio
Willow Creek	2013/14	7	0	0.00
	2014/15	8	5	0.60
	2015/16	0	0	0.00
	2016/17	12	0	0.00
	2017/18	61	0	0.00
	2018/19	27	1	0.04
	2019/20	17	0	0.00
Dutch Bill Creek	2013/14	15	0	0.00
	2014/15	18	2	0.11
	2015/16	33	0	0.00
	2016/17	69	0	0.00
	2017/18	40	0	0.00
	2018/19	49	0	0.00
	2019/20	42	1	0.02
Green Valley Creek	2012/13	74	0	0.00
	2013/14	17	2	0.12
	2014/15	44	2	0.04
	2015/16	17	0	0.00
	2016/17	109	0	0.00
	2017/18	162	0	0.00
	2018/19	26	0	0.00
	2019/20	94	0	0.00
Mill Creek	2010/11	152	0	0.00
	2011/12	68	0	0.00
	2012/13	78	1	0.02
	2013/14	7	4	0.61
	2014/15	52	0	0.00
	2015/16	14	0	0.00
	2016/17	136	3	0.02
	2017/18	54	2	0.04
	2018/19	93	0	0.00
	2019/20	96	0	0.00
			Average recruitment:	**0.05**

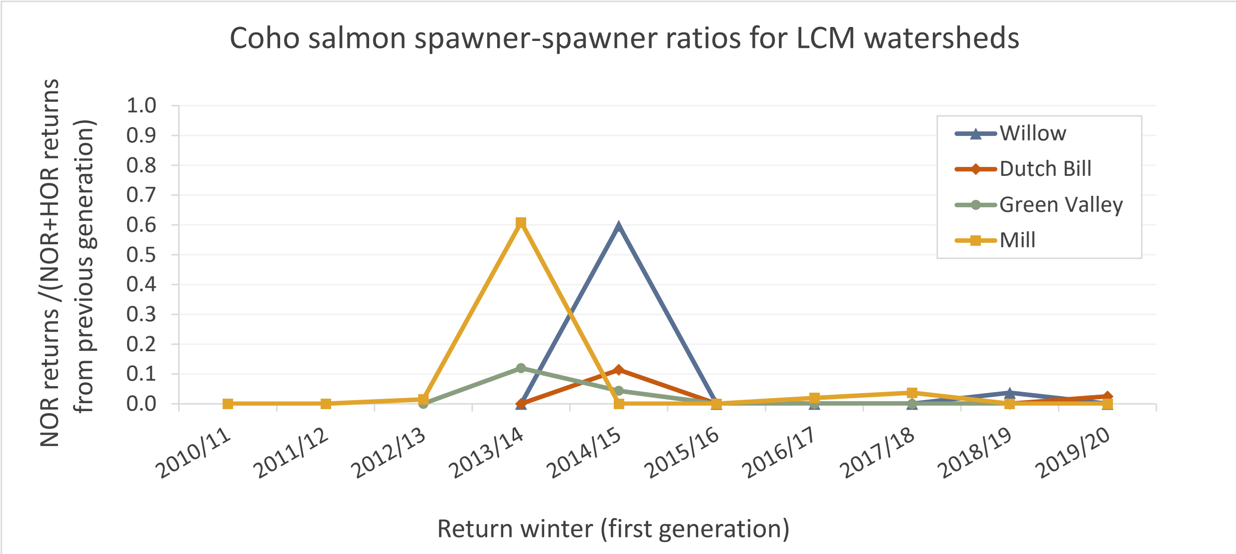

Figure 37. Coho salmon spawner-recruitment ratios in Russian River LCM streams. NOR = natural-origin, HOR = hatchery-origin.

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