Monitoring to Support Central California Coast Coho Salmon Recovery in Tributaries of the Lower Russian River Basin

Annual Report for National Marine Fisheries Service

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Prepared by:

Will Boucher, Elizabeth Ruiz, Sarah Nossaman Pierce, Mariska Obedzinski, Troy Cameron, and Laura Slater

California Sea Grant at University of California

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Contents

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1. Overview: Russian River coho salmon

The Russian River coho salmon population, which falls within the endangered Central California Coast (CCC) Coho Salmon Evolutionarily Significant Unit, is a priority for recovery at local, state, and federal levels. The population is listed as endangered by both state and federal endangered species acts and in 2015, NOAA named CCC coho salmon a "Species in the Spotlight", one of the most at-risk endangered species in the nation and a priority for immediate recovery actions. The Russian River watershed is also a Habitat Focus Area where NOAA is directing resources and working with partners and communities to address high priority habitat issues.

Multiple salmonid recovery efforts are underway in the Russian River watershed, including a conservation hatchery program, habitat enhancement projects, and streamflow improvement efforts. For over 15 years, California Sea Grant (CSG) has partnered with public resource agencies, educational institutions, non-profit organizations, consulting firms and private landowners on many ongoing recovery efforts, and has developed an extensive monitoring program to specifically inform recovery actions.

In 2019, NOAA awarded CSG funds to conduct monitoring to help 1) evaluate a potential new hatchery release strategy and 2) provide critical information to increase the effectiveness of streamflow improvement efforts. The award provided funding for three years, beginning in 2019. This report summarizes the results of the second year of monitoring conducted during the summer of 2020.

2. Remote-Site Incubator pilot study monitoring (Task 1)

2.1. Introduction

As endangered coho salmon populations continue to decline in many central California coast streams, there is an increasing interest in captive broodstock programs to help preserve remaining genetic diversity of local populations and supplement streams with hatchery fish until long-term recovery can be achieved. The US Army Corps of Engineer's Don Clausen Fish Hatchery at Warm Springs Dam currently hosts the Russian River Coho Salmon Captive Broodstock Program (Broodstock Program), a multi-partner conservation hatchery program in which natural-origin juvenile coho salmon are captured from Russian River tributaries, raised to the adult stage, and spawned according to a genetic matrix designed to maximize genetic diversity. Progeny of these broodstock are then released into 15-20 Russian River tributaries each year as fed fry (approximately 3-9 months old) and as one-year old pre-smolts and smolts. Based on the initial success of this program, there is interest in expanding the releases to include additional streams within and beyond the Russian River watershed. The Don Clausen Fish Hatchery has a limited capacity to rear fish and is unable to rear enough juveniles to stock all of the streams currently in need of hatchery support.

Remote-site incubation (RSI) is a rearing and release technique in which salmon eggs are placed in a streamside holding barrel and fish emerge volitionally into the stream. Although this method requires hatchery infrastructure to raise and spawn broodstock to produce eggs, it has the advantage of eliminating the need to raise juvenile fish in the hatchery for up to a year before release. Because one of the primary limitations to increasing the number of coho salmon produced at Don Clausen Fish Hatchery is rearing space, there is a need for alternative strategies that require less hatchery infrastructure. For example, if fish can be released at an earlier life stage, then less water and tank space is required and, ultimately, more Broodstock Program fish can be released into selected streams.

Previous work has shown that RSIs can be an effective tool for incubation of Atlantic Salmon, Arctic Grayling and Westslope Cutthroat embryos (Andrews et al. 2016; Donaghy and Verspoor 2000; Kaeding and Boltz 2004). The National Marine Fisheries Service (NMFS), in partnership with the California Department of Fish and Wildlife (CDFW), the US Army Corps' of Engineers (ACOE), and CSG, initiated a study in 2019 to evaluate the use of RSIs as a recovery tool for endangered coho salmon in California. In 2019, following release of RSI fry into Gray Creek, CSG conducted snorkel and electrofishing surveys to estimate abundance and spatial distribution of juvenile coho salmon that may have resulted from RSI releases and collected genetic samples in order to differentiate between RSI and natural-origin coho salmon young-of-the-year (yoy) (California Sea Grant 2020a). In 2020, RSI operations and follow-up monitoring surveys were conducted on Yellowjacket Creek, a tributary to Redwood Creek. It should be noted that the RSI in Yellowjacket Creek was located upstream of a 0.22 km restoration project reach, in which a fish passage barrier was remediated and a series of step pools was created for the benefit of salmon.

2.2. Methods

2.2.1. RSI releases

During the spring of 2020, NOAA operated an RSI on Yellowjacket Creek, a tributary to Redwood Creek in the Maacama Creek watershed. An estimated 10,205 fertilized eggs were delivered from Warm Springs Hatchery and placed in an RSI in Yellowjacket Creek in early February, 2020. The fry were released at a single location in the stream adjacent to the RSI located at river kilometer (rkm) 1.09.

2.2.2. Snorkeling surveys

During the summer of 2020, snorkel surveys were conducted to document the number and spatial distribution of juvenile coho salmon present following the release of RSI fish in the early spring. Snorkel surveys in Yellowjacket Creek were conducted on July 13-14 from rkm 0.3 to the upstream extent of anadromy. In addition, as a part of an additional monitoring effort (Coastal Monitoring Program), two survey reaches in Redwood Creek were surveyed on July 27-28 from the confluence of Maacama Creek (rkm 0) to rkm 4.77 in Redwood Creek.

In Yellowjacket Creek, all pools were snorkeled, while in Redwood Creek, every other pool was snorkeled. Pool habitat was defined as stream sections that met the following criteria:

- surface area > 3 m^2
- pool depth > 1 ft.
- pool length ≥ maximum wetted width

Divers sampled in a downstream to upstream direction, counting and recording the number of juvenile coho salmon and steelhead in each pool. All observed salmonids were identified to species and grouped into age classes based on size. Salmonids > 100 mm in fork length were documented as parr and those ≤ 100 fork length were considered yoy. Dive lights were used to illuminate dim areas such as undercut banks and under woody debris. In addition to salmonid counts, large woody debris counts were performed at the pool scale. Large wood was defined as logs greater than 30 cm in diameter and 2 m in length. Data from each pool was recorded in an Allegro field computer, and GPS coordinates were recorded to document spatial distribution of juvenile salmonid distribution in relation to the release site. Data were downloaded, error-checked and then uploaded to CSG's SQL database. In Redwood Creek, expanded count estimates were made by multiplying the minimum observed count by a factor of 2.

2.2.3. Electrofishing surveys

Following snorkeling surveys, electrofishing was conducted to capture juvenile coho salmon and collect genetic samples for use in determining whether or not the fish originated from the RSI release. Our objective was to obtain a minimum of 100 genetic samples from as many pools as possible based on where fish were observed during snorkeling surveys. Due to the low densities of fish observed during snorkel surveys, samples were taken from all coho salmon captured electrofishing.

Electrofishing surveys were conducted using NMFS' Backpack Electrofishing Guidelines (National Marine Fisheries Service 2000) by a crew of five people. Prior to electrofishing, temperature, dissolved oxygen, and conductivity measurements were taken to confirm that values fell within the acceptable thresholds of < 18°C, > 6.0 mg/l for dissolved oxygen and < 350 µS/cm for conductivity, and the condition of captured fish was constantly monitored to avoid mortalities.

Captured salmonids were anesthetized, measured for length and weight, and scanned for coded wire tags (CWT) and passive integrated transponder (PIT) tags. Genetic samples were collected from all unmarked coho salmon yoy by clipping a small (<1 mm^2) piece of fin tissue from the tip of the lower caudal fin. Fin tissue was placed on blotting paper inside an envelope marked with fish number, species, length, weight and origin for subsequent cross-reference. Samples were then transferred to the Southwest Fisheries Science Center in Santa Cruz for analysis to determine whether the observed fish were of the same family groups as the eggs placed in the RSI. All data were recorded in an Allegro field computer, error-checked, and uploaded to CSG's SQL database.

2.3. Results

2.3.1. RSI releases

A total of 9,947 juvenile coho salmon were released from the RSI into Yellowjacket Creek at a single location at rkm 1.09 (Figure 1) between Feb 20 and March 9, 2020.

2.3.2. Snorkeling surveys

On July 13 and 14, 2020, field crews snorkeled 115 pools throughout Yellowjacket Creek. In total, 166 coho salmon yoy), 108 steelhead yoy, and 76 steelhead parr were observed. Coho salmon and steelhead were present in 40 and 65 of the 115 surveyed pools, respectively. Large woody debris counts indicated that 28% of pools in Yellowjacket Creek contained one or more pieces of large wood.

2.3.2.1. Coho salmon

In 2020, the majority of the coho salmon observed were found in pools located within the restoration project reach boundaries (rkm 0.69-0.91) (Figure 1). Of the 166 observed coho salmon, 112 (68%) were counted within the restoration project reach boundaries which had an average density of 4.14 coho/pool. A total of 54 coho (32%) were observed in pools outside of the restoration project reach boundaries which had an average density of 0.61 coho/pool. The majority of the coho were observed downstream of the RSI release location; however, six coho were observed upstream with some as far as 22 pools (0.58 rkm) upstream of the release location (Figure 1).

In Redwood Creek, a total of 47 coho yoy were observed, for an expanded count of 94 fish (Figure 2).

2.3.2.2. Steelhead

In 2020, steelhead densities in Yellowjacket Creek were also higher within the restoration project reach with an average of 4.2 fish/pool as compared to densities of 1.7 fish/pool outside the project reach. Unlike coho, which were primarily located downstream of RSI release location, steelhead were found throughout the entire area surveyed (Figure 3).

Over four years of annual snorkeling surveys conducted on Yellowjacket Creek between 2017 and 2020, an average of 46% of steelhead observations were parr as opposed to yoy. This percentage is considerably higher than the average observed in other streams including Mill Creek (9.5%), Palmer Creek (19.1%), Green Valley Creek (17%), Purrington Creek (15.9%) and Gray Creek (18.2%) over those same years (Table 1).

Since 2017, CSG observed an average steelhead parr density of 47.4 parr/rkm in Yellowjacket Creek. This average is notably higher than that of Mill Creek (15.9 parr/rkm) and Palmer Creek (31.6 parr/rkm) and is comparable to the numbers found in Green Valley Creek (43.9 parr/rkm) and Purrington Creek (48 parr/rkm). However, it should be noted that average steelhead parr density was the highest in Gray Creek across those years (69.4 parr/rkm) (Table 1).

2.3.3. Electrofishing surveys

Electrofishing surveys were conducted between September 14 and 16 in Yellowjacket and Redwood creeks. A total of 51 pools were sampled in Yellowjacket Creek and a single pool was sampled in Redwood Creek (Figure 4). Though Redwood Creek sampling was not included in the original study plan, it was added to explore the potential of downstream movement of RSI fish. Capture totals consisted of 127 coho salmon and 250 steelhead in Yellowjacket Creek. In Redwood Creek, four coho salmon and four steelhead were captured. Neither tag type (CWT or PIT) were detected in any of the captured fish from Yellowjacket or Redwood creeks.

Genetic samples were collected from all 131 coho salmon captured. The average fork length of coho salmon was 71 mm and average weight was 4.3 g. Coho salmon captured in Yellowjacket and Redwood creeks were, on average, larger than those captured in Gray Creek in 2019 (Table 2). All genetic samples were cataloged and delivered to NOAA’s Southwest Fisheries Science Center.

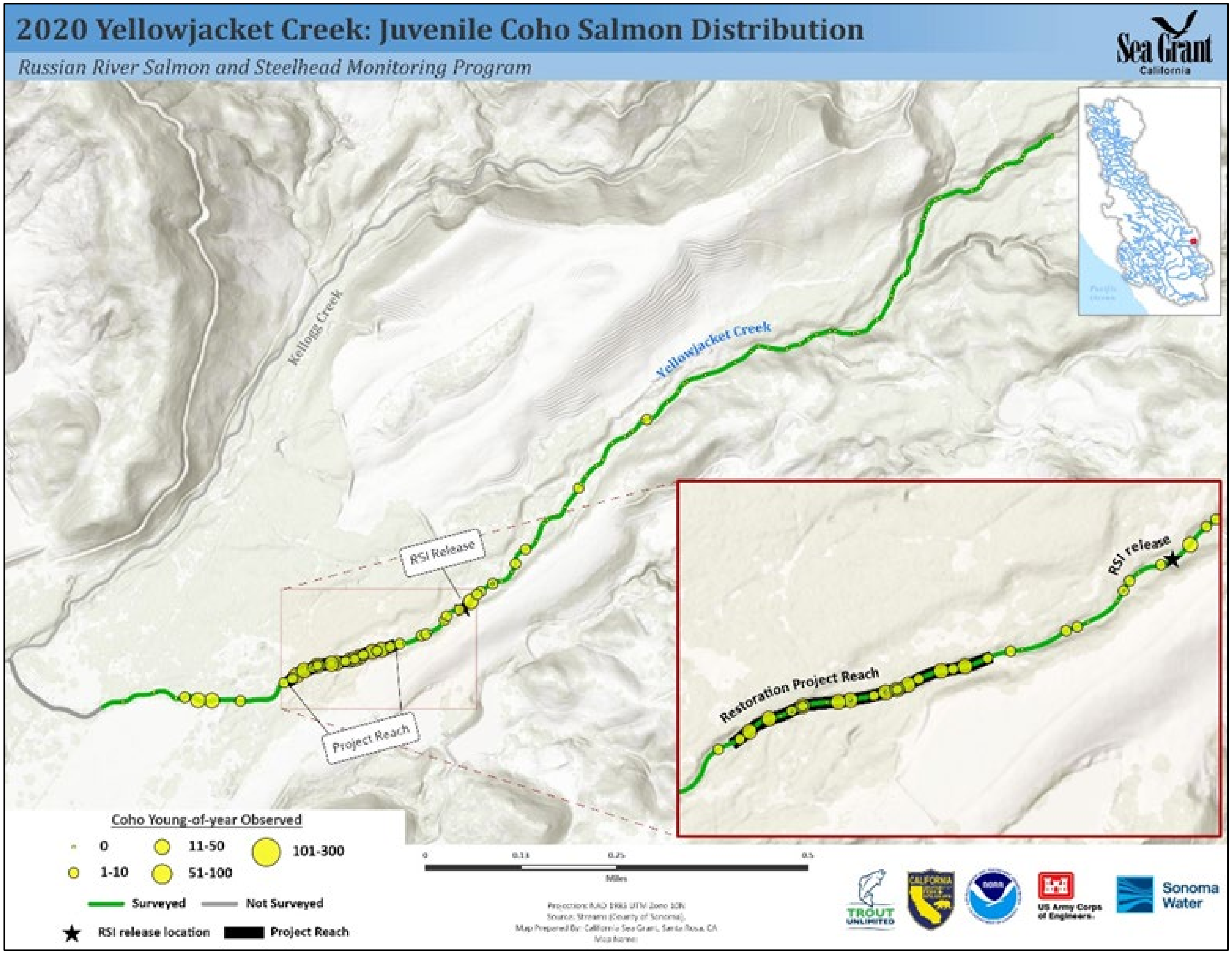

Figure 1. Juvenile coho salmon density and distribution in relation to RSI release location in Yellowjacket Creek, 2020.

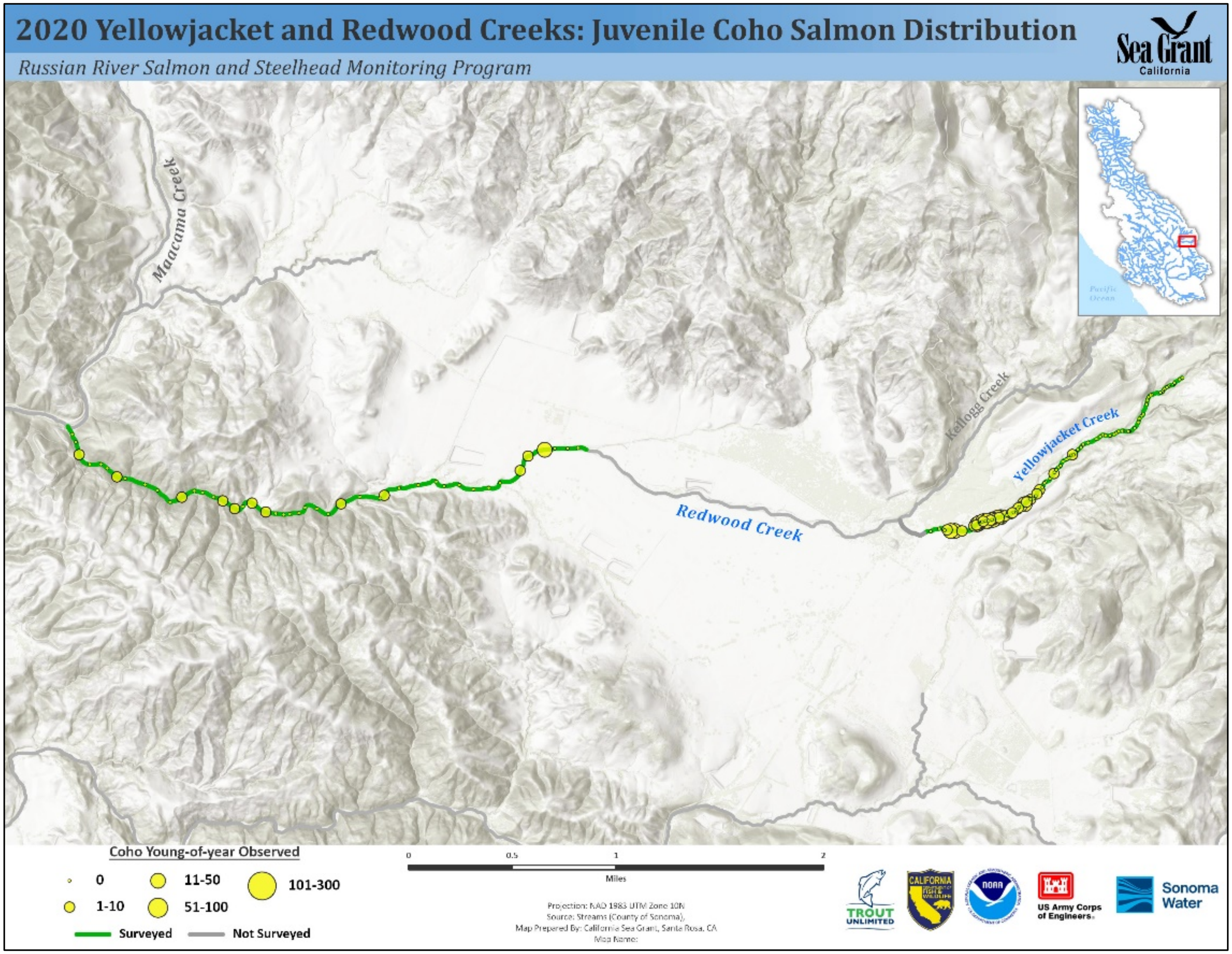

Figure 2. Juvenile coho salmon density and distribution in Yellowjacket and Redwood creeks, summer 2020.

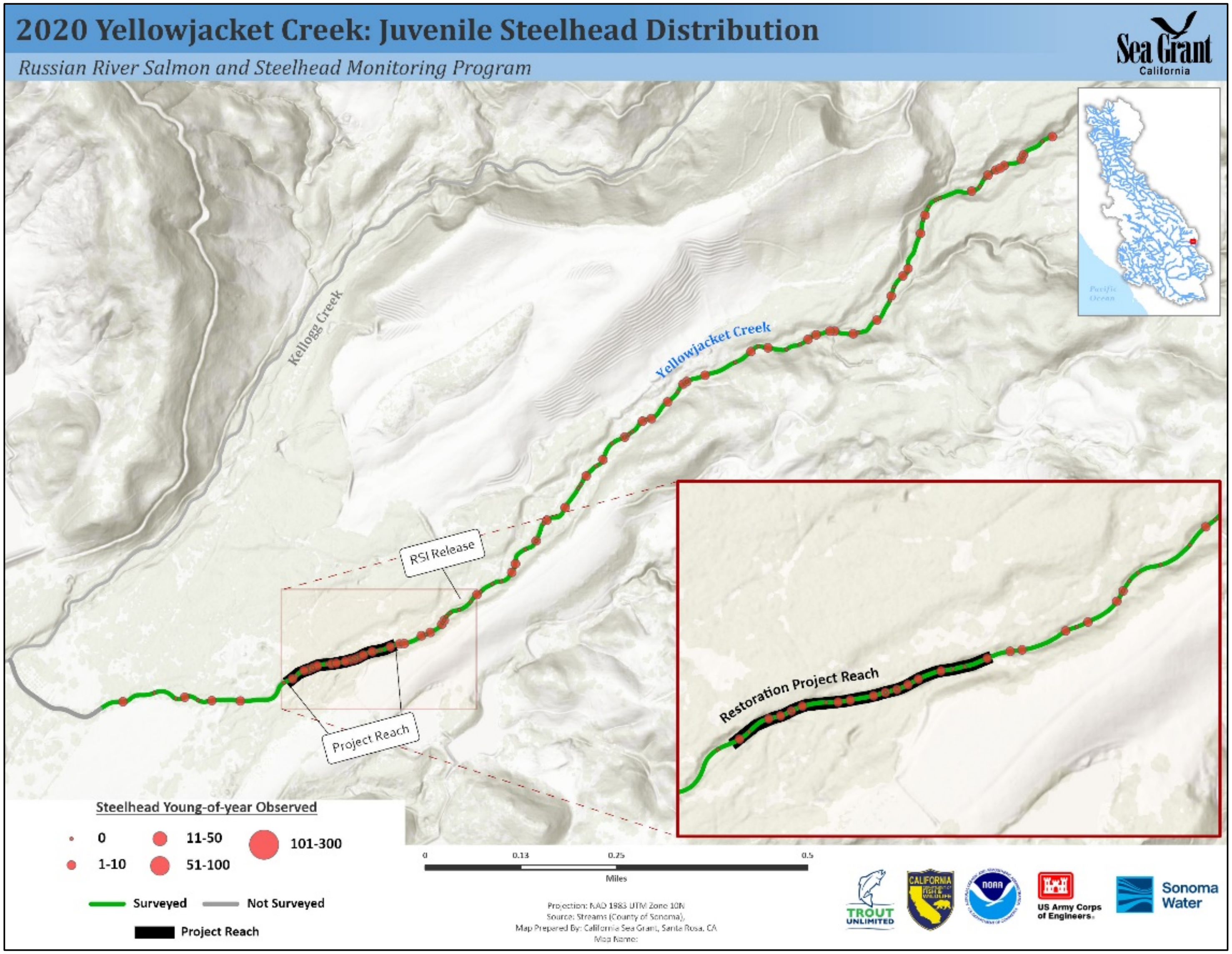

Figure 3. Juvenile steelhead density and distribution in Yellowjacket Creek, summer 2020.

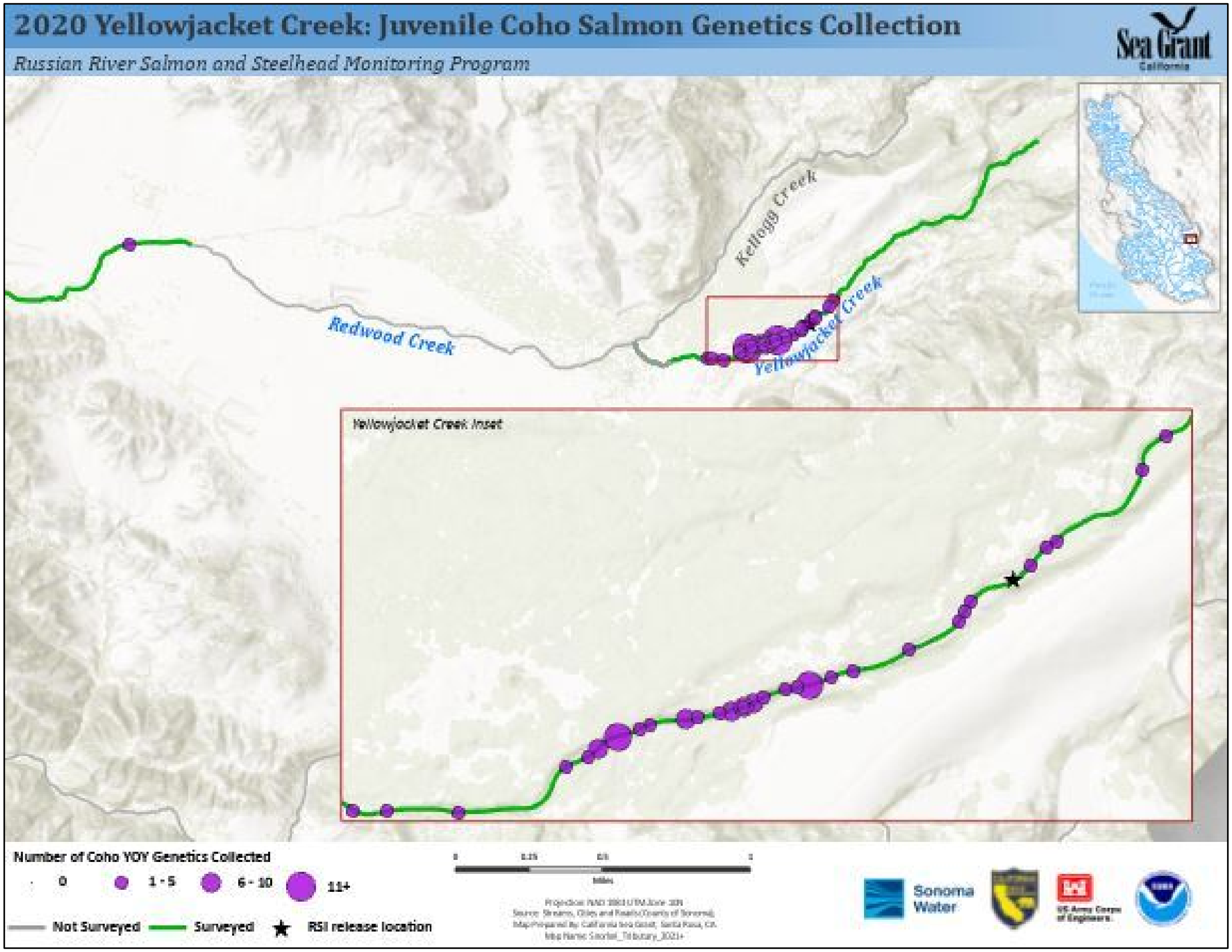

Figure 4. Density and distribution of genetic sample collection in Yellowjacket and Redwood creeks, 2020.

Table 1. Average percent of steelhead parr out of total steelhead observations and average steelhead parr density per rkm in six Russian River tributaries, 2017-2020.

Tributary	Average percent parr (parr/total steelhead)	Average parr density (parr/rkm)
Gray Creek	18.2%	69.4
Green Valley Creek	17.0%	43.9
Mill Creek	9.5%	15.9
Palmer Creek	19.1%	31.6
Purrington Creek	15.9%	48
Yellowjacket Creek	46.1%	47.4

Table 2. Average length and weight of unmarked juvenile coho captured during electrofishing surveys in Gray Creek (2019) and Yellowjacket and Redwood creeks (2020).

Year	Survey dates	Tributary	# Individuals	Average fork length (mm)	Average weight (g)
2019	9/10 - 9/12	Gray Creek	156	62.5	2.9
2020	9/14 - 9/16	Yellowjacket Creek	127	71	4.3
2020	9/15	Redwood Creek	4	75	4.4

2.4. Discussion

Monitoring results suggest there is a high likelihood that some of the RSI-release fish survived and remained in Yellowjacket Creek; however, analysis of genetic samples is necessary to confirm that the fish observed in Yellowjacket Creek originated from the RSI releases. A total of 166 coho salmon yoy were observed during snorkeling surveys and since it is possible some fish were not observed during snorkeling surveys, this estimate can be considered a minimum count. 2020 was the first year in four years of monitoring that juvenile coho salmon were documented in Yellowjacket Creek, lending evidence to the possibility that most, if not all, of the observed coho were of RSI origin. If results from genetic analysis confirm that all coho observed in Yellowjacket Creek were of RSI origin, it would be possible to conclude that a minimum of 1.3% percent (127/9,947) of the RSI released fish remained in Yellowjacket Creek and survived until the mid-Sept electrofishing survey. In addition, if the genetic samples collected in Redwood Creek (n = 4) were confirmed to be of RSI origin, it would be possible to infer that at least some of the expanded estimate of 94 coho observed during snorkeling surveys in Redwood Creek were of RSI origin.

Given a release of 9,947 coho yoy into Yellowjacket Creek, a minimum snorkel count of 166 is considerably low. One possible contributing factor was low rainfall during the winter of 2019/20, where there were near-zero precipitation totals recorded in the month of February, 2020 on Russian River streamflow gages and spring flows were considerably low. Late winter and early spring is an important time for growth of newly hatched salmon and the low flows may have impacted their development. A study in Clear Creek, an upper tributary of the Sacramento River, showed that juvenile salmonid abundance was highly correlated to flow magnitude, water temperature, or both (He and Marcinkevage 2017).

Counts in Yellowjacket Creek in 2020 were considerably lower than the observed count of 597 coho yoy in Gray Creek in 2019. With a release size of 4,774 in 2019, an estimated 12.5% of the RSI release fish survived and remained in Gray Creek until mid-July. It should be noted that even though genetic analysis confirmed that most of the samples collected in Gray Creek were of RSI origin, we were unable to confirm that all 597 coho were of RSI origin. In 2020, a minimum count of 166 coho salmon yoy were observed during snorkel surveys in Yellowjacket Creek. If these fish were of RSI origin, with a release size of 9,974, it would result in an estimated 1.7% of the RSI release fish surviving and remaining in Yellowjacket Creek until mid-July. Even with a release size of nearly double that of 2019, 2020 counts in Yellowjacket Creek were considerably lower.

There are multiple potential explanations for the lower coho yoy counts in Yellowjacket Creek in 2020 as compared to the 2019 counts in Gray Creek. First, 2019 was a substantially wetter year where spring rains kept stream flows elevated throughout the entire spring. Increased flows during spring months' likely led to an increase in food availability and a decrease in competition. Another potential explanation for lower counts is the suitability of the stream being supplemented, specifically for coho salmon. Gray Creek is a stream that consistently supports natural coho spawning and juvenile rearing. It has many of the desired characteristics of a coho-bearing stream such as preferred stream gradients, gravel size, and water quality parameters. Yellowjacket Creek appears to have a different hydrologic makeup than Gray Creek. Compared to Yellowjacket Creek, in Gray Creek, large wood is more abundant and the substrate appears smaller. Large woody debris counts in Yellowjacket Creek showed that 28% of pools had one of more pieces of large wood. That is considerably lower than numbers seen in other streams such as Mill Creek (36%), Palmer Creek (50%), Green Valley Creek (52%), as well as the basinwide average of 35% across 42 streams surveyed in 2020. Large woody debris can provide many benefits to juvenile salmon. During the summer months, it can provide cover from direct sun exposure, reducing water temperature stress. The physical woody structure can also provide as refuge from predators such as otters, kingfishers or other fishes. In the winter, it reduces flow velocities and can act as high flow refugia for juvenile salmon.

It is possible that RSI coho emigrated from Yellowjacket Creek in search of more suitable rearing conditions prior to our snorkeling surveys in July. This theory could be partially validated if genetic samples collected from Redwood Creek are confirmed to be from RSI origin fish. Most of the coho observed in Redwood Creek during snorkeling surveys were in the upper extent of the survey reaches where excessive drying and poor water quality were documented on the date of survey. It is likely that there could have been high mortality before the date of our snorkel survey. Furthermore, it should be noted that a large section of Redwood Creek was not surveyed in the summer of 2020 (Figure 2).

Finally, Yellowjacket Creek has shown to have relatively high densities and percentages of steelhead parr. One study documented that an average of 13% of steelhead smolt diets consisted of salmon yoy in February through mid-May (Beauchamp 1995). High densities of steelhead parr combined with a greater percentage of steelhead parr compared to yoy may produce an environment with greater predation risk for coho yoy.

Additional years of RSI operation and monitoring on Yellowjacket Creek will help to determine whether coho yoy densities are consistently low or whether the low densities in 2020 were an anomaly. CSG is interested in examining alternative release points that might be more suitable for unfed fry. The habitat surrounding the 2020 release point was high gradient and primarily riffle habitat. Salmon fry are thought to prefer slower stream flow velocities and shallow edge habitat. In addition, CSG would like to snorkel more of Redwood Creek, particularly in the upper reaches at an earlier date to better document the proportion of fish that are moving downstream.

3. Flow release monitoring (Task 2)

3.1. Introduction

In many intermittent tributaries to the lower Russian River, insufficient summer streamflow is a bottleneck to salmonid recovery (Obedzinski et al. 2018; RRCWRP 2015). These streams typically become intermittent in early- to mid-summer, and in drought years as early as spring. Since 2015, small-scale flow releases from private or municipal sources have been used in some tributaries to augment streamflow for the purpose of improving wetted habitat and water quality conditions for juvenile salmonids. These efforts emerged as a management tool during the peak of the 2012-2016 drought when landowners and multiple supporting agencies came together to provide relief for juvenile coho salmon and steelhead rearing in intermittent streams in the lower Russian River watershed during the dry summer months.

Instream flow augmentations can yield beneficial effects when timed appropriately. However, due to the limited amount of available release water and the dynamic nature of stream drying under variable climatic conditions, the timing, duration, and rate of each release must be determined strategically in order to maximize potential benefits. Despite the recognized value and relatively low cost of flow releases, prior to recent years, there have been no standard, dedicated procedures in place to guide their timing or monitor their effectiveness.

CSG has been monitoring flow releases in lower Russian River tributaries since 2015. Monitoring techniques and efforts have evolved over time, from opportunistic surveys and spot measurements of water quality to more routine wet/dry mapping surveys funded through a Wildlife Conservation Board (WCB) grant (2017-2019). The addition of continuous water quality loggers designated specifically for release monitoring in 2020 was made possible by this NOAA grant.

During the dry season of 2020, three private landowners voluntarily released water from off-channel storage ponds into Green Valley Creek for the benefit of juvenile salmonids (Table 3, Figure 5). One release was from the Jackson Family Winery property near Bones Road and is referred to the "JFW" release in this report. Approximately 0.5 km upstream from the JFW release was the "Maddocks" release, a new addition to the summer instream flow augmentation efforts. The uppermost release, named "GVF" in this report, was from the Green Valley Farms property. Data obtained through wet/dry mapping and water quality monitoring funded through this NOAA award, as well as streamflow data from partners at Trout Unlimited, were used to evaluate the impacts and effectiveness of these three flow releases into Green Valley Creek.

Table 3. Approximate location, average release rates, start and end dates of flow releases on Green Valley Creek, 2020.

Description	Location	Water Source	Approx. River Kilometer [1]	Start Date	Average Rate ft^3/s	End Date
Jackson Family Winery (JFW)	Below Bones Road	Off-channel pond	12.83	8/13	-	-
Maddocks	Above Bones Road	Off-channel pond	13.34	7/25	1.59	8/18
Green Valley Farms (GVF)	Above 2nd Green Valley Rd Xing	Off-channel pond	16.37	8/26	0.03	-

[1] *Approximate distance upstream of mouth along stream channel.*

3.2. Methods

3.2.1. Snorkeling surveys

Snorkel counts of juvenile salmonids were conducted on two survey reaches of Green Valley Creek, as well as Little Green Valley and Nutty Valley creeks (Figure 6) on June 22-23 to document fish presence and distribution as a part of CSG and Sonoma Water's Coastal Monitoring Program life-cycle monitoring effort. Snorkeling survey methods used were the same as those used on Yellowjacket Creek, described above, with the exception of the frequency of pools snorkeled. On Yellowjacket Creek, every pool was snorkeled as a part of the RSI monitoring effort, but on Green Valley Creek and associated tributaries, surveyors snorkeled every other pool in keeping with the Coastal Monitoring Program protocol (Sonoma Water and Califorina Sea Grant 2019). Expanded count estimates were made by multiplying the minimum observed count by a factor of 2.

In anticipation of drier-than-normal conditions, and after assessing the amount of water available for the flow releases, resource managers and partners planned to initiate the augmentations in late July at the lower two augmentation sites and in late August at the GVF site (Table 3).

3.2.2. Wet/dry mapping surveys

In the summer of 2020, two wet/dry mapping surveys (also referred to as wetted habitat surveys) were completed in upper Green Valley Creek on August 18 and October 13-14. The stream was divided into two sample reaches, beginning at the first Green Valley Road crossing and extending 4.3 miles upstream (Figure 5), the same surveyed extents as in previous years. Using the protocol developed by CSG for Russian River tributaries (California Sea Grant 2019a), crews of two surveyors walked stream reaches in an upstream direction, surveying both reaches over the course of one or two days, depending on staff availability.

Spatial data were collected with ESRI's ArcCollector Classic application, using a Trimble TDC600 rugged data collector. The surveyors documented wetted habitat conditions by mapping line features that represented wet or dry lengths of stream channel. A YSI Pro20 DO meter, inspected and calibrated daily according to a CSG protocol (California Sea Grant 2018) was used to measure DO and water temperature in nearest pools encountered at five-minute intervals. At the outflowing riffle crest thalweg (RCT) of each measurement pool, depth was measured in tenths of feet. DO, water temperature, RCT depth, and GPS location were recorded in a digital Survey123 datasheet. During the surveys, discrete DO measurements were taken with the YSI Pro20 at each of the continuous DO logger locations in the stream. Measurements associated with the loggers were used at the end of the season to adjust for instrument drift using the DO Assistant in HOBOware Pro software (California Sea Grant 2019b).

Upon return to the office, spatial data collected on ArcCollector were uploaded to an ArcGIS Online server. Raw data were inspected and corrected in ArcGIS Pro desktop software before processing through customized geospatial tools. Geospatial tools improved the continuity of line segments, assigned intermittency conditions to sections of alternating wet and dry features, and calculated statistics for the lengths and proportions of each wetted habitat condition (wet, intermittent, or dry) by survey date. Similarly, pool-level water quality data recorded in the Survey123 datasheet were uploaded to a cloud-based database and then downloaded into a Microsoft Access database. Surveyors reviewed the data for errors and made necessary corrections the same day as the survey.

Discrete measurements of DO and temperature taken during wet/dry surveys were compared to the regional daily minimum DO objective of 6.0 mg/L, the threshold set for inland cold water systems in the state of California as a part of the Water Quality Control Plan for the North Coast Region (NCRWQCB 2011). The minimum objective for the Russian River hydrologic unit, as defined within the Water Quality Control Plan, is 7.0 mg/L. Measurements of RCT depth were compared to 0.20 ft, a depth at which DO concentrations decline to levels detrimental to juvenile salmonids within the Russian River (Nossaman Pierce et al. 2019). These in-season measurements were used to guide the timing of release initiations.

3.2.3. Continuous loggers and streamflow

Seven Onset U26 continuous loggers were strategically deployed to monitor water quality conditions before, during, and after flow release initiation (Figure 5). At the JFW release site, two loggers were deployed below the augmentation, at rkm 12.56 and 12.79, and one was deployed upstream, at rkm 12.88, the same sites as previous years. New monitoring sites were established upstream and downstream of the Maddocks release, at rkm 13.36 and 13.33, respectively. To document water quality impacts from the GVF release, two loggers were deployed below the release site, at rkm 14.92 and rkm 15.07. A logger was not placed upstream of the GVF release site because it is located outside of CSG's survey reaches and access to that section of stream was limited.

For all of the continuous logger sites, the loggers were set to record dissolved oxygen and water temperature at 15-minute intervals from July to October. At the end of the season, the loggers were retrieved from the field and downloaded using HOBOware Pro software before being processed through the DO Assistant. Adjusted data were corrected for errors, which included removing measurements recorded while the logger was in air, and then data were uploaded to a SQL database.

Data were plotted by site and compared to two thresholds, the regional daily minimum DO objective of 7.0 mg/L for the Russian River (NCRWQCB 2011) and the documented mortality threshold for coho salmon of 3.0 mg/L (McMahon 1983). Temperature data were compared to the optimal juvenile coho salmon water temperature range of 10°-15°C, as well as 20°C, the temperature at which significant decreases in swimming speed and increases in mortality due to disease have been observed (McMahon 1983).

Streamflow data from three long-term monitoring sites were developed and provided by partners at Trout Unlimited. The most downstream site was located above the confluence with Little Green Valley

Creek, at rkm 12.70, the middle site was located where Bones Road crosses the stream at rkm 13.05, and the most upstream site was located at rkm 14.12, near Harrison Grade Road (Figure 5).

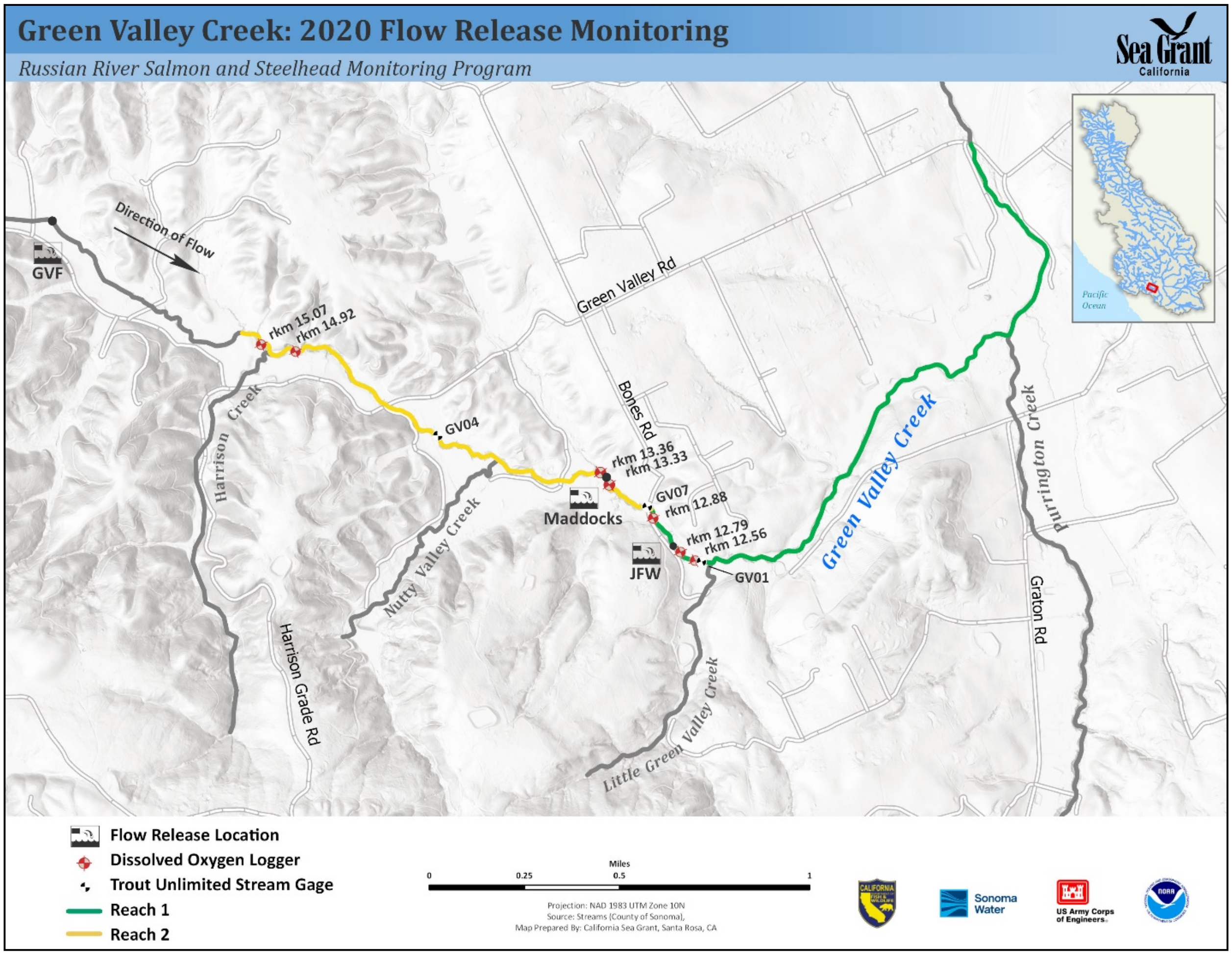

Figure 5. Map of Green Valley Creek and locations of two survey reaches, three flow release sites (GVF, Maddocks, and JFW), three Trout Unlimited streamflow gages, and seven dissolved oxygen loggers, 2020.

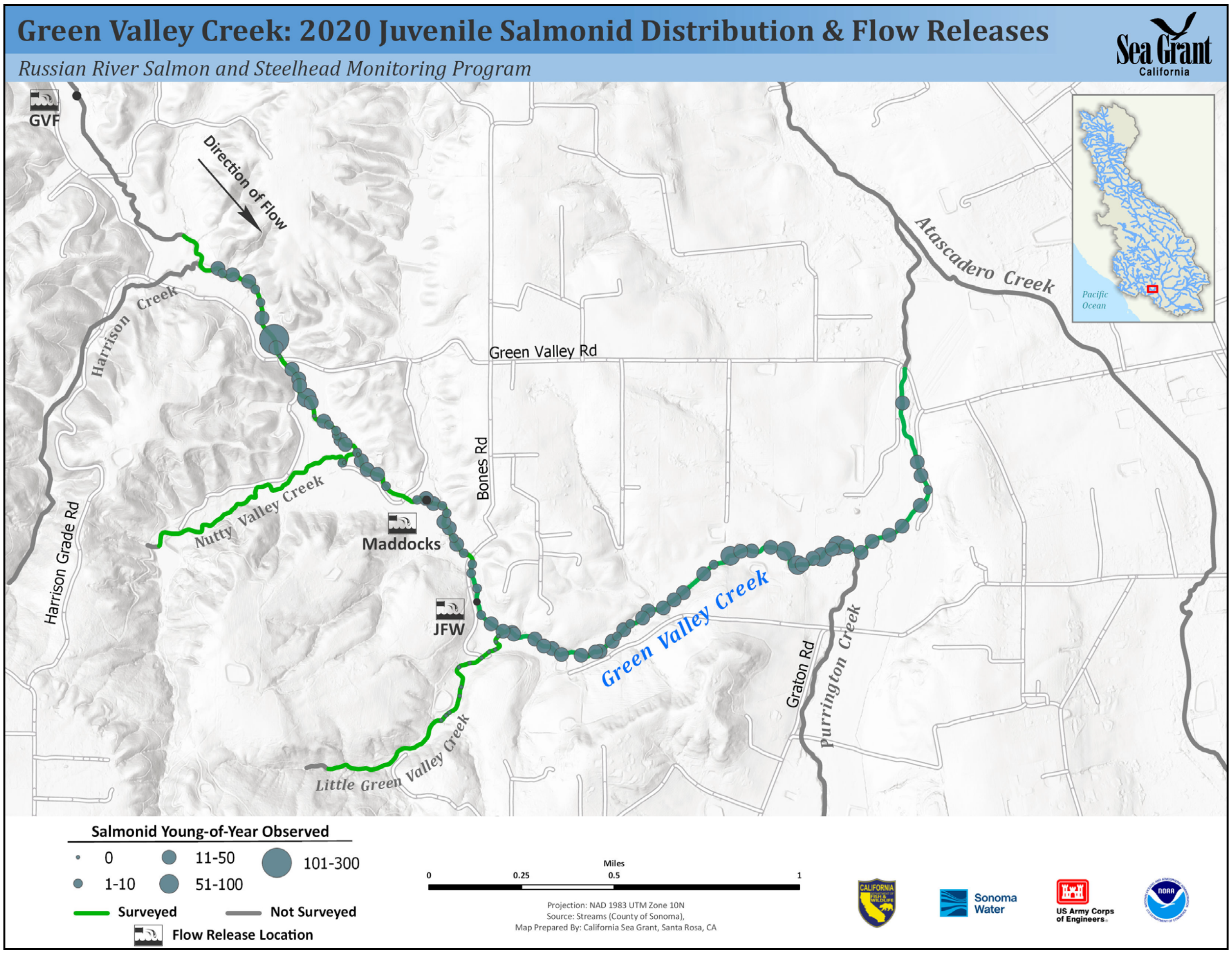

Figure 6. Distribution and abundance of young-of-year salmonids observed during snorkel surveys of Green Valley, Little Green Valley, and Nutty Valley creeks, June 2020.

3.3. Results

3.3.1. Snorkeling surveys

Juvenile coho salmon and steelhead trout were observed primarily in the mainstem of Green Valley Creek during the late-June snorkel surveys (Figure 6). Only a small number of salmonids were observed in Nutty Valley Creek, and there weren't any documented in Little Green Valley Creek. Snorkelers observed a total of 1,528 coho salmon yoy, 87 coho parr, 453 steelhead yoy, and 94 steelhead parr in the surveyed reaches (California Sea Grant 2020b). After count expansion, a total of 3,230 coho salmon and 1,094 steelhead trout juveniles were estimated to be in Green Valley and Nutty Valley creeks combined during the summer of 2020.

3.3.2. Maddocks release

The Maddocks release was initiated on July 15th, before any wetted habitat surveys were conducted. It began at a rate of 0.5 ft^3/s and was increased to 1.9 ft^3/s, a rate that was maintained until July 18th, when it was scaled back to roughly 1.5 ft^3/s. Downstream of the release site, at rkm 13.33, DO concentration was approximately 7.5 mg/L at midday on the 15th, just before the release was initiated. By noon on the 16th, less than 24 hours after the augmentation began, DO increased to 9.76 mg/L (Figure 7). Concentrations higher than 7.0 mg/L, the daily minimum objective for the Russian River basin, were sustained until the first week of August. DO remained higher below the augmentation site than above it during the flow augmentation (Figure 7).

Approximately 0.29 rkm downstream, where Bones Road crosses Green Valley Creek at stream gage GV01, average streamflow on July 15th was a mere 0.01 ft^3/s. The augmentation water reached the gage on July 26th, when the flow jumped from 0.00 ft^3/s to 0.82 ft^3/s between midnight and 1:00 am (Figure 8). Flow peaked at 1.94 ft^3/s in the early morning on July 27th. Similar flows were observed at stream gage GV07, located just upstream of the confluence with Little Green Valley Creek and approximately 0.64 rkm downstream of the Maddocks augmentation.

On August 6th, partners at Gold Ridge Resource Conservation District reported that the water from this release was approaching 20°C, the temperature at which detrimental impacts to juvenile salmonids have occurred (McMahon 1983). These high temperatures were cause for concern, and the continuous temperature data from the DO loggers confirmed that there was a negative impact to in-stream water temperature. Downstream of the release site, water temperature peaked at 21.2°C on August 4th (Figure 9).

As a result, the release was scaled back until it was completely shut off on August 18th. Flow at both of the downstream gages fell to 0.00 ft^3/s while the rate of release was being reduced (Figure 8). After this release was terminated, stream water temperature at the DO logger site, which was an isolated pool at this point, steadily decreased to ranges more appropriate for juvenile salmonids (Figure 9) while DO decreased to lethal concentrations (Figure 7).

3.3.3. Jackson Family Winery release

Initiation of the JFW release was attempted on August 13th, just a few days before the first wet/dry sample on August 18th (Figure 10). However, the crew reported that the flow release was not operational during the wet/dry survey on the 18th, five days after its proposed initiation. At that time, 4.1% of the surveyed extent of Green Valley Creek was dry, and 17.9% was intermittent.

Later in the season, partners revealed that there were immediate clogging issues with the intake at the pond which kept the augmentation water from reaching the stream. By the time these issues were resolved, the creek was almost entirely dry and the juvenile salmonids had been rescued and relocated by California Department of Fish and Wildlife. Due to the incredibly dry conditions observed in the stream during the rescue operations and the subsequent relocation of juvenile salmonids, the JFW release was not attempted again. In the absence of this flow release, DO declined to concentrations unsuitable for juvenile salmonid survival for the remainder of the sampling period (Figure 11). By mid-October, only 40% of the stream remained wet; 28.7% was dry and 31.3% was intermittent (Figure 13).

3.3.4. Green Valley Farms release

Farther upstream, at the GVF release, water quality conditions in the weeks leading up to the release initiation were poor, particularly at rkm 15.07, the monitoring site 630 m downstream of the augmentation site (Figure 12). The stream was anoxic at the upper monitoring site, and DO was depleted prior to the augmentation. Conditions at rkm 14.92 were marginally better, though were consistently below 6.5 mg/L for the entire sampling period. By the end of August, concentrations of 0.0 mg/L were frequent.

The flow release began on August 26th at a rate of 0.03 ft^3/s. According to partners at Gold Ridge Resource Conservation District, who were coordinating the augmentation effort, no reconnection of surface flow occurred downstream of the release culvert. Likewise, there was no discernable impact to water quality at rkm 15.07. Increases in DO at rkm 14.92 can be attributed to change in outflow from a seasonal impoundment between the monitoring pool and the GVF augmentation, which is managed in conjunction with the GVF release.

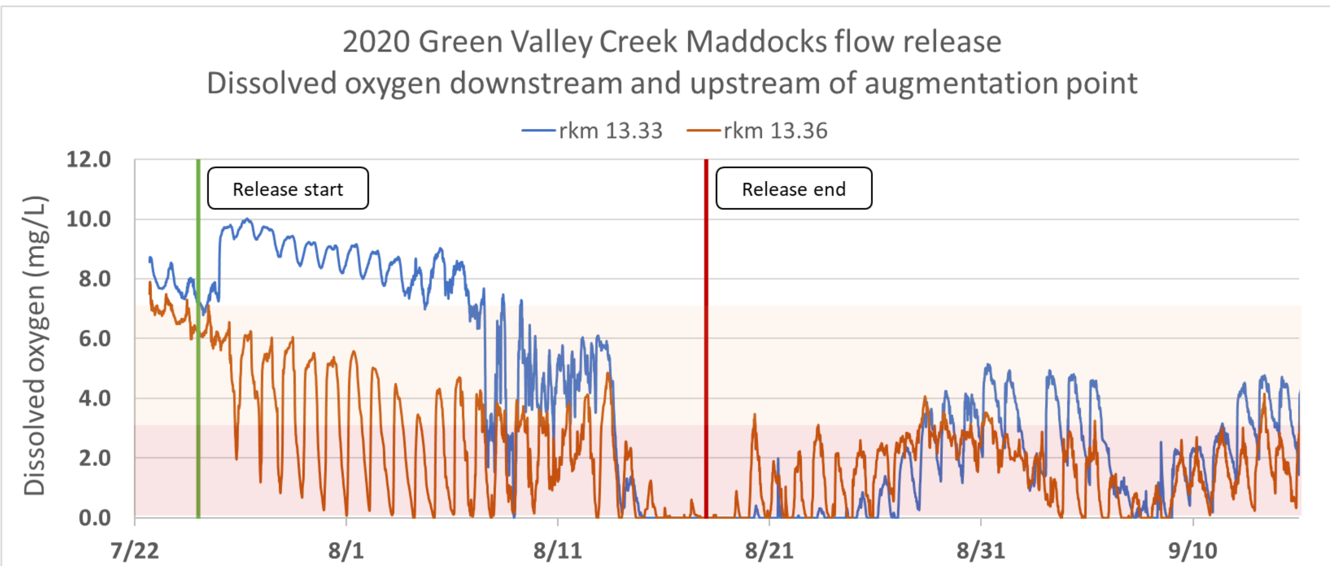

Figure 7. DO concentrations at rkm 13.33 (blue line), 10 m downstream of the Maddocks release site, and rkm 13.36 (orange line), 20 m above the release site in Green Valley Creek, 2020. Threshold DO concentrations are indicated with background shading, with values <3.0 mg/L indicated in red and values between this lower threshold and 7.0 mg/L indicated in tan. The start and end dates for the release are marked by the green and red vertical lines, respectively.

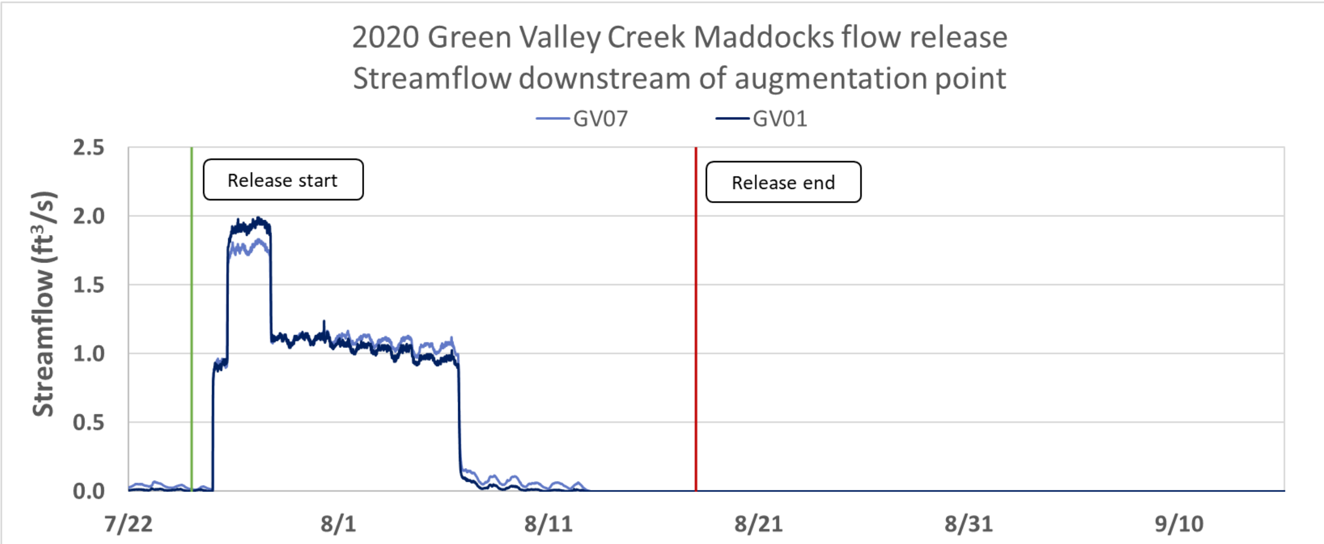

Figure 8. Streamflow in cubic feet per second (ft^3/s) at two stream gage locations downstream of the Maddocks augmentation site. The gage closest to augmentation, GV01 at Bones Road (rkm 13.05; dark blue line) was 0.29 rkm downstream of the augmentation site. The more downstream gage, GV07, was just upstream of the confluence with Little Green Valley Creek (rkm 12.70; light blue line) was 0.64 rkm downstream of the augmentation site. The start and end dates for the release are marked by green and red vertical lines, respectively.

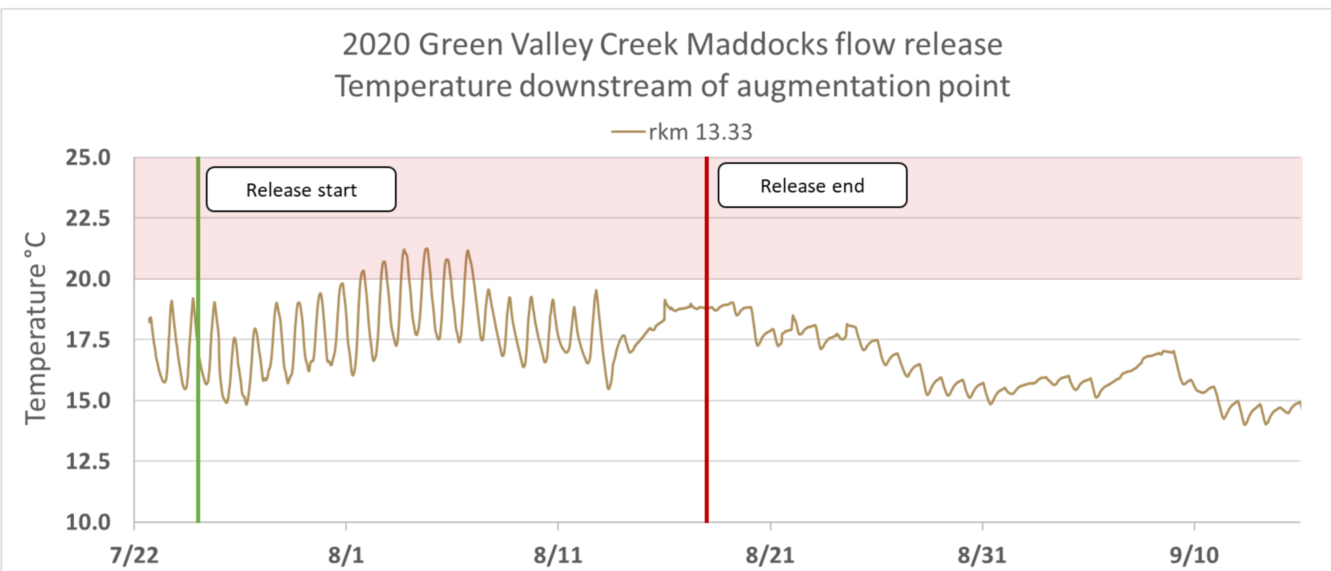

Figure 9. Water temperature at rkm 13.33, 10 m downstream of the Maddocks release site in Green Valley Creek, 2020. Temperature threshold values above 20°C are indicated by red background shading. The start and end dates for the release are marked by green and red vertical lines, respectively.

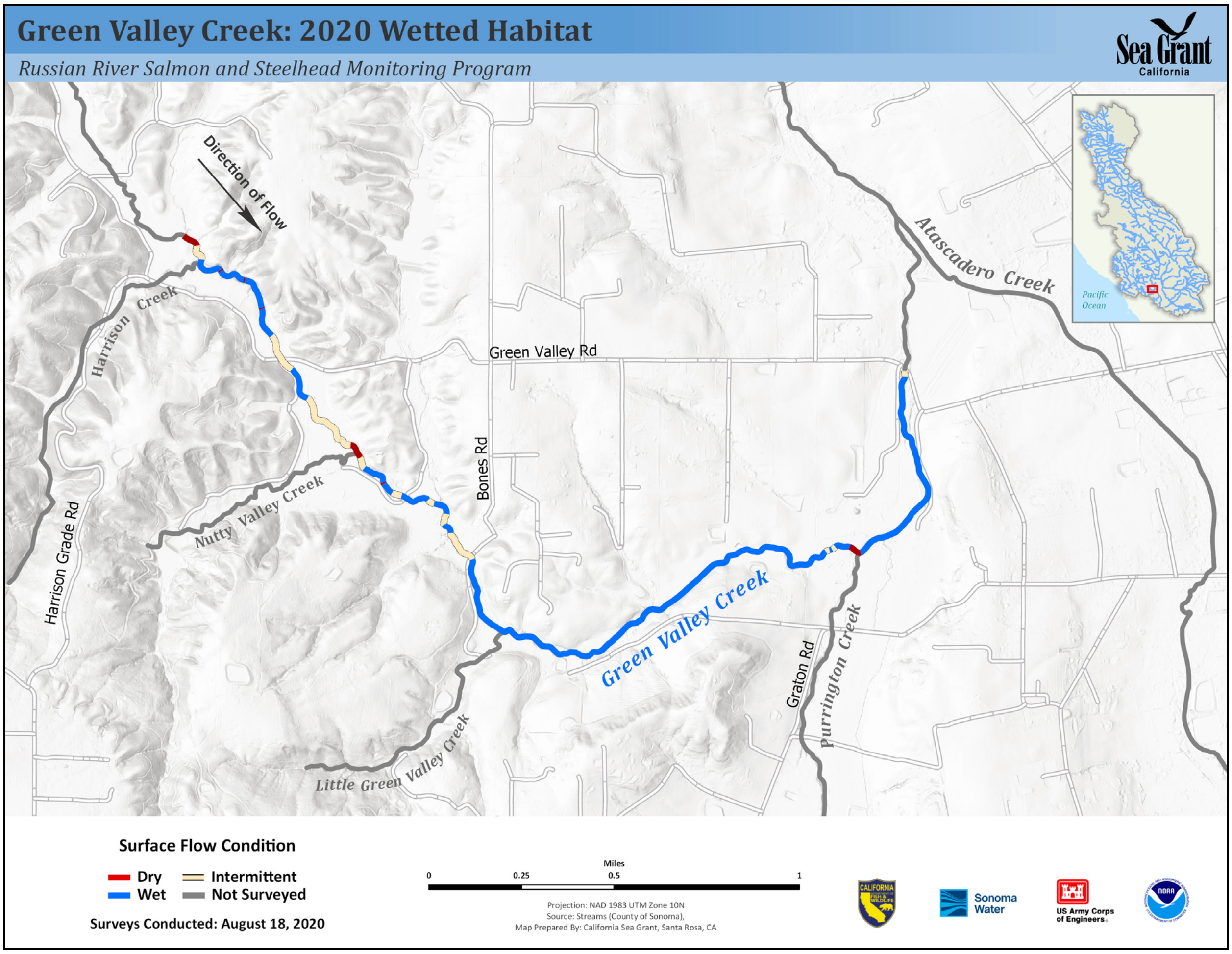

Figure 10. Wetted habitat conditions in Green Valley Creek on August 18, 2020, the first survey of the dry season.

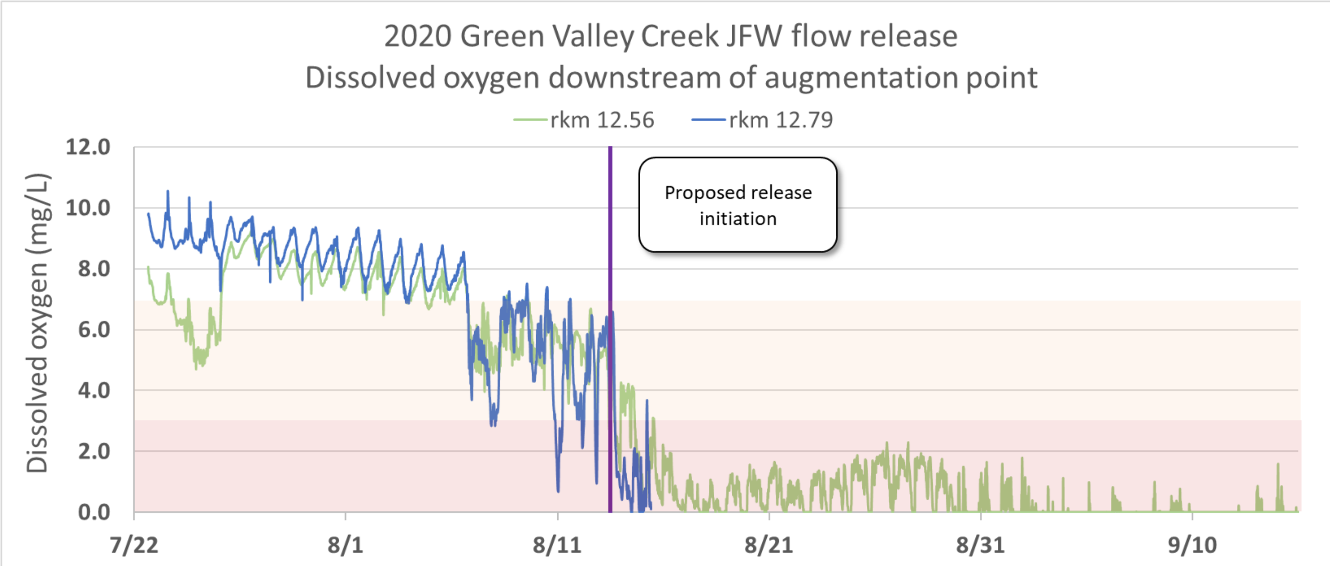

Figure 11. DO concentrations at rkm 12.79 (blue line), 200 m downstream of the JFW release site, and rkm 12.56 (green line), approximately 430 m downstream in Green Valley Creek, 2020. Threshold DO concentrations are indicated with background shading, with values <3.0 mg/L indicated in red and values between this lower threshold and 7.0 mg/L indicated in tan. The proposed (but failed) initiation of flow release is marked by the purple vertical line.

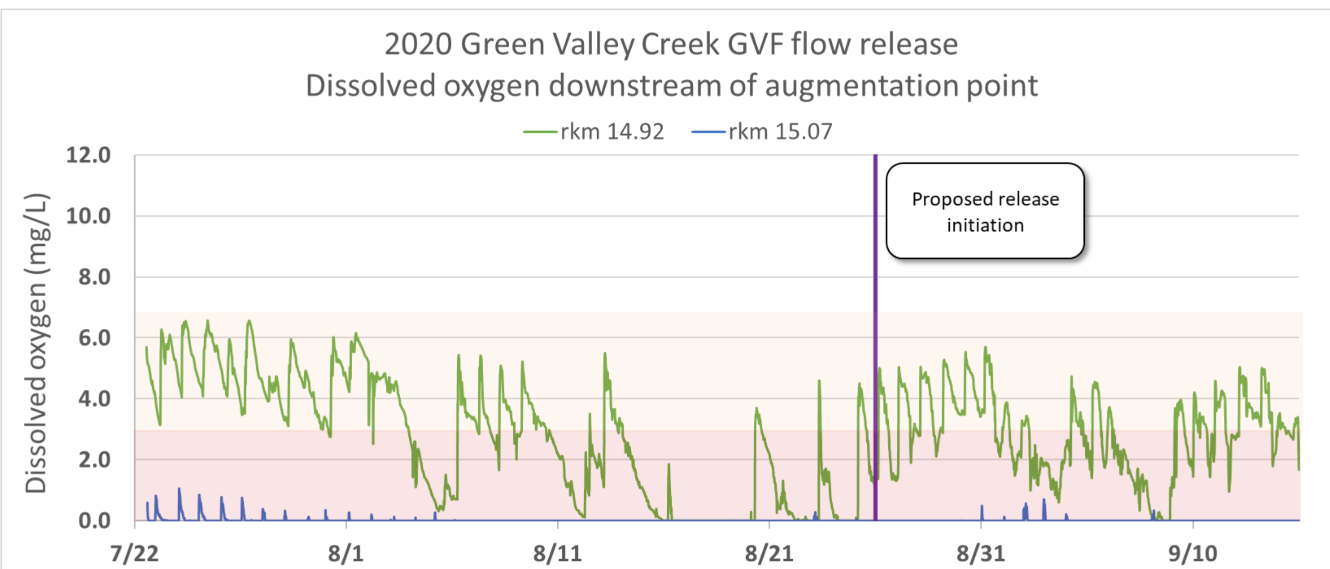

Figure 12. DO concentrations at rkm 15.07 (blue line), 630 m downstream of the GVF release site, and rkm 14.92 (green line), 780 m downstream, in Green Valley Creek, 2020. Threshold DO concentrations are indicated with background shading, with values <3.0 mg/L indicated in red and values between this lower threshold and 7.0 mg/L indicated in tan. The proposed (but failed) initiation of flow release is marked by the purple vertical line.

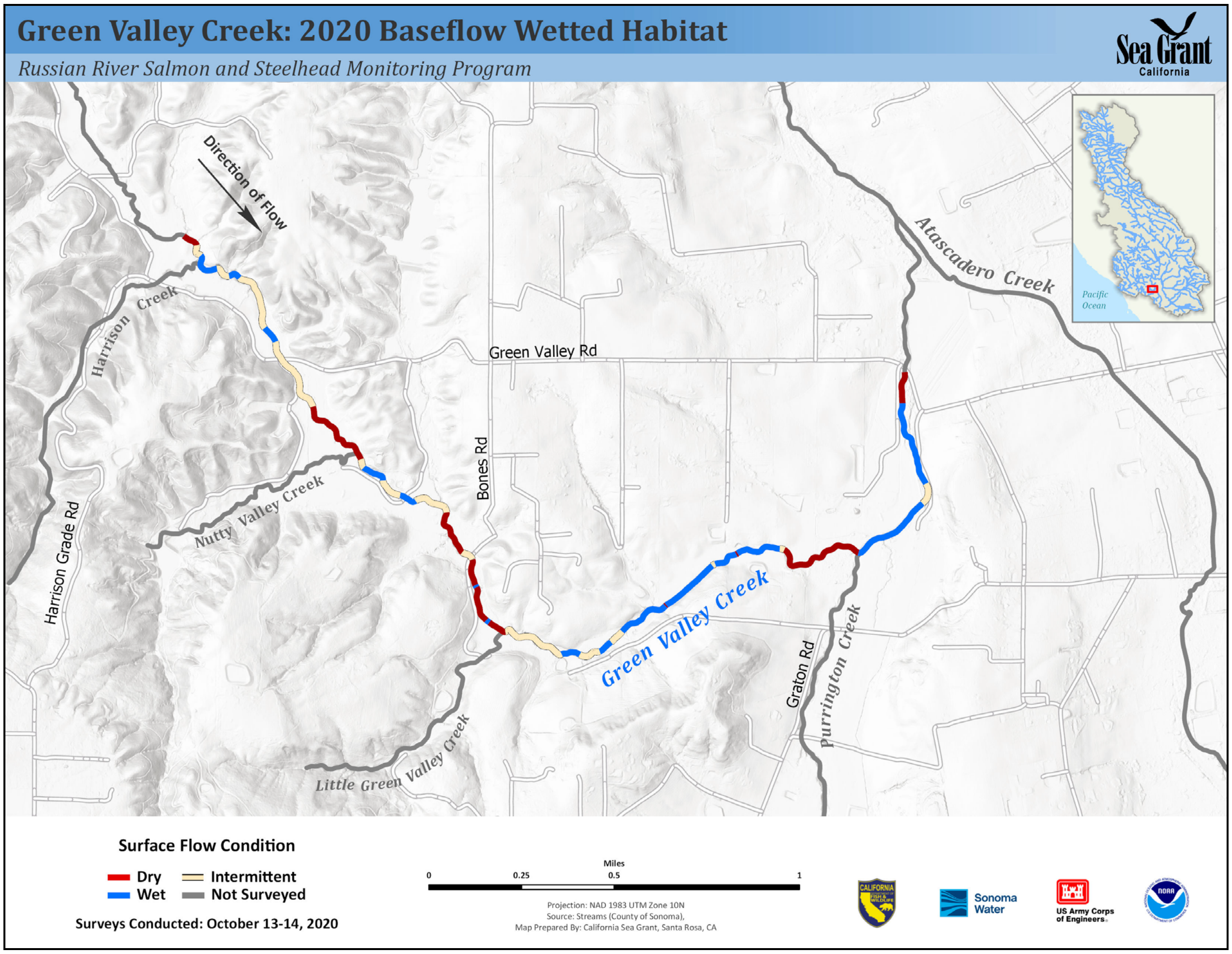

Figure 13. Wetted habitat conditions in Green Valley Creek on October 13-14, 2020, the last survey of the dry season.

3.4. Discussion

The combination of early stream drying and the estimated number of juvenile salmonids located downstream of the release sites indicated that these flow augmentations were warranted. In past years, the JFW release has increased stream flow at a gage site more than 800 m downstream of the augmentation site, with a similar rate and method of release. These three augmentation efforts were anticipated to provide relief for thousands of juvenile salmonids, as well as other native fish species present throughout the stream, during a drier-than-average year.

The 2020 release from the Maddocks property is by far the largest flow augmentation attempted on Green Valley Creek. With an average release rate of 1.59 ft^3/s and a range of 0.5-1.9 ft^3/s over the release period, the Maddocks release had immense potential as a beneficial streamflow augmentation for a very large portion of the surveyed stream. Anecdotal observations made by CSG biologists indicated that the stream reconnected at a PIT antenna array approximately 7 rkm downstream from the augmentation site. According to the streamflow records at the two downstream gage sites, this release was the only reason there was any flow in Green Valley Creek in late July and early August.

It is difficult to evaluate the timing of this release based on the results of the water quality monitoring. Due to COVID-19 restrictions, the environmental loggers were deployed too late to record much of the pre-release conditions, though DO was visibly decreasing during the few monitored days leading up to release initiation. When compared to the monitoring site upstream of the release, it is clear that the Maddocks release had an immediate beneficial impact on DO, which increased to favorable concentrations well above 7.0 mg/L until the release was scaled back during the first week of August.

According to the streamflow records for the gage at the Bones Road crossing, daily average streamflow dropped below 0.10 ft^3/s on June 20th. Based on this information and the few days of pre-release DO data available, the timing seems appropriate, but an earlier start could have likely kept the streamflow at the gage sites from reaching zero flow in June. During the August wetted habitat survey, after the augmentation had started, the reach between the release site and the confluence with Little Green Valley Creek was completely connected, unlike the stream conditions upstream of the release site.

High water temperatures, a concern for all releases from small off-channel storage ponds, caused stream water temperature to rise to unsuitable levels for rearing salmonids and lead to the early termination of this release. As the release rate was scaled back, both the dissolved oxygen concentrations and water temperature decreased.

We think that the timing for the planned JFW flow release was appropriate; had the augmentation water made it to the creek as planned, it likely would have had a beneficial impact to streamflow, surface water connectivity, and water quality, as it had in previous dry years like 2015 and 2016. Similar equipment failures kept this same augmentation effort from success in 2018, which reinforces the delicate nature of these small-scale releases.

Water from the GVF release did not make it to the monitored pool at rkm 14.92, as it had in previous years. It is possible that this small amount of water, a mere 0.03 ft^3/s, could not compete with the excessively dry conditions experienced in summer 2020. While small scale augmentations have been shown to be effective in dry years, it appears there is a threshold of limitation where there is too little water in both the stream and the storage pond to keep the creek flowing despite best efforts.

3.5. Conclusion

The 2020 water year was generally dry for most of Northern California and was the third-driest year on record for the Russian River watershed (California Department of Water Resources 2020). Small-scale flow augmentations have proven themselves useful in a variety of water year types when timed and implemented properly (Nossaman Pierce et al. 2020), and it was logical to attempt them in the summer of 2020. However, despite the experience and careful planning of resource management agencies and partners, the releases for this year had limited success in improving streamflow, surface flow connectivity, and water quality conditions.

The summer of 2020 demonstrated the pitfalls of these small, short-term, and opportunistic instream flow augmentations. Equipment failure and lack of resources to find in-season solutions, which was exacerbated by fieldwork restrictions due to COVID-19, kept two of the three releases from even occurring despite success in prior dry seasons. The newest and largest release was initially beneficial, yet ran into temperature issues that shut it down completely. It was an opportunistic release, available because the pond had to be drained for maintenance, and it is unclear whether or not this will be available as a consistent release source in the future.

It is becoming clearer and clearer that these small-scale flow augmentations may not be the solution to stream drying driven by a worsening climate. They are a stopgap measure that can largely improve water quality, but only when all factors such as planning, equipment implementation, and timing, come together. Even after infrastructure improvements to the JFW and GVF releases in past years, when the streams were at their driest, we were unable to effectively deliver water to the channel and improve streamflow. As the streams dry earlier and earlier in the season, as they did in 2020, it’s logical to initiate the releases earlier as well; however, due to the limited amount of water available, it’s an unsustainable practice that would leave resources short in the later part of the season.

Salmon bearing tributaries of the Russian River basin are fighting an uphill battle, even where we have the means to improve summer streamflow by releasing water from controlled sources under the direction of experts. Green Valley Creek represents only one stream within a basin that drains more than 1,400 square miles and it is clear that we have reached limits of this tool. Until underlying streamflow issues are addressed and improved, small-scale flow augmentations such as these will need to be evaluated on a case-by-case basis, where resource availability, effectiveness, in-stream conditions, and logistics such as equipment and permitting needs will continue to pose challenges in our worsening climate.

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