Addendum to the Upper Green Valley Creek Streamflow Improvement Plan

Salmonids and Flow-Related Habitat Impacts

Prepared for

The National Fish and Wildlife Foundation

Prepared by

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The Russian River Coho Water Resources Partnership

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1 Introduction

This addendum report compliments the *Upper Green Valley Creek Streamflow Improvement Plan* (SIP) (RRCWRP 2019; http://cohopartnership.org/sips/) by providing more detailed information for *Section 4: Salmonids and flow-related habitat impacts*. It includes a summary of the history of salmonids in the Russian River basin, historical and recent presence within the Green Valley Creek watershed, and outcomes of investigations into the impacts of insufficient streamflow on fish and their habitat. While the historical information encompasses the entire watershed, the focus of recent fish and habitat monitoring has generally been on the upper portion of the watershed, above the confluence with Atascadero Creek, where the optimal coho spawning and rearing habitat within the basin occur (Figure 1).

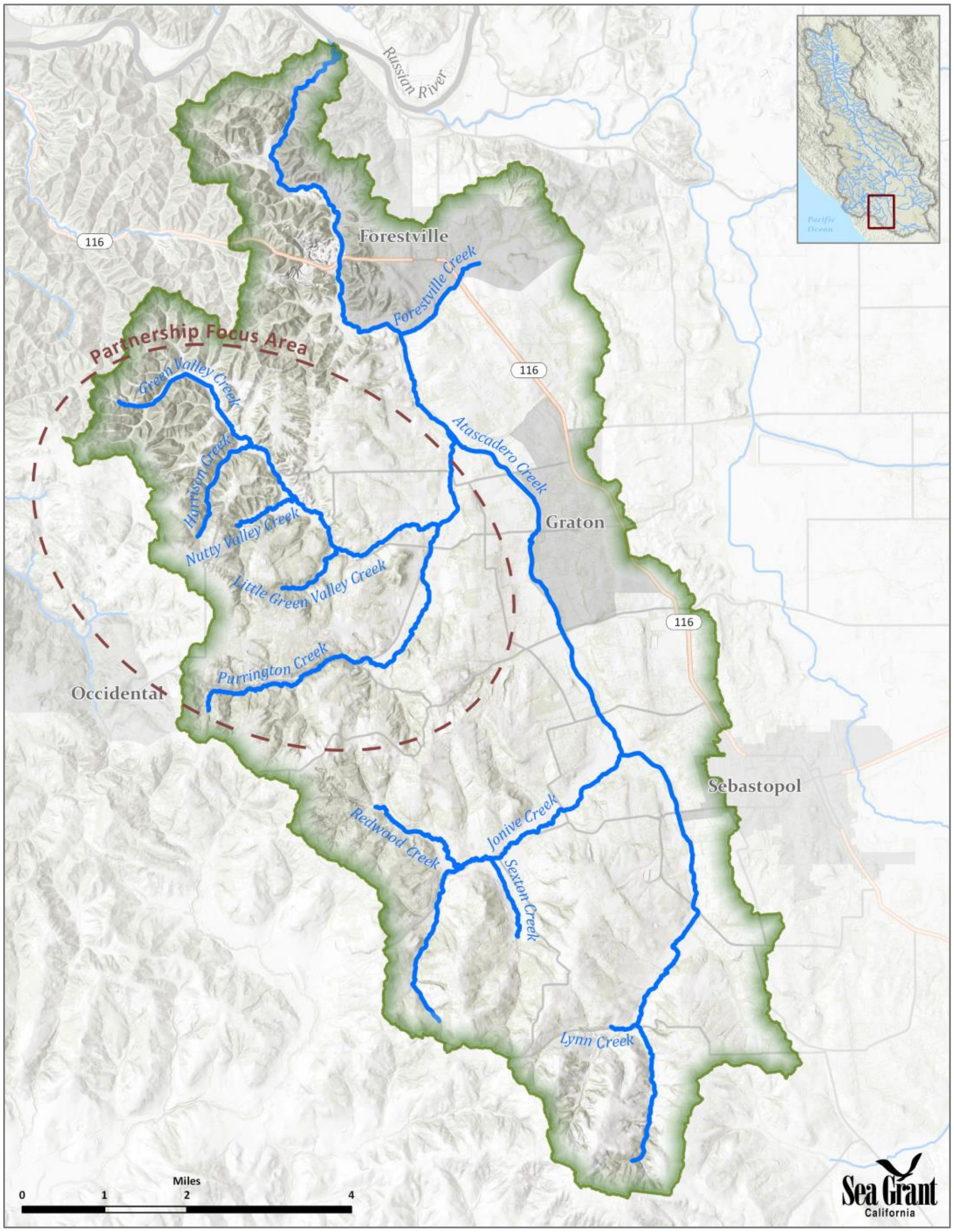

Figure 1. Focus Area within the Green Valley Creek watershed.

2 Historical salmonid presence

The Russian River watershed historically supported native runs of anadromous coho salmon (*Oncorhynchus kisutch*) and pink salmon (*O. gorbuscha*), as well as steelhead trout (*O. mykiss*) (Steiner 1996). Due to a lack of historical survey records, it is unknown whether Chinook salmon (*O. tshawytscha*) were present in the Russian River prior to the first release of hatchery fish in 1881 (Chase et al. 2007), however, a self-sustaining population of Chinook currently exists today.[1] Russian River coho salmon populations were once abundant enough to support a commercial fishery, and Russian River steelhead formed the basis of a highly-prized game fishery that attracted anglers from around the world until the 1950s (Steiner 1996).

The CCC Evolutionarily Significant Unit (ESU) of coho salmon—which extends from Punta Gorda in southern coastal Humboldt County south to Aptos Creek in Santa Cruz County, and includes the Russian River population—was estimated to have numbered in the tens of thousands as recently as the early 20th century (Steiner 1996), and the Russian River had the largest coho salmon population within this ESU (NMFS 2012). All native salmonid populations in the Russian River watershed experienced steep declines for more than a century, with records of significant decreases stemming back to the 1880s (Steiner 1996). Pink salmon are now extirpated from the watershed, coho salmon are listed as endangered under the state and federal Endangered Species Acts (ESA), and Chinook salmon and steelhead are listed as threatened under the federal ESA.

Although no formal or consistent salmonid monitoring effort existed in the Russian River watershed historically, evidence from opportunistic surveys indicates a clear decline in coho populations, which has been especially rapid in recent decades and has pushed CCC coho to the brink of extinction. The number of coho salmon smolts migrating to the ocean from the Russian River system is estimated to have declined by 85% between 1975 and 1991 (NMFS 2012).

By the time coho salmon became the focus of local resource agencies in the mid-1990s, numbers had dwindled to the point of near-collapse throughout the Russian River watershed. Extensive surveys by CDFW in the early 2000s found coho salmon to be present in extremely low numbers in only five of 39 confirmed[2] historical coho streams within the basin, and Green Valley Creek was the only stream with three consecutive year classes (Conrad 2005, Spence et al. 2005). Among those, Green Valley Creek was the only stream with three consecutive year classes (Conrad 2005, Spence et al. 2005), which highlights the ecological and genetic importance of Green Valley Creek as a stronghold for Russian River coho salmon.

[1] http://www.Water Agency.ca.gov/chinook/

[2] Number of streams with coho “presence confirmed” or “high likelihood of presence,” as defined in Spence et al. (2005). Another 11 streams were deemed as having “equivocal” or “unsupported evidence of presence.”

Surveys conducted intermittently by CDFW in the Green Valley watershed prior to 2005 indicate presence of both coho salmon and steelhead (CDFW 2000a, CDFW 2000b, CDFW 2000c). In May 1966, during the earliest complete survey of Green Valley Creek on record, coho salmon were observed throughout the entirety of the stream (CDFW 2000b). Several coho were observed during a 1993 survey and a handful were counted again in 1995 (CDFW 2000b). Coho salmon presence was also confirmed in Purrington Creek in 1969 and in 1994 (CDFW 2000c).

More comprehensive coho salmon monitoring efforts began in Green Valley Creek in 2001, with a focus on the higher-quality spawning and rearing habitat upstream of the confluence with Atascadero Creek. Coho salmon were documented in Green Valley Creek each year from 2001 through 2004, though by 2004 fewer than 10 individuals were observed (Conrad 2005, Conrad et al. 2005). The last wild coho salmon documented in the Green Valley Creek watershed, prior to population supplementation in 2006, were from the 2004 hatch year (Conrad et al. 2005, Obedzinski et al. 2006).

Steelhead have been observed in Green Valley Creek and all of its major tributaries (Atascadero, Purrington, and Harrison creeks) in all years where records exist (CDFW 2000a, CDFW 2000b, CDFW 2000c, CA Sea Grant unpublished data).

3 Coho Salmon Captive Broodstock Program

In the late 1990s, in response to the decline of Russian River salmonid populations, private landowners, organizations, and agencies engaged in efforts to conserve and enhance critical salmonid habitat within the Russian River watershed, but that effort in itself was not enough. In 2001, with Russian River coho salmon populations on the brink of extinction, a collaborative effort was formed to restore self-sustaining runs of native coho salmon within the watershed using a conservation hatchery approach. The Russian River Coho Salmon Captive Broodstock Program (Coho Program) was formed, representing a broad partnership involving CDFW, NMFS, U.S. Army Corps of Engineers (ACOE), Sonoma Water, CSG, and hundreds of private landowners. Coho Program partners carefully capture wild juvenile coho from Russian River tributaries, rear them to adulthood at the Don Clausen Fish Hatchery at Warm Springs Dam, spawn them according to a matrix that maximizes genetic diversity, and release the juvenile offspring into selected tributary streams.

Between 2001 and 2005, Coho Program partners captured the first coho salmon broodstock from remnant wild populations in a total of five Russian River tributaries (Table 1) and began releasing the offspring of these fish as juveniles into designated streams in October of 2004 (Conrad 2005, CDFW and ACOE 2017). During the first five years of broodstock collection, a total of 739 juvenile coho salmon were collected from Green Valley Creek—85% of all broodstock collected from Russian River tributaries for the Coho Program during that time period (Table 1) (Conrad 2005, Conrad et al. 2005, CDFW and ACOE 2017). This highlights the ecological and genetic importance of Green Valley Creek as a stronghold for Russian River coho salmon. Without the remnant populations that persisted in Green Valley Creek into the early 2000s, there would not have been a sufficient source of native broodstock within the Russian River watershed to support the Coho Program effort and, given the fact that coho numbers were well below the depensation threshold at that time, it is highly likely that Russian River coho salmon would have become extinct.

Juvenile coho salmon were released into Green Valley Creek in 2006, after no wild fish were observed in 2005, and it has been stocked each year since (Table 2) (CDFW and ACOE 2017, Ben White, ACOE, unpublished data). A total of 182,468 juvenile coho salmon from the Coho Program were planted into Green Valley Creek between 2006 and 2018. An additional 21,285 fish were planted in Purrington Creek from 2010 to 2017, and 3,041 fish were planted into Redwood Creek in 2017, for a total of more than 200,000 in all (Table 2). Since 2006, releases into the Green Valley watershed have averaged approximately 13% of all annual releases into Russian River tributaries, ranging from 9% to 21% when grouped by hatch year (Ben White, ACOE, unpublished data).

Table 1. Total number of wild juvenile coho salmon collected for Coho Program broodstock in all Russian River streams, years 2001 to 2005.

	Hatch year				
Capture stream	**2001**	**2002**	**2003**	**2004**	**2005**
Green Valley Creek	190	234	308	7	0
Dutch Bill Creek	0	78	0	0	37
Mark West Creek	4	0	0	0	0
Mill Creek[1]	0	0	0	0	13
Redwood Creek	1	0	0	0	0
TOTAL	**195**	**312**	**308**	**7**	**50**

[1] *Collected in Mill Creek, but believed to have originated in Felta Creek.*

Table 2. Number of juvenile coho salmon stocked into Green Valley Creek and tributaries by the Coho Program from 2006 to spring 2018 (Ben White, ACOE, unpublished data).

Stream	Hatch year	Release year(s)	Total released
Green Valley Creek	2006	2006	4,278
	2007	2007	7,883
	2008	2008/09	12,873
	2009	2009/10	8,295
	2010	2010/11	13,425
	2011	2011/12	15,284
	2012	2012/13	16,985
	2013	2013/14	13,576
	2014	2014/15	31,995
	2015	2015/16	14,158
	2016	2016/17	21,127
	2017	2017/18	22,589
Purrington Creek	2010	2010	1,018
	2011	2011	3,079
	2012	2012	3,004
	2013	2013	3,041
	2014	2014	5,012
	2016	2016	3,090
	2017	2017	3,041
Redwood Creek (Atascadero)	2017	2017	3,041
TOTAL			**206,794**

4 Programmatic salmon and steelhead monitoring

CSG's Russian River Salmon and Steelhead Monitoring Program conducts ongoing monitoring of salmonid populations in tributaries to the lower Russian River, including Green Valley Creek, in order to evaluate the effectiveness of the Coho Program and to apply advances in scientific knowledge to its management. CSG and Sonoma Water are also working to document the abundance, survival, and distribution of native salmonids throughout the Russian River basin over time, as part of the statewide California Coastal Monitoring Program (CMP). Through these programs, both wild and hatchery stocks of Green Valley Creek coho salmon have been monitored since 2005. Incidental documentation of steelhead occurred throughout the early years of CSG's monitoring, with more intensive and standardized quantitative CMP steelhead monitoring beginning in 2013. Efforts are focused on the reaches upstream of the Atascadero Creek confluence, where the optimal spawning and rearing habitat occur t (Figure 2) (GRRCD 2014).

Coho and steelhead populations within the watershed are monitored year-round using a combination of methods in order to track fish at different life stages. Snorkeling surveys are conducted during the summer months to document the presence and relative abundance of wild juveniles, a smolt trap is operated on the mainstem of Green Valley Creek during the spring season to estimate coho smolt outmigration, and spawner surveys are conducted throughout the winter months to document adult salmon and steelhead returns.

In addition, since 2014, CSG biologists have maintained a paired, flat-plate Passive Integrated Transponder (PIT) tag antenna array approximately six kilometers upstream of the mouth of Green Valley Creek to track the movement and survival of PIT-tagged program coho salmon at all life stages (furthest downstream antenna, Figure 2). Additional year-round antennas have been operated in the middle reach of Green Valley Creek, upstream of Atascadero Creek, and below Harrison Creek since 2014 and 2010, respectively (Figure 2).

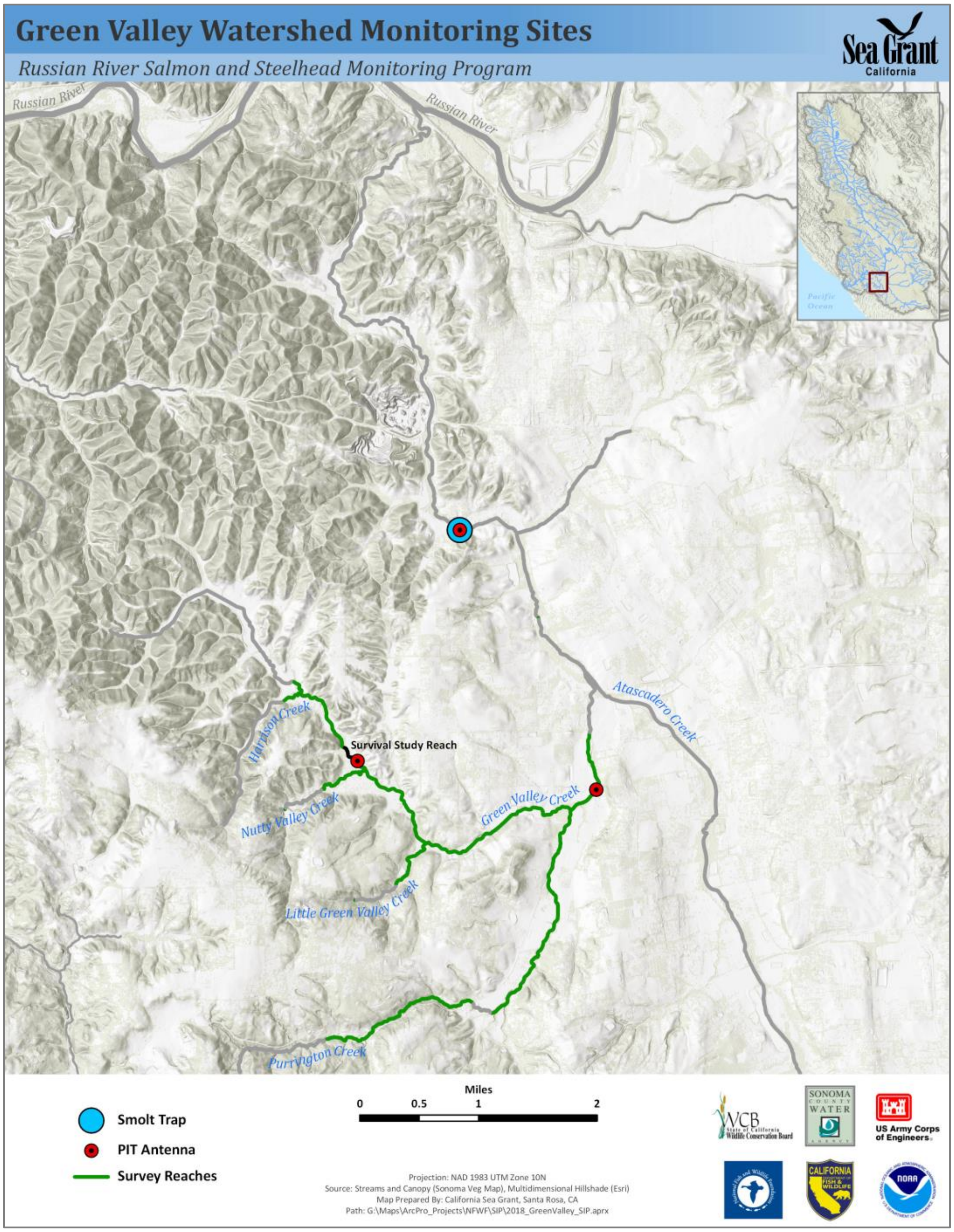

Figure 2. CSG's stationary fish monitoring sites and survey reaches in the Green Valley Creek watershed. Includes year-round PIT tag antenna arrays and the downstream migrant smolt trap operated each spring. Survey reaches, shown in green, receive routine biological and environmental sampling.

4.1 Natural production

Each summer (June-August), CSG and Sonoma Water conduct snorkeling surveys in the Green Valley Creek watershed to document the presence and relative abundance of wild juvenile coho salmon. Presence of more than 10 coho young-of-year (yoy) provides evidence that successful spawning of adults likely occurred the previous winter. Summer juvenile surveys have occurred in Green Valley Creek since 2005, Purrington Creek since 2010, and Harrison Creek since 2014. In 2015, efforts were expanded to include sections of the smaller tributaries, Little Green Valley and Nutty Valley creeks (Figure 2). In addition, a small number of pools were opportunistically snorkeled in two tributaries to Atascadero Creek in recent years; Jonive Creek was snorkeled in 2015 and Redwood Creek in 2015, 2016, and 2017. No coho were observed in those streams; however, as the sample sites represent only a small proportion of the available fish habitat in these streams, this is not definitive evidence of salmon presence or absence. CSG is continuing efforts to gain access to the Atascadero Creek system in order to facilitate future surveys.

After the 2004 broodstock collection, naturally-spawned coho yoy were not observed in Green Valley Creek until 2010—four years after the Coho Program began planting fish there (Table 2, Table 3). Since that time, the count of wild coho salmon yoy in Green Valley Creek has ranged from 13 to 4,487, and lower numbers of coho have also been observed in sampled tributaries (Table 3; see caption for count methods). The low number of coho observed in 2014 is likely explained by drought conditions during the winter of 2013/14 that prevented adult coho from accessing the stream until early February, after the peak salmon spawning months of December and January.

Steelhead were observed in Green Valley Creek and all streams snorkeled within the watershed each year but standardized count data were not collected until CMP monitoring began in 2013 (CA Sea Grant unpublished data). Steelhead observations in Green Valley Creek from 2013 through 2018 ranged from 786 to 2,086 fish (Table 4; see caption for count methods).

Table 3. Wild coho salmon yoy observed during CSG and Sonoma Water presence/absence snorkel surveys in the Green Valley Creek watershed. Methods and extent of stream sampled varied between years. Prior to 2013, every pool within a reach was snorkeled and numbers represent total number of observations. Beginning in 2013, every second pool was snorkeled, and numbers were doubled to generate an expanded count.

Year	Green Valley	Purrington	Little Green Valley	Nutty Valley	Harrison
2005	0	n/a	n/a	n/a	n/a
2006	0	n/a	n/a	n/a	n/a
2007	0	n/a	n/a	n/a	n/a
2008	0	n/a	n/a	n/a	n/a
2009	0	n/a	n/a	n/a	n/a
2010	170	0	n/a	n/a	n/a
2011	1,483	0	n/a	n/a	n/a
2012	1,486	0	n/a	n/a	n/a
2013	4,487 [1]	466	n/a	n/a	n/a
2014	13 [1]	0	n/a	n/a	0
2015	1,975 [1]	280	62	0	0
2016	1,584 [1]	358	16	14	0
2017	3,752	344	102	208	18
2018	1,766	126	24	32	16

[1] Approximately 200 - 500 Coho Program fish were stocked in the spring prior to snorkeling in years 2013 - 2016 (other releases occured after snorkeling was completed). Because hatchery fish could not be distinguished from wild fish in those cases, the number of stocked fish was subtracted from the expanded count, resulting in a conservative estimate of the number of wild juveniles present.

Table 4. Expanded counts of steelhead yoy observed during CSG and Sonoma Water presence/absence snorkel surveys in the Green Valley Creek watershed. Every second pool was snorkeled, and numbers were doubled to generate an expanded count. Though steelhead were observed in all streams sampled each year that surveys were conducted (2005 on), count data were not collected in a standardized manner until 2013.

Year	Green Valley	Purrington	Little Green Valley	Nutty Valley	Harrison
2013	786	578	n/a	n/a	n/a
2014	2,262	1,248	n/a	n/a	20
2015	2,086	104	0	0	0
2016	1,544	834	118	0	0
2017	1,446	964	90	2	0
2018	1,504	1,734	26	4	0

4.2 Smolt abundance and overwinter survival

One of the first steps in evaluating the success of hatchery-released coho salmon and identifying freshwater bottlenecks to survival, is to determine whether coho salmon released in the streams survive through their first winter and migrate out to the ocean as smolts. CSG estimates freshwater survival of hatchery released fish and smolt abundance using data from spring downstream migrant trapping and PIT tag antenna arrays. Smolt estimates are not available for steelhead because steelhead smolts generally migrate from the stream during the winter before traps can be safely installed.

Due to the limited availability of trapping sites, smolt trapping operations on Green Valley Creek have been intermittent, occurring from March to June in 2007, 2010, 2011, and from 2015 through 2018. The estimated number of smolts emigrating from Green Valley Creek in these years has ranged from 1,397 (1,153-1,641) to 23,438 (21,200-25,676). Overwinter survival probabilities of fall-released coho salmon juveniles to the smolt stage in Green Valley Creek ranged from 0.23 (0.13-0.35) in 2014/15 to 0.52 (0.50-0.55) in 2017/18, similar to rates observed in neighboring wild populations in Marin County (Reichmuth et al. 2006, Carlisle et al. 2008).

In general, coho smolts that overwinter in Green Valley Creek are notably larger at outmigration than those observed in other life cycle monitoring streams within the Russian River watershed. The average fork length of smolts leaving Green Valley Creek from 2015-2018 was 121.8 ±12.1 mm (n=12,001). This was over 10% greater in fork length than the average size of smolts passing through the traps on Willow, Dutch Bill, and Mill creeks, collectively (110.8 ± 12.1 mm, n=16,885) during that same period. Higher growth opportunity from winter through early spring in Green Valley Creek may play an important role in recovering robust salmon populations, as survival of salmonids to the adult stage is positively correlated with smolt size (Hayes et. al. 2008, Bennett et. al. 2015).

4.3 Adult returns

Data from spawner surveys (2008/09-2010/11) and PIT tag antennas (2011/12-2017/18) have been used to estimate the number of adult coho salmon returning to Green Valley Creek over the past ten winters, and numbers have generally increased during that time (Figure 3). The distribution of salmon and steelhead redds observed during annual spawner surveys conducted on Green Valley Creek from the winters of 2008/09 through 2017/18, and on Purrington Creek from the winters of 2013/14 through 2017/18, was mapped (Figure 4). While steelhead spawning is generally evenly distributed throughout upper Green Valley Creek, coho spawning has been primarily concentrated in the uppermost reaches of the stream between Little Green Valley and Harrison creeks (Figure 4). Spawning occurs at much lower densities in Purrington Creek, with coho spawning concentrated in the downstream reaches and steelhead spawning concentrated in the higher gradient reaches further upstream (Figure 4).

The number of adult coho salmon returning to Green Valley Creek has increased over the past ten years, peaking at an estimated 162 fish in the winter of 2017/18 (Figure 3). This is reflective of the larger Russian River watershed trend. After nearly two decades of concerted action by stakeholders—including the Coho Program, and coordinated habitat restoration and conservation efforts—the number of coho salmon adults returning to the Russian River basin has increased since 2000. Estimated returns each winter since 2010 have ranged from 192 to 763 fish, with the greatest numbers in 2017/18.

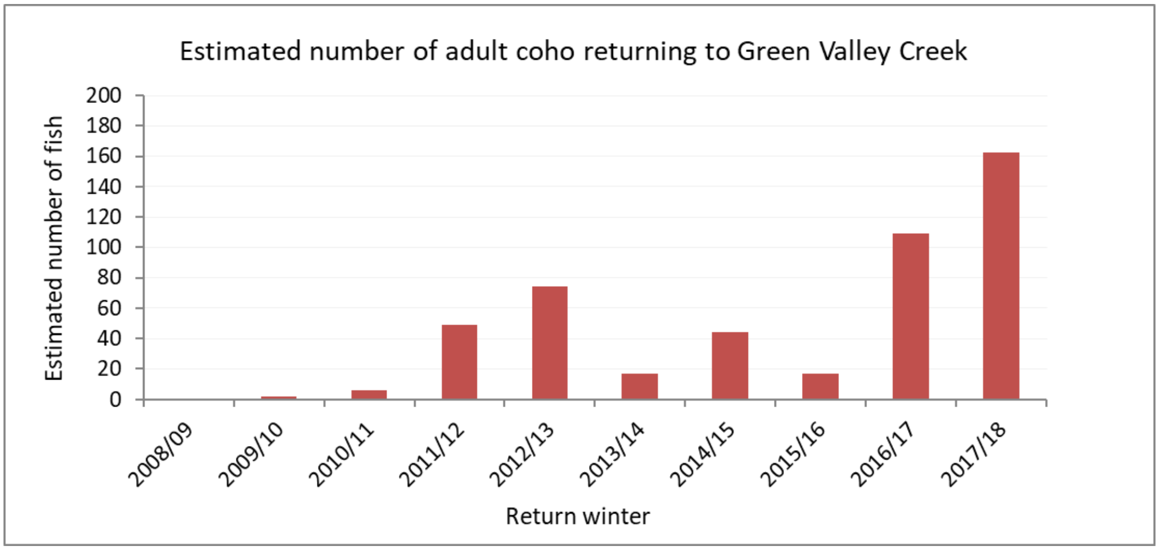

Figure 3. Estimated number of adult coho returning to Green Valley Creek each winter. Numbers from 2008/09 and 2010/11 are based on spawner survey observations, numbers from the following years are derived from PIT tag antenna data. No adult fish or redds were observed during the 2009/2010 spawner surveys, but a minimum count of two adults was included to account for wild coho young-of-the-year observed in the summer of 2010.

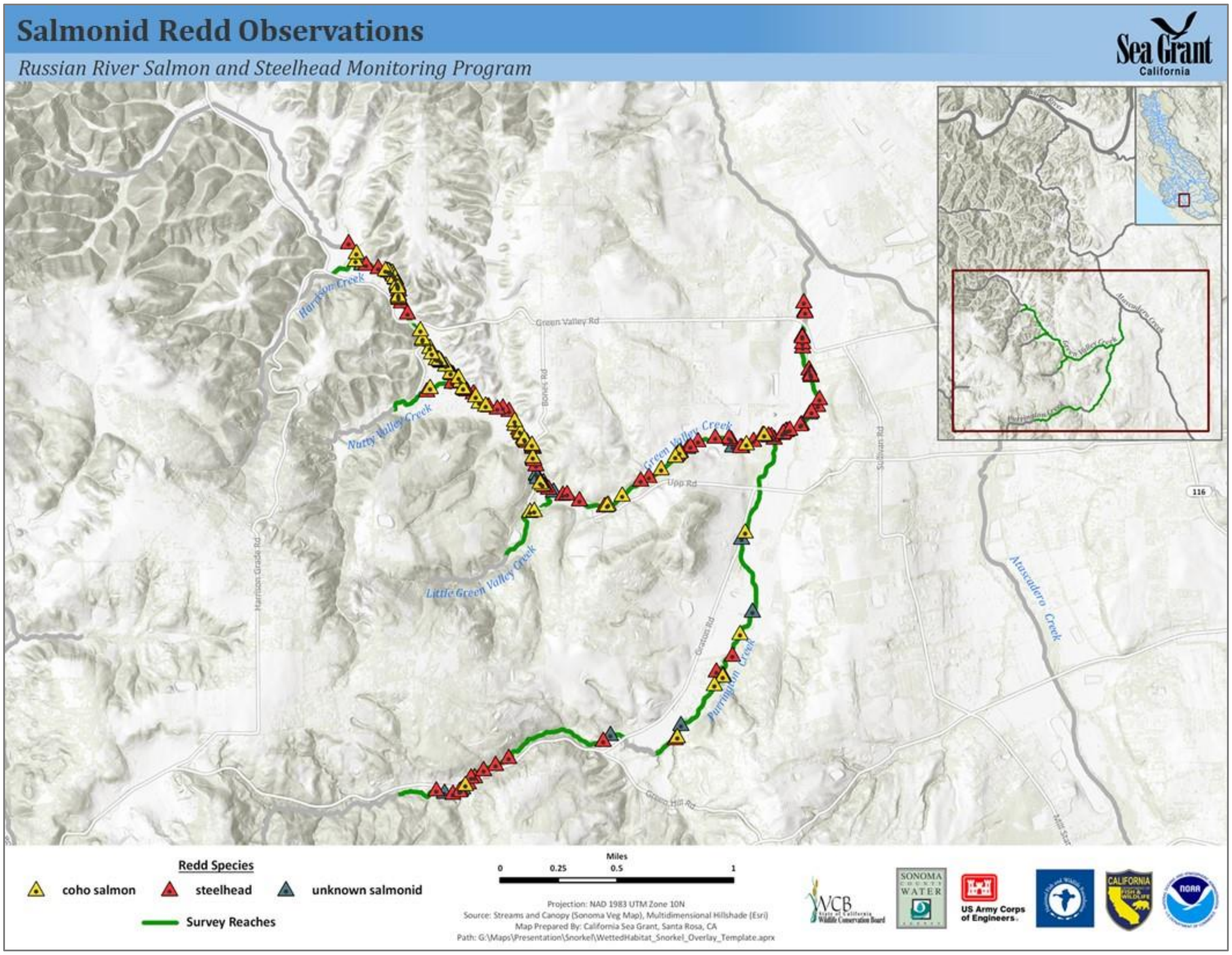

Figure 4. Salmonid redds observed in the upper Green Valley Creek monitoring reaches from winters 2010/11 through 2017/18, and in Purrington Creek from winters 2013/14 through 2017/18. No redds were observed during the first Green Valley Creek spawner surveys in the winters of 2008/09 and 2009/10. The extent of survey reaches varied by year, depending on access to streamside properties.

5 Flow-related bottlenecks to survival

Coho salmon need sufficient streamflow in order to complete their life cycle. During the summer season, juveniles need cool, connected pools in which to rear and grow. As one-year-old smolts, they need sufficient flows through late spring to migrate out of Green Valley Creek, down the Russian River and to the ocean. As adults returning from the ocean at age-2 or age-3, they need sufficient flows to allow migration passage upstream into Green Valley Creek to spawn in the winter, and enough water to submerge their redds and move ample flow through the gravel to oxygenate the eggs during incubation until alevin emerge in the spring. Steelhead have similar freshwater habitat needs, though they have a more flexible life history and may migrate to the ocean and back upstream to spawn at various ages and, in some cases, multiple times. They also spawn later than salmon, making steelhead redd success more vulnerable to low spring flows.

In Green Valley Creek and some of its tributary streams, including Little Green Valley and Nutty Valley creeks, flow limitations have had detrimental impacts on salmonids rearing in the stream over the summer months and, in the driest years, threatened outmigrating smolts. Impacts to juveniles range from mortality caused by stream drying or inadequate water quality, to stress and decreased productivity as a result of sub-optimal habitat. This may have a negative effect on fish condition and survival through later life stages. Anecdotal evidence suggests that late-spring smolt passage in Green Valley Creek has been limited by stream disconnection in recent dry years.

5.1 Summer wetted habitat

As part of an effort to identify flow-impaired reaches of Green Valley Creek, in 2013 CSG began conducting standardized wet/dry mapping surveys to document the wetted habitat available to fish during the driest point each year. Every September, the stream is walked with a GPS unit and spatial data are recorded to characterize the condition of the stream channel as dry, intermittent (wet pools with no surface flow connecting them), or wet (continuous surface flow). The wetted habitat maps show that most of upper Green Valley Creek was intermittent in the relatively dry water year of 2015 (Figure 5), while most of the stream remained wet in 2017, a relatively wet year (Figure 6).

Overall, late-summer wetted habitat conditions in Green Valley Creek between 2013 and 2017 were highly variable. The proportion of wet stream channel ranged from 25% in the driest survey year of 2015, when the majority of the stream was intermittent by July, to 86% in 2016, when only 4% of the channel was dry in September (Figure 7). There was a progressive decrease in the proportion of wet channel each year over the drought years of 2013 to 2015, with notable increases in late-summer wetted habitat availability the following two summers (Figure 7). In all of the other lower Russian River tributaries surveyed, more total wetted stream length was observed in late summer 2017 than in 2016, yet the proportion of wet channel in Green Valley Creek was 9% greater in September 2016 than 2017 (Figure 7). This is likely related to flow releases implemented in August of 2016, and it should be noted that some of the habitat documented as wet on the September 2016 survey date was dry prior to the flow release. In 2017, flow releases did not occur until after, or on, the wetted habitat survey date, so proportions of dry, wet, or intermittent channel reflect natural conditions.

Late-summer wetted habitat conditions in Purrington Creek were remarkably stable and wet over the five-year sample period (Figure 8). Even in the driest sample year of 2015, 95% of the stream channel remained wet and 5% was intermittent, with no portion of the surveyed length drying completely (Figure 8). It should be noted that surveyors did not have access to the entire stream (Figure 5, Figure 6). These outcomes illustrate the importance of Purrington Creek as oversummer habitat refuge for fish within the watershed, as well for flow contributions to the reach of Green Valley Creek downstream of the confluence.

In order to understand the impact of streamflow conditions on coho salmon and steelhead rearing in the stream during the summer months, wetted habitat data were overlaid with snorkeling count data for each survey year. This approach was used to estimate the proportion of fish that were observed in reaches that remained wet through the summer, versus reaches that dried out or became intermittent. At the time snorkeling surveys were conducted, surface flows were already extremely low and riffles were very shallow so it is unlikely that fish had the opportunity to move out of drying reaches into reaches that remained wet. PIT tag antenna data support the fact that almost no movement occurred between July and October of each year (CA Sea Grant unpublished data). We therefore conclude that salmonids observed in reaches that later became dry had no chance of surviving the summer. While continuously wet habitat is generally able to support fish throughout the summer, intermittent pools tend to experience progressive declines in water quantity and quality and so can only support fish for a limited time without increases in streamflow. Therefore, the timing of intermittency is an important factor; the fewer days that pools are disconnected, the greater the probability that fish will survive the summer (Obedzinski et al. 2018).

Distribution and densities of coho and steelhead yoy observed during early-summer (June or July) snorkeling surveys in relation to the wetted habitat conditions that fish experienced in September were significantly different in the drought conditions experienced in 2015 (Figure 9) and the relatively wet year of 2017 (Figure 10). This exercise was completed for all survey years in order to estimate the proportion of juvenile salmonids rearing in Green Valley Creek that experienced dry, wet, or intermittent conditions each summer (Figure 11). The proportion of salmon and steelhead that were observed in reaches that remained wet throughout the summer seasons of 2013 through 2017 varied significantly by year, ranging from just 16% in 2015 to 87% in 2016 (Figure 11). Because a flow release occurred in upper Green Valley Creek in August 2016 prior to the September 2016 wet/dry mapping survey, the impact of drying on fish may not be accurately reflected for that year.

In three of the five sample years, approximately half or more of the fish counted in Green Valley Creek were observed in locations that went completely dry or became intermittent relatively early in the season (Figure 11). These proportions were influenced by the number and distribution of spawning adults the previous winter—in other words, if during the previous winter adults spawned in reaches that became dry in late summer, a higher proportion of juveniles were found in those reaches (Obedzinski et al. 2016, CA Sea Grant unpublished data). Patterns in salmonid observations in relation to wetted habitat condition generally followed patterns in overall proportions of wetted habitat, indicating that salmonid juveniles were fairly evenly distributed throughout the stream channel, with the exception of 2013 when rearing salmon and steelhead were more densely concentrated in intermittent stream reaches (Figure 7, Figure 11). During the drought years of 2013 to 2015, intermittency occurred early in the summer season, so it is likely that there were high fish mortality rates in intermittent pools. These data indicate that low streamflow is a significant contributor to juvenile salmonid survival during the summer rearing season.

Due to the high proportion of late-summer available wetted habitat over the years, Purrington Creek provided critical refuge for juvenile salmon and steelhead rearing in the stream. Even in the driest survey year of 2015, 98% of salmonid yoy observed during early summer snorkel surveys were in reaches that remained wet through the end of the dry season, and in every other survey year between 2013 and 2017, 100% of the fish counted during snorkel surveys were in locations with perennial surface flow (Figure 12).

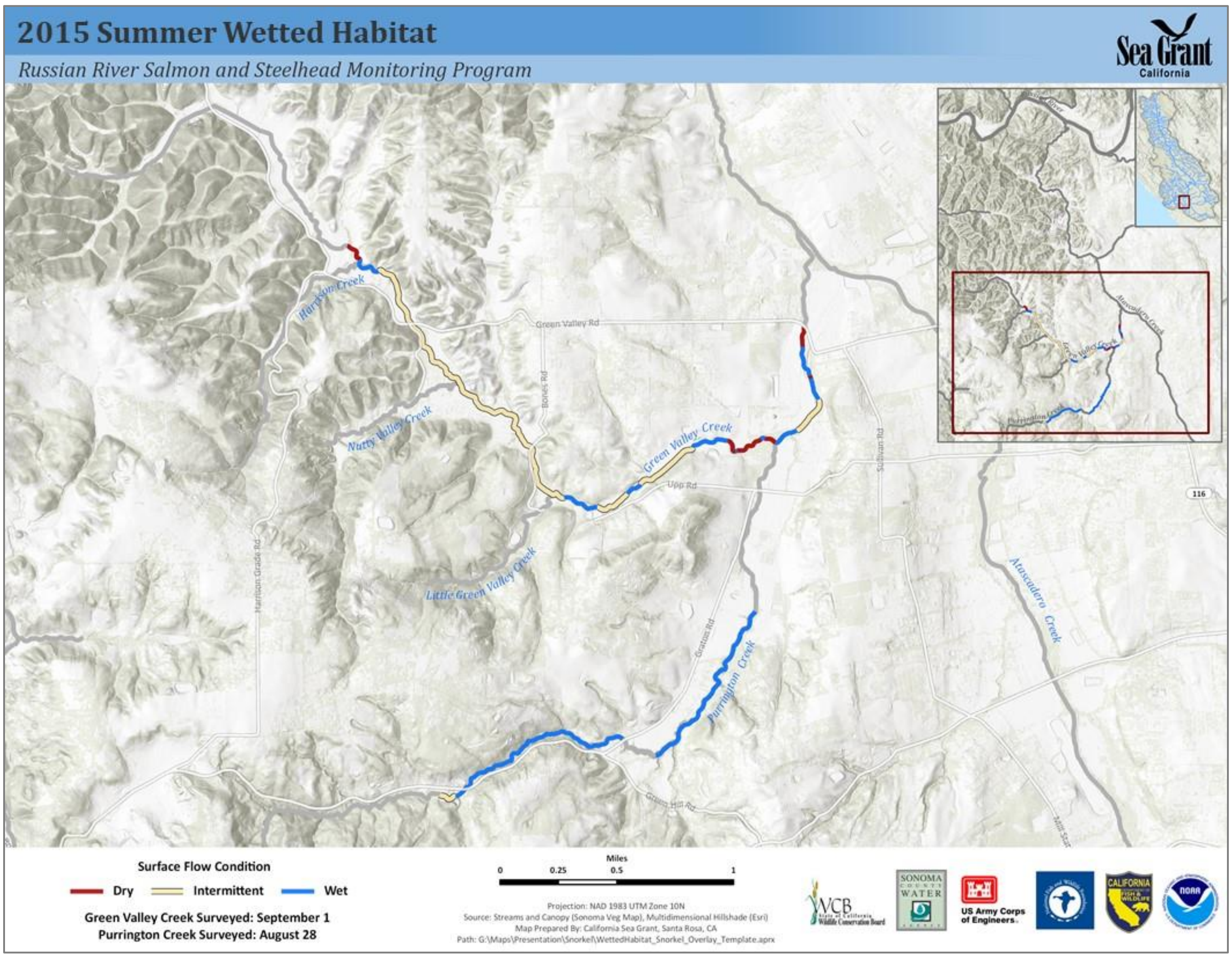

Figure 5. Map of late-summer wetted habitat conditions in Green Valley and Purrington creeks, September 2015.

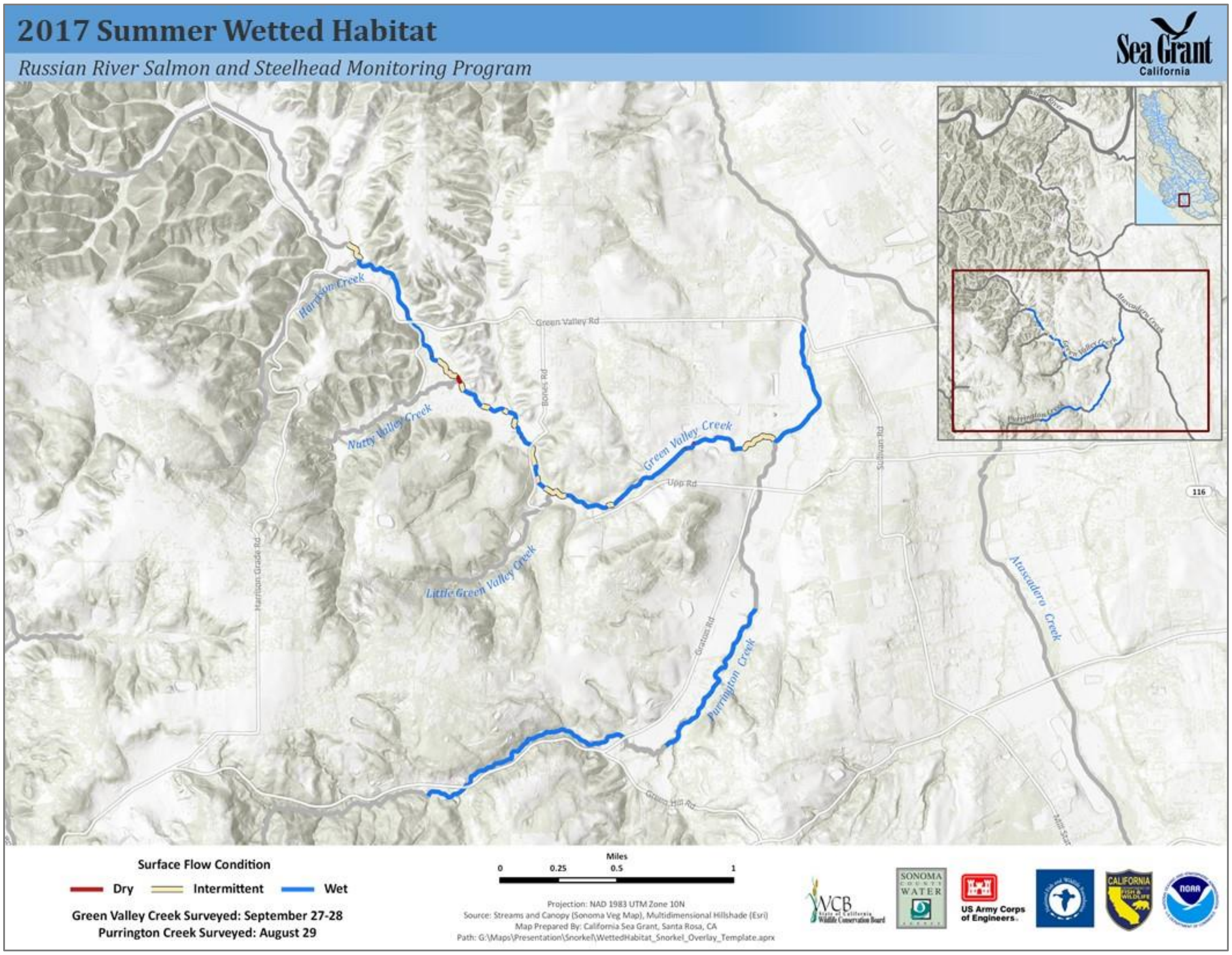

Figure 6. Map of late-summer wetted habitat conditions in Green Valley and Purrington creeks, September 2017.

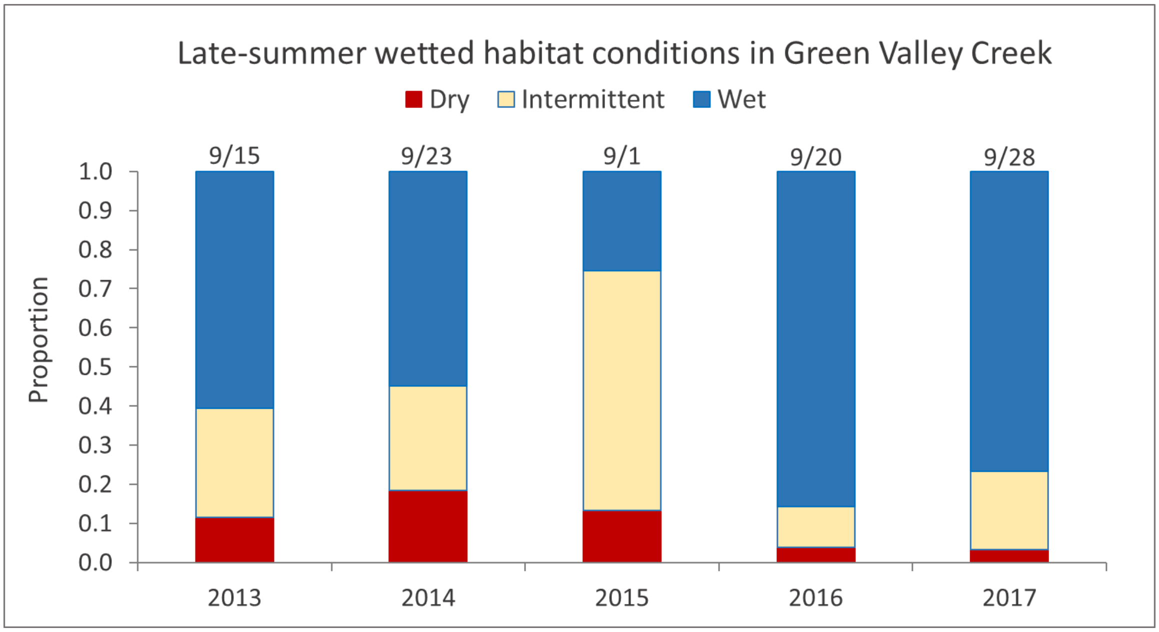

Figure 7. Proportion of dry, intermittent, and wet habitat in Green Valley Creek on September survey dates, Years 2013-2017. Only sections of stream sampled in all years were included in calculations. Years 2015 and 2016 include effects of flow releases implemented prior to the sample date.

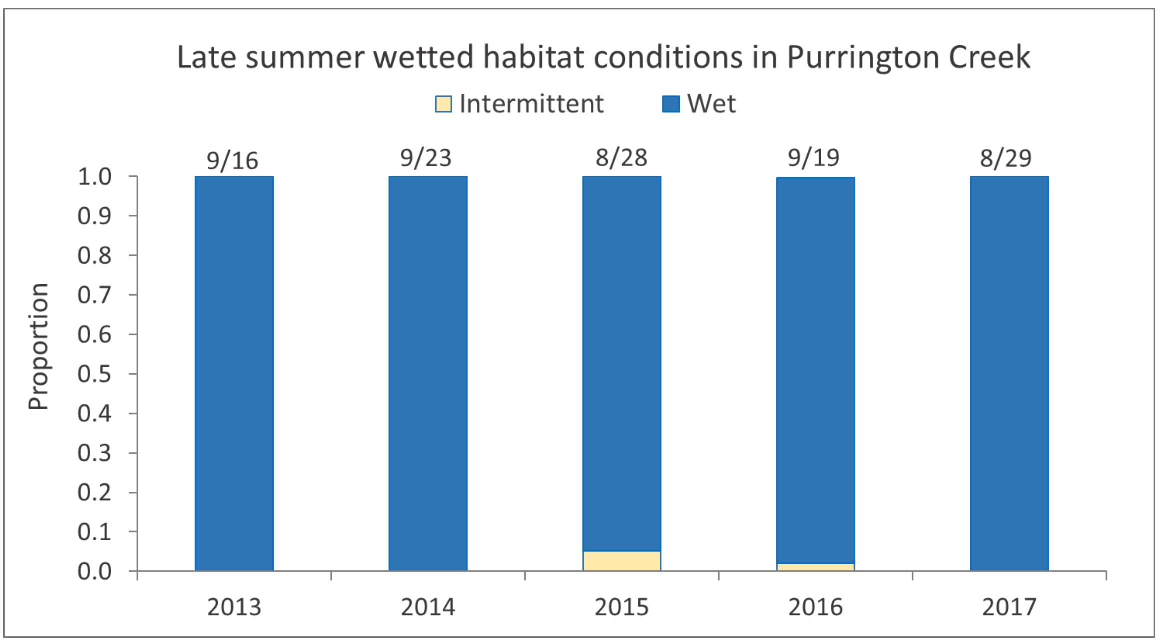

Figure 8. Proportion of dry, intermittent, and wet habitat in Purrington Creek on September survey dates, years 2013-2017. Only segments of stream sampled in all years were included in calculations.

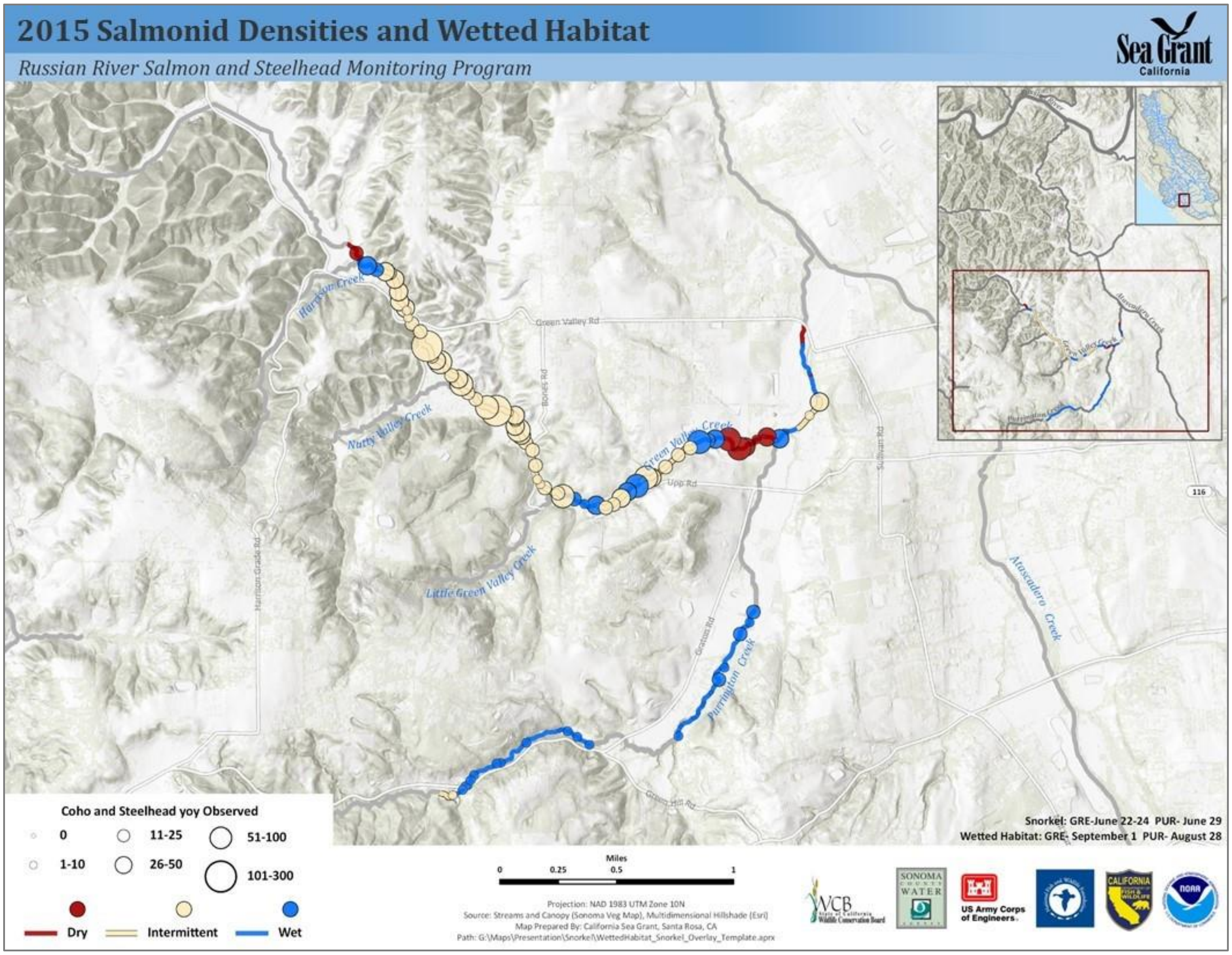

Figure 9. Early-summer salmonid yoy observations and late-summer wetted habitat conditions in Green Valley and Purrington creeks, 2015.

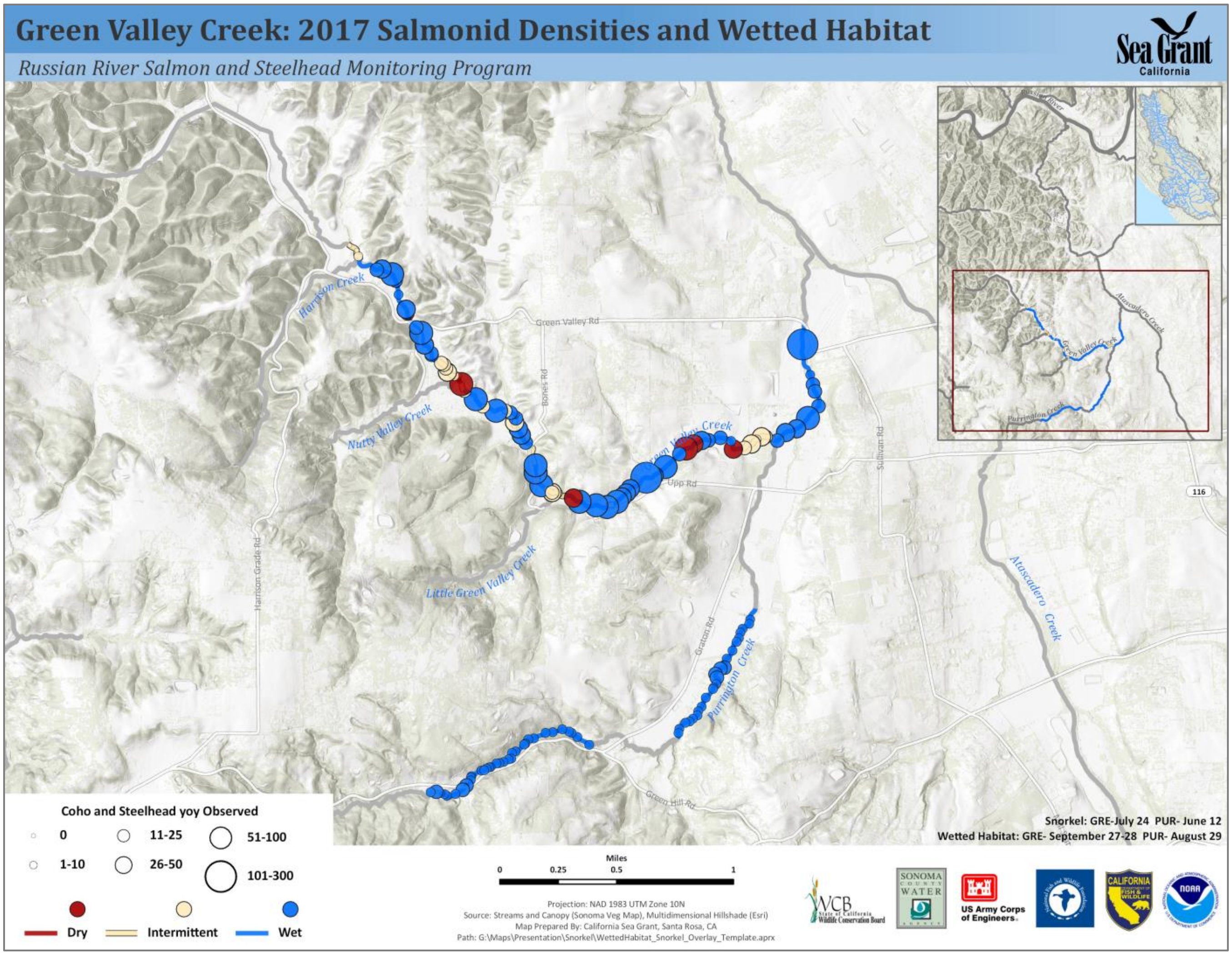

Figure 10. Early-summer salmonid yoy observations and late-summer wetted habitat conditions in Green Valley and Purrington creeks, 2017.

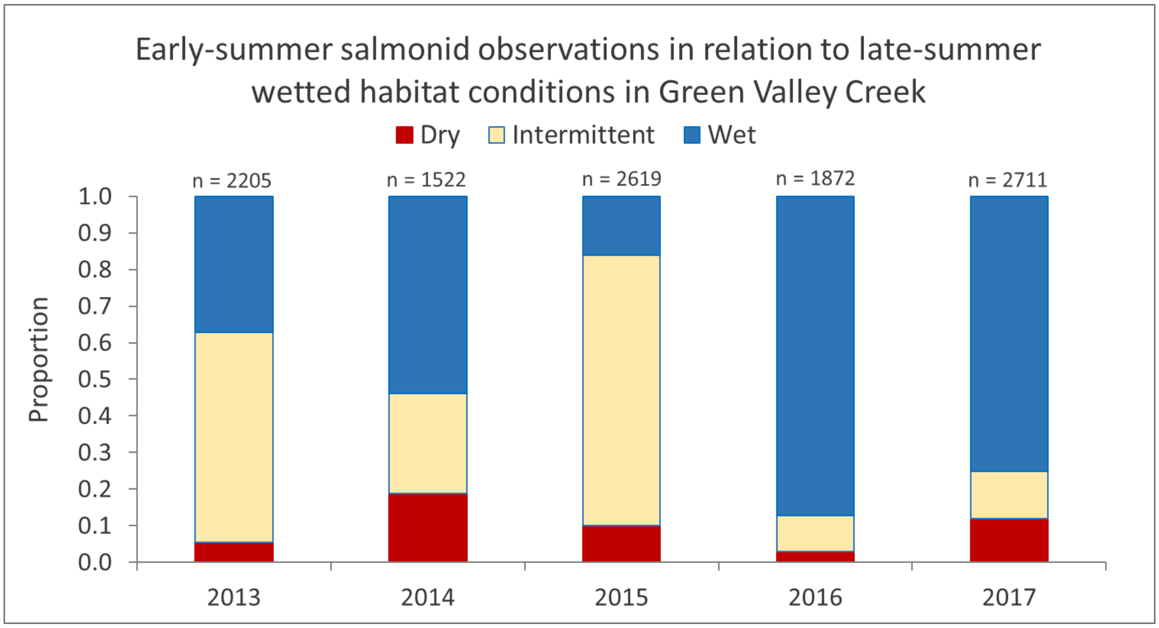

Figure 11. Proportion of all coho salmon and steelhead yoy observed during early-summer snorkel surveys in Green Valley Creek in habitat that was wet, intermittent, or dry in September, years 2013 through 2017. Only segments of stream sampled in all years were included in the calculations. N = number of juvenile salmonids observed during snorkeling surveys. 2015 and 2016 wetted habitat surveys occurred after the onset of flow releases so the impact of drying on fish may not be accurately quantified for those years.

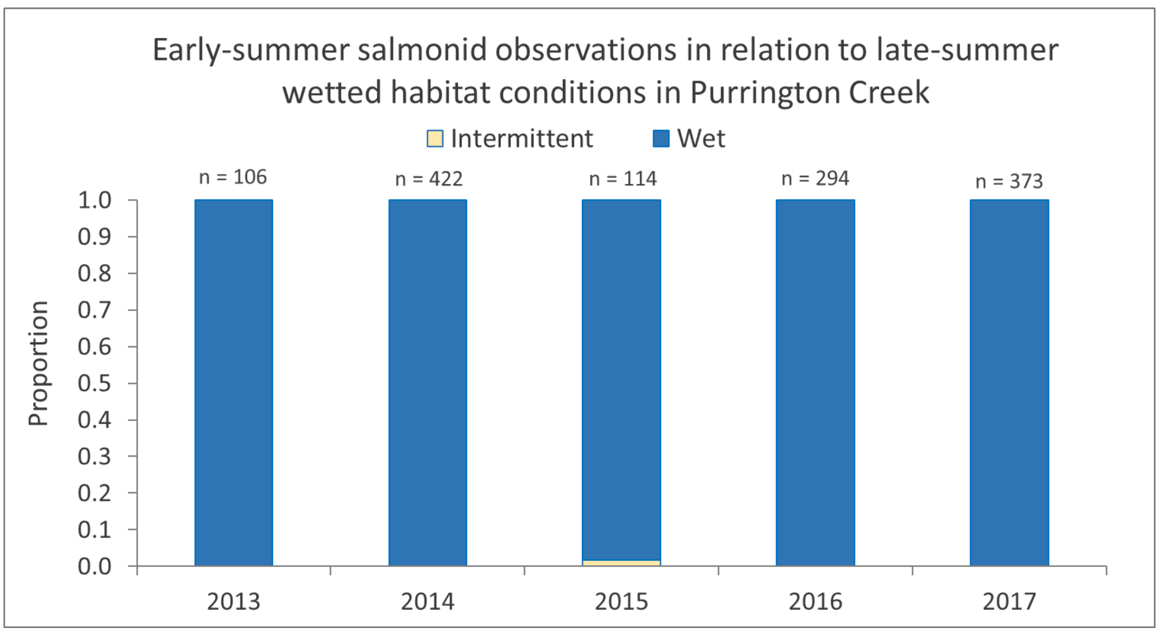

Figure 12. Proportion of all coho salmon and steelhead yoy observed during early summer snorkel surveys in Purrington Creek in habitat that was wet, intermittent, or dry in September, years 2013 through 2017. Only segments of stream sampled in all years were included in the calculations. N = number of juvenile salmonids observed during snorkeling surveys.

5.2 Survival and flow monitoring

Through its work with the Partnership, CSG conducted a study of oversummer survival of juvenile coho salmon in relation to flow and other environmental parameters in Green Valley Creek (and three other Russian River tributaries) from 2010 to 2017. The objectives of this study were to better understand the relationship between oversummer survival of juvenile coho salmon and environmental parameters, and to establish flow metrics by which to evaluate the effectiveness of Partnership streamflow enhancement projects at increasing the probability of coho salmon survival.

The primary survival study reach on Green Valley Creek extends approximately 250 meters upstream of the uppermost antenna array (Figure 2). A second study reach downstream of the first Green Valley Road crossing was originally included in the study, but fish were only stocked there for two years, due to extensive drying, so outcomes from that reach are not included in this discussion. Each summer between 2010 and 2017, survival was estimated at defined intervals for a study population of approximately 500 PIT-tagged juvenile hatchery coho salmon and these results were compared with reach-scale data for multiple environmental parameters, including streamflow, pool connectivity, pool volume, water temperature, and dissolved oxygen (DO).

Oversummer survival of juvenile coho salmon in the upper Green Valley Creek study reach was highly variable, ranging from 0.02 to 0.90 (Figure 13). The highest survival probabilities generally occurred in wetter years and the lowest survival probabilities generally occurred in the driest years. One notable outcome was the remarkably high oversummer survival observed in 2010 (0.90), 2011 (0.88), and 2016 (0.80), despite average daily oversummer flows of just 0.20 ft^3/s, 0.19 ft^3/s, and 0.05 ft^3/s, respectively. These survival rates were higher than those observed in any of the eight reaches studied on all four streams from 2010-2017. This provides empirical evidence that salmonids are able to survive in Green Valley Creek at high rates at relatively low summer streamflows of just tenths of a cubic foot per second.

In order to better understand the variation in survival among years, we tested the influence of flow-related variables on survival probability by incorporating environmental metrics as covariates in survival models (Obedzinski et al. 2018). In an analysis of data collected in years 2011 through 2013, we found that oversummer survival of juvenile coho salmon was positively associated with streamflow, wetted volume, and DO, and negatively associated with water temperature and days of pool disconnection. Of all parameters sampled, days of disconnection—the number of days that pools were disconnected from surface flow—best explained fish survival. Using data from the Green Valley Creek study reach, we generated a model that describes the negative relationship between the number of days of pool disconnection and the probability of fish survival (Figure 14). For this purpose, pool disconnection was assumed when average daily streamflow fell below 0.01 ft^3/s. The model shows that the probability of fish survival becomes progressively lower as the number of days of disconnection increases (Figure 14). These results highlight the importance of keeping pools connected in order to increase the probability of juvenile fish surviving the dry summer months.

The onset of pool disconnection represents a turning point at which water quality and quantity, and fish survival decline. DO is necessary in sufficient concentrations for salmon and other aquatic organisms to survive. Salmonid impairment has been documented at concentrations below 4.5 mg/L and mortality has been documented below 3.0 mg/L (McMahon 1983). DO is influenced by several chemical, biotic, and hydrologic variables but is primarily replenished in coho rearing pools in Green Valley Creek through the inflow of agitated surface water (i.e., upstream riffles). We observed a negative correlation between days of disconnection and DO levels, with DO concentrations declining further the longer pools were disconnected (Obedzinski et al. 2018). A significant positive relationship was also observed between fish survival and DO, supporting the fact that declines in DO concentration correspond to a decrease in survival probability. Over all study years, average reach-scale oversummer DO concentrations below the 6.0 mg/L daily minimum objective established by the North Coast Regional Water Quality Control Board (NCRWQCB 2015) were associated with survival below 0.50 (Figure 15).

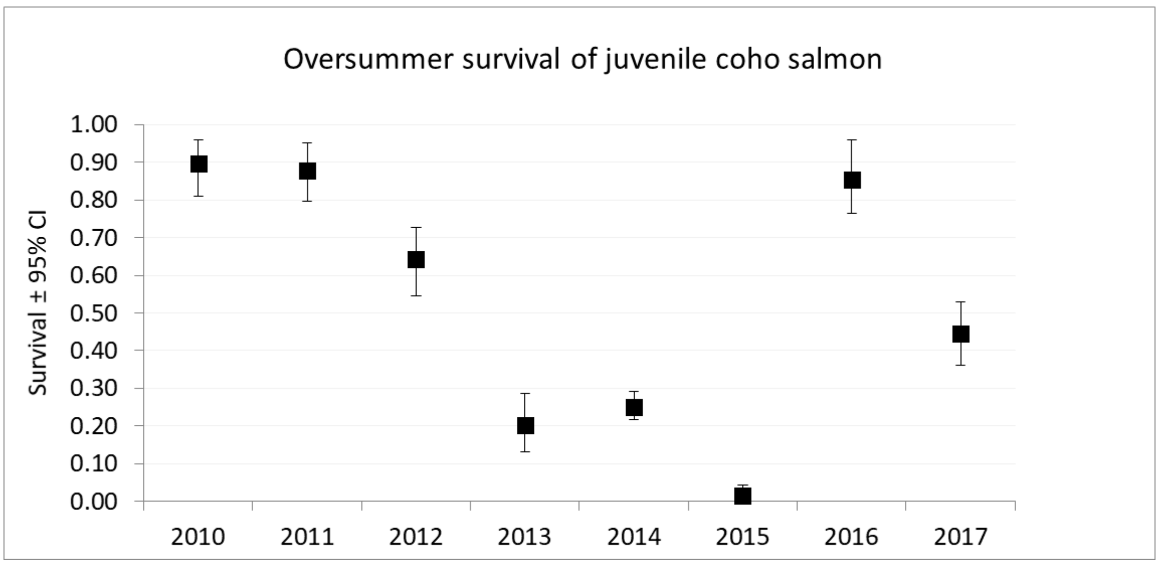

Figure 13. Juvenile coho salmon survival in the upper Green Valley Creek study reach from June 15 to October 15, years 2010-2017.

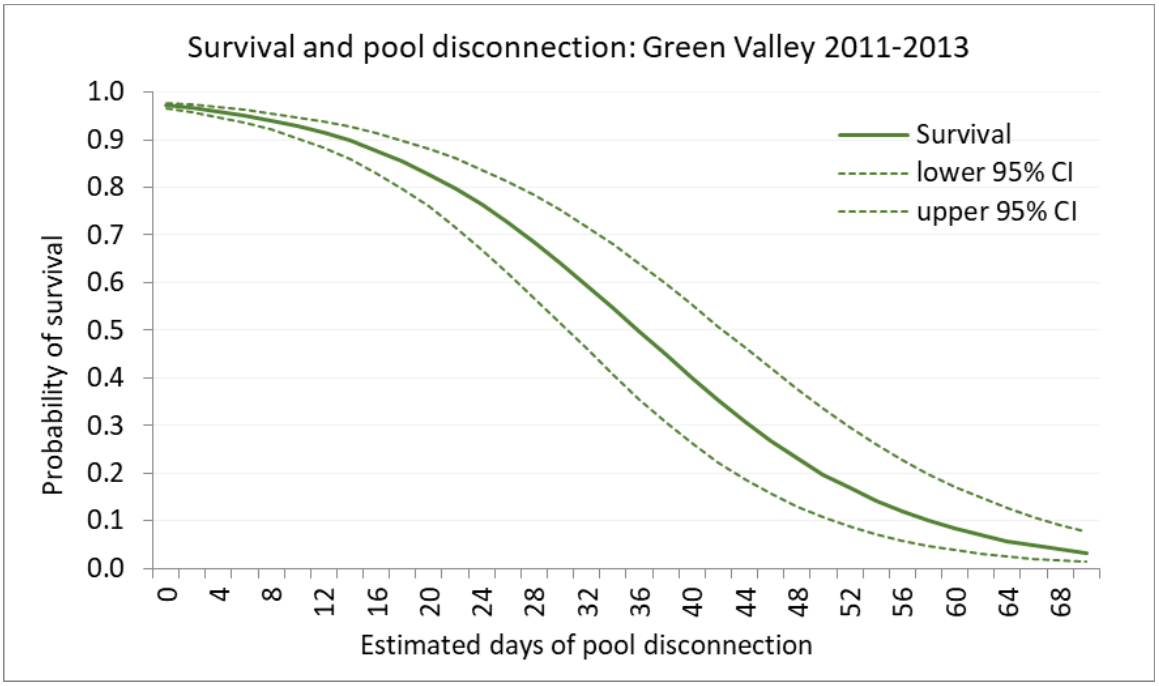

Figure 14. Predictive model showing the negative relationship between the probability of juvenile coho salmon survival and days of pool disconnection in the Green Valley Creek study reach, years 2011-2013. Disconnection was assumed on days where average daily streamflow was lower than 0.01 ft^3/s.

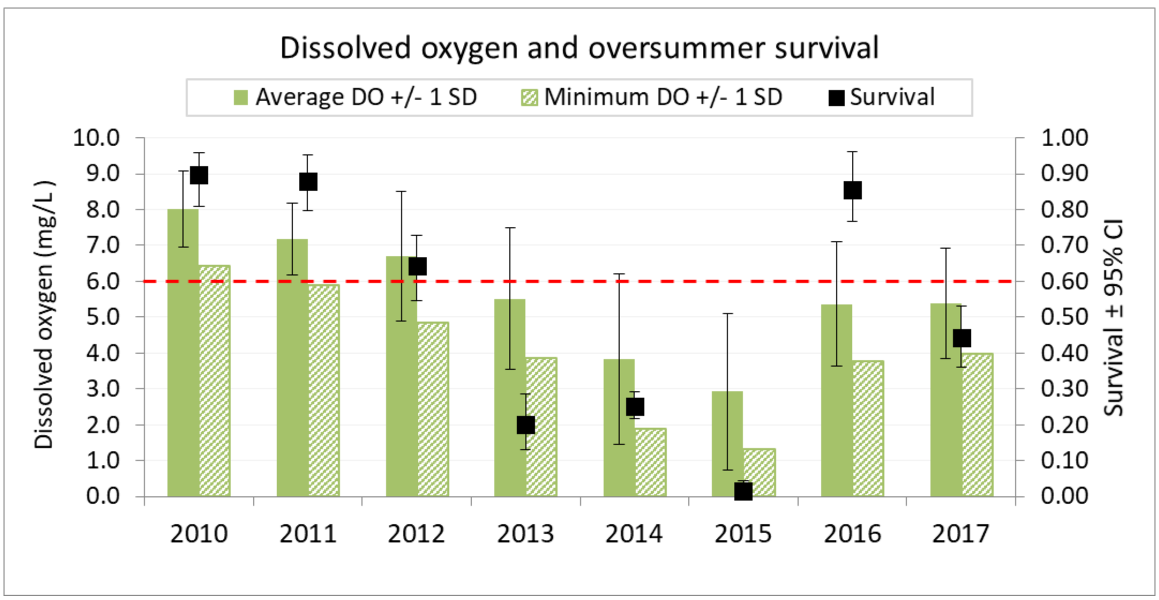

Figure 15. Oversummer, reach-scale average DO concentrations and minimum average DO at the lowest sample interval in the Green Valley Creek study reach in relation to oversummer survival of juvenile coho salmon, years 2010-2017. The red line indicates the regional minimum daily DO objective (NCRWQCB 2015).

6 Summary and discussion

Green Valley Creek is a critical stream for endangered coho in the Russian River basin. It was the last stream within the watershed to support three consecutive year classes of wild coho salmon and was the primary source of broodstock fish used to initiate the Coho Program's effort to restore native coho salmon populations. Green Valley Creek also appears to be important in terms of overwinter growth and commonly produces the largest outmigrating coho smolts observed in the life cycle monitoring streams within the lower Russian River basin.

Insufficient dry-season streamflow in Green Valley Creek has had a considerable negative impact on rearing juvenile salmonids in most recent years and is a significant limiting factor to local coho salmon recovery. On average between 2013 and 2017, approximately 40% of the fish-bearing sample reaches of upper Green Valley Creek became dry or intermittent during the summer months, impacting nearly half (46%) of the juvenile salmon and steelhead rearing in Green Valley Creek in those years. By contrast, Purrington Creek was completely wet for the entire summer in all but the driest survey year of 2015, when just 2% of the stream became intermittent. This underscores the importance of Purrington Creek as a flow refuge for salmonids rearing in the Green Valley Creek watershed during the dry summer season.

Notably high oversummer coho salmon survival was observed in the upper Green Valley Creek study reach in years when average daily streamflow ranged from just 0.05-0.20 ft^3/s. By contrast, in 2015, when average daily streamflow dropped to 0 ft^3/s, survival was only 2%. Despite having the highest survival rates observed in any study reach in multiple years, this reach also exhibited the most variability in annual oversummer survival. This suggests that the system is very sensitive to drought-related environmental changes, making streamflow a critical variable.

As we have observed in other Russian River tributaries, a strong environmental predictor of summer survival of juvenile coho salmon in Green Valley Creek is the number of days of pool disconnection, with increased days of disconnection having a negative effect on survival. Based on the results of this analysis, the Partnership has made attaining pool connectivity in the priority stream reaches a primary goal. Comparisons of streamflow data with wetted habitat data have indicated that flows as low as 0.20 ft^3/s are sufficient to keep all pools connected within the Partnership's focus area on Green Valley Creek. These data have been used to develop an approach for identifying, prioritizing, and evaluating projects in terms of their cumulative ability to attain pool connectivity throughout priority reaches (see SIP). The impact of returning streamflow equivalent to the connectivity threshold of 0.20 ft^3/s may vary significantly by year, depending on environmental conditions. In all cases, however, we can expect that increasing streamflow by the value required to keep pools connected will decrease the number of days that pools would otherwise be disconnected in any given dry season. Results from the upper Green Valley Creek juvenile salmon survival study demonstrate that this will increase the probability of fish survival.

Other environmental predictors of fish survival at the reach and interval-specific scales in Green Valley Creek included average and minimum daily flow, wetted volume and DO. DO appears to be of critical importance. During September of 2015, when nearly all of the fish in the study reach died, researchers observed coho salmon gasping at the surface of the water and exhibiting other behavior indicative of oxygen deprivation. Because of the positive influence of streamflow on DO, it is highly likely that maintaining pool connectivity would also improve DO conditions in stream reaches that currently become intermittent over the summer months.

We observed juvenile coho salmon surviving in Green Valley Creek at flows that dropped well below 0.50 ft^3/s. These small surface flows that sustain connectivity should be considered minimum persistence flows, and not levels that support high growth or sufficient production. Although fish may be able to persist at extremely low flows, if they are in poor condition at the end of the summer (e.g., small size, disease, parasites, etc.), survival may be compromised at later life stages.

Additionally, low flow conditions reduce the habitat and benthic prey available to fish. Flow has been positively correlated with both benthic macroinvertebrate (BMI) production (Gore et al. 2001), which are the primary prey for rearing juvenile salmon, and the amount of foraging habitat in a stream (Nislow et al. 2004). Harvey et al. (2006) found that invertebrate drift and juvenile rainbow trout growth increased with increased streamflow in a small California stream. Similarly, Nislow et al. (2004) found higher growth in stream-rearing juvenile Atlantic salmon in years with higher streamflow. Survival of salmonids to the adult stage is positively correlated with smolt size (Bennett et. al. 2015, Hayes et. al. 2008); therefore, increased growth in the stream environment can increase the chances of fish returning as adults to spawn.

While smolts that overwinter in Green Valley Creek are commonly larger than those leaving the other life-cycle monitoring streams in the lower Russian River basin, average oversummer growth in the Green Valley Creek study reach from 2010-2016 (0.05 mm/day in fork length) was below the average growth for all study streams (0.07 mm/day). Based on the findings cited above, we can expect that increasing summer discharge beyond minimum persistence flows would likely promote higher oversummer growth in juvenile salmon and, in turn, support more adults returning to spawn.

Achievement of long-term recovery goals for Russian River coho populations will require more than minimum connectivity of pools. Growth, fish condition, and habitat availability in relation to flow are all important factors to consider when determining what flow levels will support the long-term viability of salmon and steelhead in Green Valley Creek. Identifying such flows is beyond the scope of this study; however, these values were estimated for the Mattole Headwaters sub-basin, an area slightly smaller than the Green Valley Creek watershed (McBain and Trush, Inc. 2012). In an instream flow needs study, McBain and Trush, Inc. recommended summer juvenile rearing flow thresholds ranging from 1.5 to 5 ft^3/s (depending on location in the watershed) to avoid poor or negative growth, high risk of disease and predation, shrinking habitat availability, and heightened competition for food. The average daily streamflow observed in upper Green Valley Creek from June 15 to October 15, over the study years of 2010-2017, was 0.08 ft^3/s. CSG research and the Mattole study suggest that current oversummer streamflow in Green Valley Creek, while able to support high survival of rearing juveniles in the wettest years, is generally insufficient to support the biological needs of rearing juvenile salmonids to full productivity.

CSG's research provides compelling evidence that increasing daily discharge, pool connectivity, wetted volume, and DO concentrations in salmonid-rearing reaches of Green Valley Creek would support increased survival of salmonids through the juvenile life stage. Each of these parameters would be positively affected by enhancing streamflow. Furthermore, the literature shows that increasing summer discharge beyond minimum persistence flows would likely promote higher growth in juvenile salmon and, in turn, more adults returning to spawn.

Efforts to improve streamflow in Green Valley Creek are a critical step towards coho salmon recovery in the watershed.

References

Bennett, T.R., P. Roni, K. Denton, M. McHenry, and R. Moses. 2015. Nomads no more: early juvenile Coho Salmon migrants contribute to the adult return. Ecology of Freshwater Fish 24:264–275.

Boudreau, E. 1978. Geology, Groundwater and Wells in the Green Valley Study Area. Report Prepared for County of Sonoma.

California Department of Fish & Wildlife (CDFW). 2000a, revised 2006. Atascadero Creek Stream Inventory Report. Hopland, California.

California Department of Fish & Wildlife (CDFW). 2000b, revised 2006. Green Valley Creek Stream Inventory Report. Hopland, California.

California Department of Fish & Wildlife (CDFW). 2000c, revised 2006. Purrington Creek Stream Inventory Report. Hopland, California.

California Department of Fish and Wildlife (CDFW) and United States Army Corps of Engineers (ACOE). 2017. Hatchery and Genetics Management Plan, Don Clausen Fish Hatchery, Russian River Coho Salmon Captive Broodstock Program.

Carlisle, S., M. Reichmuth, E. Brown, S.C. Del Real, and B.J. Ketcham. 2008. Summer 2007 Monitoring Progress Report. National Park Service, San Francisco Bay Area Inventory and Monitoring Program, Point Reyes Station, CA. Prepared for: California Department of Fish and Game PO530415.

Chase, S.D., D. J. Manning, D.G. Cook, and S.K. White. 2007. Historic accounts, recent abundance, and current distribution of threatened Chinook salmon in the Russian River, California. California Fish and Game 93 (3): 130-148.

Conrad, L. 2005. 2001-2004 Annual Report for the Russian River Coho Salmon Captive Broodstock Program. Pacific States Marine Fisheries Commission/California Department of Fish and Game.

Conrad L., M. Obedzinski, D. Lewis, and P. Olin. 2005. Annual Report for the Russian River coho salmon captive broodstock program: hatchery operations and monitoring activities. July 2004 – June 2005.

Gold Ridge Resource Conservation District, O'Connor Environmental, Inc., and Prunuske Chatham, Inc. 2014. The Green Valley Creek Watershed Management Plan, Phase II, March 2014.

Gore J.A., J.B. Layzer, and J. Mead. 2001. Macroinvertebrate instream flow studies after 20 years: a role in stream management and restoration. Regulated Rivers: Research & Management 17: 527-542.

Harvey, B.C., R.J. Nakamoto, and J.L. White. 2006. Reduced streamflow lowers dry-season growth of rainbow trout in a small stream. Transactions of the American Fisheries Society 135: 998-1005.

Hayes, S.A., M.H. Bond, C.V. Hanson, E.V. Freund, J.J. Smith, E.C. Anderson, A.J. Ammann, and R.B. MacFarlane. 2008. Steelhead growth in a small Central California watershed: Upstream and estuarine rearing patterns. Transactions of the American Fisheries Society 137: 114-128.

McBain and Trush, Inc. 2012. Streamflow thresholds for juvenile salmonid rearing and adult spawning habitat in the Mattole Headwaters Southern Sub-basin. Technical Memorandum.

McMahon, T.E. 1983. Habitat suitability index models: Coho salmon. U.S. Dept. Int., Fish Wildl. Serv. FWS/OBS-82/10.49.

National Marine Fisheries Service (NMFS). 2012. Final Recovery Plan for Central California Coast Coho Salmon Evolutionarily Significant Unit. National Marine Fisheries Service, Southwest Region. Santa Rosa, California.

Nislow, K.H., A.J. Sepulveda, and C.L. Folt. 2004. Mechanistic linkage of hydrologic regime to summer growth of age-0 Atlantic salmon. Transactions of the American Fisheries Society 133: 79-88.

North Coast Regional Water Quality Control Board (NCRWCQB). 2007. Water Quality Control Plan for the North Coast Region. Santa Rosa, California.

North Coast Regional Water Quality Control Board (NCRWCQB). 2015. Resolution No. R1-2015-0018 Amending the Water Quality Control Plan for the North Coast Region to Update Section 3 Water Quality Objectives. Santa Rosa, California.

Obedzinski, M., J.C. Pecharich, G. Vogeazopoulos, D.J. Lewis, and P.G. Olin. 2006. Monitoring the Russian River Coho Salmon Captive Broodstock Program: Annual Report, July 2005-June 2006. University of California Cooperative Extension and Sea Grant Program. Santa Rosa, California.

Obedzinski, M., N. Bauer, A. Bartshire, S. Nossaman, and P. Olin. 2016. UC Coho Salmon and Steelhead Monitoring Update: Winter 2015-16.

Obedzinski, M. S. Nossaman Pierce, G. Horton, M. Deitch. 2018. Effects of Flow-Related Variables on Oversummer Survival of Juvenile Coho Salmon in Intermittent Streams. Transactions of the American Fisheries Society 147:588–605.

Reichmuth, M., B.J. Ketcham, K. Leising, and B. Craig. 2006. Olema Creek watershed summary monitoring report, Marin County, CA 1997-2006. National Park Service. San Francisco Area Network. Inventory and Monitoring Program. PORE/NR/WR/06-02.

Spence, B.C., S. L. Harris, W.E. Jones, M.N. Goslin, A. Agrawal, and E. Mora. 2005. Historical occurrence of coho salmon in streams of the Central California Coast Coho Salmon Evolutionarily Significant Unit. National Marine Fisheries Service, Southwest Fisheries Science Center. NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFCS-383.

Steiner Environmental Consulting. 1996. A History of the Salmonid Decline in the Russian River. Potter Valley, California.