Summer survival of hatchery released young-of-year coho in relation to flow and other environmental variables in Russian River tributaries.

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INTRODUCTION

Coho Partnership

In response to the precipitous decline of coho salmon in the Russian River watershed, a group of agencies and organizations formed the Russian River Coho Water Resources Partnership (Partnership) to specifically address low streamflows that are limiting coho recovery in Russian River tributaries. The Partnership is funded by the National Fish and Wildlife Foundation (NFWF) and includes the Center for Ecosystem Management and Restoration (CEMAR), Gold Ridge Resource Conservation District, Occidental Arts and Ecology Center WATER Institute, Sotoyome Resource Conservation District, Trout Unlimited, UC Cooperative Extension (UCCE) and California Sea Grant (CSG), and the Sonoma County Water Agency. The goal of the Partnership is to improve streamflow for coho as well as water supply reliability for landowners and water users. The multidisciplinary team is using a science-based approach to identify stream reaches that have the greatest potential for successful flow-enhancement project implementation and benefit to coho populations. The Partnership works with landowners in these areas to implement alternative water management strategies. Initial efforts are focusing on five priority streams where streamflow is known to limit coho survival and where cooperative projects could provide opportunities for both salmon and water users. The five priority streams include Dutch Bill, Green Valley, Mark West, Mill, and Grape Creeks (**Figure 1**).

Russian River Coho Salmon Keystone Initiative

This project is a component of NFWF's Russian River Coho Salmon Keystone Initiative, a multi-strategy plan to return a viable, self-sustaining population of coho salmon to the Russian River watershed. Key strategies for this plan include 1) development and implementation of a water management plan, 2) riparian/instream habitat restoration, conservation, and augmentation, and 3) population augmentation, monitoring, and evaluation. The work summarized in this report was designed to provide baseline data for evaluating the effects of Key Strategy 1 on coho survival, and to implement Key Strategy 3E, expanding monitoring efforts to include estimates of oversummer growth, movement, and survival of salmonids in priority streams in relation to environmental conditions such as flow and temperature.

Monitoring goals

To evaluate the effects of changes in flow management on coho survival that result from Partnership activities described in the Russian River Coho Salmon Keystone Initiative, UCCE/CSG's goal is to estimate juvenile coho salmon survival in flow-impaired "treatment" reaches, which are likely to be influenced by project implementation, and less flow-impaired "reference" reaches, which are not likely to be influenced by project implementation. Both types of reaches will be sampled before and after changes in flow management in each of the five priority creeks. Estimates of monthly survival during the dry season will be compared with measurements of flow, temperature, wetted volume, and dissolved oxygen. Data will be used to develop target instream flows as well as to document improvements in flow and survival that result from project implementation in treatment reaches. The monitoring goal for 2010 was to collect baseline data in reference and treatment reaches in Green Valley, Mill, and Grape Creeks.

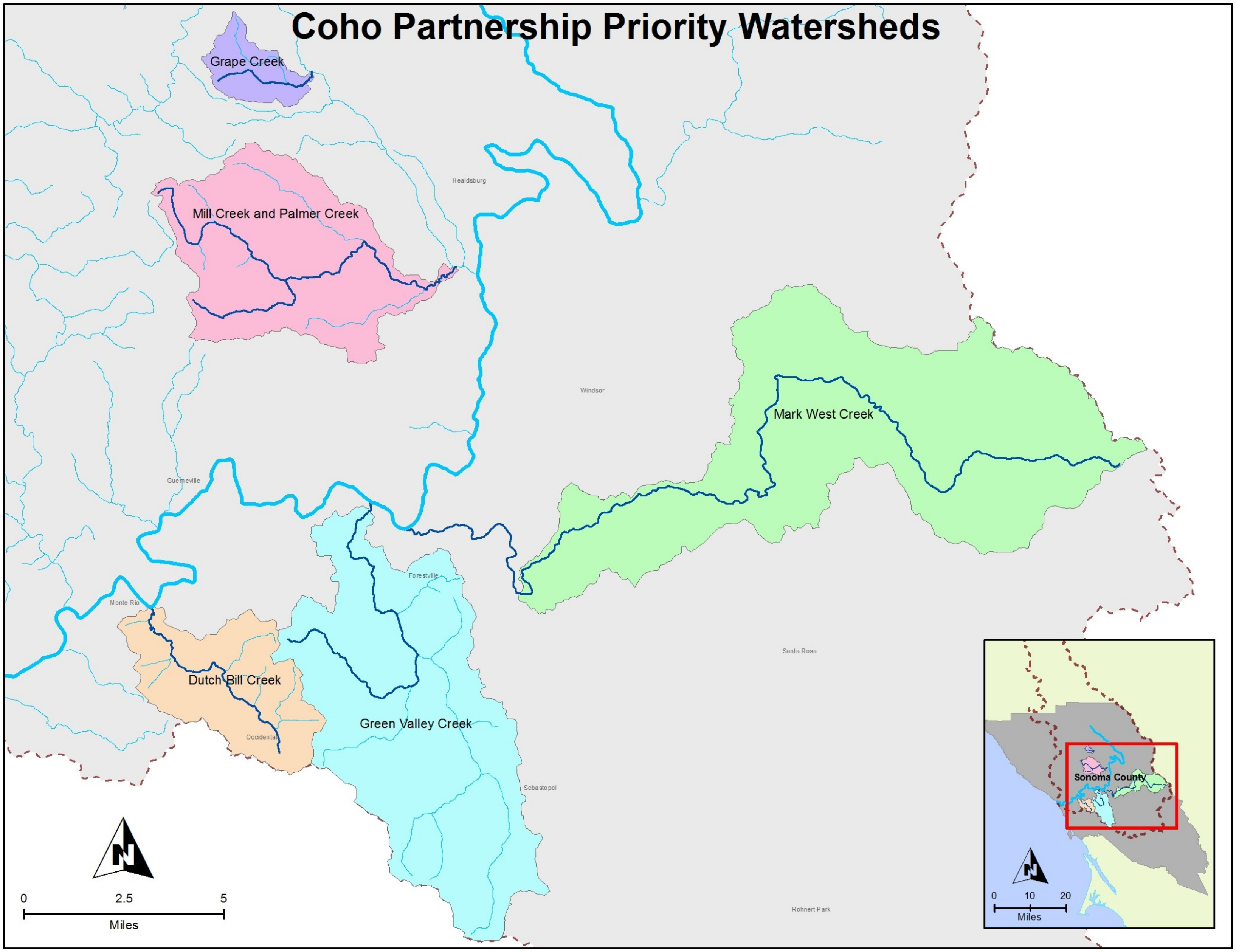

Figure 1. Coho Partnership Priority watersheds in the Russian River Basin.

METHODS

Study reaches

Surveys were conducted on two reaches of Green Valley, Mill, and Grape Creeks; one reference reach and one treatment reach in each creek (**Table 1**, and **Figure 2** to **Figure 4**). Data was also collected in a reference reach on Palmer Creek, in the Mill Creek watershed, to evaluate the suitability of that reach as a reference for conditions in an un-impaired reach of Mill Creek (**Table 1** and **Figure 3**).

Study reaches were selected based on previously observed flow conditions, habitat characteristics, and availability of landowner access. All reference reaches exhibited relatively unimpaired habitat and flow conditions, while treatment reaches exhibited sub-optimal flow conditions over the dry summer months. In general, reference reaches will not be altered by changes in flow management as a result of projects implemented through the Partnership, while treatment reaches were located downstream of potential future flow-enhancement project sites. With the exception of the Mill Creek treatment reach, we were granted landowner access to all of the reaches we selected. An alternative treatment reach was selected on Mill Creek that was not as flow impaired as the original reach selected, but where access was granted.

Stream lengths of these reaches ranged from approximately 220 meters to 370 meters (**Table 1**). The variability in reach length was due to the physical restrictions associated with reach boundaries, which were defined by a natural low-flow fish barrier at the upstream end and a channel-spanning PIT tag antenna on the downstream end. Previously established, longer reaches were used on Mill and Palmer Creeks for comparison with data collected between 2005 and 2009.

Table 1. Stream reaches surveyed between June and October, 2010.

Reach name	Reach code	Treatment or reference	Downstream river km	Upstream river km	Reach length (m)
Lower Green Valley Creek	GRE Treat	Treatment	8.84	9.07	230
Upper Green Valley Creek	GRE Ref	Reference	13.4	13.62	220
Lower Mill Creek	MIL Treat	Treatment	8.58	8.95	370
Upper Mill Creek	MIL Ref	Reference	12.33	12.7	370
Upper Palmer Creek	PAL Ref	Reference	1.83	2.2	370
Lower Grape Creek	GRP Treat	Treatment	0.16	0.39	230
Upper Grape Creek	GRP Ref	Reference	1.14	1.37	230

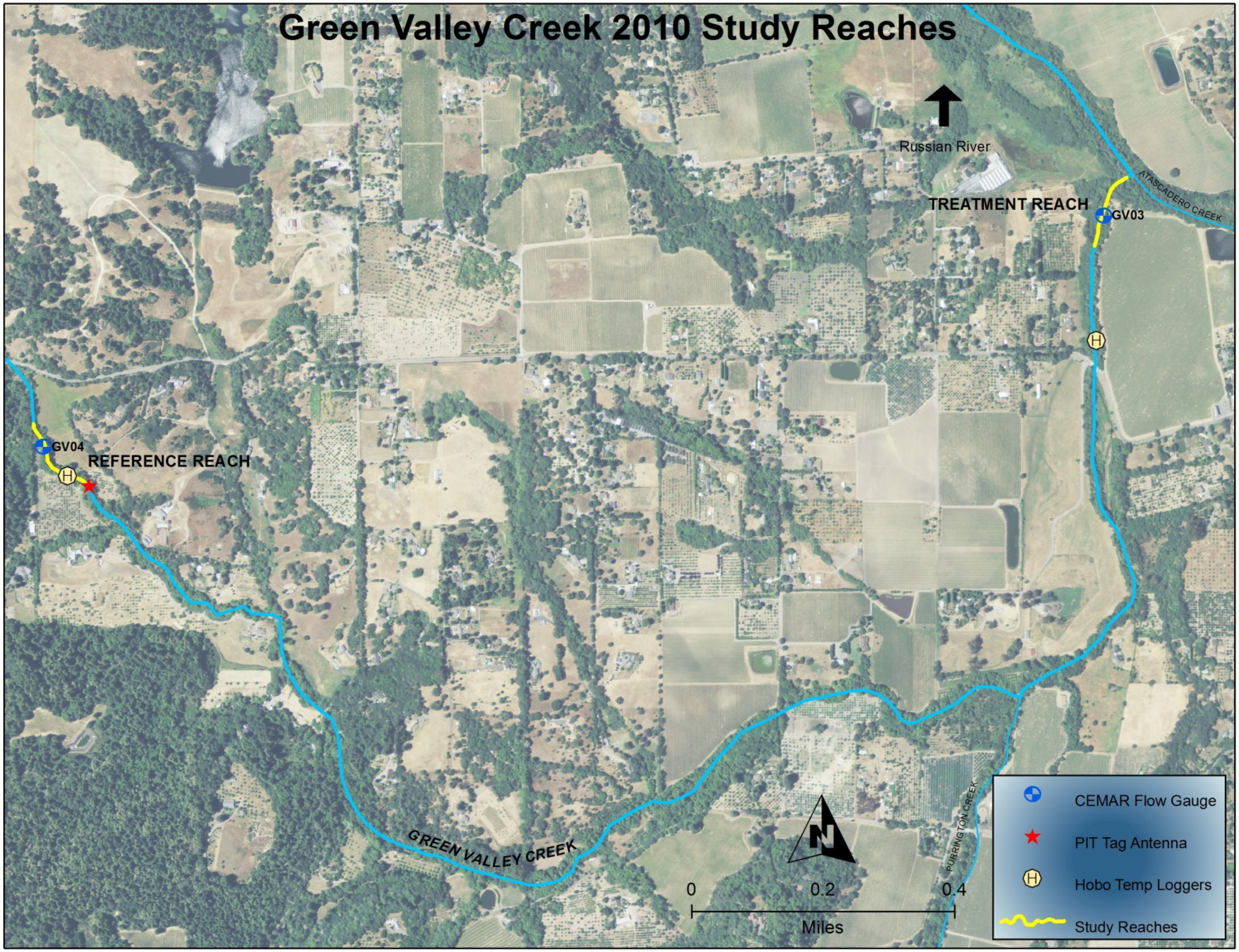

Figure 2. Green Valley Creek study reaches, flow gauges, antennas, and temperature loggers, 2010.

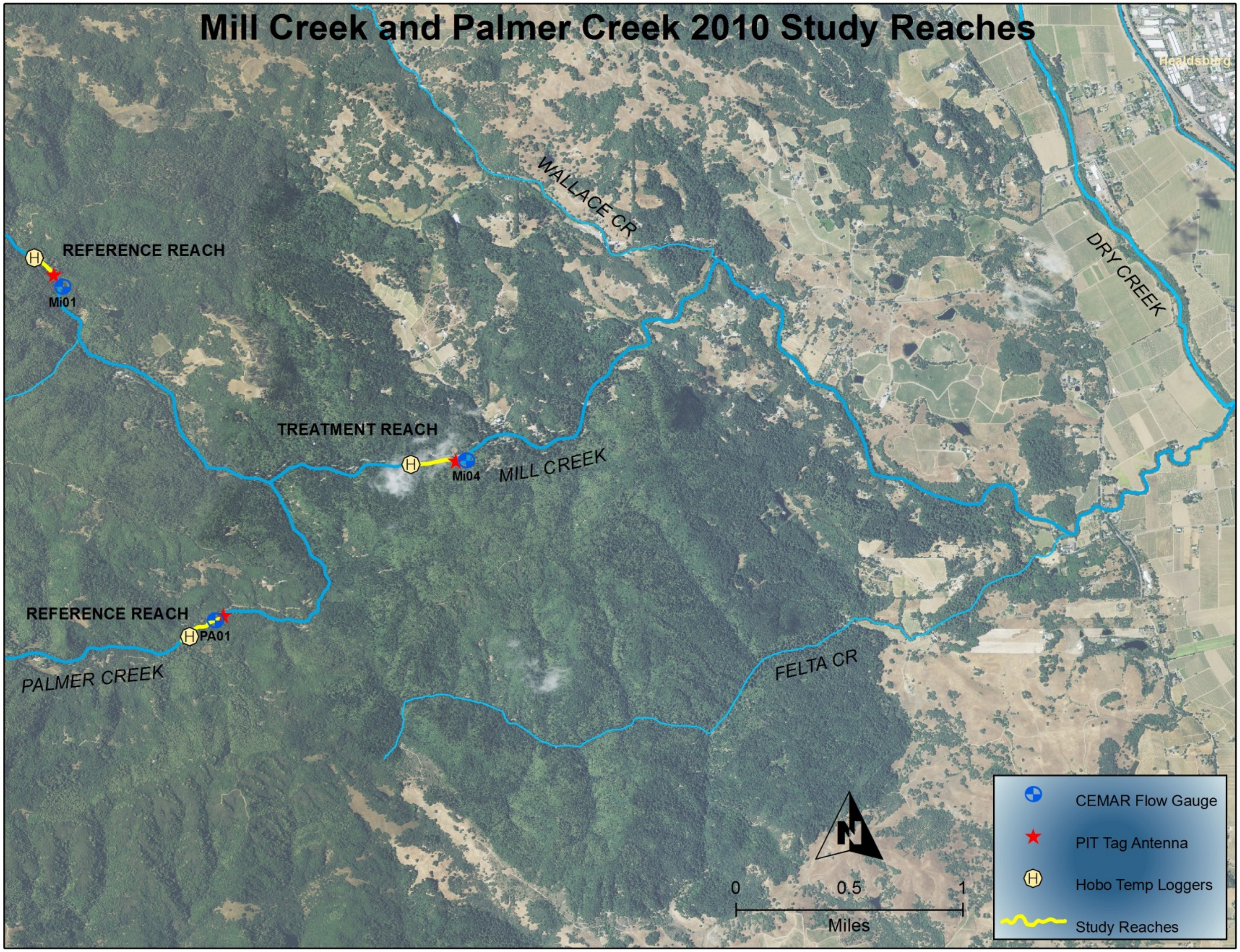

Figure 3. Mill and Palmer Creeks study reaches, flow gauges, antennas, and temperature loggers, 2010.

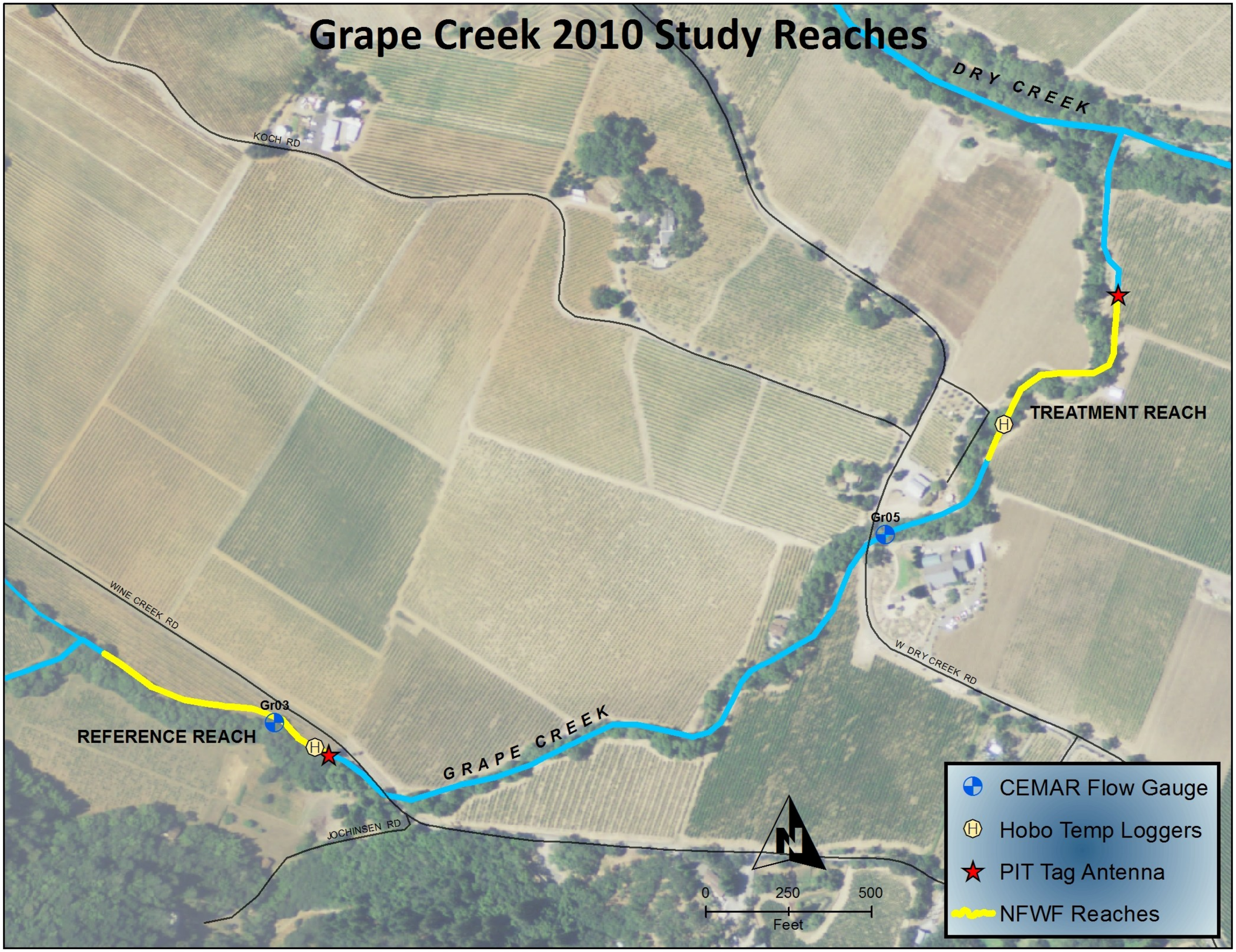

Figure 4. Grape Creek study reaches, flow gauges, antennas, and temperature loggers, 2010.

Habitat surveys

Between June and October, habitat surveys were conducted at four-week intervals in each reach using a modified version of the habitat typing methods outlined in the California Department of Fish and Game (CDFG) *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 1998, revised 2004). During the first survey, distinct units were classified as pool, riffle or flatwater habitat types and flagged accordingly. During monthly habitat surveys, each unit was measured for length, average width, average depth, and maximum depth. The location of the maximum depth measurement was marked in each unit during the initial survey to ensure consistent repetition and an accurate record of changes in maximum depth. Pool tail crest depth was measured during the initial survey to determine residual pool depth. A standardized ranking system was used to assign a shelter value to all pool and flatwater units based on the composition and quality of available shelter (Flosi et al. 1998, revised 2004). Each pool and flatwater unit also received an estimate of instream cover, recorded as the percentage of the unit covered. Over-channel canopy cover was assessed with a handheld densiometer during the June and October surveys on all units greater than 20 feet in length. Canopy was measured every 50 feet of channel length, at a minimum; twice at equal lengths for units greater than 99 feet long, and three times at equal lengths for units greater than 149 feet long. Total percent coniferous cover was also documented with each canopy measurement. Canopy was measured at flagged locations to ensure consistency between the first and final measurements.

Length, average width, and depth measurements were used to calculate average wetted volume (length x average width x average depth). Shelter value and percent instream cover were used to calculate instream shelter ratings (shelter value x percent instream cover) for pool and flatwater units. Canopy measurements were used to characterize canopy cover and dominant riparian tree type (i.e., coniferous or hard wood) in each stream reach.

Dissolved oxygen sampling

Discrete dissolved oxygen (DO) sampling was conducted in all survey reaches using a handheld YSI 6820 multi-parameter sonde equipped with a rapid pulse DO sensor and interfaced with a YSI 650MDS field computer. All YSI units were calibrated prior to each survey following the protocols outlined in YSI's *6-Series Multiparameter Water Quality Sondes User Manual* (2009). DO charge was also checked prior to surveys. If the charge was out of the acceptable range of 50 ± 25 (a function of the roughness of the electrodes on the surface of the probe face), sensor membranes were changed and, if necessary, tips were resurfaced until a DO charge within the desired range was achieved.

DO concentration was measured at a consistent depth (0.8-0.9') at pre-defined and marked maximum depth locations in every pool within each study reach once monthly between June and October. These measurements were averaged to obtain a reach-scale mean DO concentration value for each month.

The majority of the DO surveys (80%) were conducted in the morning on the day of the fish survival survey. The remainder were conducted within two days of the fish survival survey, with the exception of the first sample on the lower Mill Creek treatment reach, which was conducted a week after the wanding sample. Approximately 90% of the DO sampling occurred between 9:12 and 10:34 a.m. (start time). Samples were not taken at the lowest point in the diel cycle, which was generally in the early morning hours but varied considerably between different reaches, according to initial data from continuous DO loggers.

Flow data collection

Streamflow data used in this study were provided by CEMAR. CEMAR deployed and operated pressure transducers to serve as streamflow gauges in or near (within ~300m) each reference and treatment reach (Azonde 2220 transducer and data collector in the reference reach and In-Situ Level TROLL 500s in the treatment reach). Each gauge measured and recorded water stage every fifteen minutes for the duration of the study period. Streamflow was measured approximately one time each month in each reach using a USGS Price Mini current meter. Measured streamflow values were correlated with stage data at the time of measurement to create rating curves according to standard USGS protocols (Rantz, 1982); these curves were used to estimate streamflow in cubic feet per second at fifteen-minute intervals for all stage data from June through October.

Temperature data collection

Onset HOBO U22 Water Temp Pro v2 continuously recording temperature loggers were deployed in pools within each of the study reaches for the duration of the study period. Temperature loggers were calibrated, using standard calibration procedures as outlined in Lewis (1999), prior to deployment and collected temperature data hourly until they were removed.

Coho survival data collection

In coordination with the Russian River Coho Salmon Captive Broodstock Program, 3,954 hatchery coho young-of-year (yoy) ≥ 56mm and 2g were PIT tagged and measured for fork length (+/- 1mm) and weight (+/- 0.1g) between 6/1/10 and 6/4/10. These fish were held in tanks at the Don Clausen Warm Springs Hatchery until they were transported in a hatchery truck and released into specified study reaches. The fish were transported from the holding tank in the truck to the creeks in aerated backpack containers, and each pool or flatwater unit was stocked with the number of fish to reach a density of approximately two fish per meter of stream length. All study reaches were stocked, with the exception of the Green Valley Creek treatment reach, where oversummer survival prospects were deemed too risky (**Table 2**).

Prior to releasing juvenile coho, a stationary PIT tag detection system was constructed and placed at the downstream end of each reach in order to document emigration from the study reaches throughout the summer survival interval (**Figure 5a**). Migration upstream from each reach was partially impeded by natural flow barriers. In addition, two block seines were placed in each reach prior to stocking, one at the downstream reach boundary, and one at the midpoint of the reach. The block seines were left in place for approximately one week to prevent the stocked coho from immediately moving out of the reach as a flight response often observed during the first few days after stocking events.

In order to estimate monthly survival of stocked coho between June and October, a total of five PIT tag "wanding" samples were completed on each reach using a portable PIT tag detection system (**Figure 5b**). Surveys were conducted from downstream to upstream by wading each habitat unit and waving a portable PIT tag "wand" through the water column to detect PIT tagged fish. All PIT tags detected using this method were recorded on a portable PIT tag transceiver. Every four weeks from June through October, a paired wand sample was conducted on two consecutive days to provide an estimate of wanding efficiency. Three passes of each pool and flatwater unit were conducted per sample. During the June sample, it was determined that a significant number of fish had moved upstream of the study reach boundaries. Beginning with the July sample, paired PIT tag wanding samples were extended upstream of the original reach boundaries to a point where fish were no longer detected. A single-pass electrofishing sample was also conducted at the end of September to collect size data on PIT tagged coho.

Table 2. Juvenile coho stocked into study reaches in June, 2010.

Reach	Release Date	# Released	Mean Fork Length (mm) +/- 95% CI	Mean Weight (g) +/- 95% CI
GRE Treat	6/14/2010	0	n/a	n/a
GRE Ref	6/14/2010	506	65.8 ± 0.5	3.39 ± 0.09
MIL Treat	6/15/2010	810	66.8 ± 0.4	3.58 ± 0.08
MIL Ref	6/15/2010	812	65.6 ± 0.3	3.43 ± 0.06
PAL Ref	6/15/2010	824	65.9 ± 0.4	3.53 ± 0.07
GRP Treat	6/16/2010	495	66.0 ± 0.5	3.48 ± 0.09
GRP Ref	6/16/2010	507	66.8 ± 0.4	3.50 ± 0.08

Figure 5. Stationary (a) and portable (b) PIT tag detection systems used to detect movement and presence of PIT tagged coho in study reaches.

Survival analysis

The robust design mark recapture model (Lebreton 1982, Kendall 1997) was used in program MARK to estimate monthly survival for each reach between June and October (White and Burnham 1999). For each reach, multiple stream flow metrics were evaluated as possible flow-related variables that may have a direct effect on survival. Flow metrics included average discharge, minimum discharge, maximum discharge, days discharge=0 cfs, days discharge<0.1 cfs, days discharge<0.2 cfs, days discharge>0.2 cfs, and days discharge>0.3 cfs. The effects of other environmental variables that may affect survival but are themselves at least partially related to stream flow (i.e., average wetted volume, total wetted volume, average DO, minimum DO, average maximum depth, average temperature, and maximum temperature) were evaluated in a similar manner. To evaluate model support, we used the following guidelines (Burnham and Anderson 2002): a QAICc difference of two or lower indicated similar support for models; differences of 4–7 indicated moderate support for the model with the lower QAICc; and differences greater than 10 indicated strong support for the model with the lower QAICc.

RESULTS

Habitat

Study reach characteristics

Channel type, average over-channel canopy cover, average oversummer shelter rating, and residual pool depth, were used to describe general morphological and habitat characteristics within each stream reach (**Table 3**).

Channel type describes a stream reach using eight morphological characteristics, including channel width, depth, velocity, discharge, slope, roughness, sediment load and sediment size. The channel types listed here are taken from CDFG stream reports (CDFG 2000). CDFG used a modified stream channel classification system developed by D.L. Rosgen to assign channel types to each reach (Rosgen 1996). The delineation criteria includes a general description of the channel geometry, gradient, bank stability, substrate, habitat type occurrence, as well as width to depth ratio, water surface gradient, dominant particle size, entrenchment, and sinuosity.

All of the study reaches, except for the Green Valley Creek reference reach, were F channel types with gravel (F4) or cobble (F3) substrates (**Table 3**). F channel types are entrenched, meandering, riffle-pool channels on low gradients with a high width to depth ratio (Flosi et al. 1998, revised 2004). The reference reach on Green Valley Creek was a B4 channel (**Table 3**). A B4 channel is defined as a moderately entrenched, moderate gradient, riffle dominated channel with infrequently spaced pools, very stable plan and profile, stable banks, and a gravel-dominated bed (Flosi et al. 1998, revised 2004).

Canopy was assessed during the June and October surveys in order to quantify the amount of vegetation providing shade cover over the stream channel. Canopy is critical to fish since it provides shade to maintain cool water temperatures and reduce evaporation during the hot summer months. Canopy is also indicative of the amount of woody vegetation on the stream banks. Trees in the riparian corridor provide essential nutrients for macroinvertebrates, which salmonids feed upon. Riparian trees also provide erosion control, instream shelter, and habitat complexity through root structure and large wood recruitment. Canopy cover greater than or equal to 80% meets CDFG's established criterion for habitat suitability for salmonids (Flosi et al. 1998, revised 2004).

All of the study reaches had good to excellent canopy cover. The lowest average canopy occurred in the Mill Creek treatment reach (81.2%) and the greatest occurred in the Grape Creek reference reach (97.8%) (**Table 3**). Since the final survey occurred before the bulk of the autumn leaf fall, canopy measurements did not differ significantly between the June and October samples, with canopy remaining static in all reaches with the exception of the Mill Creek treatment reach and Palmer Creek reference reach. These reaches experienced a decrease of less than 1% of average canopy cover between June and October. The values listed in **Table 3** are from the June sample.

Average percent coniferous cover was assessed by reach in order to characterize dominant riparian tree composition. All of the study reaches are dominated by hardwood riparian species

(**Table 3**). Hardwood trees comprised 100% of the total canopy cover on the Green Valley treatment reach and both reaches of Grape Creek (**Table 3**). On average, coniferous trees comprised a significant portion of the over-channel cover on the Mill Creek reference reach (46.9%), the Mill Creek treatment reach (35.5%), and the Palmer Creek reference reach (31.9%), while comprising a low percentage of the total average canopy on the Green Valley Creek reference reach (11.1%) (**Table 3**).

Shelter was assessed for all pool and flatwater units in order to quantify the amount of instream cover available to fish. Instream shelter provides protection from predation, separation between territorial niches to reduce density-related competition, and areas of reduced water velocities where fish can rest. CDFG's criterion for salmonid habitat suitability is defined as a shelter rating greater than or equal to 80 (Flosi et al. 1998, revised 2004). Shelter rating is the product of the instream shelter value, which refers to shelter composition and quality, and the percent total cover within the stream channel.

The shelter rating values listed in **Table 3** were averaged over the sample period of June to October. Average instream shelter in all reaches fell significantly below CDFG's shelter rating benchmark of 80 (**Table 3**). The average shelter rating was greatest in the Mill Creek reference reach (47.9) and lowest in the Grape Creek treatment reach (20.4) (**Table 3**). Shelter ratings varied considerably between units.

Shelter remained relatively stable over the summer, changing 0-0.2%, in five of the seven study reaches: the Green Valley Creek reference reach, the Mill Creek treatment and reference reaches, the Palmer Creek reference reach and the Grape Creek reference reach. In the Green Valley Creek and Grape Creek treatment reaches, shelter remained static until flows dropped significantly in September and October. In October, the average instream shelter rating in the Green Valley Creek treatment reach increased by 25% (from 34 to 42.7). In September, the average instream shelter rating in the Grape Creek treatment reach decreased by 23% (from 25 to 19.2), followed by a decrease of an additional 60% (from 19.2 to 7.7) in October. No direct correlation between flow and shelter was apparent. Shelter rating increased or decreased depending on characteristics specific to individual habitat units (e.g, location of instream cover structures in relation to banks and scour points, bank gradient, etc).

The depth of pool tail crest was measured at the maximum thalweg depth in each pool tail-out during the June survey and subtracted from maximum pool depth to determine maximum residual pool depth. This metric refers to the depth of water in a pool below the elevation of the downstream riffle crest and can be thought of as the maximum water depth that would be present if there were no surface flow in the stream and units had become disconnected. Residual pool depth is a good indicator of size of pools within a stream channel independent of discharge. The *Draft Russian River Basin Fisheries Restoration Plan* (Coey et al. 2002) established a threshold of 3.0 feet (91.4 cm) residual pool depth for third order streams, and 2.0 feet (60.9 cm) for second order streams to meet the habitat needs of all salmonid species within the Russian River basin.

Green Valley, Mill, and Grape creeks are third order streams. Both reaches on each of the third order streams fell short of the established criterion (91.4 cm), with average residual pool depths ranging from 54.2 to 86 cm (**Table 3**). The lowest average residual depth was in the Green Valley Creek treatment reach, while the greatest average residual depth was in the Grape Creek reference reach (**Table 3**). Palmer Creek is a second order stream. Palmer Creek also fell short of the established criterion (60.9 cm), with an average residual pool depth of 44.7 cm (**Table 3**).

Table 3. Study reach characteristics.

Reach	Channel type*	Avg canopy (%) +/- 1 SD	Avg coniferous cover (%) +/- 1SD	Avg shelter rating +/- 1 SD	Avg residual pool depth (cm) +/- 1 SD
GRE Treat	F3	95.3 +/- 4.8	0 +/- 0	35.7 +/- 42.5	54.2 +/- 25.6
GRE Ref	B4	97.5 +/- 5.1	11.1 +/- 6.8	33.2 +/- 19.5	62.9 +/- 17.2
MIL Treat	F4	90.2 +/- 7.5	35.5 +/- 20.7	29.3 +/- 16.6	69.2 +/- 23.6
MIL Ref	F4	81.2 +/- 17.8	46.9 +/- 17.5	47.9 +/- 20.0	60.6 +/- 12.4
PAL Ref	F3	96.9 +/- 3.8	31.9 +/- 18.0	42.0 +/- 44.5	44.7 +/- 25.9
GRP Treat	F4	91.0 +/- 8.3	0 +/- 0	20.4 +/- 11.8	73.4 +/- 33.3
GRP Ref	F4	97.8 +/- 4.5	0 +/- 0	42.7 +/- 24.0	86.0 +/- 17.8

*Rosgen stream channel classification from CDFG stream reports.

Changes in environmental conditions over study period

Pool and flatwater habitat

Pool and flatwater habitat units in all reaches experienced steady declines in average width and maximum depth throughout the summer dry season (**Table 4**). The average decline in width for all reaches, *excluding the Grape Creek treatment reach*, was 15% (with a range of 11% to 19%) between June to October (**Table 4**). The average decline in maximum depth of pool and flatwater units for all reaches, *excluding the Grape Creek treatment reach*, was 12% (with a range of 8% to 16%) (**Table 4**). The Grape Creek reference reach exhibited the lowest reduction in width (11%) and maximum depth (8%) (**Table 4**). The most significant changes occurred in the Grape Creek treatment reach, where the decrease in average width of pool and flatwater units totaled 64% and the decrease in maximum depth totaled 74% over the study period (**Table 4**).

Average depth and wetted volume declined in pool and flatwater units over the study period but fluctuated less predictably between months in most reaches (**Table 4**, and **Figure 6** to **Figure 11**). The decline in average depth for all reaches, *excluding the Grape Creek treatment reach*, averaged 13% (with a range of 6% to 20%) (**Table 4**). Total wetted volume decreased in all reaches, *excluding the Grape Creek treatment reach*, by an average of 24.5% (reach experienced the lowest decrease in depth (6%) and wetted volume (18%) (**Table 4, Figure 6,** and **Figure 7**). Changes were most extreme in the Grape Creek treatment reach, with an oversummer decline of 56% in average depth and 81% in wetted volume (**Table 4**, **Figure 8,** and **Figure 11**). In September, two of the 12 pools and the only flatwater unit in this reach went completely dry and, by October, only six pools remained wet (**Table 4**). The Green Valley Creek treatment reach experienced the second greatest decline, with a decrease of 20% in average depth and 34% in wetted volume of pool and flatwater units, but did not lose any pool or flatwater units to drying over the study period (**Table 4**, **Figure 6**, and **Figure 9**).

Because the treatment reaches were located downstream of the reference reaches in this study, they generally had a higher volume of water than their corresponding reference reaches due to greater cumulative flow inputs (**Table 4** and **Figure 6** to **Figure 11**). However, the average reduction in wetted volume of pool and flatwater units in the treatment reaches over the study period (46%) was more than double that of the reference reaches (22%) (**Table 4** and **Figure 6** to **Figure 11**). The variability in wetted volume between months in the Grape Creek treatment reach is indicative of modified flow conditions (**Figure 8** and **Figure 11).**

Table 4. Environmental characteristics measured monthly in pool and flatwater units on study reaches between June and October, 2010.

Reach	Sample month	Number habitat units (n)	Number wet units	Avg width (m) +/- 1 SD	Avg depth (cm) +/- 1 SD	Avg max depth (cm) +/- 1 SD	Avg wetted volume (m^3) +/- 1 SD	Total wetted volume (m^3)
GRE Treat	June	15	15	3.7 +/- 0.8	25.8 +/- 14.9	54.1 +/- 29.6	21.3 +/- 24.3	320.0
	July	15	15	3.3 +/- 0.8	24.9 +/- 13.0	52.2 +/- 29.0	18.1 +/- 20.2	272.1
	August	15	15	3.1 +/- 0.8	24.3 +/- 13.1	51.3 +/- 29.1	17.1 +/- 18.9	255.8
	Sept	15	15	3.1 +/- 0.9	18.4 +/- 11.5	47.8 +/- 28.9	13.4 +/- 16.1	201.6
	Oct	15	15	3.0 +/- 0.8	20.7 +/- 11.4	45.9 +/- 28.3	14.0 +/- 15.2	210.4
GRE Ref	June	11	11	3.7 +/- 1.1	25.8 +/- 13.2	63.2 +/- 21.7	18.3 +/- 11.3	201.6
	July	11	11	3.3 +/- 1.1	26.8 +/- 13.0	62.4 +/- 21.6	18.0 +/- 11.9	198.0
	August	11	11	3.3 +/- 1.1	26.1 +/- 11.4	60.3 +/- 21.8	17.2 +/- 10.8	188.9
	September	11	11	3.3 +/- 1.1	22.7 +/- 11.3	57.9 +/- 22.3	15.0 +/- 9.9	165.2
	October	11	11	3.1 +/- 1.2	23.8 +/- 11.1	57.3 +/- 22.3	14.6 +/- 9.6	160.9
MIL Treat	June	14	14	5.4 +/- 1.3	28.7 +/- 11.4	69.1 +/- 31.8	47.2 +/- 45.1	660.3
	July	14	14	4.8 +/- 1.1	27.7 +/- 9.9	65.2 +/- 28.9	39.8 +/- 36.7	557.5
	August	14	14	4.7 +/- 1.1	27.3 +/- 10.6	63.5 +/- 28.3	38.8 +/- 35.7	542.6
	September	14	14	4.5 +/- 1.1	25.9 +/- 10.1	61.7 +/- 28.9	35.3 +/- 33.4	494.4
	October	14	14	4.5 +/- 1.2	24.1 +/- 10.9	61.7 +/- 30.5	35.7 +/- 35.6	499.3
MIL Ref	June	16	16	3.9 +/- 0.8	25.1 +/- 6.2	67.8 +/- 17.2	13.6 +/- 6.7	217.6
	July	16	16	3.5 +/- 0.7	23.6 +/- 5.7	65.1 +/- 17.5	11.9 +/- 7.0	190.9
	August	16	16	3.4 +/- 0.7	25.9 +/- 5.5	62.1 +/- 18.5	12.9 +/- 6.8	205.7
	September	16	16	3.4 +/- 0.6	24.1 +/- 6.5	60.7 +/- 18.3	11.5 +/- 6.1	184.5
	October	16	16	3.2 +/- 0.7	23.5 +/- 6.3	59.0 +/- 17.2	11.1 +/- 6.2	178.4
PAL Ref	June	17	17	3.9 +/- 0.8	24.1 +/- 10.0	53.5 +/- 26.3	13.6 +/- 8.7	231.0
	July	17	17	3.7 +/- 0.8	24.4 +/- 10.0	49.9 +/- 23.9	13.0 +/- 7.9	221.7
	August	17	17	3.5 +/- 0.8	23.5 +/- 9.0	48.6 +/- 24.2	11.9 +/- 8.0	201.8
	September	17	17	3.5 +/- 0.9	21.9 +/- 10.0	47.3 +/- 26.0	11.0 +/- 8.4	187.7
	October	17	17	3.4 +/- 0.8	21.7 +/- 10.8	44.8 +/- 24.8	10.6 +/- 8.0	179.6
GRP Treat	June	13	13	3.1 +/- 0.8	27.5 +/- 12.8	76.7 +/- 34.0	15.5 +/- 13.6	201.6
	July	13	13	3.0 +/- 0.8	27.7 +/- 13.0	74.3 +/- 33.2	14.8 +/- 9.7	191.9
	August	13	13	3.0 +/- 0.8	28.6 +/- 12.1	75.3 +/- 33.7	16.3 +/- 13.2	211.4
	September	13	10	1.8 +/- 1.3	16.1 +/- 14.7	41.7 +/- 36.4	5.6 +/- 8.6	72.3
	October	13	6	1.1 +/- 1.6	12.2 +/- 16.7	20.2 +/- 29.2	3.0 +/- 6.6	39.2
GRP Ref	June	15	15	2.5 +/- 0.4	40.1 +/- 13.6	89.0 +/- 27.6	16.2 +/- 12.1	243.2
	July	15	15	2.3 +/- 0.5	37.4 +/- 12.8	89.1 +/- 28.3	13.9 +/- 10.0	208.2
	August	15	15	2.2 +/- 0.5	35.3 +/- 9.6	88.0 +/- 26.3	12.3 +/- 8.6	184.6
	September	15	15	2.2 +/- 0.4	32.7 +/- 9.3	85.4 +/- 25.2	11.1 +/- 7.5	166.7
	October	15	15	2.2 +/- 0.4	33.7 +/- 9.5	82.2 +/- 24.3	11.5 +/- 7.7	173.0

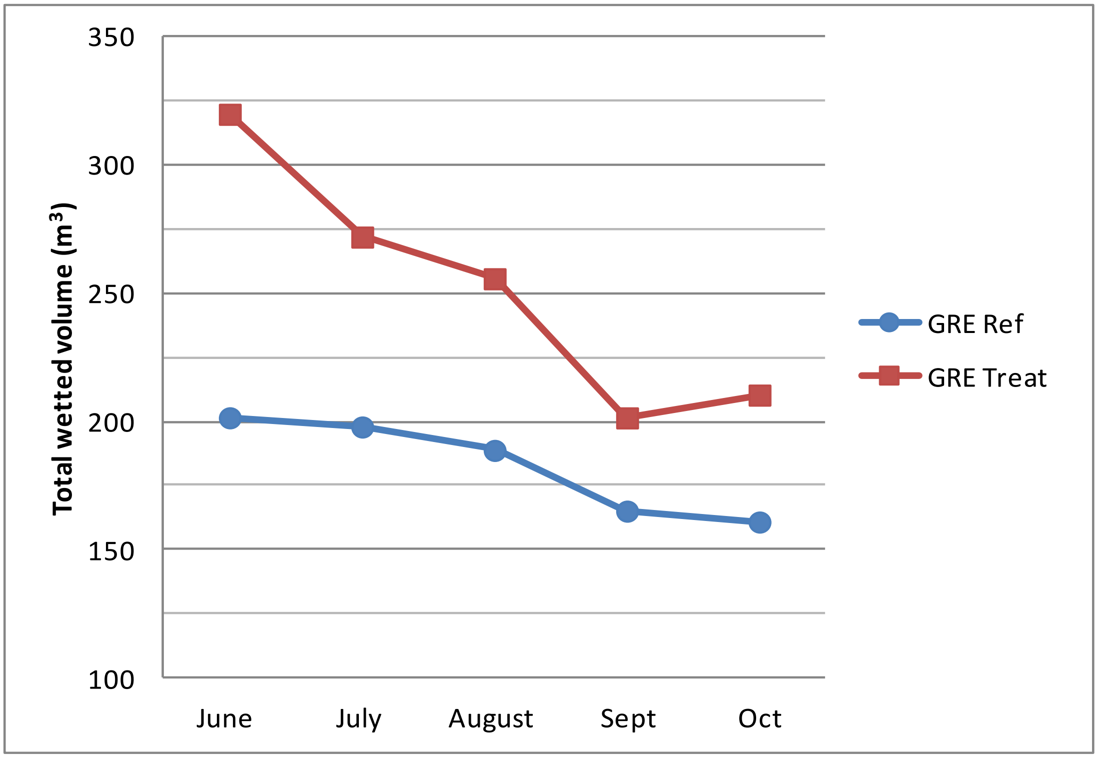

Figure 6. Total wetted volume of pool and flatwater habitat in Green Valley Creek reference and treatment reaches between June and October, 2010.

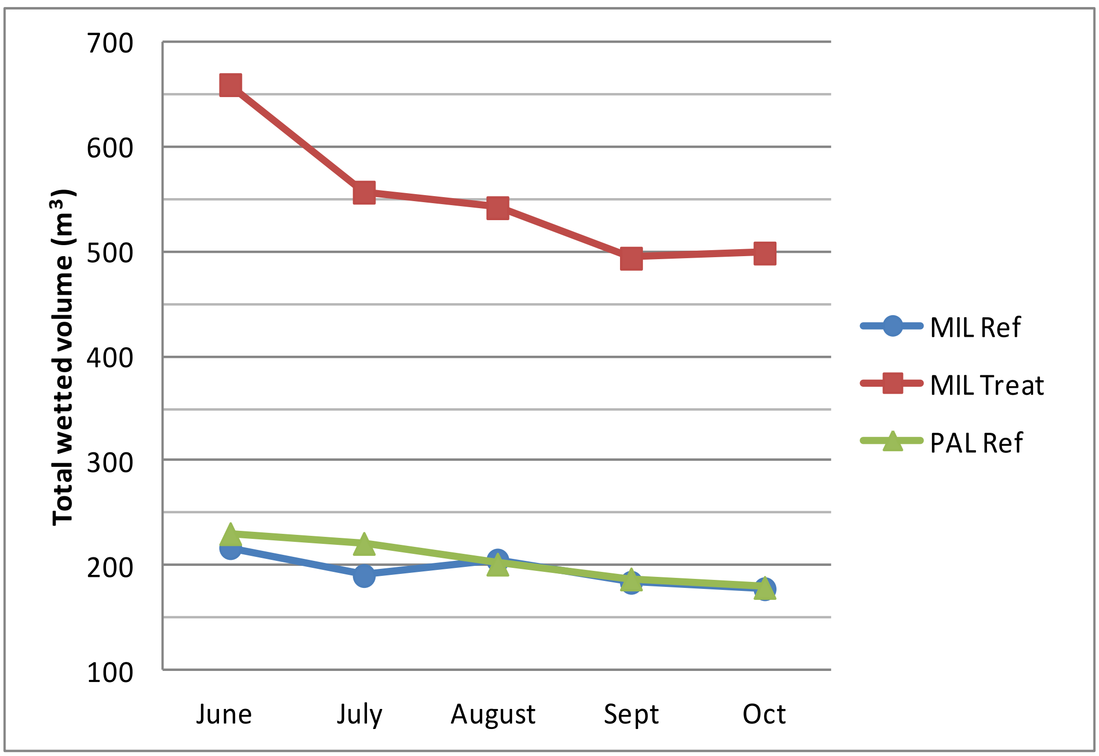

Figure 7. Total wetted volume of pool and flatwater habitat in Mill Creek and Palmer Creek reference and treatment reaches between June and October, 2010.

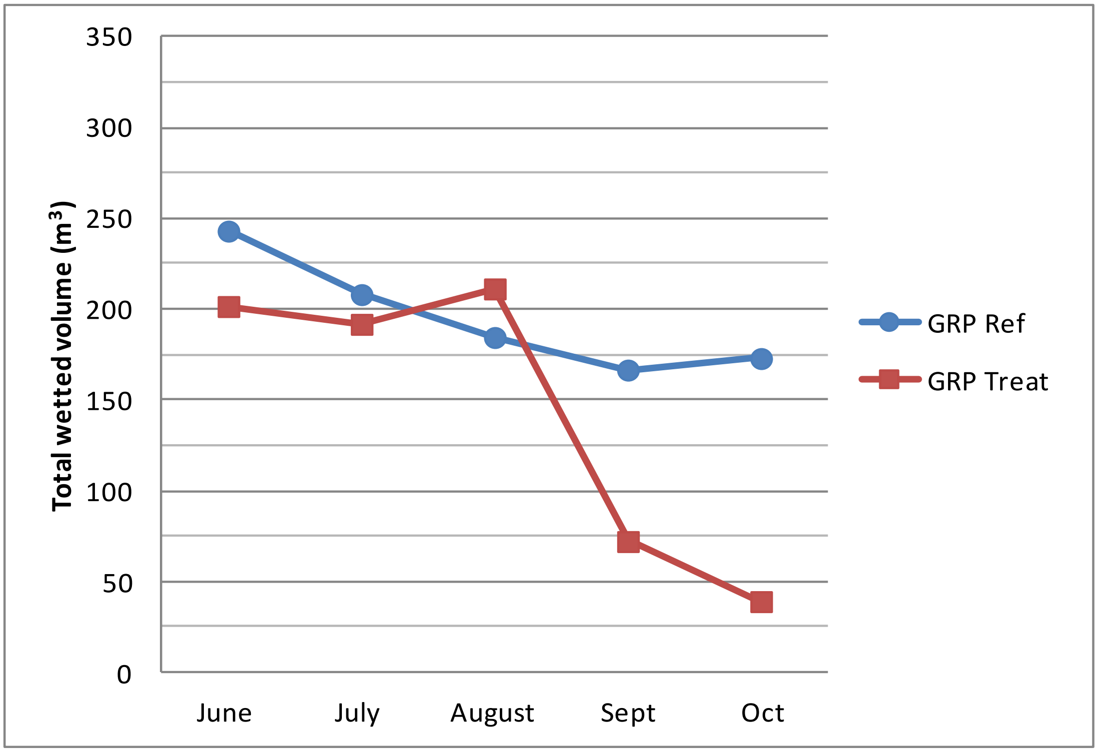

Figure 8. Total wetted volume of pool and flatwater habitat in Grape Creek reference and treatment reaches between June and October, 2010.

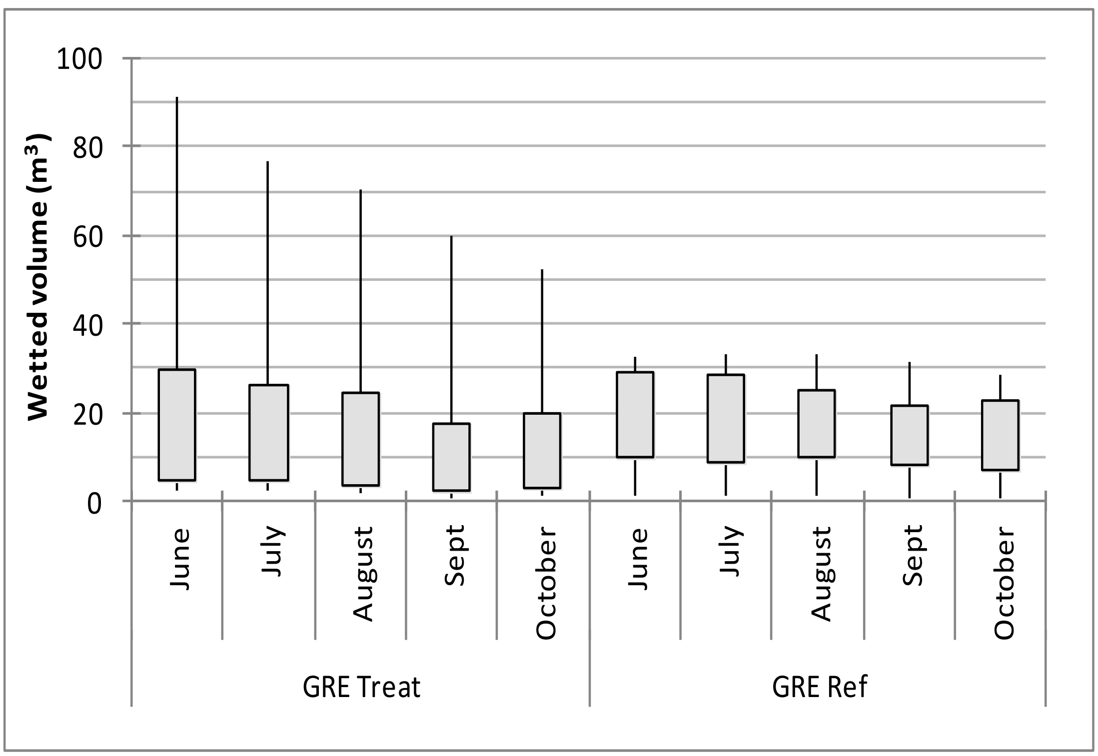

Figure 9. Minimum, maximum, 25 percentile, and 75 percentile of average wetted volume of pool and flatwater habitat in Green Valley Creek reference and treatment reaches between June and October, 2010.

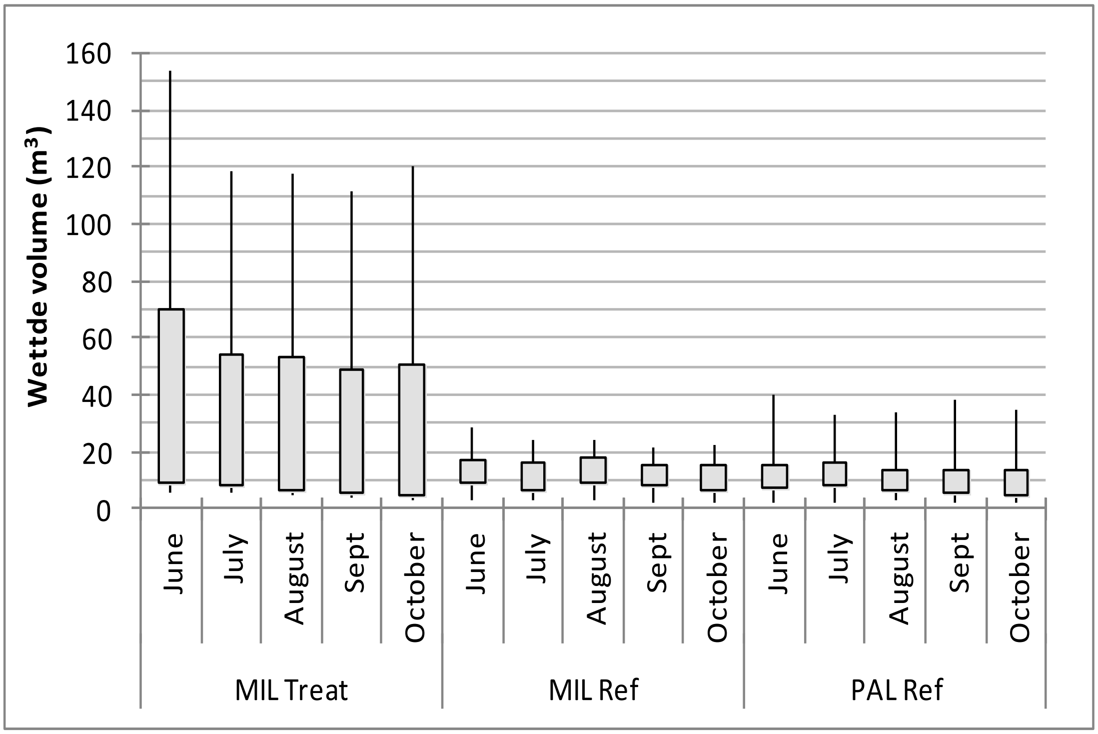

Figure 10. Minimum, maximum, 25 percentile, and 75 percentile of average wetted volume of pool and flatwater habitat in Mill Creek and Palmer Creek reference and treatment reaches between June and October, 2010.

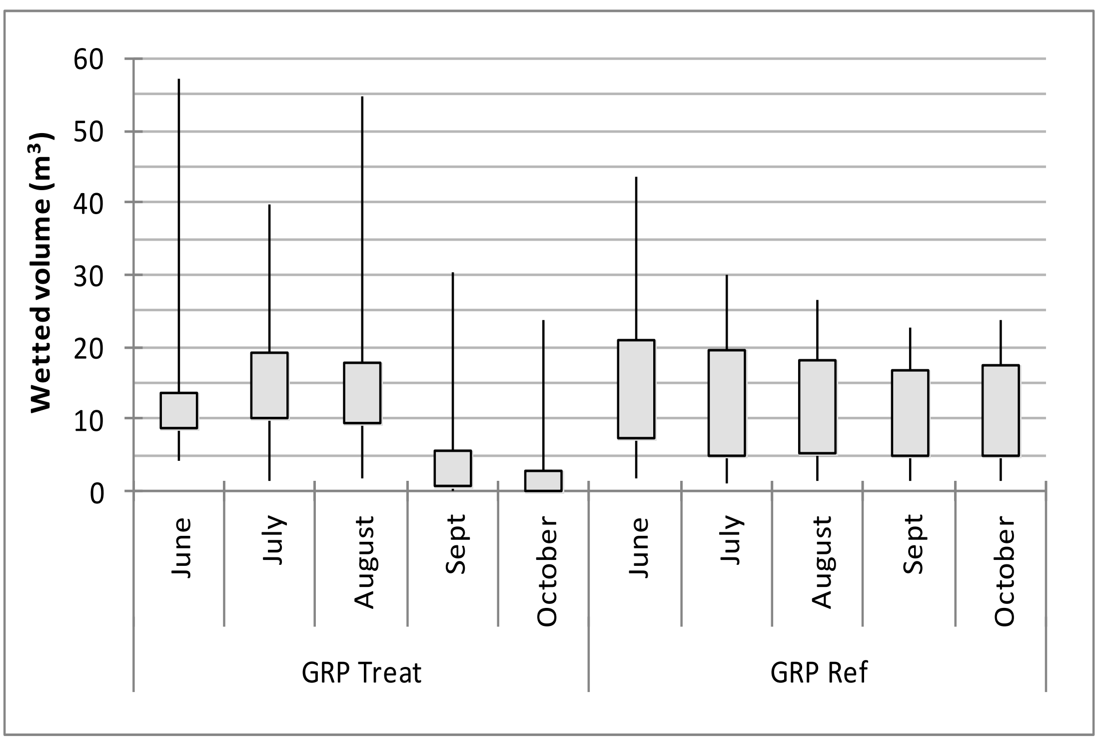

Figure 11. Minimum, maximum, 25 percentile, and 75 percentile of average wetted volume of pool and flatwater habitat in Grape Creek reference and treatment reaches between June and October, 2010.

Riffle habitat

Changes in riffle habitat were more extreme than those observed in pool and flatwater units, when evaluated by percent change. This was expected given that riffle habitat accounted for a lower proportion of total wetted volume in the study reaches. With the exception of some minor fluctuations in both Grape Creek reaches, the average width and maximum depth in riffles decreased steadily over the study period (**Table 5**). For all reaches, *excluding the Grape Creek reaches*, average loss in riffle width was 42% (with a range of 30% to 59%) and average loss in maximum depth was 33% (with a range of 26% to 47%) (**Table 5**). Average depth also declined in riffles over the study period but fluctuated significantly between months in most reaches (**Table 5**).

The wetted volume of riffles decreased significantly over the study period in most reaches (**Figure 12** to **Figure 14**). *In all but the Grape Creek reaches*, wetted volume decreased an average of 58%, with a drop of greater than 50% in the Palmer Creek reference reach (53%), the Mill Creek treatment reach (55%), the Green Valley Creek reference reach (67%), and the Green Valley Creek treatment reach (75%) (**Figure 12** and **Figure 13**).

The Grape Creek reference reach exhibited the least amount of change to wetted habitat, with an 8% decrease in average width, a 6% decrease in maximum depth, and a 16% decrease in wetted volume over the study period (**Table 5** and **Figure 14**). The Grape Creek treatment reach exhibited the greatest drop in width, depth, and wetted volume (100%), as all seven of the riffles in that reach were dry by the date of the September survey (**Table 5** and **Figure 14**). This was the only reach to lose entire habitat units, but disconnectivity also occurred in portions of the Green Valley Creek treatment reach. By August, low flow in riffle habitat likely inhibited movement between some pool and flatwater units within all study reaches, with the exception of the Grape Creek reference reach.

Table 5. Habitat characteristics measured monthly in riffle habitat on study reaches between June and October, 2010.

Reach	Sample month	Number habitat units (n)	Number wet units	Avg width (m) +/- 1 SD	Avg depth (cm) +/- 1 SD	Avg max depth (cm) +/- 1 SD	Avg wetted volume (m^3) +/- 1 SD	Total wetted volume (m^3)
GRE Treat	June	5	5	2.6 +/- 0.5	8.1 +/- 1.0	18.3 +/- 3.7	0.8 +/- 0.3	3.9
	July	5	5	2.2 +/- 0.7	8.3 +/- 1.5	17.6 +/- 4.2	0.7 +/- 0.5	3.7
	August	5	5	2.1 +/- 0.5	7.9 +/- 1.5	16.9 +/- 4.7	0.6 +/- 0.4	3.2
	Sept	5	5	1.7 +/- 0.4	4.5 +/- 1.0	14.0 +/- 5.9	0.3 +/- 0.1	1.3
	Oct	5	5	1.2 +/- 0.4	4.9 +/- 1.4	9.6 +/- 4.1	0.2 +/- 0.1	1.0
GRE Ref	June	9	9	2.0 +/- 0.7	6.8 +/- 2.1	17.3 +/- 5.9	0.6 +/- 0.5	5.6
	July	9	9	1.5 +/- 0.8	7.1 +/- 2.1	15.1 +/- 5.7	0.6 +/- 0.5	5.2
	August	9	9	1.2 +/- 0.4	7.6 +/- 2.2	14.9 +/- 5.1	0.5 +/- 0.4	4.3
	September	9	9	0.9 +/- 0.4	4.7 +/- 2.1	12.0 +/- 5.1	0.2 +/- 0.2	1.9
	October	9	9	0.8 +/- 0.3	5.0 +/- 1.7	11.8 +/- 5.3	0.2 +/- 0.2	1.9
MIL Treat	June	10	10	5.0 +/- 1.0	10.4 +/- 2.6	23.2 +/- 6.1	5.1 +/- 4.1	51.5
	July	10	10	4.2 +/- 0.7	11.4 +/- 2.8	22.6 +/- 7.0	5.0 +/- 4.0	49.9
	August	10	10	3.9 +/- 0.8	10.3 +/- 2.2	20.8 +/- 5.5	4.2 +/- 3.3	41.8
	September	10	10	3.6 +/- 0.6	8.8 +/- 3.0	17.8 +/- 4.8	3.2 +/- 2.1	32.0
	October	10	10	3.3 +/- 0.6	6.8 +/- 2.4	17.0 +/- 4.5	2.3 +/- 1.5	23.3
MIL Ref	June	14	14	3.2 +/- 1.0	8.8 +/- 2.0	20.7 +/- 6.7	2.8 +/- 2.4	39.7
	July	14	14	2.8 +/- 0.8	9.3 +/- 1.9	18.9 +/- 6.6	2.5 +/- 2.0	35.6
	August	14	14	2.5 +/- 0.8	9.5 +/- 2.2	18.2 +/- 6.2	2.5 +/- 2.2	35.4
	September	14	14	2.2 +/- 0.8	7.0 +/- 2.6	15.8 +/- 6.4	1.6 +/- 1.4	22.3
	October	14	14	2.2 +/- 0.7	7.0 +/- 2.4	14.8 +/- 6.3	1.7 +/- 1.5	23.5
PAL Ref	June	14	14	3.1 +/- 0.9	11.8 +/- 1.6	23.5 +/- 6.4	5.0 +/- 5.4	70.3
	July	14	14	3.1 +/- 0.7	12.2 +/- 2.8	22.1 +/- 5.8	4.8 +/- 4.2	67.8
	August	14	14	2.5 +/- 0.9	11.5 +/- 2.5	20.2 +/- 6.6	3.8 +/- 3.7	53.9
	September	14	14	2.3 +/- 0.6	8.7 +/- 1.3	18.1 +/- 4.8	2.7 +/- 2.6	38.0
	October	14	14	2.2 +/- 0.5	7.6 +/- 1.7	15.9 +/- 4.8	2.3 +/- 2.5	32.8
GRP Treat	June	7	7	1.5 +/- 0.3	5.4 +/- 2.2	13.9 +/- 7.6	0.5 +/- 0.4	3.2
	July	7	7	1.5 +/- 0.3	5.3 +/- 1.7	13.5 +/- 4.8	0.4 +/- 0.4	2.9
	August	7	7	1.5 +/- 0.4	5.8 +/- 2.6	14.0 +/- 6.8	0.5 +/- 0.5	3.3
	September	7	0	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0	0.0
	October	7	0	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0	0.0 +/- 0.0	0.0
GRP Ref	June	11	11	1.4 +/- 0.8	7.0 +/- 4.5	17.5 +/- 14.7	0.3 +/- 0.4	3.8
	July	11	11	1.5 +/- 0.9	7.4 +/- 3.9	16.4 +/- 12.9	0.4 +/- 0.3	3.9
	August	11	11	1.4 +/- 0.8	6.7 +/- 3.7	16.1 +/- 13.1	0.3 +/- 0.3	3.6
	September	11	11	1.2 +/- 0.8	6.4 +/- 4.3	14.5 +/- 13.7	0.2 +/- 0.2	2.6
	October	11	11	1.3 +/- 0.7	7.4 +/- 3.0	16.5 +/- 14.1	0.3 +/- 0.3	3.2

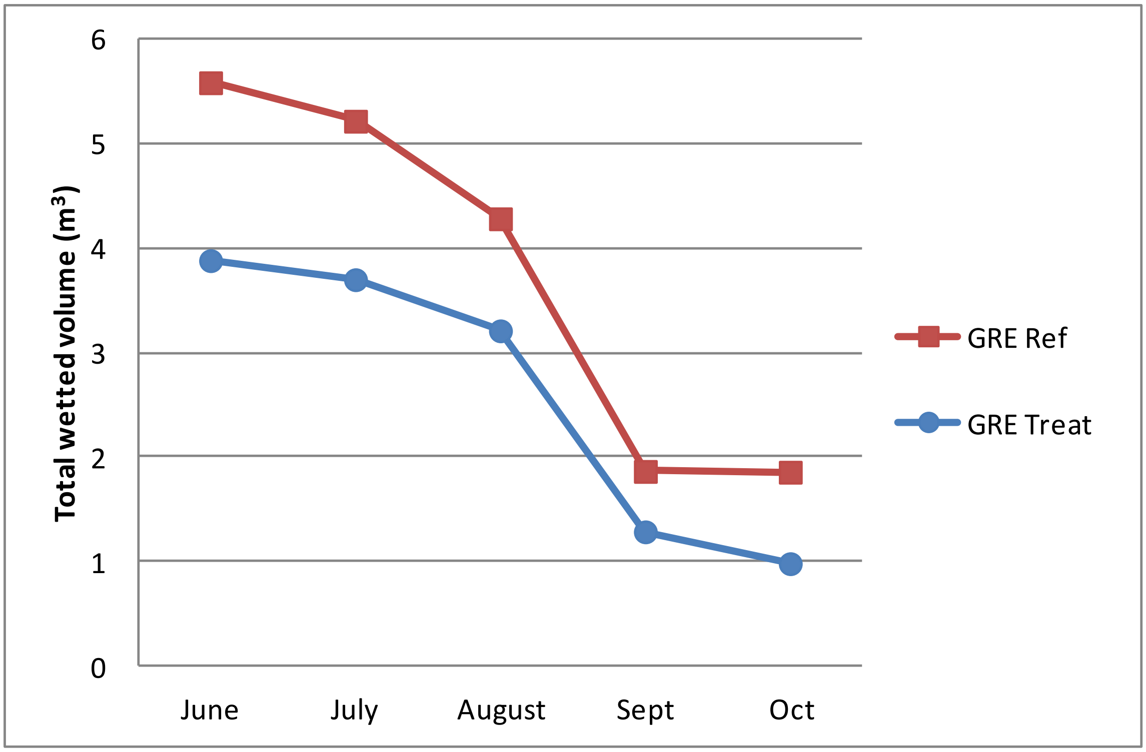

Figure 12. Total wetted volume of riffle habitat in Green Valley Creek reference and treatment reaches between June and October, 2010.

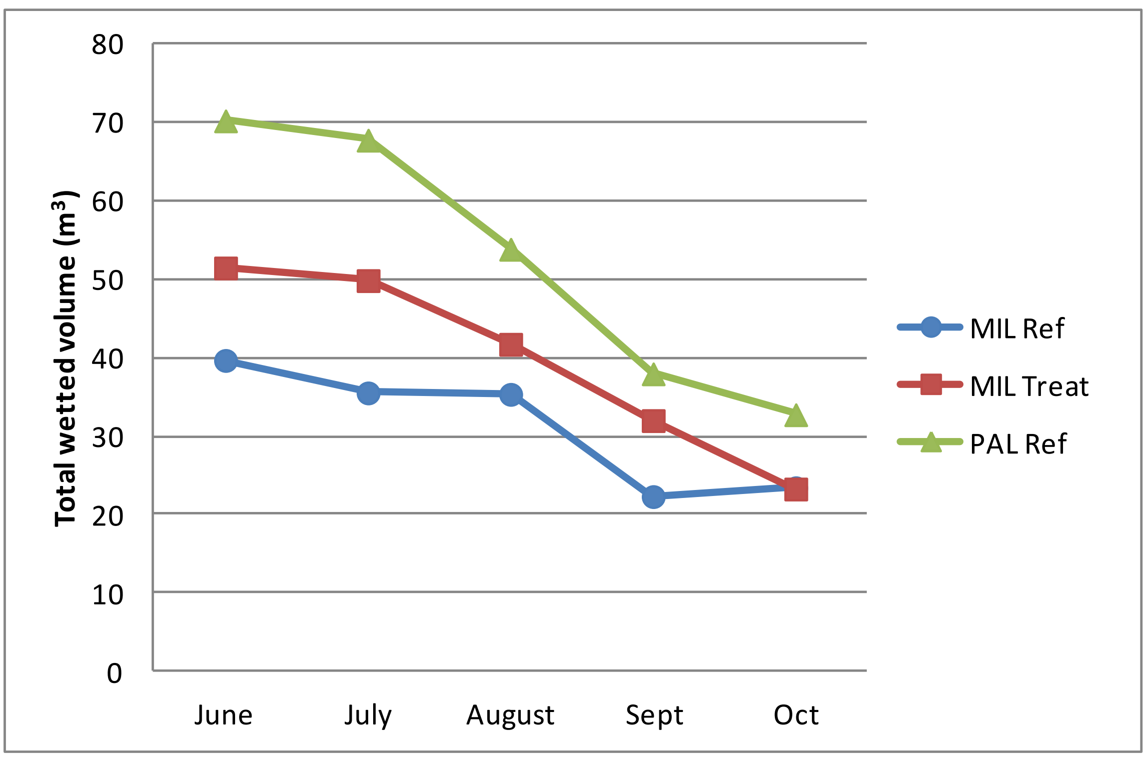

Figure 13. Total wetted volume of riffle habitat in Mill and Palmer Creek reference and treatment reaches between June and October, 2010.

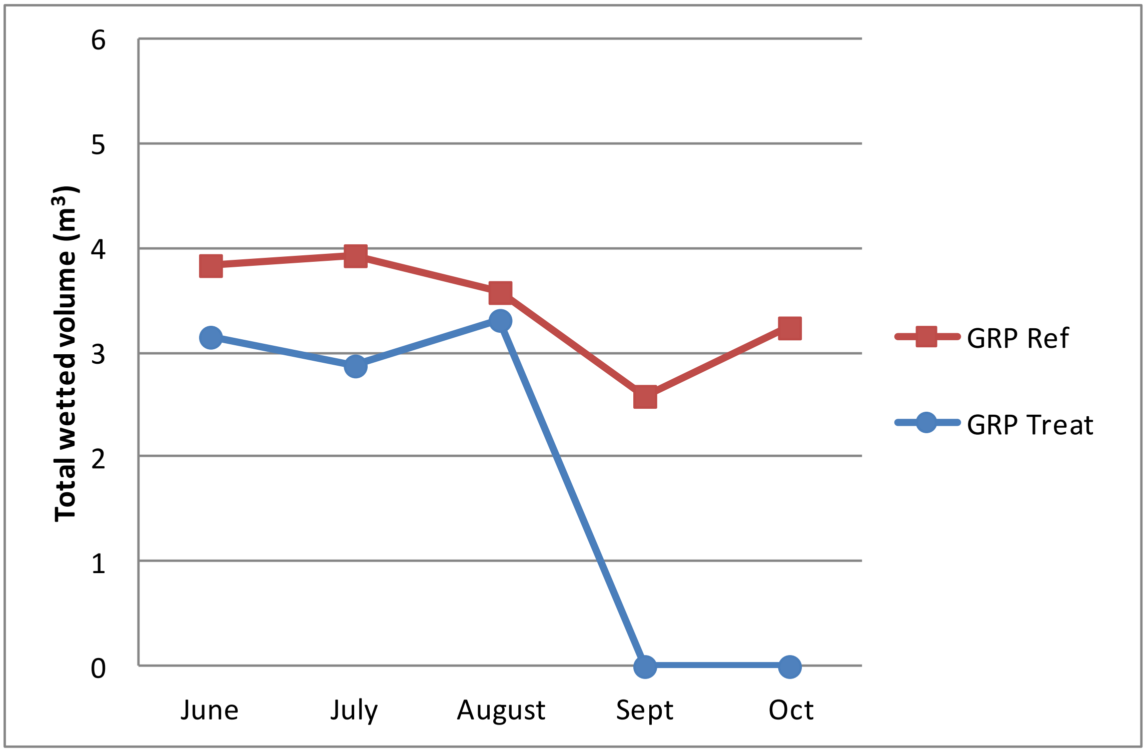

Figure 14. Total wetted volume of riffle habitat in Grape Creek reference and treatment reaches between June and October, 2010.

Dissolved oxygen sampling

DO values were summarized at the reach scale. The highest average DO concentrations were observed in the Mill reference reach, Palmer reference reach, and Mill treatment reach (**Table 6**). The lowest average DO concentrations were observed in both reaches of Grape Creek (**Table 6**). With the exception of the Grape reference reach, DO values in the references reaches were higher than those in the treatment reaches. The Mill treatment reach, however, exhibited values similar to those observed in the reference reaches.

The Green Valley treatment reach and Grape Creek reference reach showed continuous decreases in average DO concentrations for each month between June and October (**Table 6, Figure 15,** and **Figure 17**). Aside from a slight increase between the June and July sample, the Grape Creek treatment reach also showed a general decline in average DO over the study period (**Table 6** and **Figure 17**). The remaining reaches exhibited unique patterns with varying decreases and increases in average DO concentrations from month to month (**Table 6**, and **Figure 15** to **Figure 17**).

The Grape Creek treatment reach exhibited the greatest variation in average DO concentrations, with a difference of 5.0 mg/L between the highest and lowest readings in July and October, respectively (**Table 6** and **Figure 17**). This could be partially explained by the fact that pools were disconnected in October, when only four of the 12 pools in the Grape Creek treatment reach retained enough water to sample and the lowest values were recorded. The Green Valley treatment reach also had significant variation in average values between months, with a decrease of 3.2 mg/L between June and October (**Table 6** and **Figure 15**). The Mill Creek treatment reach exhibited the most stable DO values of all reaches sampled, with a range of only 1.0 mg/L between the highest and lowest monthly averages. The Mill Creek reference reach also maintained a relatively stable concentration of DO, with a range of 1.3 mg/L (**Table 6** and **Figure 16**).

The North Coast Regional Water Quality Control Board listed a DO objective of 7.0 mg/L as a year-round daily minimum in the Russian River Hydrologic Unit (NCRWQCB 2007). Average DO concentrations fell below 7.0 mg/L on more than half of the months sampled in both Grape Creek reaches. Average DO was also less than 7.0 mg/L on the Green Valley treatment reach in September and October, and the Green Valley reference reach in October (**Table 6**). Moderate production impairment is known to occur below 5.0 mg/L (NCRWQCB 2007). The Grape Creek reference reach had an average concentration of 4.9 mg/L in October (**Table 6**). Food conversion decreases below 4.5 mg/L, inhibiting growth in juvenile salmonids, who have been documented avoiding waters with DO concentrations this low (McMahon 1983). Average DO concentrations were 4.5 mg/L or less in October in the Green Valley treatment reach and September in the Grape Creek treatment reach (**Table 6**). Below 4.0 mg/L, severe production impairment occurs in juvenile salmonids (NCRWQCB 2007). In the Grape Creek treatment reach, average DO dropped to 3.6 mg/L in October (**Table 6**). The lower limit to avoid acute mortality in salmonids is 3.0 mg/L (NCRWQCB 2007). No study reaches exhibited average DO values below 3.0 mg/L during the study period. DO samples were collected during the late morning and values do not represent the lowest point in the diel cycle, which was generally in the early morning hours but varied considerably between different reaches, according to initial 24-hour continuous logging data.

Table 6. Average monthly DO by reach between June and October, 2010.

Reach	Sample month	Number of pools sampled (n)	Average DO (mg/L) +/- 1 SD
GRE Treat	June	10	7.7 +/- 0.1
	July	10	7.5 +/- 0.1
	August	10	7.2 +/- 0.2
	September	10	6.6 +/- 0.2
	October	10	4.5 +/- 0.5
GRE Ref	June	9	9.1 +/- 0.2
	July	9	8.0 +/- 0.1
	August	9	8.1 +/- 0.3
	September	9	8.4 +/- 0.7
	October	9	6.4 +/- 1.0
MIL Treat	June	10	9.5 +/- 0.1
	July	10	9.6 +/- 0.1
	August	10	9.9 +/- 0.1
	September	10	10.0 +/- 0.2
	October	10	9.0 +/- 0.3
MIL Ref	June	14	9.9 +/- 0.0
	July	14	9.6 +/- 0.1
	August	14	9.4 +/- 0.1
	September	14	10.5 +/- 0.2
	October	14	10.7 +/- 0.2
PAL Ref	June	15	10.1 +/- 0.1
	July	15	9.5 +/- 0.1
	August	15	10.1 +/- 0.1
	September	15	11.1 +/- 0.4
	October	15	8.8 +/- 0.2
GRP Treat	June	12	8.4 +/- 0.4
	July	12	8.6 +/- 0.4
	August	12	5.3 +/- 1.6
	September	9	4.2 +/- 1.1
	October	4	3.6 +/- 2.2
GRP Ref	June	13	7.3 +/- 0.3
	July	13	6.2 +/- 0.7
	August	13	5.8 +/- 0.3
	September	13	5.7 +/- 0.9
	October	13	4.9 +/- 0.9

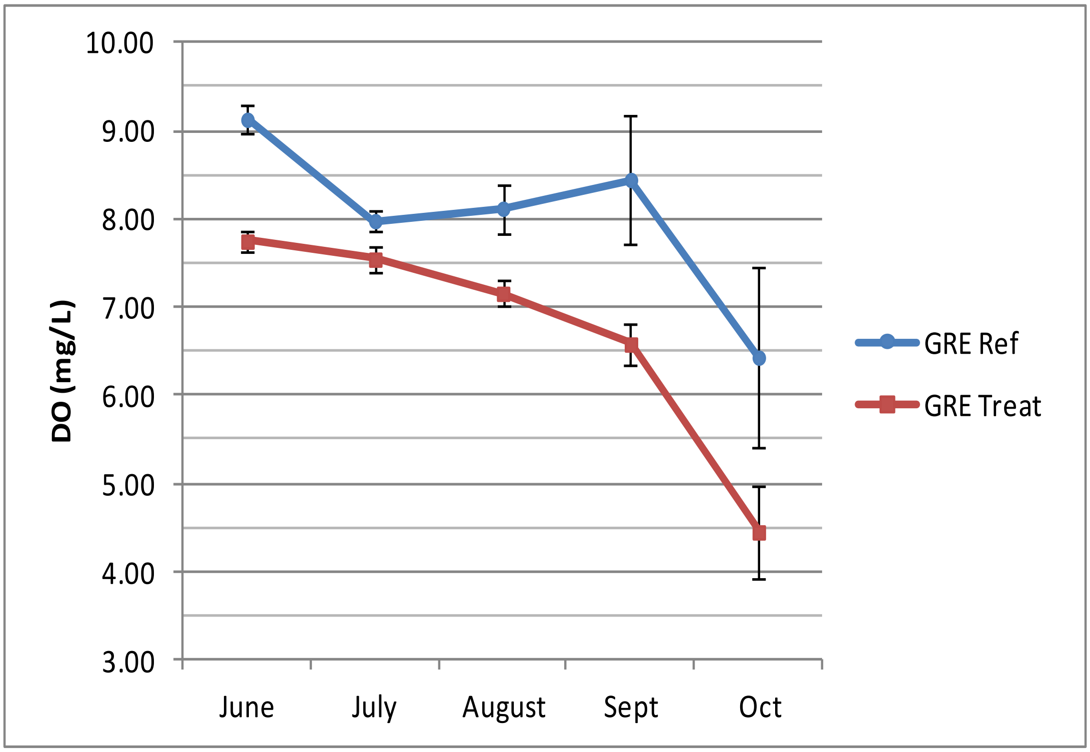

Figure 15. Average DO in Green Valley Creek reference and treatment reaches between June and October, 2010.

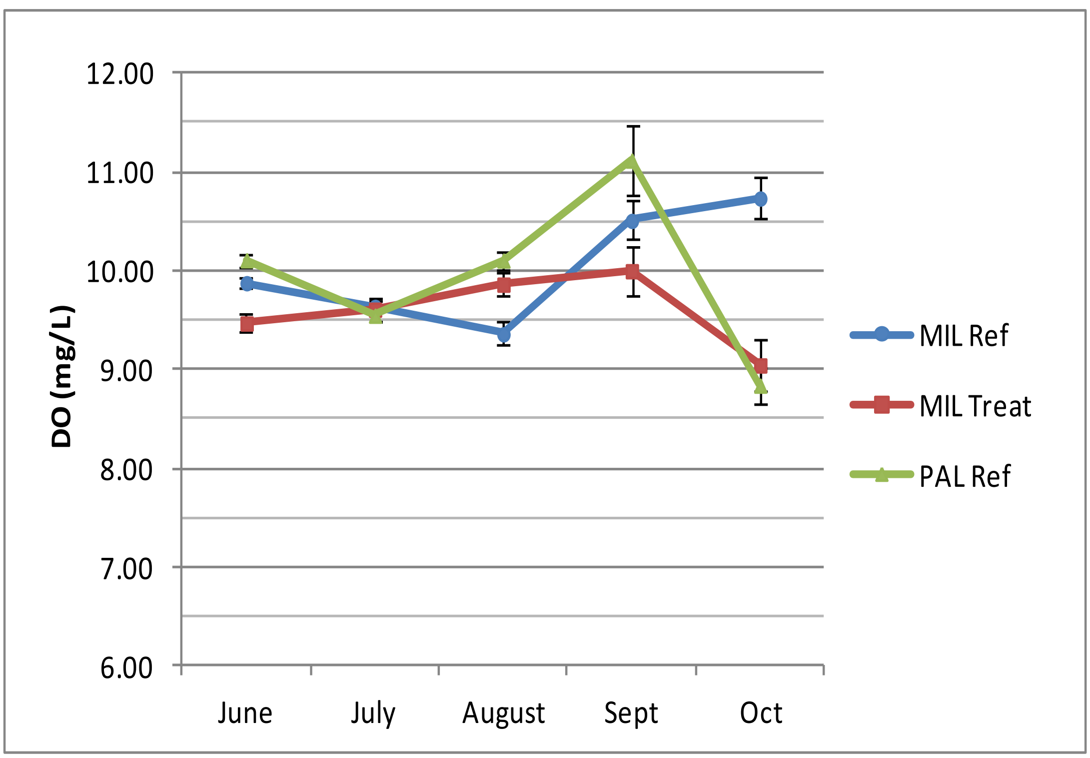

Figure 16. Average DO in Mill Creek and Palmer Creek reference and treatment reaches between June and October, 2010.

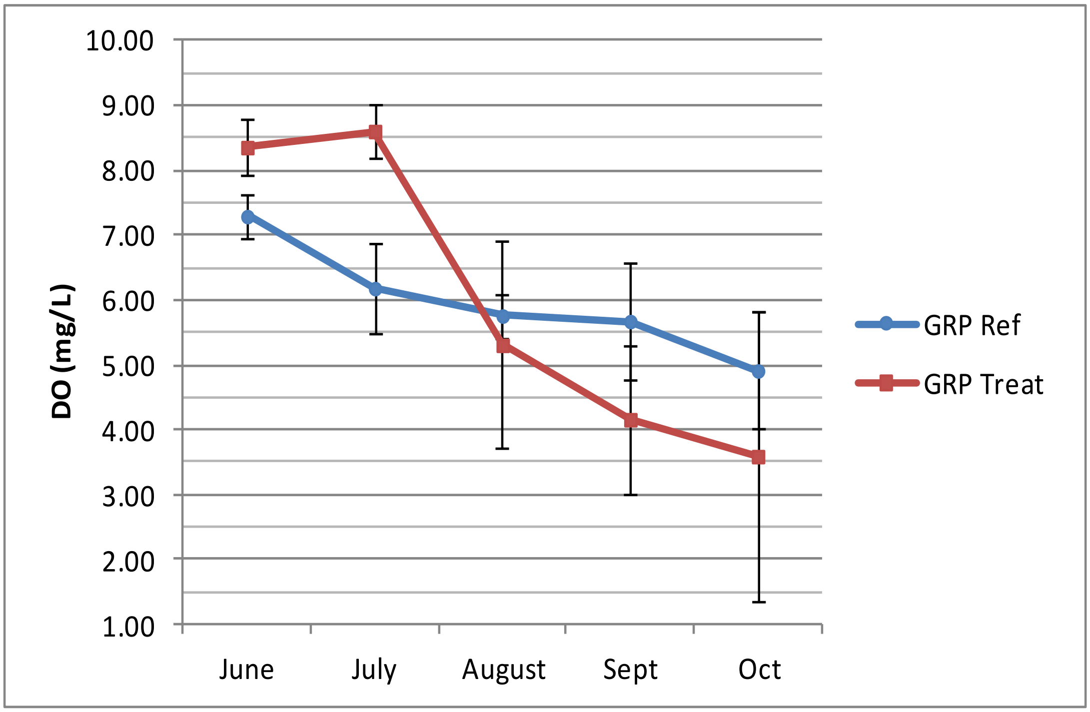

Figure 17. Average DO in Grape Creek reference and treatment reaches between June and October, 2010.

Temperature

Temperatures in all reaches of Mill and Palmer Creeks, and the references reaches on Green Valley and Grape Creeks, remained relatively cool throughout the study period, with the warmest peaks in late June, late July, and late August (**Figure 19** to **Figure 22,** and **Figure 24).** The warmest water temperatures occurred in the Green Valley Creek treatment reach, followed by the Grape Creek treatment reach (**Figure 18** and **Figure 23**). In all streams, average and maximum daily water temperatures observed in treatment reaches were higher than those observed in reference reaches (**Figure 18** to **Figure 24**).

The optimum summer temperature range for juvenile coho is 10° to 15°C (McMahon 1983). At water temperatures greater than 20° C, significant decreases in swimming speed and increases in mortality due to disease have been noted to occur (McMahon 1983). 25.8°C is the upper lethal limit for coho at all life stages (Raleigh et al 1984). *Average* daily water temperatures in all study reaches were below 20° C during the study period (**Figure 18** to **Figure 24**). *Maximum* daily temperatures exceeded this stress threshold in the Green Valley treatment reach on four days in June, 18 days in July, 17 days in August, and six days in September, with an season high of 22.1° C on August 24, 2010 (**Figure 18**). *Maximum* daily temperature also exceeded 20° C in the Grape Creek treatment reach on one day in June and three days in July, with a season high of 20.6° C on June 28, 2010 (**Figure 23**). Maximum daily temperatures reached the following highs in the remaining reaches: 18.5° C in the Green Valley Creek reference reach, 19.6° C in the Mill Creek treatment reach, 18.4° C in the Mill Creek reference reach, 18.0° C in the Palmer Creek reference reach, and 18.1° C in the Grape Creek reference reach (**Figure 19** to **Figure 22,** and **Figure 24).**

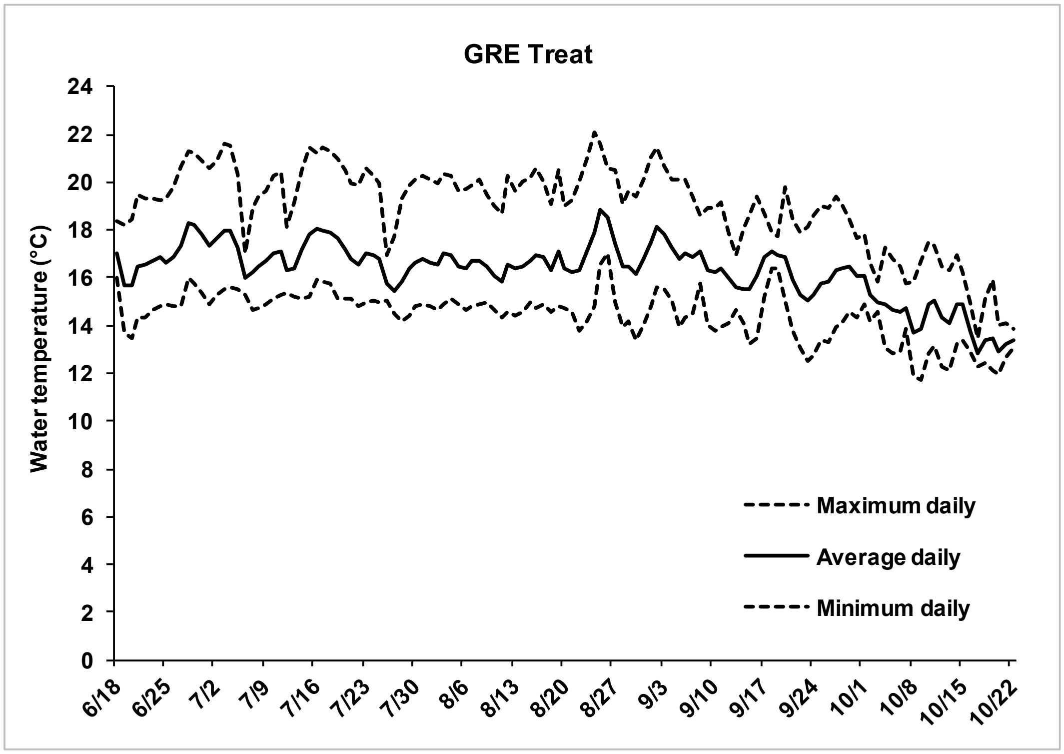

Figure 18. Average daily, maximum daily and minimum daily temperatures in the Green Valley Creek treatment reach between June 18 and October 22, 2010.

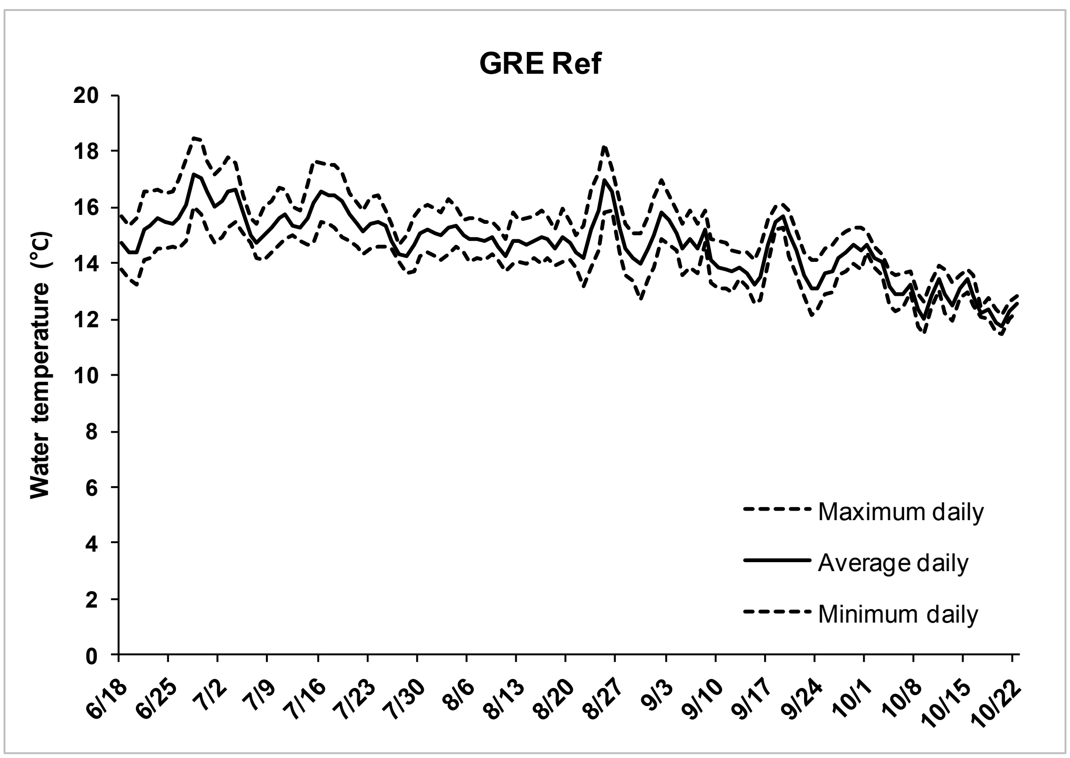

Figure 19. Average daily, maximum daily and minimum daily temperatures in the Green Valley Creek reference reach between June 18 and October 22, 2010.

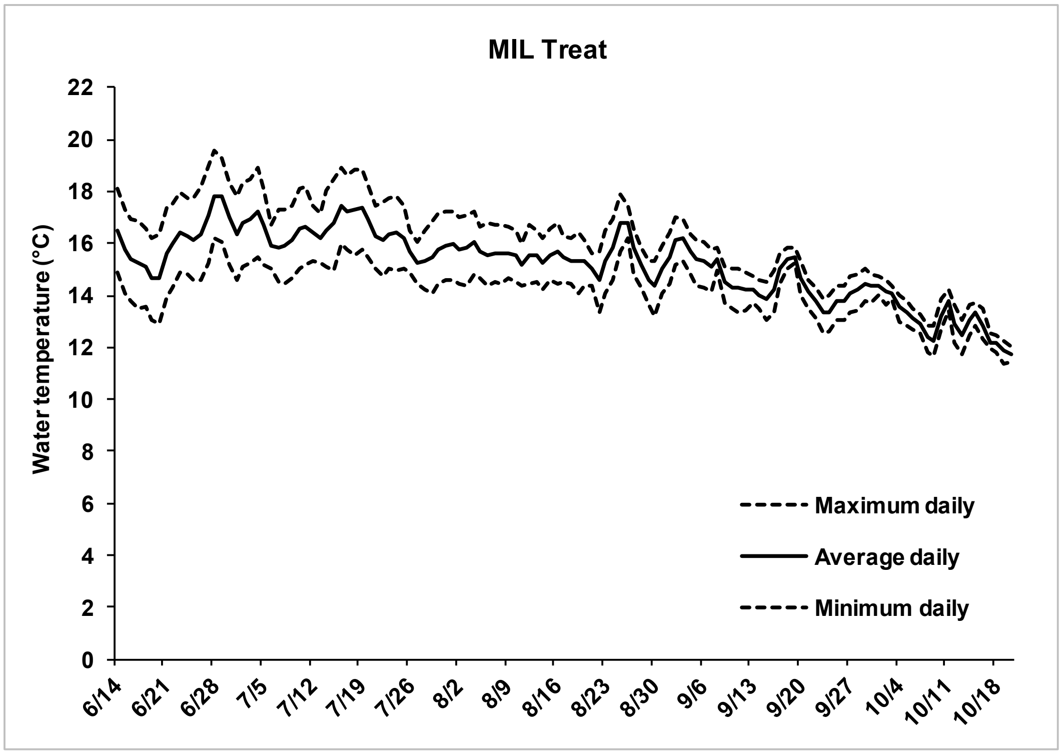

Figure 20. Average daily, maximum daily and minimum daily temperatures in the Mill Creek treatment reach between June 14 and October 20, 2010.

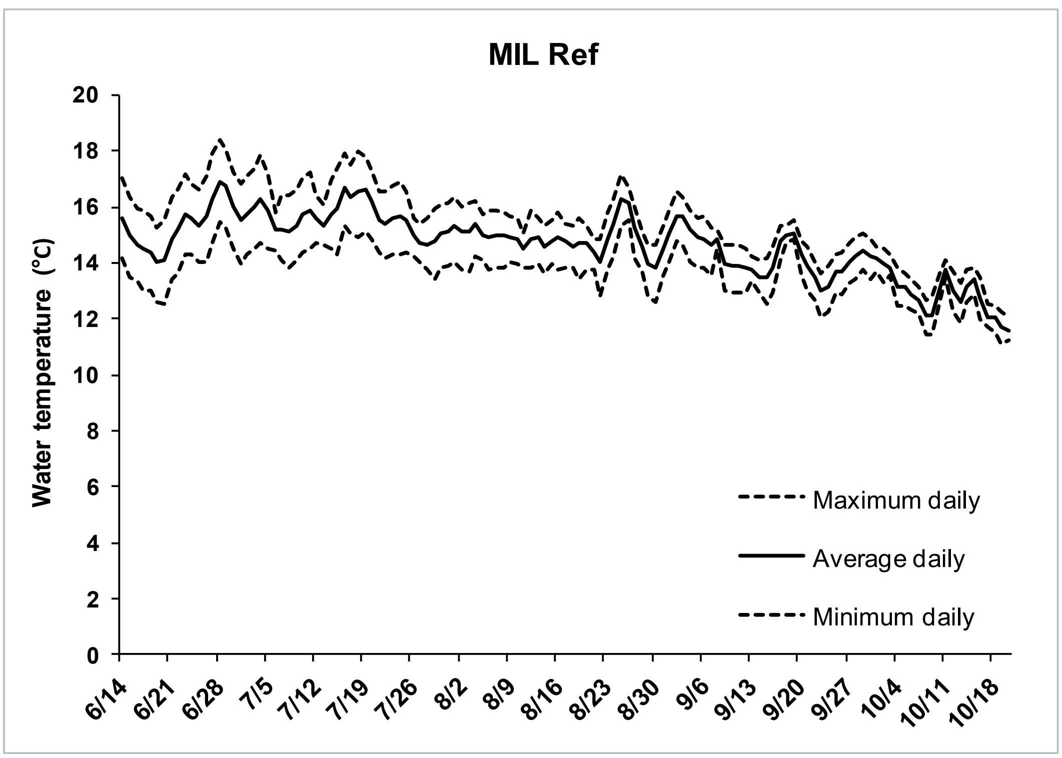

Figure 21. Average daily, maximum daily and minimum daily temperatures in the Mill Creek reference reach between June 14 and October 20, 2010.

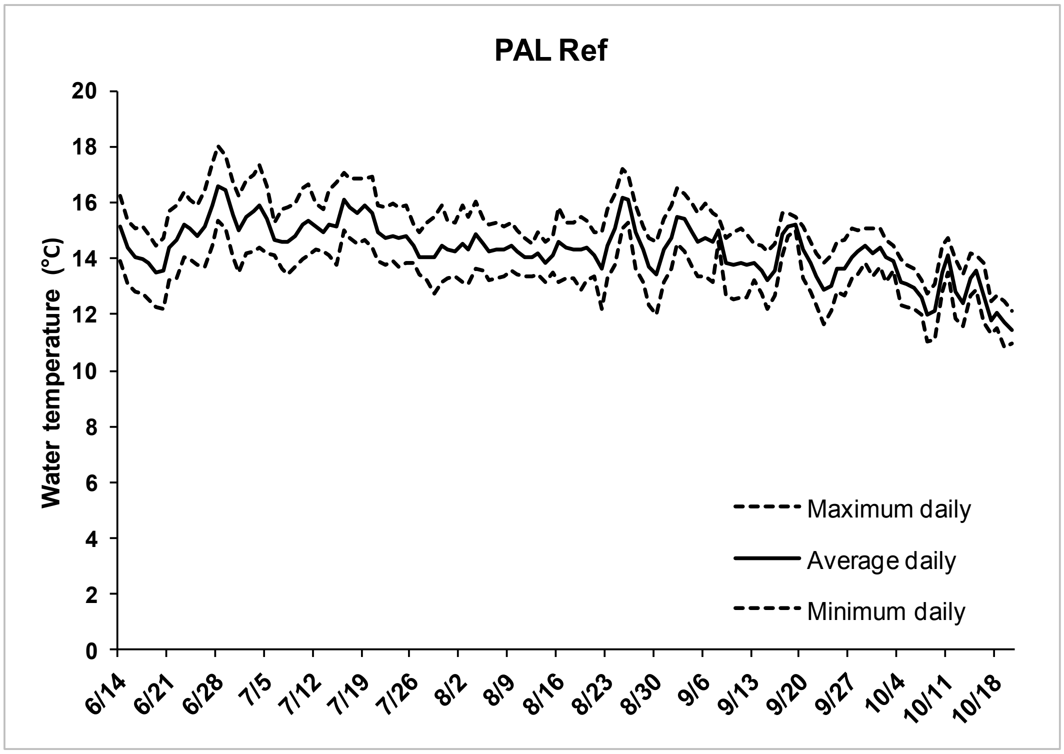

Figure 22. Average daily, maximum daily and minimum daily temperatures in the Palmer Creek reference reach between June 14 and October 20, 2010.

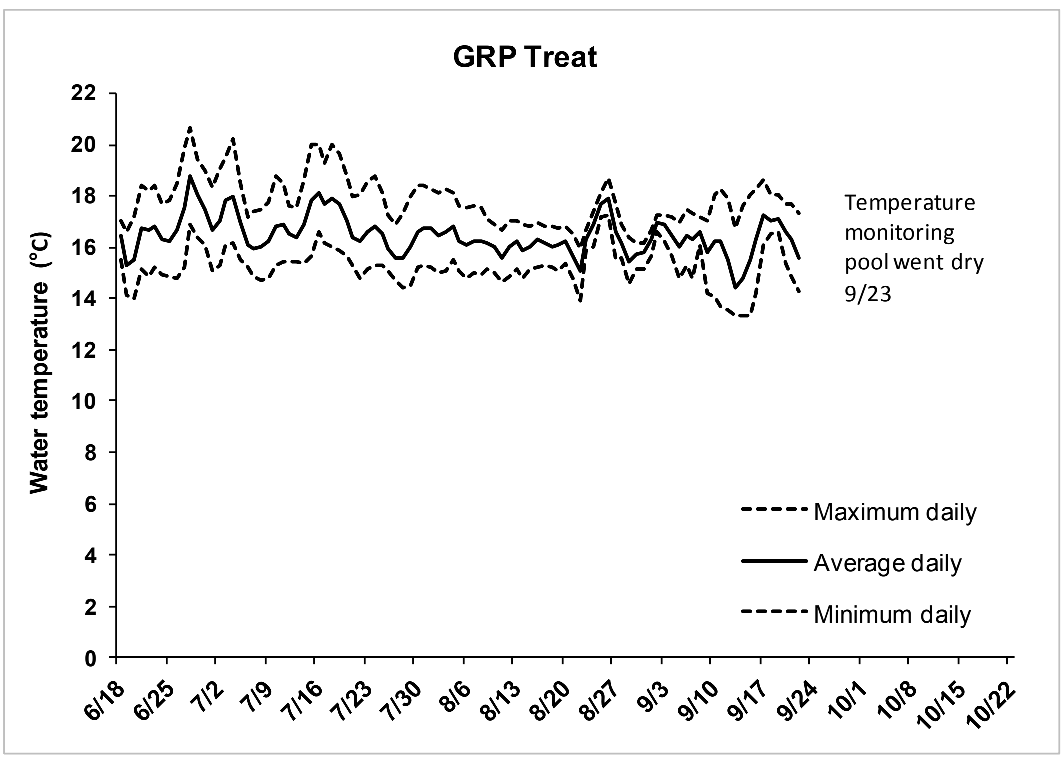

Figure 23. Average daily, maximum daily and minimum daily temperatures in the Grape Creek treatment reach between June 18 and October 22, 2010.

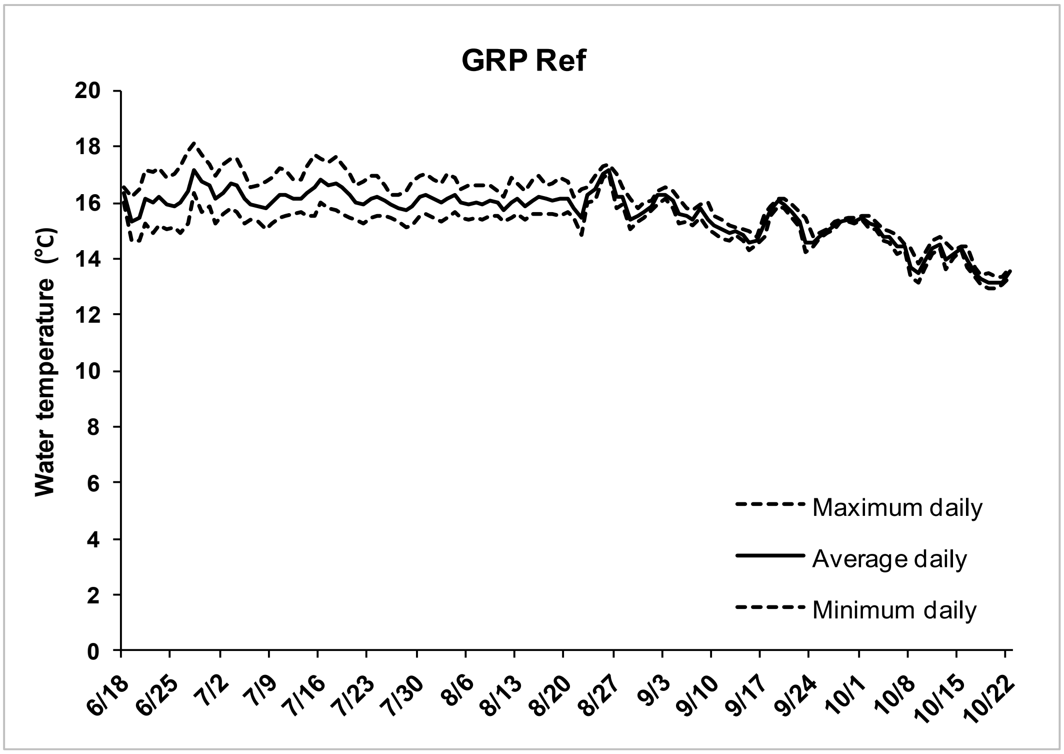

Figure 24. Average daily, maximum daily and minimum daily temperatures in the Grape Creek reference reach between June 18 and October 22, 2010.

Coho movement from study reaches

Block seines were placed at the downstream ends and midpoints of each reach for the first week after stocking in order to limit fish movement out of the study reaches. Despite this, many coho were detected leaving each reach. This was likely a result of one or more small passage points in or around the block nets and the ability of coho fry to surmount what appeared to be low-flow barriers at the upstream reach boundaries, combined with the fishes' natural tendency to move during the first few days after being released. Because PIT tag antennas were only installed at the downstream end of each reach, the study design was modified to extend paired PIT tag wanding samples upstream of the original reach boundaries to the point where fish were no longer detected, beginning with the July sample.

A total of 3,954 PIT tagged fish were released into all of the study reaches, excluding the Green Valley treatment reach, which was not stocked (**Table 2**). Of these, a total of 466 (12%) moved out during the study period. Eighty percent of the fish that moved left during the first two weeks after stocking and prior to the first wanding event at the end of June (**Table 7**). The majority of movement was in an upstream direction, with 91% of the movers detected upstream of the study reach, and 9% detected on the antenna at the downstream end of each reach. Little movement occurred in Grape Creek compared with the other creeks (**Table 7**). Movement was relatively high in both reaches of Mill Creek (**Table 7**).

Table 7. Number of PIT tagged coho detected upstream or downstream of study reaches.

Reach Code	Downstream movement		Upstream movement	
	Between stocking and 1st wand sample	Between 1st and last wand samples	Between stocking and 1st wand sample	Between 1st and last wand samples
GRE Ref	0	4	21	22
MIL Treat	13	0	118	4
MIL Ref	7	1	165	19
PAL Ref	3	5	44	28
GRP Treat	0	6	0	1
GRP Ref	2	1	1	1

Oversummer survival

Oversummer survival of coho yoy, between the mid-June release and the final wand sample in mid October, varied among streams and between reaches within streams (**Figure 25**). Oversummer survival was lowest in Grape Creek (0.19 treatment reach, 0.42 reference reach) (**Figure 25**). These rates were within the range of streamwide estimates on other Coho Broodstock Program streams between 2005 and 2009 (Obedzinski et. al. 2009, UCCE/CSG unpublished data). Survival within the Mill Creek watershed ranged between 0.6 in the Mill Creek reference reach and 0.75 in the Palmer Creek reference reach (**Figure 25**). Survival in the Green Valley Creek reference reach (0.87) was higher than any summer survival rate previously observed in Russian River tributaries as part of the Coho Broodstock Program's monitoring effort (Obedzinski et. al. 2009, UCCE/CSG unpublished data) (**Figure 25**).

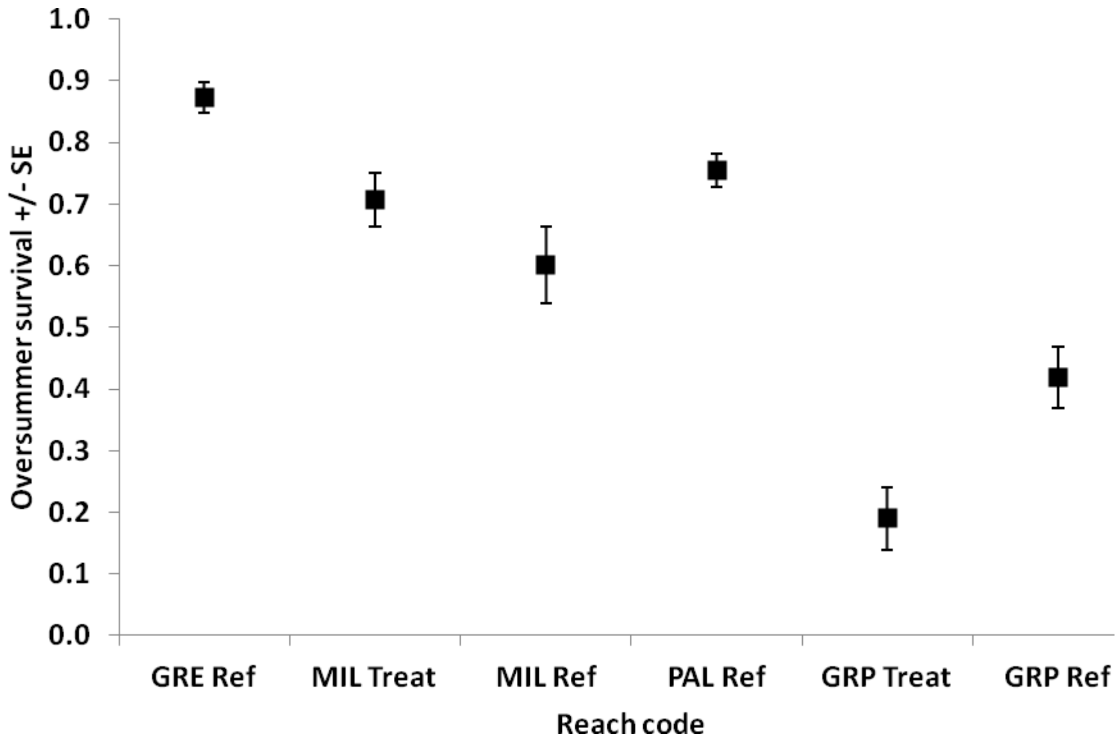

Figure 25. Cumulative oversummer survival (June to October) of juvenile coho released into reference and treatment reaches in spring 2010.

Monthly survival in relation to flow and environmental variables

In the Green Valley, Mill, and Palmer Creek reaches, survival remained high throughout the study period, despite declines in average daily flow and, in some cases, periods of zero surface flow (**Figure 26** to **Figure 29**). In the Mill Creek reaches, survival was lower during the first two-week interval between stocking and the first PIT tag wand sample (**Figure 27** and **Figure 28**). This has been observed in previous years (UCCE/CSG unpublished data) and is likely related to the fact that the fish are undergoing a stressful transition from the hatchery to the stream environment. In the Grape Creek treatment reach, survival decreased during the last two intervals when mean daily cfs fell below 0.1 (**Figure 30)**. Survival in the Grape Creek reference reach was generally high, with the exception of the third interval during the month of August when it dropped from 0.87 in July to 0.62 (**Figure 31**). This dip in survival did not appear to be related to flow or other environmental variables.

In all study reaches, QAICc values indicated that there was no strong evidence that the flow metrics tested affected survival. In both Mill Creek reaches, there was weak to moderate evidence that minimum and average flow affected survival. Given that survival remained high over the study period in both reaches, however, this result did not appear to be biologically significant. Similarly, there was no evidence for a relationship between survival and other environmental variables, with the exception of the Grape Creek treatment reach, where QAICc values indicated moderate support for models that included total or average wetted volume.

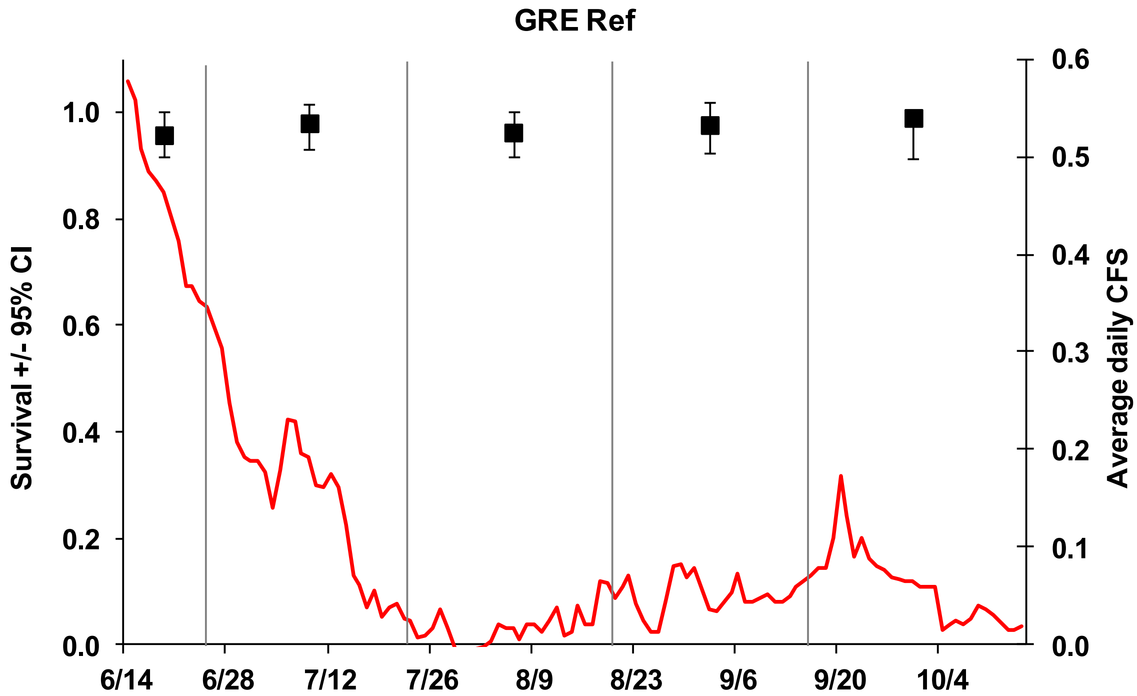

Figure 26. Monthly survival of coho yoy released into the Green Valley Creek reference reach in relation to stream flow. Gray bars represent PIT tag wand sampling occasions.

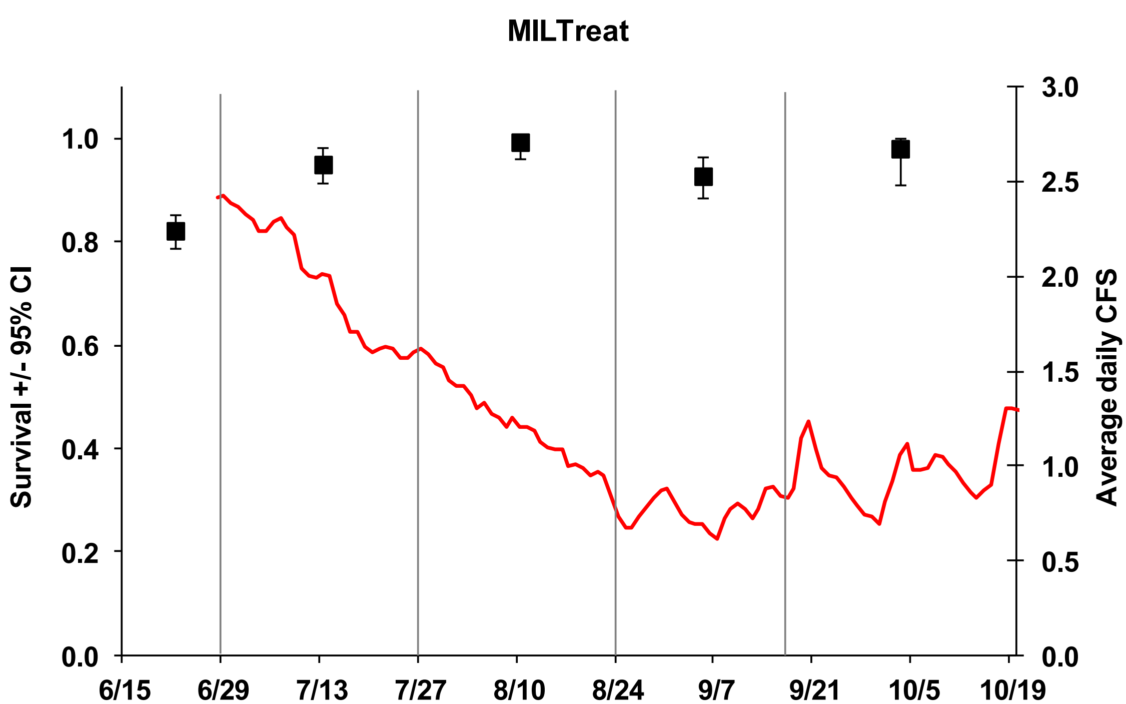

Figure 27. Monthly survival of coho yoy released into the Mill Creek treatment reach in relation to stream flow. Gray bars represent PIT tag wand sampling occasions.

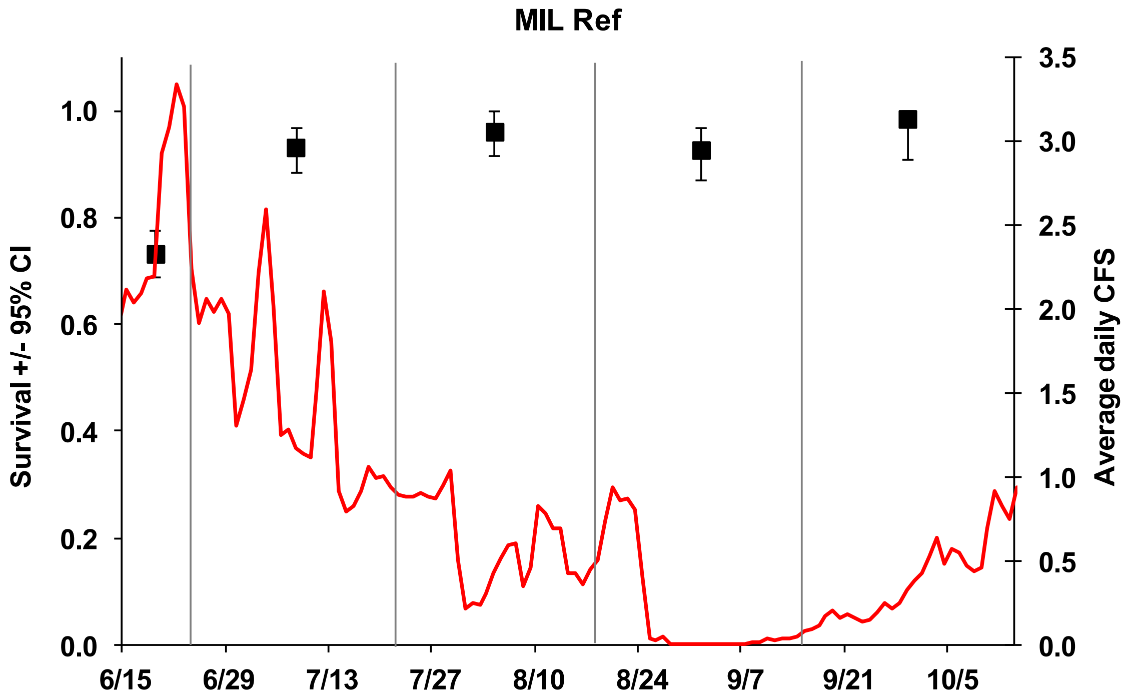

Figure 28. Monthly survival of coho yoy released into the Mill Creek reference reach in relation to stream flow. Gray bars represent PIT tag wand sampling occasions**.**

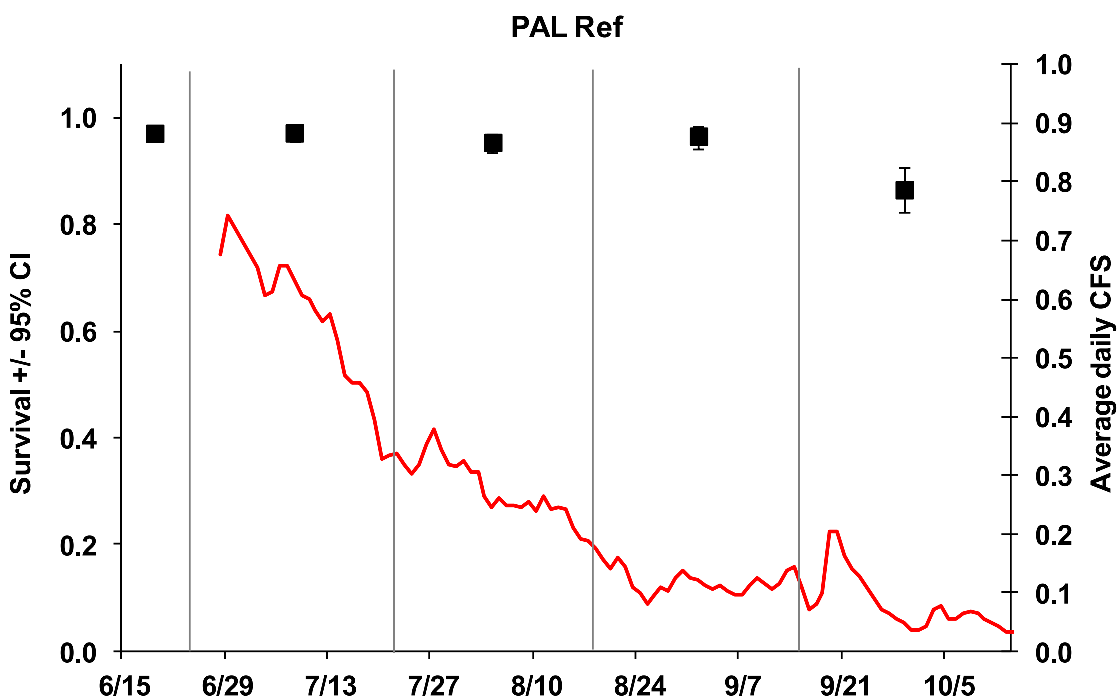

Figure 29. Monthly survival of coho yoy released into the Palmer Creek reference reach in relation to stream flow. Gray bars represent PIT tag wand sampling occasions.

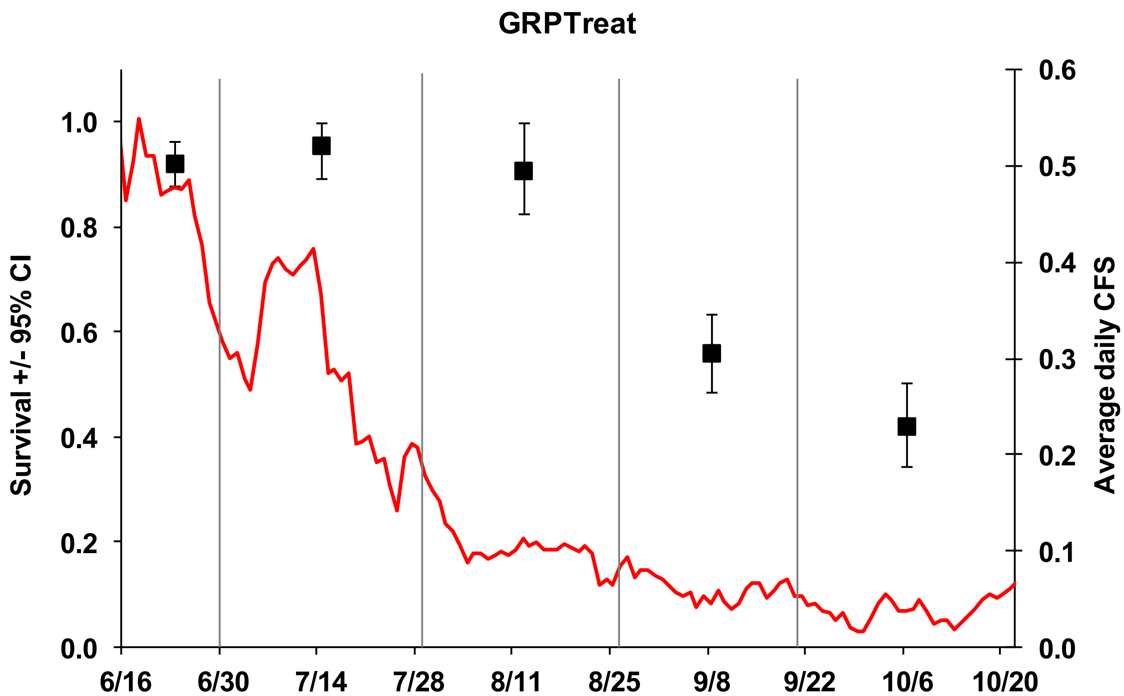

Figure 30. Monthly survival of coho yoy released into the Grape Creek treatment reach in relation to stream flow. Gray bars represent PIT tag wand sampling occasions.

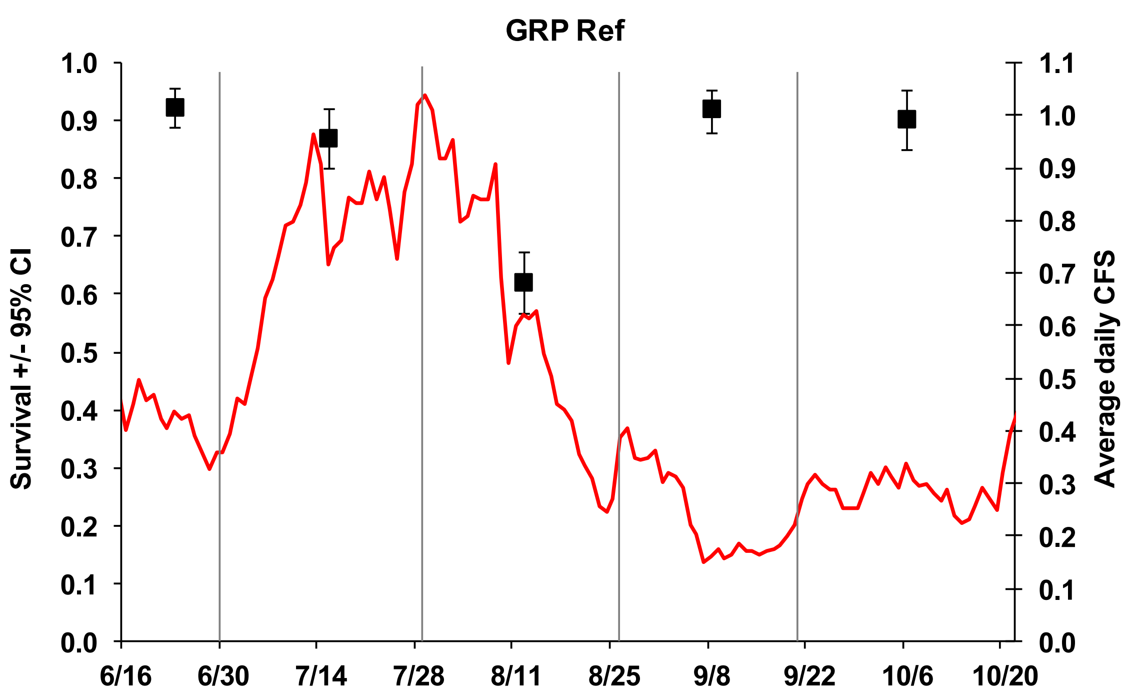

Figure 31. Monthly survival of coho yoy released into the Grape Creek reference reach in relation to stream flow. Gray bars represent PIT tag wand sampling occasions.

Size, condition, and oversummer growth

Between the first week of June when the coho were tagged and the fall electrofishing sample, coho yoy increased in length and weight, and decreased in condition factor (**Figure 32**). On average, coho increased in size by 9mm and 1.1g over the course of the study period. Average condition factor decreased by 0.12 (**Figure 32**). Growth rates were highest in the Mill Creek treatment reach and similar in all other reaches (**Figure 33** and **Figure 34**).

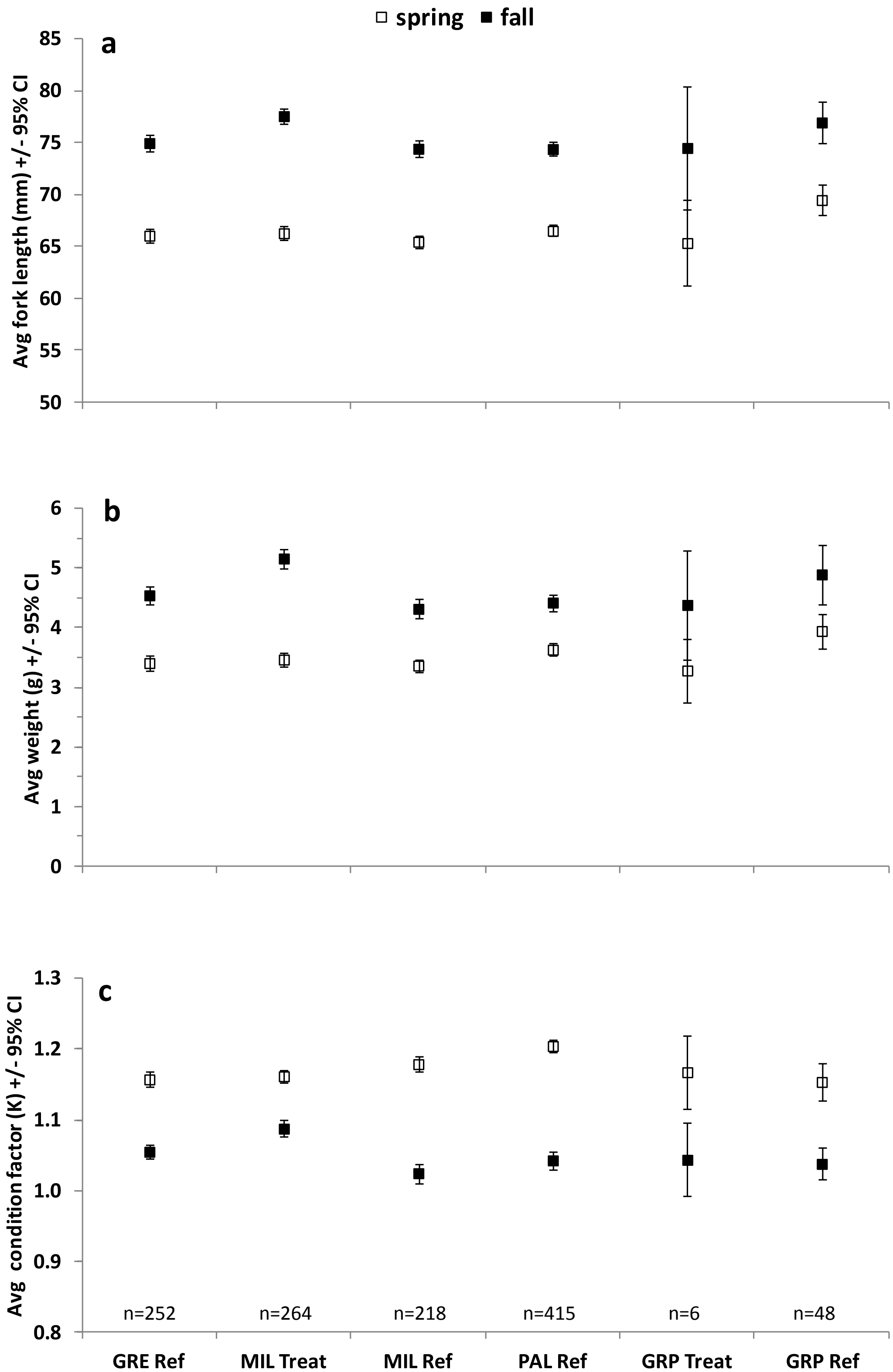

Figure 32. Average fork length (a), weight (b), and condition factor (c) of PIT tagged coho measured at the hatchery prior to release and during the fall electrofishing sample.

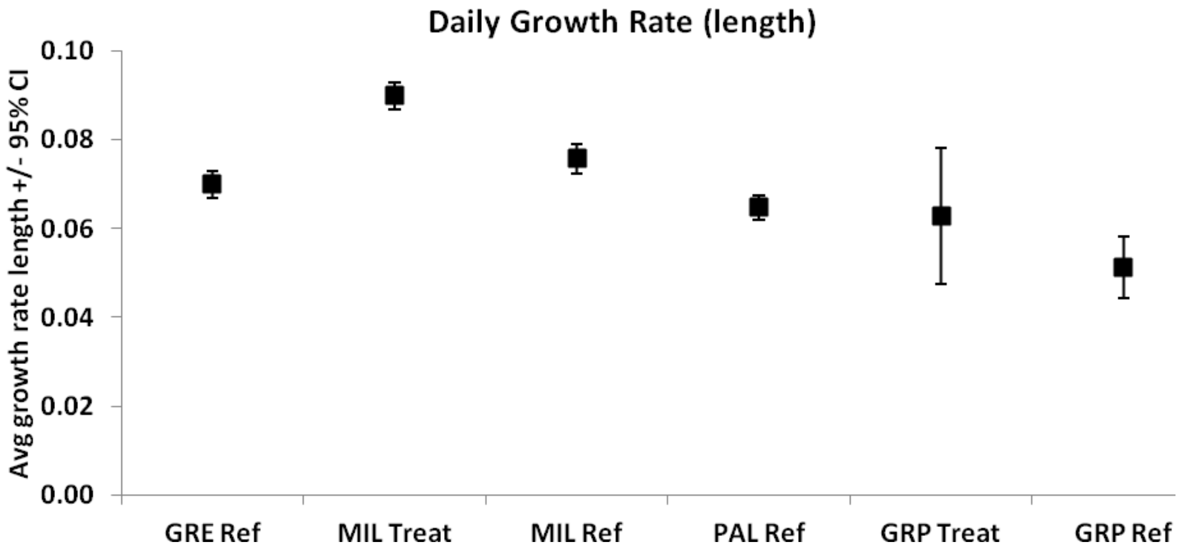

Figure 33. Average specific growth rates of juvenile coho stocked in spring and recaptured in fall 2010. Specific growth rate was calculated for individual PIT tagged fish as $(FL_2\text{-}FL_1)/(t_2\text{-}t_1)$ where FL_1= fork length at hatchery prior to release, FL_2= fork length during fall electrofishing sample, t_1=date measured at hatchery, and t_2= date captured electrofishing.

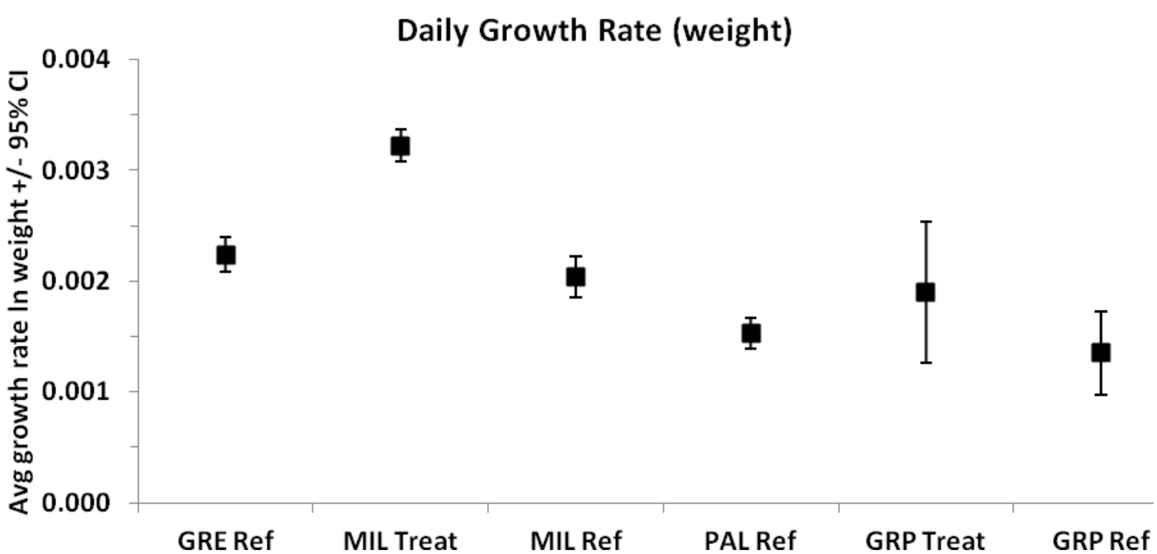

Figure 34. Average specific growth rates of juvenile coho stocked in spring and recaptured in fall 2010. Specific growth rate was calculated for individual PIT tagged fish as $(\ln(WT_2)\text{-}\ln(WT_1))/(t_2\text{-}t_1)$ where WT1=weight at hatchery prior to release, WT_2= weight during fall electrofishing sample, t_1=date measured at hatchery, and t_2= date captured electrofishing.

DISCUSSION

The 2010 water year was relatively "wet" with annual precipitation at a California Irrigation Management and Information Service (CIMIS) weather gauge in Windsor, CA recording a total of 36.9 inches, 17% higher than the median of annual data collected between 1991 and 2010. Nearly six inches of precipitation was recorded between April and June, over 27% above the 1991-2010 median of 4.45 inches. Although stream flow gauges were not operated in all reference and treatment reaches prior to 2010, observations made during UCCE/CSG summer snorkeling surveys between 2005 and 2009 indicate that 2010 stream flows were generally higher than in previous years. Because of this, it is likely that flows were not low enough to have a strong impact on summer survival of coho in many of the study reaches.

The relatively high stream flows of 2010 allowed us to establish target survival rates for juvenile coho, given sufficient stream flow and environmental conditions (e.g. temperature, dissolved oxygen). In the Mill Creek watershed, oversummer survival ranged between 0.6 and 0.74, and in the Green Valley Creek reference reach survival was 0.87 (**Figure 26** to **Figure 28)**. These rates are generally higher than stream scale apparent survival estimates observed on Russian River tributaries between 2005 and 2008 (Obedzinski et. al. 2009, UCCE/CSG unpublished data).

During the course of the study season, average daily stream flow was not greater than 3.5 cfs in any stream reach, and in most reaches was below 1 cfs for the majority of the time. In conjunction with high survival rates, this suggests that juvenile coho can survive in extremely low surface flow conditions, assuming that other environmental variables remain within the range of established coho preferences. In the Grape Creek treatment reach, the only reach in which survival declined significantly over time, average daily flow fell below 0.1 cfs (**Figure 30**). Of the flow metrics included in our survival analysis, the number of days with flow < 0.1 cfs had the strongest relationship to survival, indicating that the duration of time below this level of flow is important. It is interesting to note that, in three of the reference reaches (Green Valley, Mill and Palmer Creeks), average daily flow also fell below 0.1 cfs in at least one interval of the study and these low surface flows did not correspond to decreases in survival (**Figure 26, Figure 28**, and **Figure 29**). In fact, survival was highest in the Green Valley reference reach, where surface flows were lower than any other reach (**Figure 26**).

The fact that no consistent relationship between survival and surface flow metrics was observed might be explained by the environmental conditions present in each reach. For example, in the Grape Creek treatment reach, where average daily surface flow dropped below 0.1 cfs, total wetted volume decreased by 81% over the study period, to the point where six of 12 pools dried up (**Figure 35**). Average dissolved oxygen decreased 57% over the study period in pools that remained wet, below levels known to cause impairment to salmonids (NCRWQCB 2007) (**Figure 36**). By contrast, in the Green Valley reference reach, wetted volume and dissolved oxygen decreased by only 20% and 30%, respectively, and did not reach levels of known impairment, despite even lower surface flows observed than in the Grape Creek treatment reach (**Figure 37** and **Figure 38**). Correlations between survival and total wetted volume and dissolved oxygen were observed in the Grape Creek treatment reach, but not in the Green Valley reference reach, where values were likely not low enough to impact survival (**Figure 39**).

The difference in physical characteristics between these two reaches likely played a role in whether or not wetted volume and dissolved oxygen remained relatively stable as average daily flows decreased. Average shelter and canopy were higher in the Green Valley reference reach than in the Grape Creek treatment reach (**Table 3**). Residual pool depth was higher in the Grape Creek treatment reach, however, variation among pools was also higher. The average residual depth of the pools that went dry in the Grape Creek treatment reach was 57.9 cm +/- 11 cm SD, slightly lower than the average residual pool depth in the Green Valley Creek reference reach (62.9 cm +/-17.2 cm SD) (**Table 3**). The deeper pools and higher shelter in the Green Valley Creek reference reach likely buffered the effects of low flow on survival in this reach. Such physical habitat characteristics should be considered in developing flow targets for individual stream reaches.

It is also highly probable that groundwater characteristics and subsurface flow had a significant influence on environmental conditions in all stream reaches as surface flows dropped, but these factors were not examined in this study. In the Grape Creek treatment reach, while all pools decreased in wetted volume and dissolved oxygen, it was in the upper two thirds of the reach that we saw the most extreme declines and where pools dried out completely. Future monitoring will attempt to describe the groundwater characteristics in this reach.

This study provided us with baseline information on oversummer survival of juvenile coho in reference and treatment reaches on three priority coho streams. It also supported preliminary evaluations of the inter-relatedness of flow, physical habitat characteristics, and environmental conditions. Due to the complex nature of these relationships, and the implications on coho survival, we believe that this data would be most productive in the context of a long-term study. It is also necessary to collect data in a variety of water years in order to accurately portray how oversummer survival varies based on annual fluctuation in precipitation and local climatic conditions. The conclusions drawn from the initial year of this study will be strengthened or challenged as a more robust data set reveals patterns in relationships and trends over time.

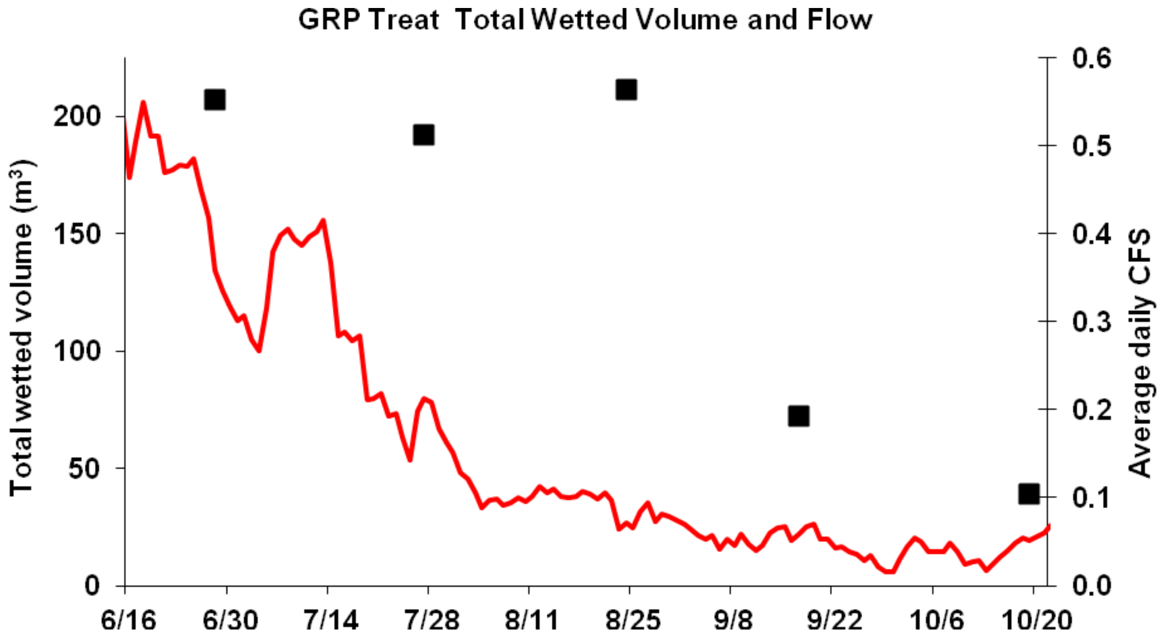

Figure 35. Stream flow and total wetted volume in the Grape Creek treatment reach, 2010.

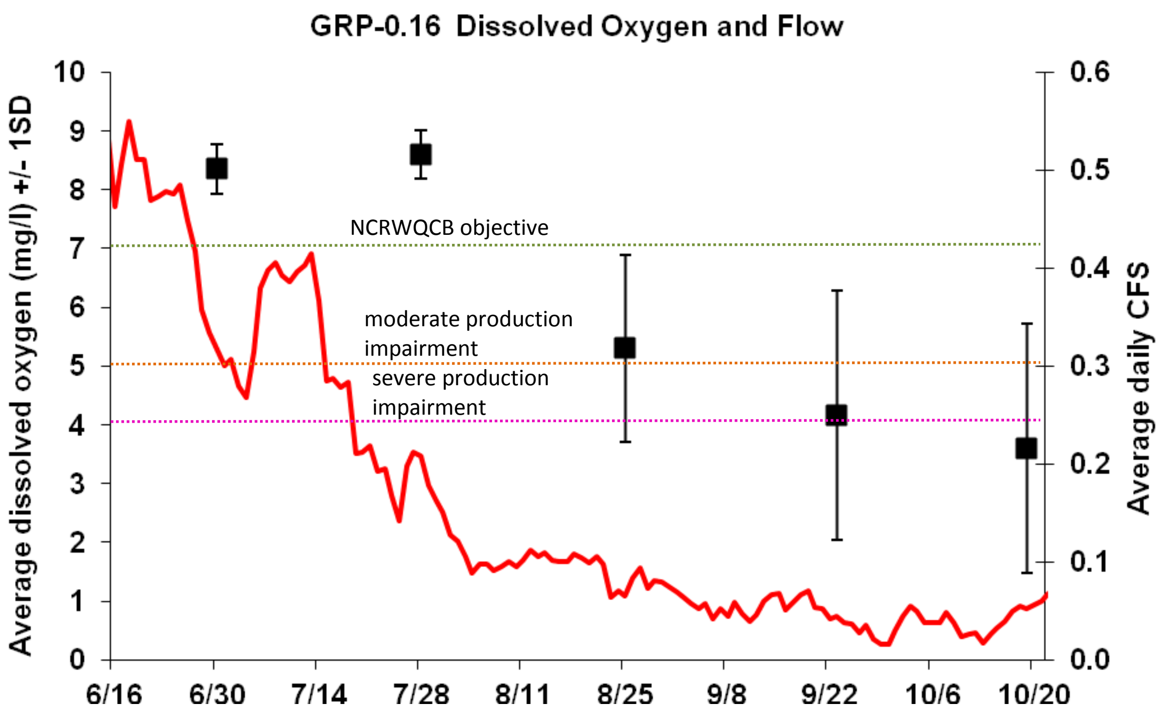

Figure 36. Stream flow and dissolved oxygen in the Grape Creek treatment reach, 2010.

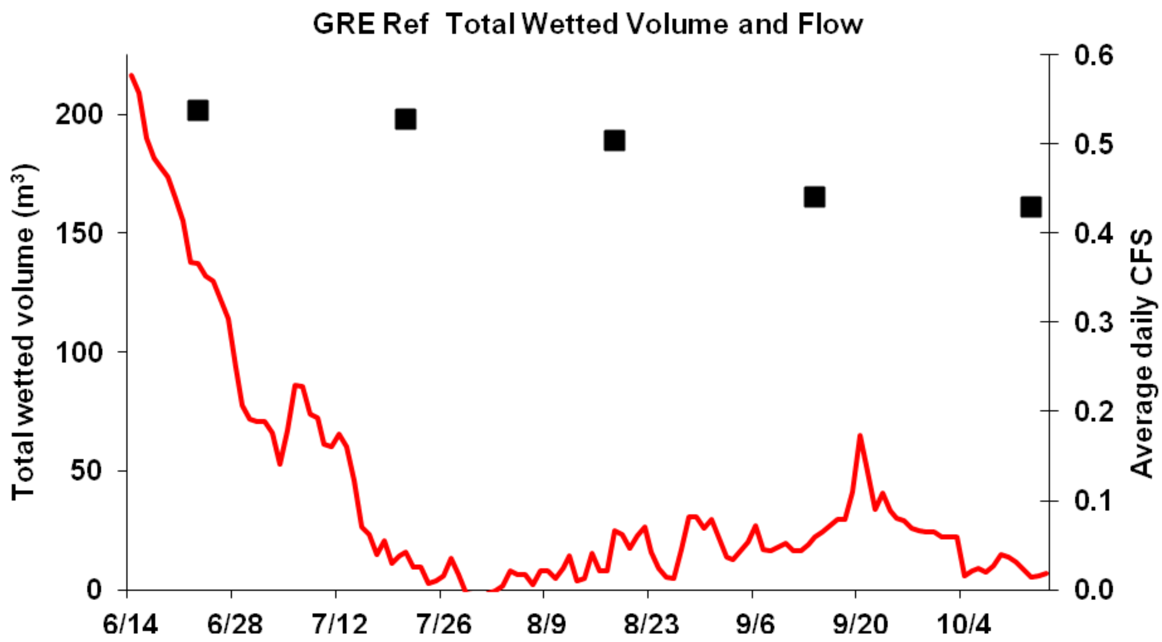

Figure 37. Stream flow and total wetted volume in the Green Valley Creek reference reach, 2010.

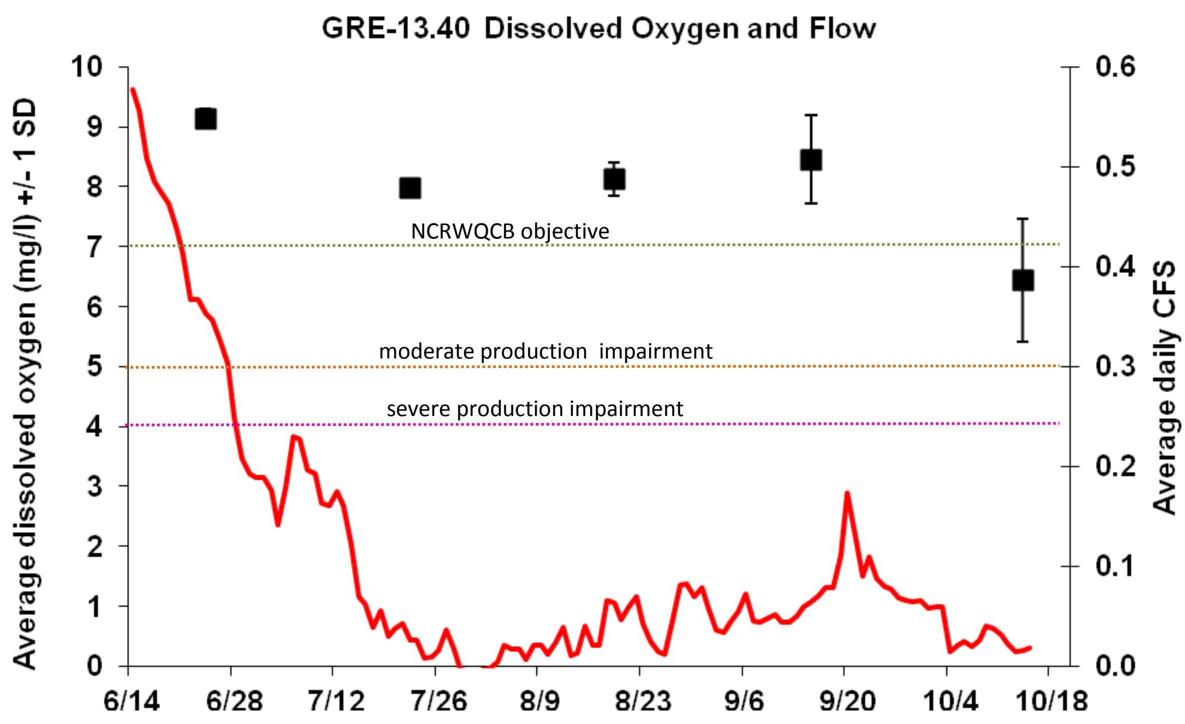

Figure 38. Stream flow and dissolved oxygen in the Green Valley Creek reference reach, 2010.

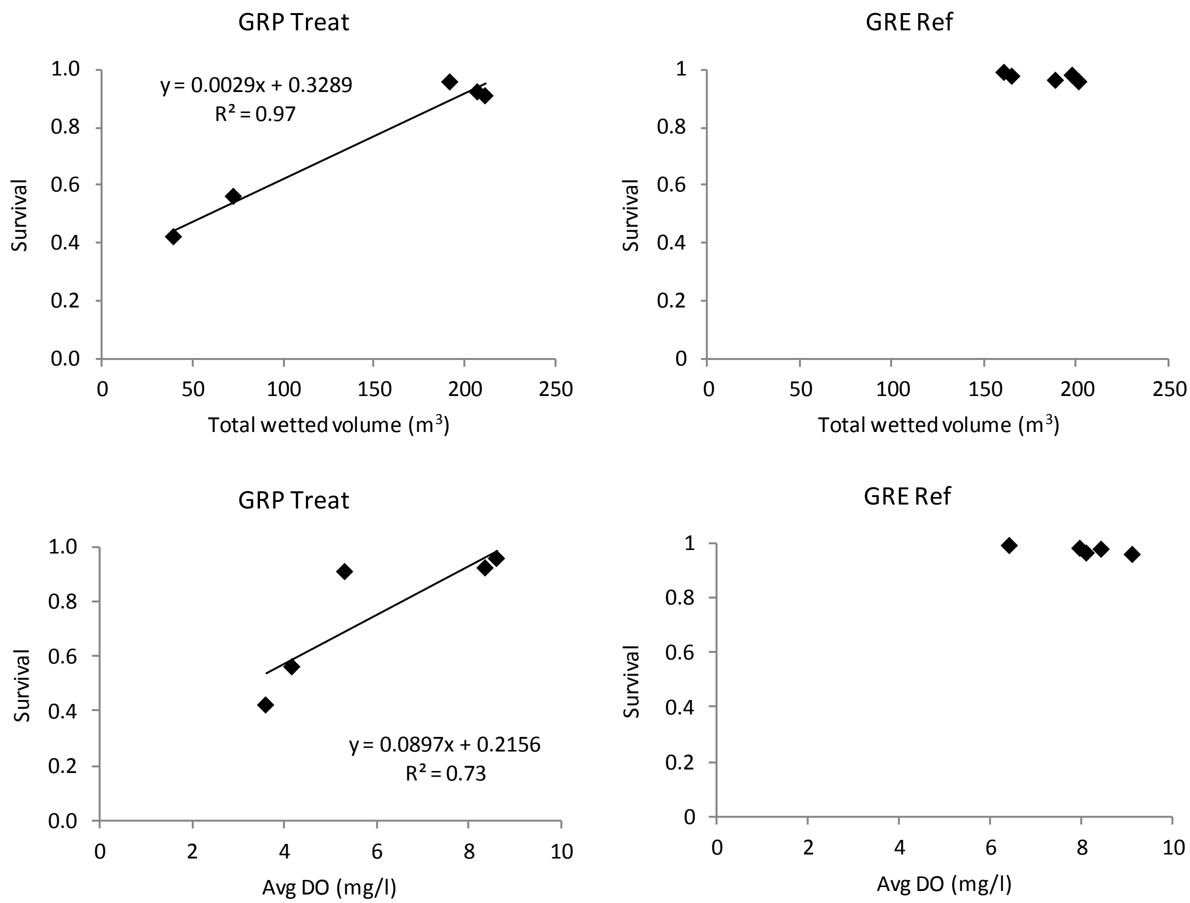

Figure 39. Survival in relation to total wetted volume and average dissolved oxygen in Grape Creek treatment and Green Valley Creek reference reaches in 2010.

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