# Executive Analysis of Restoration Actions in Big Springs Creek March 2008-September 2011

**Jeffrey F. Mount, Peter B. Moyle, and Michael L. Deas,**
**Principal Investigators**

***Project Team:***

**Carson A. Jeffres (Project Team Lead), Andrew L. Nichols, Ann D. Willis**

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Center for Watershed Sciences
University of California, Davis • One Shields Avenue • Davis, CA 95616

## Introduction

The management and restoration of Big Springs Creek has previously been identified as critical to the recovery of the salmonid population in the Shasta River to which it is a tributary. Improving physical habitat, flow, and water temperature regimes in Big Springs Creek was shown to have the highest potential for maintaining and eventually restoring coho salmon in the Shasta River watershed (Jeffres et al., 2009). In March 2009, The Nature Conservancy, California (TNC) initiated a multi-year river restoration effort on Big Springs Creek through the acquisition of Shasta Big Springs Ranch (SBSR) and an easement on the adjacent Busk Ranch (Figures 1 and 2). Together, Shasta Big Springs Ranch and the Busk Ranch easement provided access and restoration opportunities along the entire length of Big Springs Creek. Unlike many restoration efforts, the UC Davis Center for Watershed Sciences in association with Watercourse Engineering Inc. (Watercourse Engineering) was able to obtain baseline data prior to the beginning of restoration activities (Jeffres et al., 2009), thus allowing for the quantification of physical, chemical, and biological responses to restoration actions. The primary component of the restoration project was the construction of cattle exclusion fencing, which has eliminated cattle access to the riparian zone and river channel. This passive restoration approach was augmented by the targeted planting of riparian trees and emergent plants. The restoration actions have resulted in a rapidly changing ecosystem both physically and biologically, with changes largely initiated by the growth of aquatic macrophytes. Herein, changes in aquatic macrophyte biomass following cattle exclusion are quantified. This is followed by a description and quantification of the complex response of physical conditions (channel hydraulics and water temperature) and biotic communities to aquatic plant (macrophyte) growth between March 2008 and September 2011, providing a unique understanding of a spring-fed lotic ecosystem's response to passive restoration.

For this project an interdisciplinary river restoration case study was employed using a "Before-After (BA)" experimental design to explore the trajectory and rate of ecosystem response to cattle exclusion in Big Springs Creek, a large spring-fed creek in northern California. Rarely in restoration is the opportunity available to quantitatively assess the results/outcomes of restoration actions at this scale on spring creeks. Monitoring change and the associated effects on physical, chemical and biological processes within the Big Springs Creek and nearby Shasta River reaches has helped guide the continuing restoration activities, determined the success to date of this project, and allowed the transfer and application of restoration actions defined at SBSR. Activities completed to date have documented the ecosystem response to restoration actions, tested hypotheses that currently guide management activities, and have continued to support future refinements of those activities.

## Study Area

Big Springs Creek is a 3.7-km, low gradient spring-fed tributary to Shasta River, located at an elevation of approximately 800 m in the Shasta Valley of northern California, U.S.A (Figure 1). Located along the western edge of the Cascade Volcanic Range and approximately 26 km north of Mount Shasta (4322 m), Big Springs Creek emanates from a large groundwater spring complex located at the terminus of a fractured and porous basalt flow (Blodgett et al., 1988). Big Springs Creek is the primary source of summertime water to the Shasta River. Spring water entering Big Springs Creek exhibits nearly invariant and "slightly thermal" temperatures (10-12ºC) (Nathenson et al., 2003; Jeffres et al., 2009; Jeffres et al., 2010) and has a mean recharge elevation of 2880 m on Mount Shasta (Dahlgren et al., 2010). During transport as groundwater, nitrogen and phosphorous are released from underlying marine sedimentary and volcanic rocks, resulting in elevated nutrients in the exsurgent spring water (Dahlgren et al., 2010). This cool and nutrient-rich water fuels tremendous primary productivity (principally aquatic macrophyte growth), providing food and habitat for aquatic invertebrates, which in turn support cold-water fish populations including the federally-threatened coho salmon.

Since the late 1800s upland riparian areas surrounding Big Springs Creek have been used for cattle grazing. The lack of exclusion fencing, combined with typically wide and shallow channel morphologies of spring creeks, allowed cattle to graze on submerged and emergent aquatic macrophytes growing throughout the channel bed, removing biomass from the lotic system and further widening the channel. Cattle foraged extensively on aquatic vegetation during the winter months when upland grazing conditions were poor. In March 2009, exclusion fencing eliminated cattle access to Big Springs Creek, allowing the identification and quantification of the rate of change to the hydrogeomorphic and ecological conditions throughout Big Springs Creek following the increased growth of aquatic macrophytes, including 1) channel hydraulics; 2) surface water temperature; 3) water quality; and 4) fish habitat use. Methods for quantification of these baseline monitoring elements are presented in Jeffres et al. (2009, 2010).

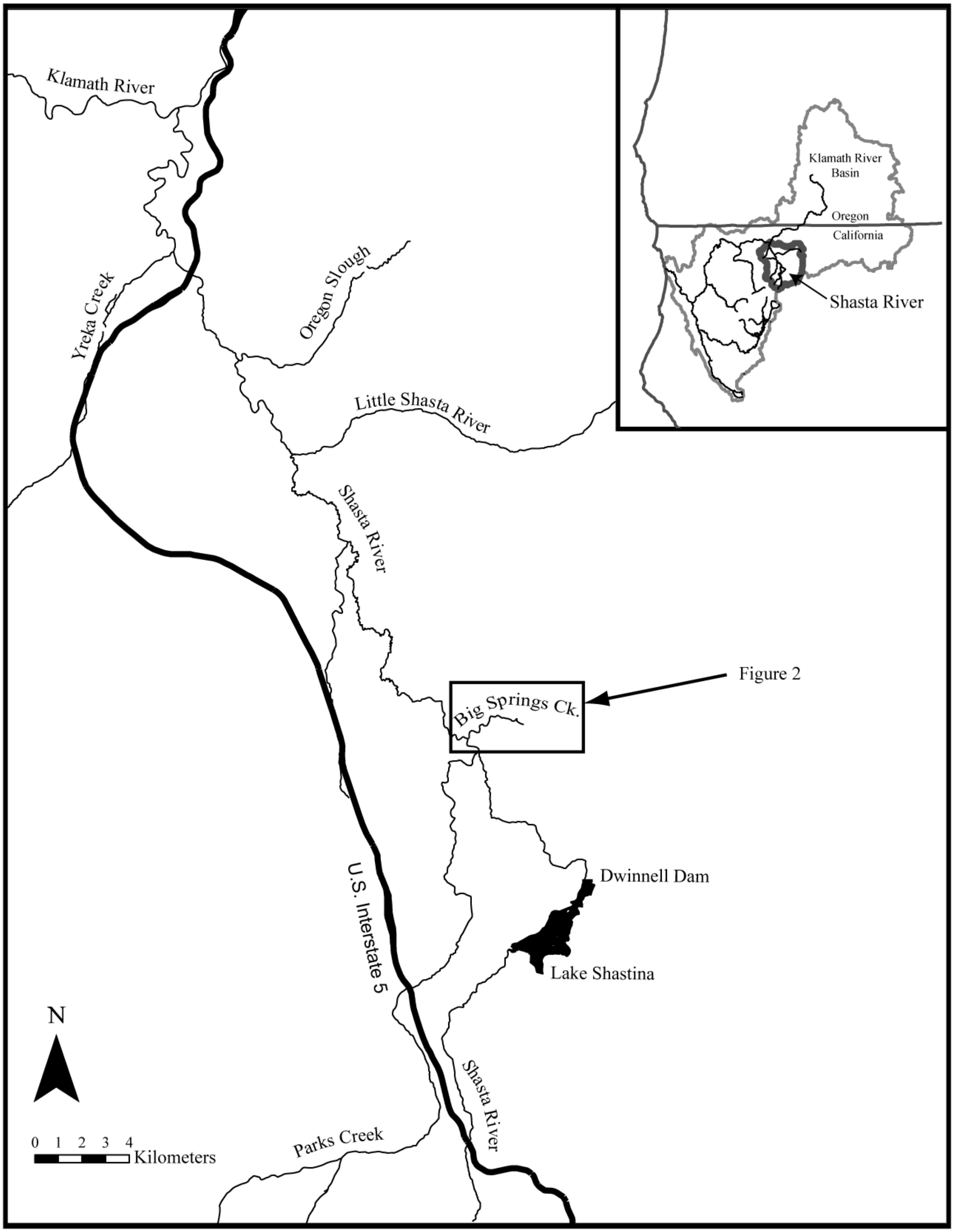

Figure 1. Map of the Shasta River basin.

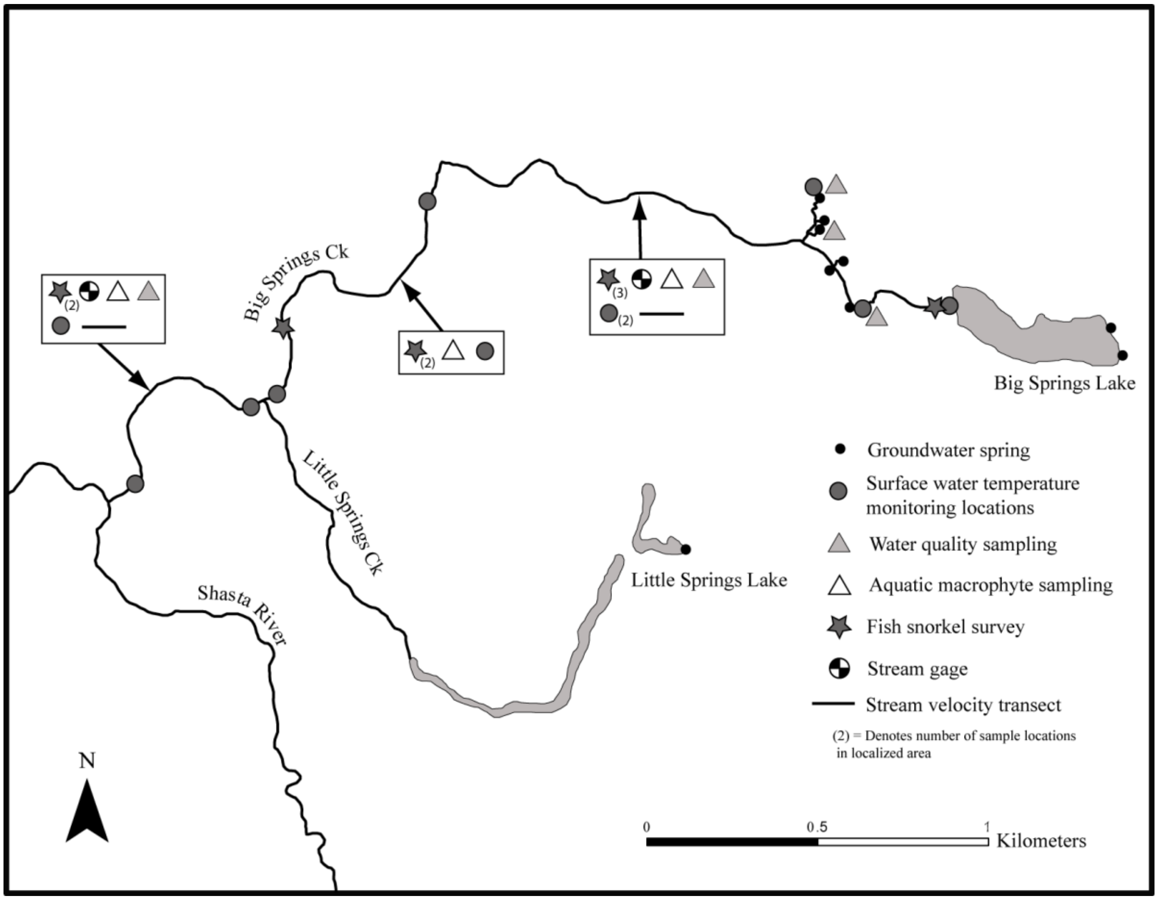

**Figure 2. Sampling locations in Big Springs Creek.**

## Results:

The results of field work at Big Springs Creek relating to quantification of aquatic plants, channel hydraulics, water temperature, water quality, and fish from March 2008 through September 2011 are outlined below. Consistent application of methods over this extended period provides directly comparable results that are subsequently used to identify changes through space and time of physical, chemical and biological processes within Big Springs Creek.

## Aquatic Plants

The standing crop of aquatic plants (i.e., macrophytes + filamentous algae) at sample location RKM 1.5 throughout the year prior to cattle exclusion (March 2008 to April 2009) exhibited seasonal growth patterns typical of aquatic vegetation in temperate regions (Figure 3), with minimum biomass in winter and early spring and maximum in summer. Total standing crop in March 2008 averaged 35.7 ± 10.7 g AFDM·$m^2$ (*n* = 6). Mean total standing crop increased by 282% (136.2 ± 33.0 g AFDM·$m_{-2}$; *n* = 6) between March 2008 and June 2008, and by an additional 34% (182.1 ± 60.6 g AFDM·$m^2$; *n* = 6) between June 2008 and September 2008. The temporal increase in plant biomass between June 2008 and September 2008 was not statistically different (ANOVA, *p* = 0.06) due to high variability among the replicate samples. Total standing crop in April 2009, immediately following a winter of unrestricted cattle grazing in the river channel, averaged 32.4 ± 12.2 g AFDM·m$^2$ ($n$ = 12), a 132 g AFDM·m$^2$ decrease from September 2008 (Figure 3).

Following cattle exclusion in March 2009, aquatic plant biomass averaged across sampling locations RKM 0.4, 1.5, and 2.6 exhibited a similar spring/summer growth trend to that observed at RKM 1.5 prior to cattle exclusion (Figure 3). Between April 2009 and July 2009, mean standing crop increased from 32.4 ± 12.2 AFDM·m$^2$ ($n$ = 12) to 200 ± 10.7 g AFDM·m$^2$ ($n$ = 18). In all years, biomass increases after March (the approximate seasonal minimum), reaching maximum biomass in September. Seasonal minima varied throughout the study period, but generally showed an increase following cattle exclusion. During September 2010 and 2011 the highest measured biomasses during the study were collected with 345.61± 20.71 g AFDM·m$^2$ (n=18) and 311.94 ± 44.14 g AFDM·m$^2$ (N=18) respectively.

In summary, seasonal growth and senescence patterns in Big Springs Creek pre- and post-restoration identify the importance of cattle exclusion. Further, aquatic plants are directly related to almost all metrics within Big Springs Creek including hydraulic characteristics, sediment dynamics, stream stage, water temperature, invertebrate populations, and fish habitat.

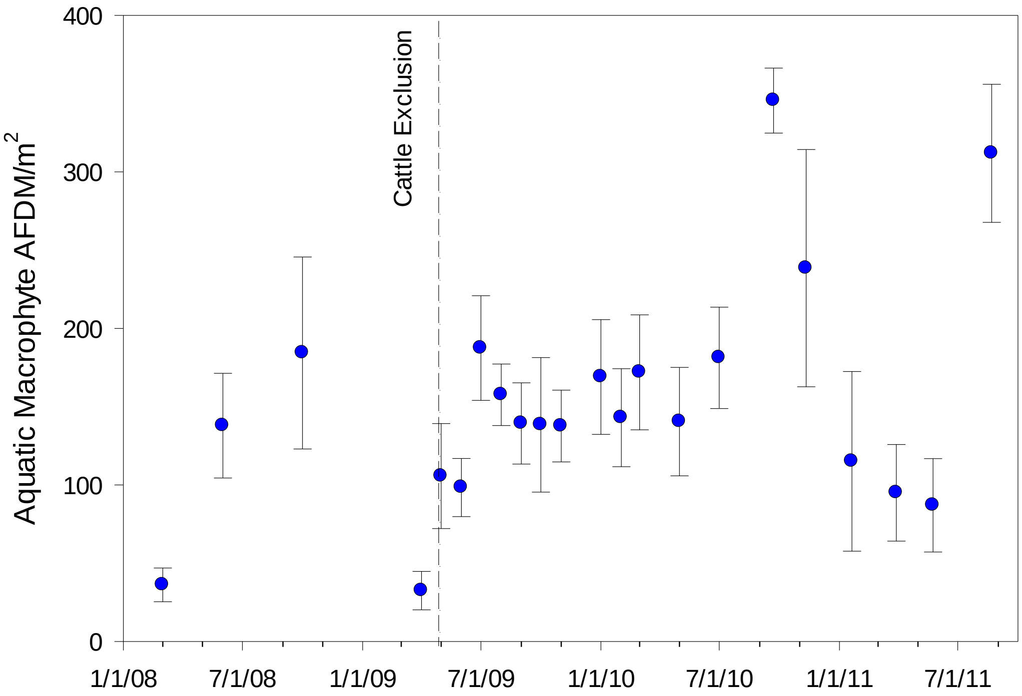

**Figure 3. Ash Free Dry Mass (AFDM) of aquatic macrophytes collected in Big Springs Creek from April 2009 through September 2011. Circles represent the mean value of all the subsamples from all locations and error bars are standard error.**

## Channel Hydraulics

Hydrologic and sediment transport conditions in Big Springs Creek are largely determined by groundwater-derived springflow and adjacent land use. Without upstream tributaries, streamflow magnitudes are relatively stable with respect to changes in seasonal or annual precipitation patterns or snowmelt. Agricultural water use alters hydrologic conditions during the annual April through September irrigation season, as a 0.3 $m^3/s$ surface water diversion and unquantified local groundwater pumping reduce flow magnitudes and increase variability. From April 2008 through September 2011, mean non-irrigation season (i.e. unimpaired) streamflow was 2.37 $m^3/s$ ($\sigma = 0.13$), while mean irrigation season streamflow was 1.85 $m^3/s$ ($\sigma = 0.34$) (Jeffres et al., 2009; Jeffres et al., 2010). Minimum streamflow in Big Springs Creek during the entire period was 1.21 $m^3/s$. Alluvial sediment is derived entirely by localized channel bed and bank erosion, and qualitative observations suggest available streamflow is only capable of transporting sand-sized and finer bed materials. Rounded, gravel- and cobble-sized bed material appears to be mobilized only during redd-construction by spawning salmonids.

One feature of aquatic macrophyte growth is to obstruct water flow, which subsequently impacts flow velocities and dependent hydraulic variables such as water stage (i.e., depth), wetted cross-sectional area and channel resistance (Marshall & Westlake, 1990; Green, 2005b). In Big Springs Creek, flow obstruction by both submerged and emergent aquatic macrophytes along channel margins as well as large patches within the main channel created complicated flow and velocity fields generally characterized by low flow velocities (<0.1 m/s) within macrophytes and notably higher flow velocities (~0.2 to 1.0 m/s) between patches. The acceleration of flow around macrophytes patches created a mosaic of flow fields (Cotton et al., 2006), resulting in a relatively unique channel pattern often referred to as "pseudo-braided" (Green, 2005b) (Figure 4).

**Figure 4. Photo showing macrophyte growth and multiple channels in Big Springs Creek.**

Seasonal patterns in hydraulic conditions prior to and following cattle exclusion from Big Springs Creek largely co-varied with seasonal patterns of aquatic macrophyte biomass. During the macrophyte growing season (March through September) mean flow velocities progressively decreased, resulting in a concomitant increase in channel depth (Figure 5) and cross-sectional area (Figure 6). Following the senescence of macrophytes throughout the fall and winter, mean flow velocities typically increased while channel depth and cross-sectional area decreased. Such seasonal patterns in hydraulic conditions appear related to patterns of channel resistance associated with macrophyte growth, although some observers suggest this resistance-biomass relationship may be indirect (Green, 2005a). In contrast with observed seasonal covariance of hydraulic conditions and aquatic macrophyte biomass, spatial variations in hydraulic conditions throughout Big Springs Creek appeared to be largely controlled by the size and structural properties of localized macrophyte growth (e.g., patches). In channel locations with distributed patches of macrophytes, very complex flow fields developed (Figure 4), while large homogenous patches or channel margin growth created relatively simple flow fields dominated by one or several channels around these patches through which the majority of flow was routed (Figure 6).

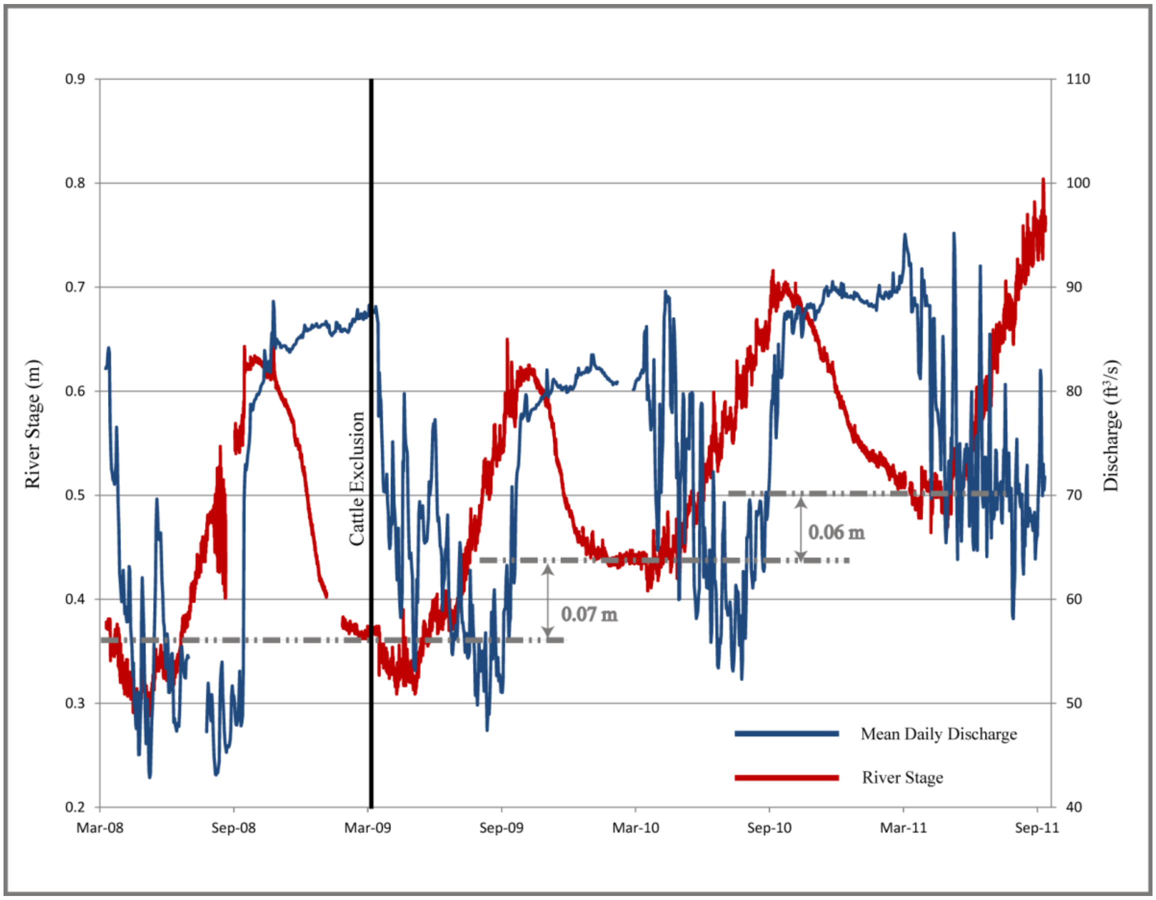

**Figure 5. River stage continuously measured at RKM 0.4 streamflow monitoring station in Big Springs Creek. The grey line represents the minimum unimpaired stage during each year.**

Interestingly, hydraulic conditions, as tracked by channel depth, in March 2009 were nearly identical to those observed in 2008 (Figure 5). However, after one year of complete cattle exclusion (March 2009 to March 2010), seasonal minimum channel depths in March 2010 exhibited a 0.07 meter, or 19%, increase over minimum channel depths observed at the same location the previous year, even though flow magnitudes remained nearly identical. Further, minimum channel depths in March 2011 exhibited an additional 0.06 m, or 14%, increase over the same period in 2010 (Figure 5). In addition to increased seasonal water depths and wetted cross-sectional areas, hydraulic variability increased in response to increased biomass following the reduction of grazing pressures by cattle. This variability was often characterized by large local variations in lateral and vertical flow velocities. Increases in both habitat area and spatial flow velocity variability provided improved habitat for both juvenile and adult fish.

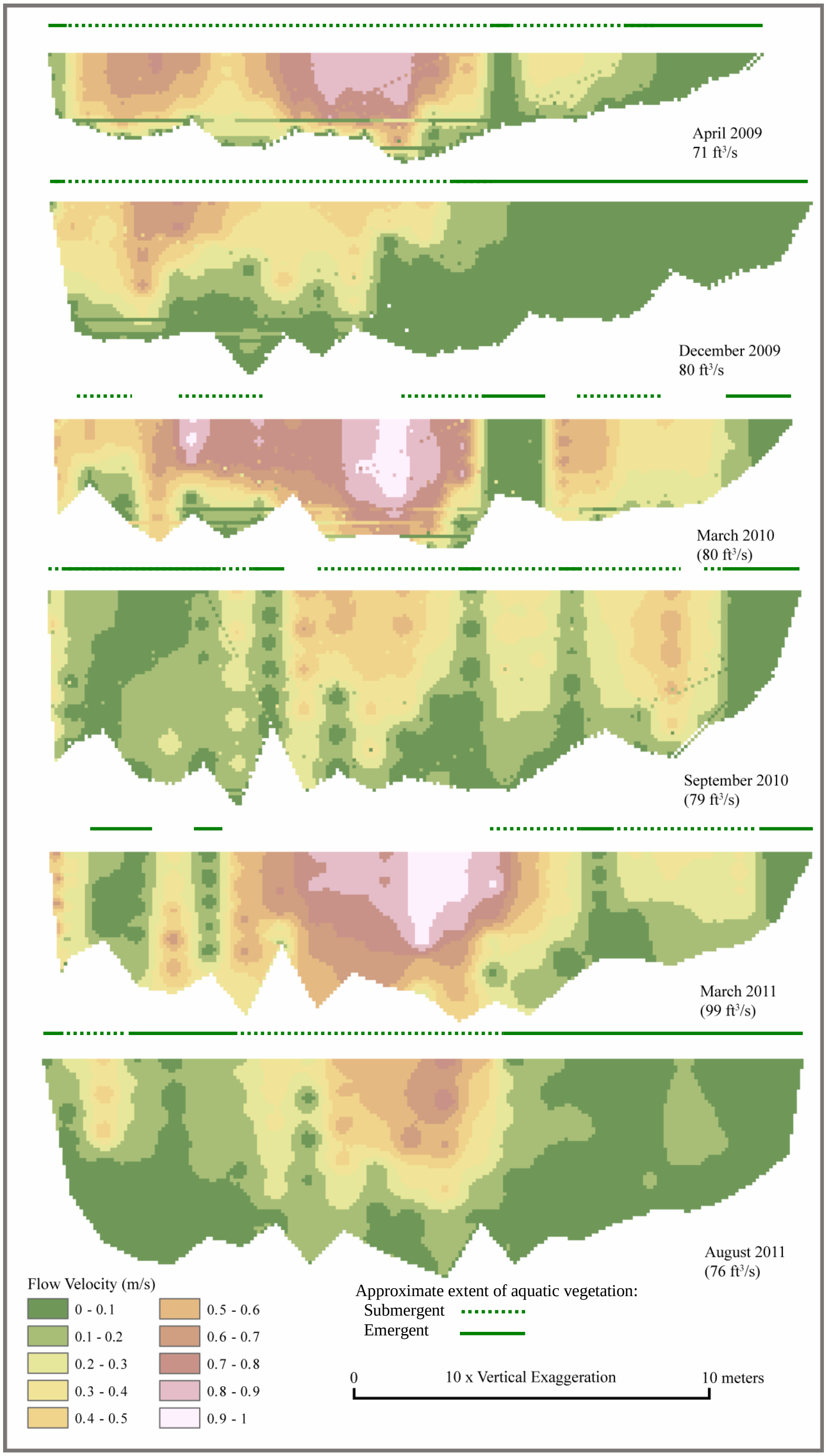

**Figure 6. Flow velocity contour plots created from point velocity measurements collected at the Big Springs Creek Downstream Crossing study site transect location, with approximate submergent and emergent vegetation distribution.**

## Water temperature

A baseline assessment of Big Springs Creek in 2008 illustrated that peak water temperatures during the spring and summer (approximately April through September) were the key impairment to salmonid habitat (Jeffres et al., 2009). As such, this temperature analysis is limited to peak temperatures during the study period (April 2008-September 2011). Field observations illustrated that spring sources emerged at stable temperatures of 10-12$^{o}$C and contributed a steady source of cool water (~1.13 $m^3/s$) to Big Springs Creek. Water temperatures of other significant inflow sources, such as releases from Big Springs Dam, were also monitored. However, the water temperatures of those small or more diffuse spring sources and Big Springs Dam were more variable than spring sources.

Following the implementation of restoration actions (primarily cattle exclusion), water temperature trends began to change in response to the recovering aquatic macrophyte community. The presence of aquatic vegetation and the underlying effects of aquatic vegetation growth on stream geomorphology, hydraulics, and shading resulted in generally decreased rates of heating from pre-restoration to post-restoration conditions and seasonal water temperature shifts in response to the aquatic vegetation's annual growth and senescence.

Peak water temperatures declined as annual minimum levels of aquatic vegetation biomass increased. Comparing 2008 to 2011 water temperature conditions at the mouth of Big Springs Creek shows that seasonal peak water temperatures declined by an average of 2.5°C from 2008 to 2011 (Figure 7). The maximum rate of heating from the principal spring sources to the mouth decreased from 4.6°C/km in 2008 to 3.3°C/km in 2011 (local heating rates varied depending on channel geometry). These results suggest that cool water was transported more quickly through Big Springs Creek as vegetation biomass increased. This result is consistent with the decreased travel times that occurred as increased vegetation growth created high velocity corridors within Big Springs Creek through which a majority of the streamflow was conveyed.

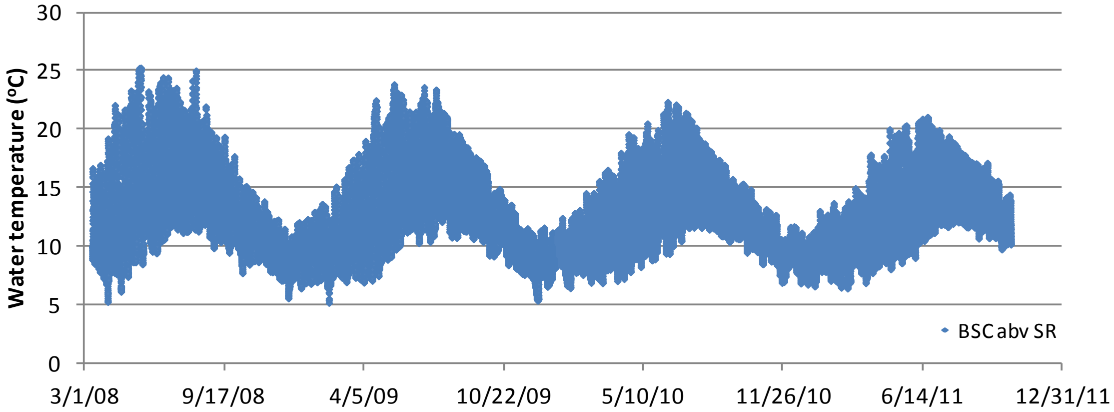

**Figure 7. Water temperatures in Big Springs Creek above its confluence with the Shasta River (BSC abv SR).**

Other metrics that are commonly used to assess salmonid habitat are the mean weekly maximum temperature (MWMT) and mean weekly average temperature (MWAT)

(Welsh et al., 2001). Both metrics decreased from 2008 to 2011. MWMT decreased from 24.2°C in 2008 to 20.3°C in 2011, while MWAT decreased from 17.1°C in 2008 to 15.6°C in 2011 (Table 1). Absolute water temperature decreased from 25.3°C to 21.1°C during this same period (Table 1). While the period of occurrence for MWMT coincided with annual absolute maximum water temperature, MWAT generally occurred later in the summer, when both maximum and minimum temperatures increased.

**Table 1. Maximum weekly maximum temperature (MWMT), maximum weekly average temperature (MWAT), and absolute maximum water temperature in Big Springs Creek at the mouth during 2008-2011.**

| | MWMT* (°C) | Period | MWAT* (°C) | Period | Absolute maximum water temperature (°C) | Period |
|---|---|---|---|---|---|---|
| 2008 | 24.2 | May 13-19 | 17.1 | Jul 7-13 | 25.3 | May 19 |
| 2009 | 22.8 | May 16-22 | 17.4 | Jul 16-22 | 23.9 | May 17 |
| 2010 | 21.6 | Jun 24-30 | 16.4 | Jul 9-15 | 22.3 | Jun 13 |
| 2011 | 20.3 | Jun 15-21 | 15.6 | Jul 2-8 | 21.1 | Jun 19 |

*MWMT = Maximum weekly maximum temperature, MWAT = Maximum weekly average temperature

Project goals (i.e., water temperatures < 20°C) were generally met for the reach beginning at RKM 0.4 (representing the mouth of Big Springs Creek) and extending upstream to the headwaters of the creek. Water temperatures periodically exceeded project goals from April through July (for all study years) at the mouth of Big Springs Creek (Figure 8). This April through July period coincided with the early growing season of aquatic macrophytes, when the macrophytes were still submerged below the water surface. Following the emergence of aquatic macrophytes above the water surface, the associated shade resulted in a reduced solar radiation load, and peak water temperatures did not exceed 20°C throughout Big Springs Creek. Preliminary measurements of solar radiation were made in both open water and aquatic macrophyte-covered areas of Big Springs Creek. Results indicated that where aquatic macrophytes were present, the solar radiation load at the water surface was reduced 84-93%. A survey of aquatic macrophyte distribution toward the end of the growing season indicated that aquatic macrophytes covered approximately 52% of Big Springs Creek, providing an appreciable reduction in incoming solar radiation. Additional research is underway to better understand the relationship between aquatic macrophytes, solar radiation, and water temperature in this system.

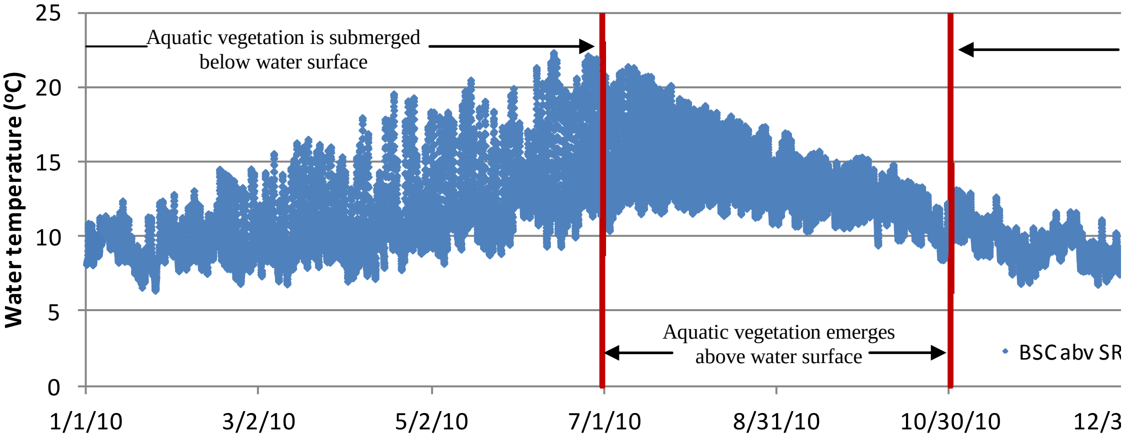

**Figure 8. An example of seasonal water temperature trends measured in Big Springs Creek above its confluence with the Shasta River (BSC abv SR). The red lines bound the period during which aquatic vegetation emerges past the water surface and provides shade to portions of the creek.**

Finally, a comparison of water temperatures in Big Springs Creek to the mainstem Shasta River illustrated the key value of restored conditions in Big Springs Creek: cool water temperatures were maintained in Big Springs Creek during the summer, when other waterways experienced elevated water temperatures. Water temperatures measured in the Shasta River above the confluence with Big Springs Creek generally exceeded those at the mouth of Big Springs Creek from July through October.

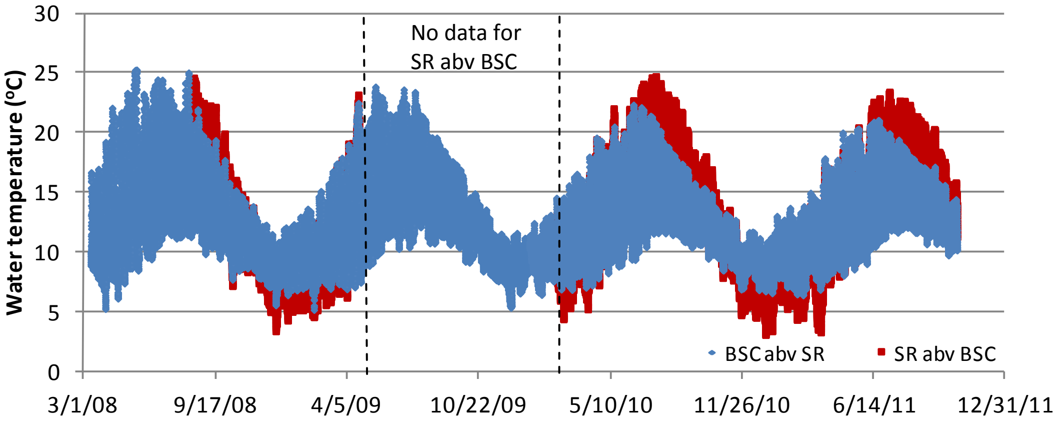

**Figure 9. Water temperatures measured in Big Springs Creek above its confluence with the Shasta River (BSC abv SR) and in the Shasta River above its confluence with Big Springs Creek (SR abv BSC). Periods when water temperatures in the Shasta River exceed or fall below water temperatures in Big Springs Creek are illustrated. No data is available between 4/15/2009-5/1/2010 for SR abv BSC.**

Overall, water temperatures at the mouth of Big Springs Creek were cooler in 2011 compared to 2008 and resulted in increased habitat available to salmonids. Furthermore, the benefit likely extended into the Shasta River downstream of its confluence with Big Springs Creek, extending improved habitat conditions downstream of Big Springs Creek.

## Water quality (nutrients)

Water quality samples were collected to identify water chemistry conditions and understand the source and fate of nutrients in Big Springs Creek. Due to their biological importance in aquatic systems and the potential role of these constituents in restoration actions (Jeffres et al., 2009; Jeffres et al., 2010), the water quality analysis focused on nutrients. Both total and inorganic concentrations of nitrogen and phosphorus were analyzed for the period March 2008 through July 2011. An analysis was completed to determine the source of nutrients in groundwater-fed springs in Big Springs Creek. Finally, the seasonal role of nutrients in primary productivity was examined.

Nutrient concentrations in waters emanating from the Big Springs complex were high for natural waters experiencing limited impact from human activities. Mean soluble-reactive $PO_4$-P (SRP) concentrations over a four-year period were 0.135 (±0.014) and 0.154 (±0.007) mg $L^{-1}$ (n=33) in the north and east springs, respectively. These findings suggest that during transport from the groundwater source area on Mt. Shasta, groundwater interacts with the underlying volcanic and marine sedimentary rocks, which results in mobilization of nutrients. The SRP concentrations were in equilibrium with hydroxyapatite ($Ca_2OHPO_4$), suggesting that release of SRP by chemical weathering of the highly weatherable volcanic deposits was the primary source of the $PO_4$. Mineral nitrogen concentrations were also unexpectedly high with mean $NO_3$-N of 0.44 (±0.07) and 0.17 (±0.01) mg $L^{-1}$ in the north and east springs, respectively, and $NH_4$-N concentrations of 0.01 mg $L^{-1}$ in both springs (n=33). The primary source of nitrogen is assumed to originate from detrital organic matter incorporated in the marine sedimentary rocks during diagensis. This “geologic” nitrogen is released from rocks by hydrothermal waters and transported with the groundwater.

Downstream trends in constituent concentrations illustrated that despite elevated loads contributed from groundwater-fed springs, nitrate concentrations seasonally declined in downstream reaches while SRP remained relatively stable. During summer, nitrate concentrations declined from an average of .31 mg $L^{-1}$ in the north and east springs (located at RKM 3.3) to .12 mg$L^{-1}$ at RKM 0.4 (ammonia values were typically near or below detection). Similarly, SRP concentrations showed little variation: an average of .151 mg$L^{-1}$ in the north and east springs to .157 mg $L^{-1}$ at RKM 0.4. These results supported preliminary conclusions made by Jeffres et al. (2009) that seasonal aquatic macrophyte growth resulted in a nitrogen-limited system. These decreased concentrations, when considered along with aquatic macrophyte biomass data, indicated that the geologically derived nutrients formed the chemical foundation of a robust food web. A previous food web and stable isotope analyses support this conclusion (Jeffres et al., 2009).

## Fish

The single largest change in habitat for salmonids in Big Springs Creek was the growth of aquatic macrophytes following the exclusion of cattle from the stream benefiting all life stages of salmonids in Big Springs Creek from egg incubation to adult spawning. Macrophytes increased stream depth (Figure 5), allowing for dramatic increases in margin habitat for newly emerged fry that was not available prior to cattle exclusion. During summer, increased depth, cover and velocity heterogeneity benefited fish rearing in Big Springs Creek (figure 6). Where macrophyte growth created high velocity channels, fine sediments were scoured away, exposing spawning gravels for adults. Further, the geomorphic changes associated with macrophyte growth (narrow channels), coupled with macrophyte shading during summer periods, expanded the thermally suitable habitat from a few lineal meters to several kilometers of appropriate over-summering temperatures for multiple species of anadromous fish.

Coho salmon have been the driver for much of the restoration actions in the Shasta River. Over-summering habitat, primarily water temperature, has been determined to be a limiting factor for juvenile coho and a target for restoration (Jeffres et al., 2008; Jeffres et al., 2009). In 2008, after May, coho were only observed in Big Springs Creek in a single pool at the outlet of Big Springs Lake. The outlet was the only location where suitable depth, velocity, cover, and temperature were located in Big Spring Creek (Jeffres et al., 2009). Because two of the three coho cohorts are functionally extinct with very low returns (Chesney, 2010), 2011 was the next opportunity to observe coho rearing in Big Spring Creek. In 2011 the dramatically increased habitat available to over-summering coho resulted in juvenile coho salmon distributed throughout Big Springs Creek and also in Parks Creek and the Shasta River above Highway A-12. This broader distribution of coho resulted in reduced counts compared to the 2008 snorkel surveys, likely due to the larger distribution of the rearing fish in the system and the growth of aquatic macrophytes providing cover and making observations difficult. Despite observing few individual coho in 2011, observations were made at five dive locations throughout Big Springs Creek, where as in 2008, only one dive location had coho during the summer.

In October 2008, adult Chinook returned to Big Springs Creek and spawned in the lower portion of the creek (RKM 0 to RKM 1.6). Cattle were allowed access to the river following the spawning season and were observed trampling redds while walking in the channel. In the 2008-2009 sampling effort, only three juvenile Chinook were observed in Big Springs Creek. During the following spawning season (October-November 2009), cattle had been excluded from Big Springs Creek since March 2009. Consequently, juvenile Chinook were protected from egg deposition to emergence and rearing. Furthermore, the exclusion of the cattle allowed for redds to remain intact and mostly free from fine sediment. Seventy-eight (78), 101, and 31 redds were counted in Big Springs Creek in 2008, 2009, and 2010 respectively (CDFG unpublished data). The 2008 and 2009 redd counts are relatively similar, yet the apparent juvenile productivity between the two years is markedly different. Juvenile Chinook were observed at relative densities of .0004/m and .086/m in 2009 and 2010 respectively (Figure 10). A small percentage of the juvenile Chinook remained in Big Springs Creek in 2010 and appeared to mature and spawn with returning adults in the fall (Figure 10). Due to this project period ending in the September, a full analysis of juvenile Chinook relative abundance in the 2011 will be provided in a future report.

In the 2009-2010 sampling season 0+ steelhead were observed at .219/m while in 2008-2009 only .138/m were observed (Figure 10). The single greatest change in habitat was in margin habitat for newly emerged fish created by remnant non-growing season aquatic macrophytes that increased the baseline stream stage (Figure 5). This habitat had adequate depth, velocity refuge, and cover from overhanging riparian vegetation. Prior to cattle exclusion, this habitat was not present throughout the majority of Big Springs Creek.

Observations of 1+ steelhead more than doubled from .068/m to .182/m between the pre- and post-restoration activities (Figure 10). Along with the increased number of observations, the number of sample locations where 1+ steelhead were observed also increased. In 2008, the majority of 1+ steelhead observed were in the vicinity of the waterwheel (RKM 2.6) where stream depth was adequate. The increase in depth created by the roughness in aquatic vegetation increased the area of Big Springs Creek where depth was suitable for the larger 1+ steelhead. From 2009-2011, 1+ steelhead have been regularly observed at all dive locations on Big Springs Creek.

Poorly managed grazing practices can lead to aquatic vegetation removal, sediment mobilization, degraded stream banks. Additionally, grazing practices that allow cattle access to streams can result in trampled salmonid redds, having a considerable effect on the salmonid population (Roberts & White, 1992; Gregory & Gamett, 2009). When cattle were allowed access to Big Springs Creek during the fall Chinook salmon spawning period, they were often observed physically trampling redds and mobilizing fine sediment capable of smothering downstream salmonid redds. Adult Chinook redd counts were relatively similar in pre- and post-exclusion (78 and 101 respectively), yet the apparent fry production between the two years is remarkably different. Following removal of cattle from the stream, a 215-fold increase in juvenile Chinook was observed despite comparable adult returns between the two years. Abundant high quality habitat was available throughout Big Springs Creek due to the growth of aquatic macrophytes, which provided cover, depth, and a velocity refuge, as well as decreased water temperatures. Because coho populations are currently so low, degradation and restoration of Chinook salmon spawning and early rearing habitat was used as a proxy of what benefits may be realized as coho populations begin to grow.

Livestock grazing practices around streams can have profound impacts on instream conditions. For example, allowing livestock access to streams can reduce the quantity of trout that utilize any given reach of stream, while limiting access through livestock exclosures have been shown to increase the abundance of trout in reaches (Stuber, 1985; Bayley & Li, 2008). A similar trend was observed in Big Springs Creek where steelhead were more than two times more abundant after cattle exclusion from the riparian area. Exclusion of cattle not only allowed for successful spawning, but provided additional rearing habitat for juvenile salmonids.

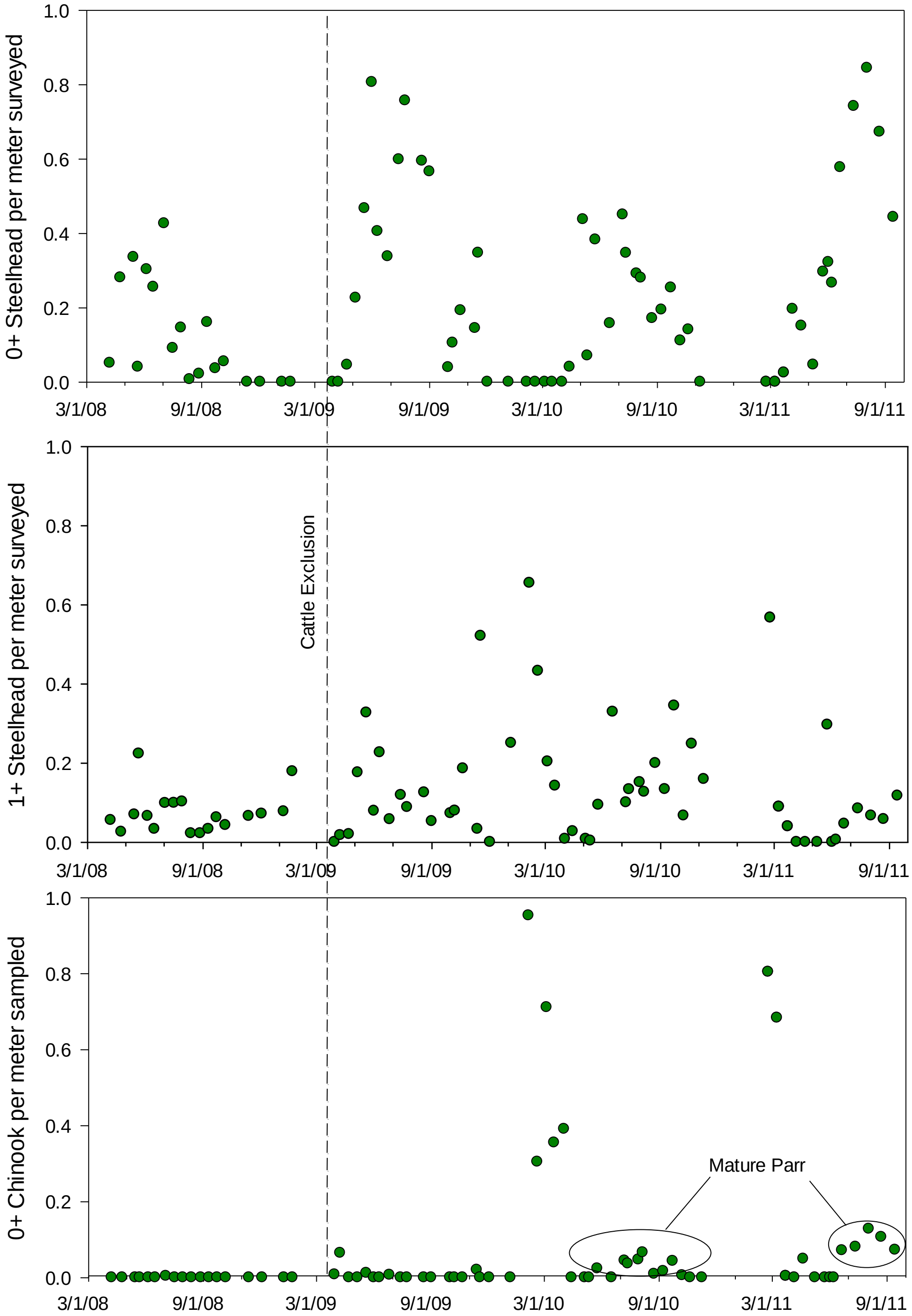

**Figure 10. Relative abundance of 0+ steelhead (top), 1+ steelhead (middle), and 0+ Chinook (bottom) from snorkel surveys in Big Springs Creek from March 2008 to September 2011.**

# Discussion

Big Springs Creek was an ideal candidate for a passive restoration approach due to stable hydrologic conditions, water chemistry and thermal regimes inherited from local springs. Predictable hydrologic conditions allowed for the growth of aquatic macrophytes and trapping of fine sediment without scouring events typical of streams governed by precipitation-derived hydrologies. By removing the cattle access to the stream channel, restoration of ecological and geomorphic processes has created conditions suitable for the recovery of threatened salmonids.

The role of aquatic vegetation in Big Springs Creek is critical to the restoration of the aquatic habitat. Observed feedbacks between seasonal growth of aquatic vegetation and abiotic stream conditions in a spring-fed system indicate aquatic macrophytes act not only as geomorphic agents with impacts to hydraulic processes, but also play a critical role in reducing water temperature on a reach scale (through hydraulic effects and shading), impact water quality (principally through nutrient retention), and directly benefit salmonid habitat by providing food resources and refuge (Whiting & Moog, 2001; Clarke, 2002; Barquin & Death, 2004). Under existing management conditions, a natural succession of aquatic plant communities and hydrogeomorphic conditions will likely occur, a process sometimes referred to as “fluvial biogeomorphic succession” (Corenblit et al., 2007). It is anticipated that the initial phase of this succession regime will be dominated by the continued seasonal growth and senescence of aquatic macrophytes. Two years after cattle exclusion, qualitative observations suggest macrophyte root masses and more resilient stem materials have allowed the capture of mobile sediments and organic material sourced from upstream macrophyte senescence. This feedback between macrophyte growth/senescence and hydraulic conditions favorable to sediment deposition may ultimately create a peat/marsh habitat (dominated by emergent vegetation) along the channel margins and low-velocity channel areas adjacent the main flow paths. This hypothesized outcome is consistent with the original condition at Big Springs Creek documented during initial (1856) public land surveys, in which Big Springs Creek was described as a wide marsh with a several meters wide freshwater creek flowing through it.

It is anticipated that physical conditions and biological community structure will continue to evolve throughout Big Springs Creek as passive restoration actions mature across annual to decadal time scales. Expected changes include:

- continued decreases in water temperatures,
- temporal succession in vegetation assemblages from principally submerged aquatics to a mixture of submerged and emergent aquatics within the channel and along the channel margins,
- a reduction in the functional cross-sectional area of the stream,
- reduced water residence times through increases in streamflow velocities, and
- increased shade and cover following the emergence of aquatic vegetation past the water surface and the transition from soft-stemmed and woody aquatic vegetation to seral growth.

These abiotic responses to changes in aquatic vegetation assemblages will be the principal drivers of continued improvements to salmonid habitat throughout Big Springs Creek.

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