Report

Effects Of A Riparian Forest On Water Temperatures In The Restoration Area

2015 Annual Technical Report

SAN JOAQUIN RIVER RESTORATION PROGRAM

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Abbreviations and Acronyms

SJRRP	San Joaquin River Restoration Program
° F	degrees Fahrenheit
ACOE Park	Army Corps Park Ripon River Crossing
cfs	cubic feet per second
mph	miles per hour

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1.0 Effects Of A Riparian Forest On Water Temperatures In The Restoration Area

1.1 Background

Predictions from the HEC-5Q water temperature model suggest that at a Friant release of 4,500 cfs, the daily maximum water temperatures in reaches 4B and 5 will exceed the upper critical threshold for juvenile Chinook salmon by about March 10 and the upper lethal threshold for adult spring-run Chinook salmon by about April 28 (SJRRP 2014, Figure 1). Previous water temperature model analyses for the SJRRP Restoration Area suggest that increasing riparian shading and narrowing the low-flow channel could result in moderate reductions in daily maximum water temperatures when flows were confined to the main channel (< 2,000 cfs) primarily upstream of Mendota Pool (SJRRP 2008a). No analysis has been conducted for the reaches below Mendota Pool where riparian shading and channel narrowing may have little effect in the northerly flowing channel (SJRRP 2014; SJRRP *in press*).

The overall objective of this study and a companion HEC-5Q modeling study is to estimate the effect of a riparian forest on daily maximum water temperatures in reaches 4B and 5 during the spring. Wide riparian canopies reduce air temperatures at the river and reduced air temperatures may reduce water temperatures (Moore et al. 2005). Studies in upper watersheds in northern California indicated that a 30-meter wide riparian tree canopy reduced above stream air temperatures by 8.6^{o}F compared to sites without riparian trees (Moore et al. 2005). The rate of decline in air temperature due to riparian tree canopies is highest up to a width of 30 meters and only 0.36^{o}F for each additional 10 meters of width. The upper watershed studies also showed that riparian forests offset temperature reductions by a small degree by reducing wind speed by about 15% and by increasing relative humidity by about 12.5% (Moore et al. 2005).

The preliminary results of this study conducted in spring and early summer 2014 indicated that the riparian forests in the San Luis National Wildlife Refuge (Reach 4) were too small to substantially affect air temperatures (SJRRP 2014; SJRRP *in press*). The preliminary 2014 results also indicated that Central Valley floor riparian forests reduced wind speed and increased relative humidity to a much greater than had been observed during the upper watershed studies (Moore et al. 2005; SJRRP 2014). To provide data that would better reflect a fully restored forest, this study was expanded to include large riparian forests on the Stanislaus River at Caswell Memorial State Park (258 acres), Army Corps Park at Ripon (31 acres), and newly restored forests in the San Joaquin River National Wildlife Refuge (Figure 1). Once this study has been completed, the companion HEC-5Q modeling study could use this study’s data and the SJRRP HEC-

5Q model to predict the effects of a riparian forest on water temperatures in the Restoration Area.

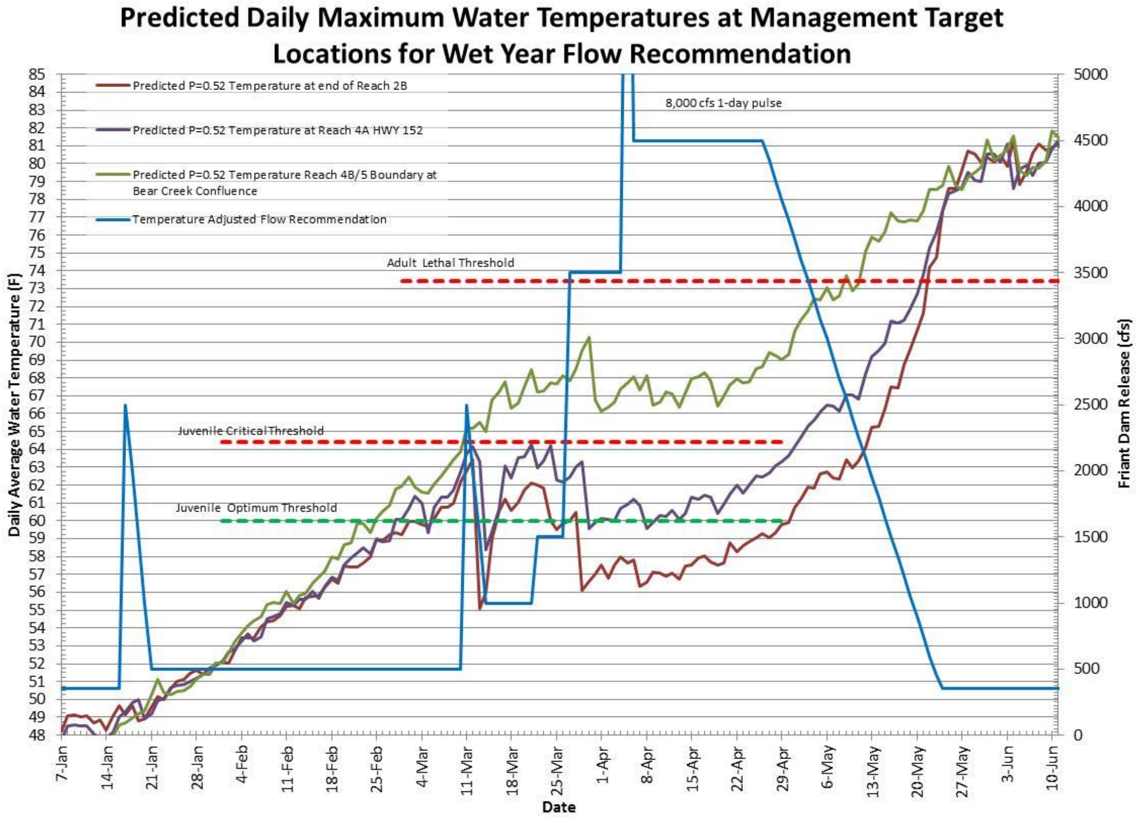

Figure 1. Possible Wet Year flow recommendation designed to maximize adult spring-run passage and two brief pulse flows for juvenile passage relative to the predicted daily maximum water temperatures (SJRRP 2008b) during average meteorological conditions from 1980 to 2005 (P = 0.52 exceedance) just upstream of Mendota Pool (Reach 2B), at Highway 41 (Reach 4A), and the confluence with Bear Creek (Reach 4B-5 boundary). The lethal threshold for adult salmon is a 7-day mean daily maximum temperature of 73.4°F (23°C). Temperatures that exceed the lethal threshold for fewer than 7 days may not be lethal. The water temperature predictions in reaches 4B and 5 in this figure may exceed actual temperatures by about 2°F in April and by 1-2°F in May (SJRRP 2012).

1.2 Methods

1.2.1 Weather Stations

Onset weather stations were deployed with sensors for air temperature (S-THB-M002), relative humidity (S-THB-M002), wind speed (S-WSA-M003), wind direction (S-WDA-M003), and solar radiation (S-LIB-M003) on aluminum tripods (M-TPB-KIT). The pyranometers (solar radiation), anemometers (wind speed), and wind direction sensors were set at 2 meters above the ground on leveled tripods anchored to the ground with 3 guy wires (Figure 2). The relative humidity and air temperature sensor was attached to the tripod 1.5 meters above the ground within the Onset RS3 solar radiation shield and the readings. Sensor data were recorded in 15-minute intervals during 2014 and in 5-minute intervals during 2015. Differences in air temperature, wind speed, and relative humidity between forested and open sites were quantified as the mean daily difference between afternoon measurements (12 PM to 4 PM daylight savings time). Daily means were used because microclimate estimates recorded at 5-minute and 15-minute intervals are not independent. For example, the temperature at 1 PM is highly dependent on the temperature at 12:55 PM. Independent data are required for statistical analyses as described below.

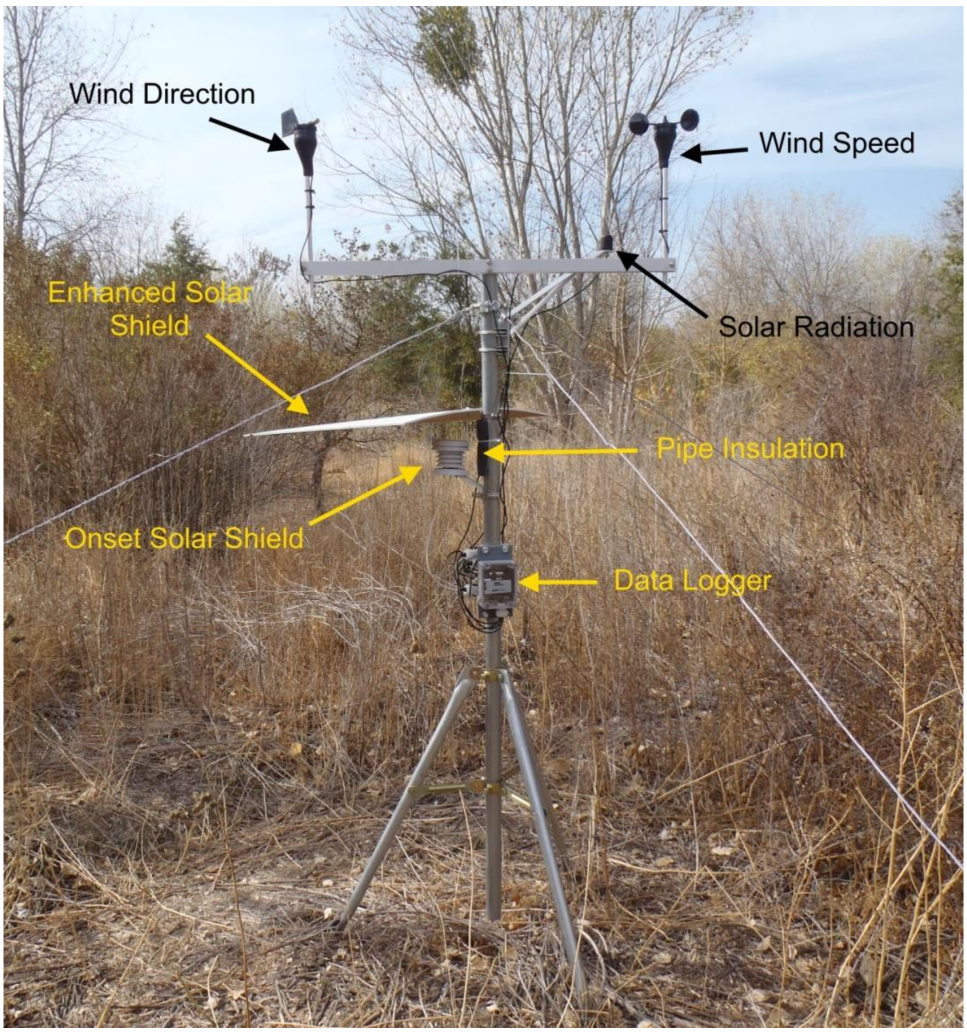

Figure 2. Weather station with an enhanced solar shield, an Onset solar shield with temperature and relative humidity sensors, a solar radiation sensor, wind speed sensor, and a wind direction sensor in the mixed-species forested site on the San Joaquin River National Wildlife Refuge.

To isolate the temperature sensors from solar radiation, three solar shields were used. During preliminary studies, only Onset solar shields (model RS3) were used. However, they are not 100% effective, particularly at wind speeds less than 5 mph, which was common in the forested sites. For example under laboratory conditions, the temperature rise due to solar radiation for a ventilated radiation shield was 9.4^{o}F when the sun was directly overhead and wind speed was 0.45 mph (Gill 1983). The second shield used for this study, hereafter referred to as an enhanced solar shield, was a 2 ft^2 1/8-inch plywood sheet painted white and suspended 3 inches above the Onset solar shields (Figure 2). The enhanced solar shields were oriented south to maximize shading. They were observed to completely shade the Onset solar shield (model RS3) containing the air temperature and relative humidity sensor between 9:30 AM and 3:30 PM during early November 2014 after daylight savings time had ended. The third shield was polyethylene pipe insulation (3/8-inch wall thickness) wrapped around the weather station tripod near the temperature sensor. The tripod conducted a substantial amount of heat from above the enhanced solar shield to below the shield and the pipe insulation minimized radiation of this conducted heat to the temperature sensor. To test the effectiveness of the enhanced solar shade and pipe insulation, two weather stations were deployed approximately 10 feet apart, one in full sun and the other in full shade for three days in September 2014. The results indicated that the mean afternoon air temperatures recorded by a sensor under the enhanced shield in full sun was 0.1^{o}F cooler (range 0.59^{o}F cooler to 0.62^{o}F warmer compared to the nearby sensor in full shade over the 3-day study. It was assumed that the observed temperature differences were due to (1) actual differences in temperature between the two stations and (2) the reported 0.4^{o}F error of the Onset sensors. Therefore, it was assumed that the combination of the three solar shades was 100% effective.

A total of 18 weather stations were deployed within four areas within the San Joaquin River Basin (Figure 3, Table A1). Weather stations were deployed at two small forested areas, called Site 3 (Figure 4) and Site 7 (Figure 5), in the San Luis National Wildlife Refuge, which is within Reach 4B2 of the SJRRP Restoration Area. At each of these two sites, two weather stations were deployed near the center of the forested area, one near the riverbank, and one in a nearby non-forested area. These two sites were among the largest forested areas in the Restoration Area; eight other sites that were included in the preliminary study were deemed to be too small to provide useful data. Three weather stations were established near the riverbank in forested areas along the Stanislaus River in the Caswell Memorial State Park (Caswell) and the Army Corps Park near Ripon (ACOE Park). Caswell has a dense, old growth, valley oak woodland that is about 7.4 km (4.6 miles) long (Figure 6). Caswell Site 1 had to be relocated about 37 meters east on September 10, 2014 after a 2-foot diameter oak limb fell on the weather station. The ACOE Park site is also a relatively large (300-meter diameter), old growth woodland (Figure 7). The ACOE Park weather station was relocated to Caswell Site 3 in March 2015 after the ACOE Park site was vandalized twice (Figure 6). Two stations were established in non-forested areas on City of Ripon property between the Caswell and ACOE Park sites (Figure 7). One non-forested station was established on the riverbank (Ripon Site 1) and the other on top of the levee (Ripon Site 2). Only Ripon Site 2 was used because it was most similar to the non-forested sites in the Restoration Area.

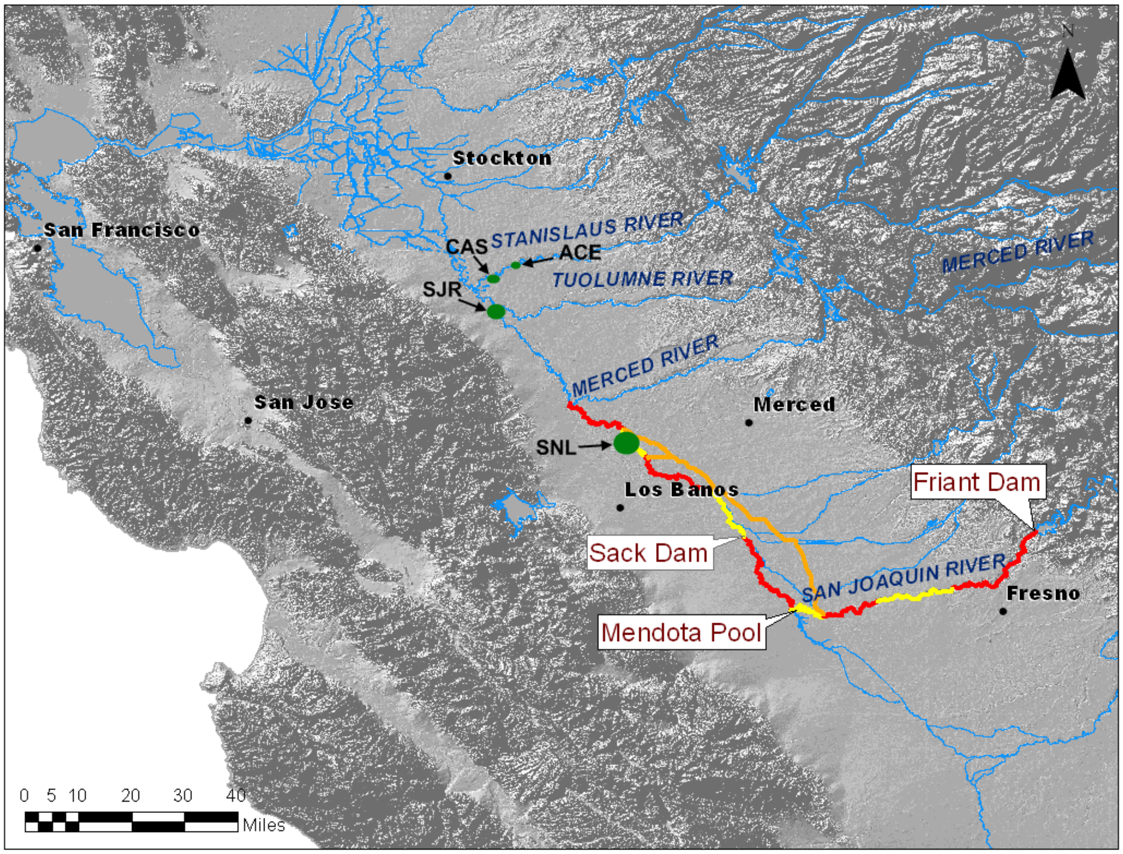

Figure 3. Study site locations (green ovals) in the San Luis National Wildlife Refuge (SNL, Reach 4B2), San Joaquin River National Wildlife Refuge (SJR), Caswell Memorial State Park (CAS), and ACOE Park near Ripon (ACE).

Two weather stations were established in restored forested areas in the San Joaquin River National Wildlife Refuge (Figure 8). One station was established in a Fremont Cottonwood forest that was planted in an agricultural field by River Partners in 2002. The other station was established in a mixed-species forest that was planted by River Partners in 2004. A third station was established on a non-forested area near the riverbank on Dos Rios Ranch, which had been acquired by River Partners (Figure 8).

The water year types were Critical High and Critical Low in 2014 and 2015, respectively. The flow range for each study period at the CDEC Stevinson gauge (SJS), which is about 4 miles downstream of Site 3, is presented in Table 1.

Table 1. Flow range and mean flow at the CDEC Stevinson gauge in 2014 and 2015.

Study Period	Minimum Flow (cfs)	Maximum Flow (cfs)	Mean Flow (cfs)
July-Aug 2014	0	14	4.0
Oct-Nov 2014	2	45	12.1
Jan-Feb 2015	7	22	11.6
Apr-May 2015	0	40	20.6

Figure 4. Site 3 in the San Luis National Wildlife Refuge near rivermile 138. Yellow pins show the locations of the weather stations near the riverbank (RB), middle of the forest (For), and the non-forested site (Open).

Figure 5. Site 7 in the San Luis National Wildlife Refuge near rivermile 144. Yellow pins show the locations of weather stations near the riverbank (RB), middle of the forest (For), and the non-forested site (Open). The blue line shows the botanical transect, which was 50 meters in length. Rivermiles 143 and 144 are shown.

Figure 6. Caswell Memorial State Park Sites 1, 2, and 3 on the Stanislaus River about 5 miles upstream from the confluence with the San Joaquin River. Yellow pins show the locations of the weather stations on September 10, 2014 after Caswell 1 was relocated.

Figure 7. Weather station sites near rivermile 16 on the Stanislaus River at the ACOE Park and a non-forested site called Ripon Open 2. The sites are near State Highway 99 in the City of Ripon, California.

Figure 8. Google Earth March 2014 image of the locations of weather stations in a restored cottonwood forest (SJR Cottonwood) and a restored mixed-species forest (SJR Mixed) in the San Joaquin River National Wildlife Refuge and another station in a non-forested site (SJR Open) on the Dos Rios Ranch.

1.2.2 Botanical Surveys

Vegetation monitoring sites were established at all forested and open sites at the San Luis National Refuge where plant density, percent cover, canopy height, and species composition were recorded (Technical Service Center botanists, Greg Reed and Rebecca Siegle). Surveys were made in May 2014 in the San Luis National Wildlife Refuge and May 2015 at the Stanislaus River and San Joaquin River National Wildlife Refuge. Hemispheric photos were taken in the forested areas to quantify tree canopy density. A single photo was taken immediately above a t-post in the middle of the botanical transect at each forested site in the San Luis National Wildlife Refuge just after dusk in May and June 2014. Three hemispherical photos were taken at random locations within each forested site in the Stanislaus River and San Joaquin River National Wildlife Refuge on an overcast day in May 2015. A white plastic pointer was used to indicate magnetic North in each photo to provide the ability to replicate the analysis in the future.

1.2.3 Statistical Methods

Nonparametric bootstrap methods with 1,000 replicates (Stata 13.1) were used to develop quantitative models of reduced afternoon air temperatures associated with mature riparian forests relative to air temperature, wind speed, and solar radiation at the non-forested sites. The statistical models can be directly applied to HEC-5Q input files which include estimates of air temperature, wind speed, and solar radiation needed to simulate water temperatures. Nonparametric bootstrapping methods avoid most of the assumptions of parametric methods (Efron and Tibshirani 1986), except that observations are assumed to be independent (Good 2005). Some models violated the assumption of independence based on Durbin-Watson tests. Autocorrelation was caused by the nonrandom patterns in climate, such as gradually warming, sunny trends followed by gradual cooling, cloudy trends. Corrections for autocorrelation were made to all model's chi-square (χ^2) and variable's *z*-values by dividing them by the square root of ((1+r)/(1-r)), where r equaled the autocorrelation statistic computed by JMP 10.0 (van Belle 2008; Dale and Fortin 2009). Corrected probability levels were computed using online calculators for statistical table entries (http://vassarstats.net/tabs.html).

Separate models were developed for summer (July and August 2014), fall (October and November 2014), winter (January and February 2015), and spring (April and May 2015) to reflect changes in leaf-out, seasonal lag in air temperatures, and seasonal changes in rainfall that were not included in the statistical models. The winter model reflects riparian forests without leaves and minimal solar radiation. In contrast, the spring model reflects nearly full leaf-out and moderate solar radiation levels. Rainfall was unusually low during winter 2015 (total rainfall 1.05 inches at Los Banos) and spring 2015 (total rainfall 1.18 inches at Los Banos). The summer model (July and August 2014) reflects near-peak solar radiation, maximum air temperatures, and no rainfall. The fall model (October and November 2014) reflects the beginning of leaf drop associated with extreme drought conditions as well as moderate solar radiation, moderate air temperatures, and no rainfall.

Potential model microclimate variables that were tested included the mean afternoon observations of solar radiation (Watts/m^2), air temperature (degrees Fahrenheit), and wind speed (miles/hour) at the non-forested sites. If these variables were not significantly correlated with air temperature reductions, then the mean afternoon gust speed at the forested sites was tested. Variables were selected using the minimum Bayesian Information Criterion (BIC) in a forward stepwise procedure to generate the best model (JMP 10.0).

Daily means of the percent differences in the afternoon wind speeds and relative humidity levels between the forested and non-forested sites were computed using JMP 10.0.

1.3 Results

1.3.1 Botanical Surveys

The riparian tree species in the San Luis National Wildlife Refuge Site 3 and Site 7 forested areas were predominately Goodding's willow (*Salix gooddingii*). The predominate grass and forbs at these forested sites were ripgut brome (*Bromus diandrus*) and California mugwort (*Artemisia douglasiana*). The percentage of tree canopy cover was estimated to be 86.9% near Site 3 For-A (Figure 9) and 58.3% near Site 7 For-A (Figure 10) based on the hemispherical photos. Introduced grasses, including ripgut brome, mouse barley (*Hordeum murinem*), and Mediterranean barley (*Hordeum marinum ssp gussoneanum*), were the predominate species at the San Luis open sites.

Figure 9. Hemispherical photo of Site 3 For-A in the San Luis National Refuge taken June 5, 2014.

Figure 10. Hemispherical photo of Site 7 For-A in the San Luis National Refuge taken June 17, 2014.

The Caswell State Park study sites had a typical Valley Oak (*Quercus lobate*) forest that also included box elder (*Acer negundo*), Oregon ash (*Fraxinus latifolius*), and northern California black walnut (*Juglans hindsii*) on the upper terrace where the weather stations were located and Fremont cottonwood (*Populus fremontii*), coyote willow (*Salix exigua*), and Goodding's willow along the riverbank. Herbaceous species in the upper terrace included sedge (*Carex* sp.), Queen Anne's lace (*Daucus carota*), bedstraw (*Gallium* sp.), stinging nettle (*Urtica dioica*), and California grape (Vitis californica). The percentage tree canopy cover was estimated to be 88.0% at Caswell Site 1 (Figure 11), 82% at Caswell Site 2 (Figure 12), and 85% at Caswell Site 3 (Figure 13) based on the hemispherical photos. Although a hemispherical photo was taken at the ACOE Park site (Figure 14), tree canopy cover could not be digitally analyzed because it was taken during the day and there was too much sunlight on the canopy. Based on a simple visual comparison with the other sites, the tree canopy density at the ACOE Park site was at least 90% in May 2014.

Figure 11. Hemispherical photo of Caswell Site 1 on the Stanislaus River taken July 25, 2014.

Figure 12. Hemispherical photo of Caswell Site 2 on the Stanislaus River taken July 25, 2014.

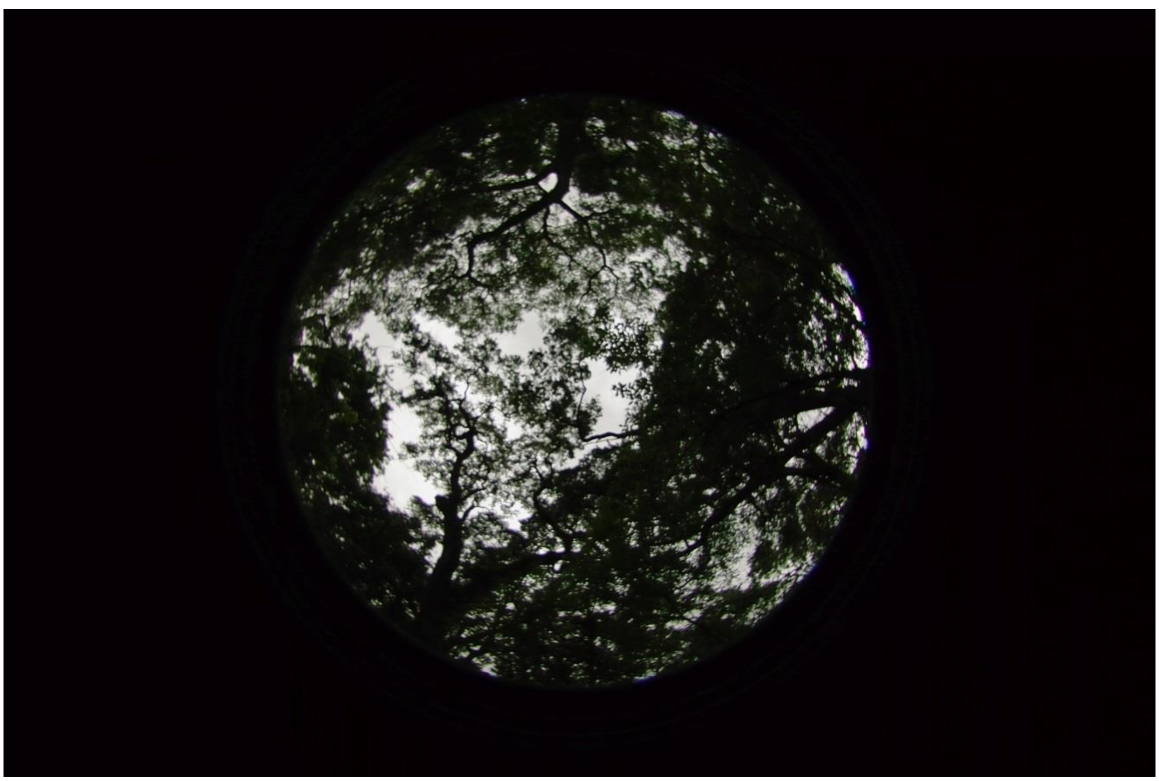

Figure 13. Hemispherical photo of Caswell Site 3 on the Stanislaus River taken June 8, 2015.

Figure 14. Hemispherical photo of the ACOE Park site on the Stanislaus River taken July 25, 2014.

The tree species at the SJR Cottonwood site were predominately Fremont cottonwood with a few valley oak. The mean height of the cottonwoods and valley oak was 15.8 meters and 4.2 meters, respectively. The predominate understory was yellow sweetclover (*Melilotus officinalis),* prickly sow thistle (*Sonchus asper*), and gum plant (*Grindelia camporum*). The percentage tree canopy cover was estimated to be 49.0% (Figure 15), based on the hemispherical photos.

Figure 15. Hemispherical photo of the SJR Cottonwood site in the San Joaquin River National Wildlife Refuge taken May 7, 2015.

The tree species at the SJR Mixed site were predominately Fremont cottonwood, valley oak, and box elder. The mean height of the cottonwoods, valley oak, and box elder was 12.2 meters, 6.8 meters, and 4.8 meters, respectively. The predominate understory was yellow sweetclover, black mustard (*Brassica nigra*), and creeping wildrye (*Leymus triticoides*). The percentage tree canopy cover was estimated to be 32.0% (Figure 16), based on the hemispherical photos.

Figure 16. Hemispherical photo of the SJR Mixed site in the San Joaquin River National Wildlife Refuge taken May 7, 2015.

1.3.2 Microclimate effects

The effects of riparian forests on the air temperatures varied diurnally and seasonally. The differences in air temperatures between the large, mature forests and the non-vegetated sites on the Stanislaus River were greatest from noon to about 8 PM during the summer (Figure 17); peaked sharply between 4 and 6 PM during the fall (Figure 18); were less than 2^{o}F during the winter (Figure 19); and peaked between noon and 3 PM during the spring (Figure 20). Conditions from noon to 4 PM (daylight savings) were used in statistical models because (1) this period has the greatest effect on daily maximum water temperatures and (2) this period was when the solar shades provided the most accurate air temperature data.

The statistical models suggest that large mature riparian forests, such as those at Caswell and the ACOE Park study sites, could reduce afternoon air temperatures compared to non-forested open sites by 5.6 to 7.5^{o}F during summer (Table 2), 3.7 to 4.8^{o}F during fall (Table 3), and 5.5 to 6.5^{o}F during spring (Table 4) on warm, sunny days with average wind speeds in Reach 4B2 (San Luis National Wildlife Refuge). Afternoon air temperatures at the open sites were the best predictor (highest *t*-values or *z*-values) of temperature reductions during the spring (Table 4) and summer (Table 2) at the large mature forests. The reduction in air temperature within the forested areas was greatest when air temperatures were highest at the open sites. During the fall, solar radiation at the open sites was the best predictor of temperature reductions at the large mature forests (Table 3). The reduction in air temperature at the forested sites was greatest when the solar radiation was highest at the open sites. Temperature reductions were relatively low at the small mature riparian forests in Reach 4B2 (Sites 3 and 7) compared to the large forests at Caswell and the ACOE Park. The magnitude of the summer temperature reductions at the small mature forests in Reach 4B2 was inversely related to the wind speed and positively related to solar radiation and air temperature at the non-forested sites (Tables 2, 3, and 4). Minimal temperature reductions were observed at the restored forested areas in the San Joaquin River National Wildlife Refuge probably because the canopy densities were low at both of the recently planted forests compared to the Stanislaus River and San Luis National Wildlife Refuge sites. The statistical models for the large, mature forests at Caswell and the ACOE Park were highly significant (Tables 2, 3, and 4). The air temperatures within the smaller and less mature forests were highly variable probably because they were substantially affected by hot air blowing into the forested areas from nearby non-forested areas and by openings in the tree canopy that allowed solar radiation to reach different locations on the forest floor depending on the time of day.

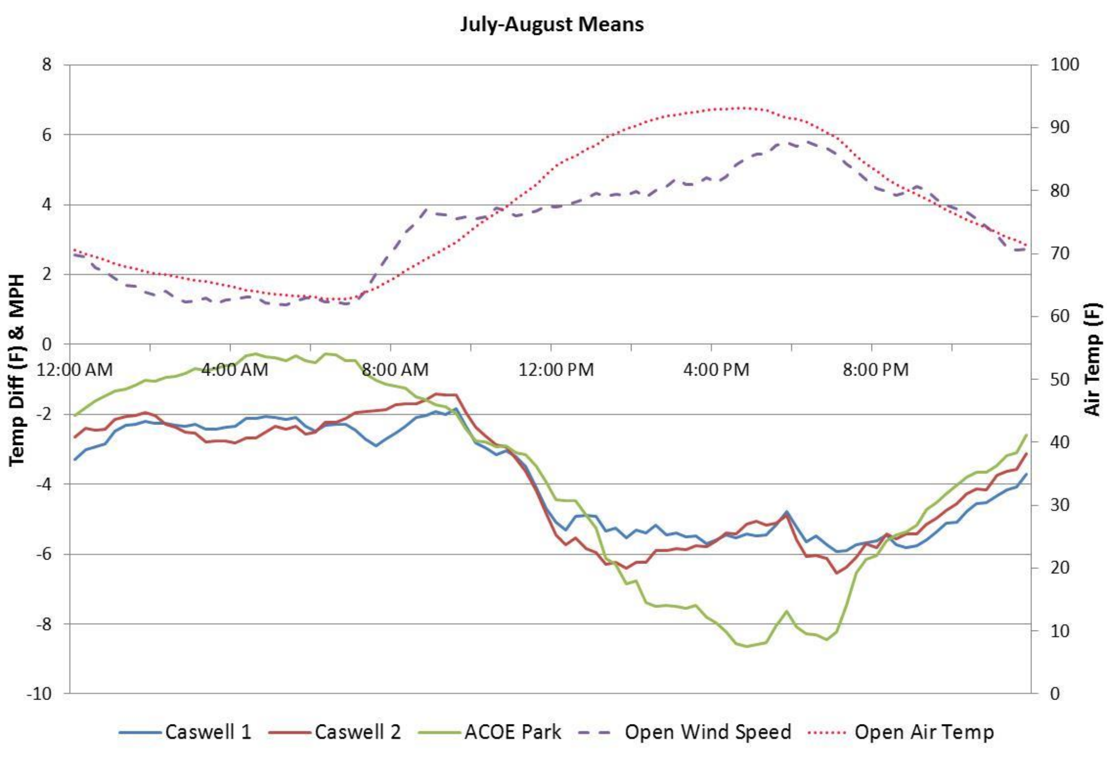

Figure 17. Mean hourly differences in air temperatures at Caswell 1, Caswell 2, and ACOE Park forested sites and a non-vegetated site (Ripon Open 2) as well as the mean wind speed and mean air temperature at Ripon Open 2 during July and August 2014. Daylight saving time was in effect and solar noon occurred about 1 PM, when solar radiation was typically at the daily maximum.

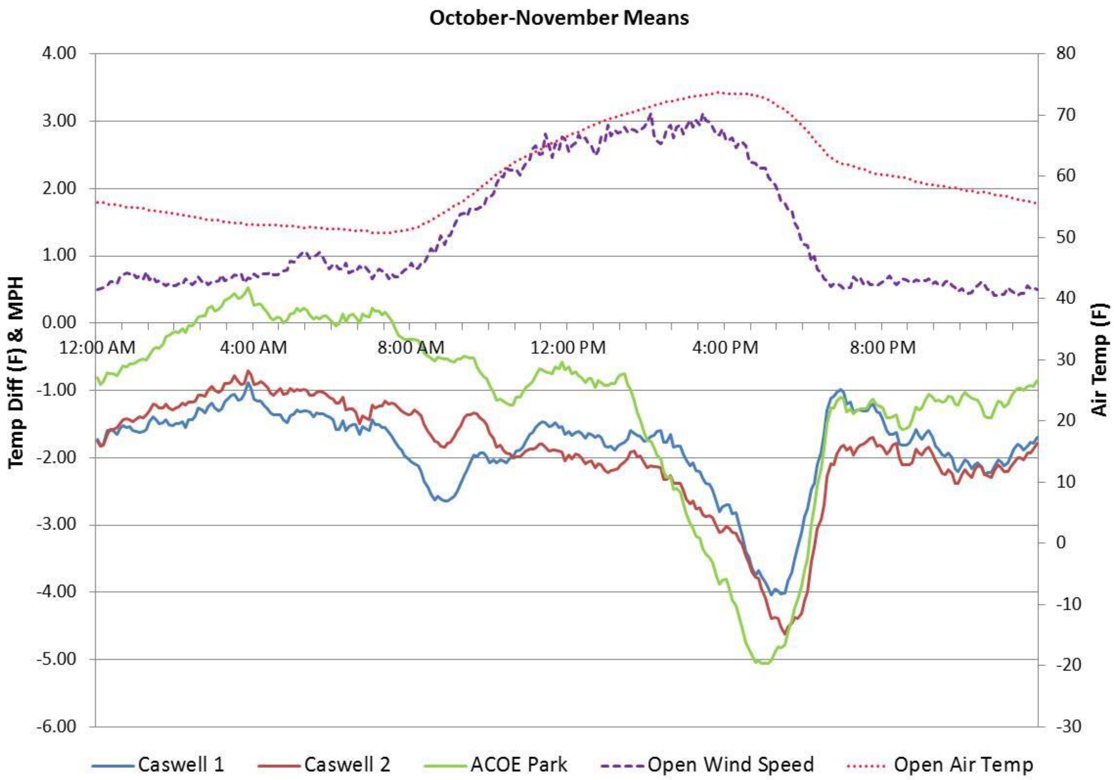

Figure 18. Mean hourly differences in air temperatures at Caswell 1, Caswell 2, and ACOE Park forested sites and a non-vegetated site (Ripon Open 2) as well as the mean wind speed and mean air temperature at Ripon Open 2 during October and November 2014. Daylight saving time was in effect and solar noon occurred about 1 PM.

Wind direction may have affected the temperatures at the SJR Mixed site because it was near the southern border of the forest (Figure 8) and relatively warm air would have blown into the forest from the non-forested sites to the south. The average wind direction at SJR Mixed was from the south east south during fall 2014 (148 degrees; Table 3) and south west south during spring 2015 (197 degrees; Table 4). The same was true for Caswell Site 1, which was near the western border of the forest (Figure 6) where it would have received warm air blowing in from the non-forested sites to the west. The average wind direction at the Caswell sites was from the west (260 degrees, Table 3) during fall 2014 and west south west (238 degrees, Table 4) in spring 2015. Both of these sites exhibited smaller reductions in air temperature during the fall than the other nearby sites. During spring 2015, the SJR Mixed site was warmer compared to the SJR Cottonwood site; whereas the Caswell 1 site had intermediate temperatures (Table 4) compared to the other Caswell sites. Sites 3 and 7 in the San Luis National Wildlife Refuge were both near the western borders of the forest (Figures 4 and 5) and relatively warm air would have blown into the forest from the non-forested sites to the West. The cooling effect of the forests at these sites was dependent on wind speed, particularly during fall 2014 (Table 3).

Wind speeds at the Caswell and San Luis National Refuge sites were 90% to 100% lower in the forested sites than in the non-forested sites in summer 2014 (Table 2), 92% to 100% lower during fall 2014 (Table 3) and 68% to 100% lower during spring 2015 (Table 4).

Relative humidity at the Caswell sites was 35% to 45% higher in the forested sites than the non-forested sites during summer 2014 (Table 2), 10% to 14% higher during fall 2014 (Table 3), and 12% to 15% higher during spring 2015 (Table 4). The extremely low flows at the San Luis National Wildlife Refuge sites may have affected the relative humidity measurements and so they should not be used to calibrate the HEC-5Q model.

The temperature sensor at Site 7 For-B produced erroneous measurements during spring 2015 as evidenced by measurements that were about 10°F higher than the other Caswell sites. No statistical model was generated with these data (Table 4). Although this was the only instance of erroneous measurements, other failures of the sensors and microloggers caused the micrologger batteries to drain within a few days, which prevented the collection of measurements from any of the sensors. Sensors were replaced after battery failure occurred.

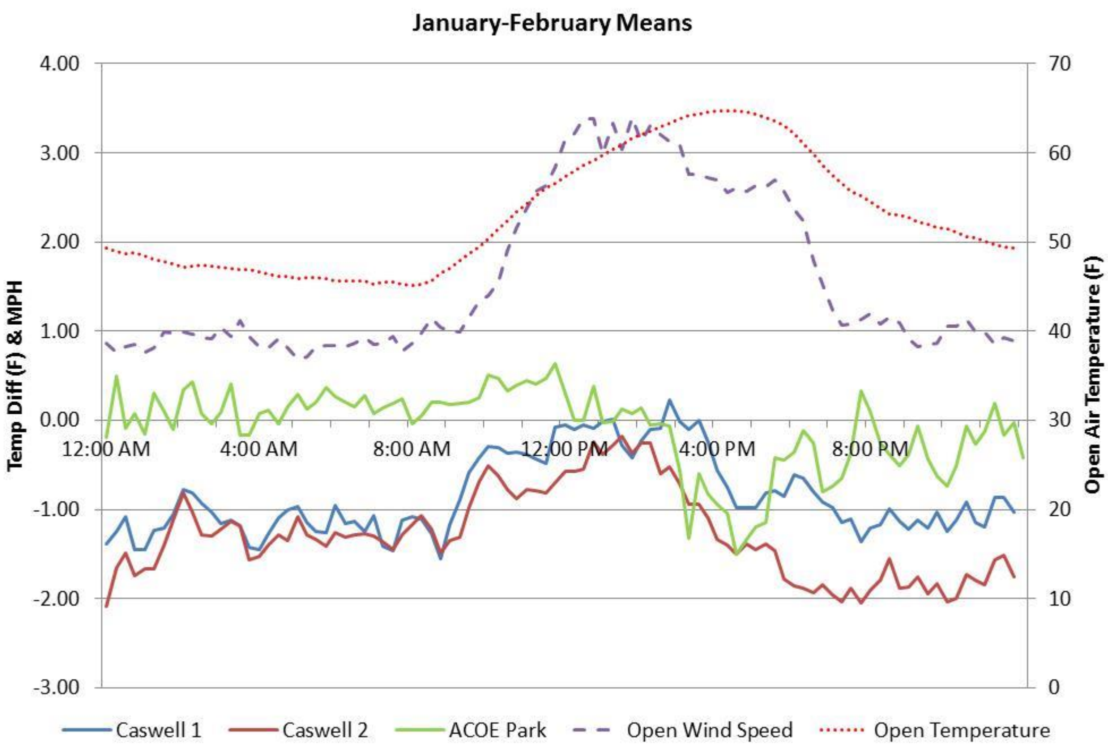

Figure 19. Mean hourly differences in air temperatures at Caswell 1, Caswell 2, and ACOE Park forested sites and a non-vegetated site (Ripon Open 2) as well as the mean wind speed and mean air temperature at Ripon Open 2 during January and February 2015. The data shown reflects daylight saving time for consistency and solar noon occurred about 1 PM.

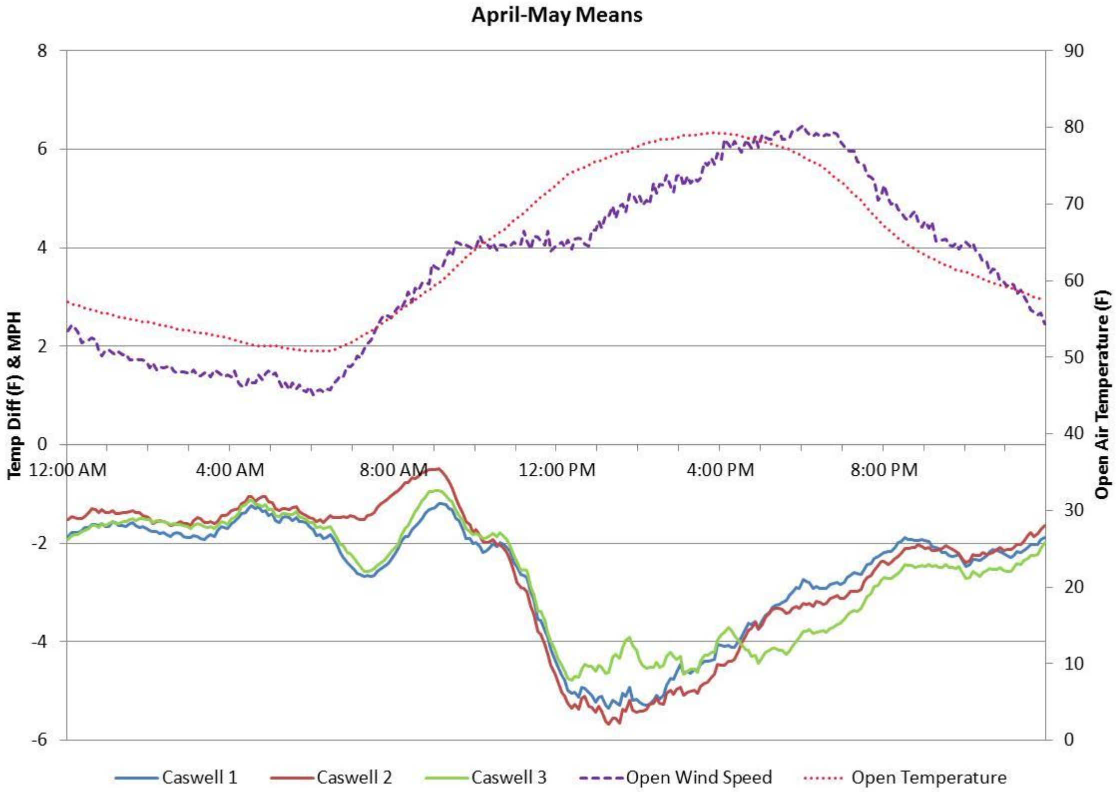

Figure 20. Mean hourly differences in air temperatures at Caswell 1, Caswell 2, and Caswell 3 forested sites and a non-vegetated site (Ripon Open 2) as well as the mean wind speed and mean air temperature at Ripon Open 2 during April and May 2015. The data shown reflects daylight saving time for consistency and solar noon occurred about 1 PM.

Table 2. Bootstrap models corrected for autocorrelation effects are presented for difference in mean daily afternoon air temperatures (degrees Fahrenheit) between non-forested open sites and nearby forested sites relative to the mean daily solar radiation (Watts/m²), wind speed (miles/hour), and air temperatures (^{o}F) at the open sites and/or the gust speed within the forested sites during July and August 2014. Model predictions are given for a solar radiation of 900 Watts/m², an afternoon air temperature of 90^{o}F at the open site, a wind speed at the open site of 4 miles/hour, and a gust speed within the forested site of 1.5 miles/hour. The mean reduction in wind speed and relative humidity for afternoon conditions in July and August are also presented.

	Caswell 1	Caswell 2	ACOE	Site 3 RB	Site 3 For-A	Site 3 For-B	Site 7 RB	Site 7 For-A	Site 7 For-B
adj-R^2	0.691	0.765	0.865	0.384	0.451	0.010	0.280	0.173	0.210
adj χ^2	51.9	114.6	151.1	19.07	24.46	2.05	16.46	6.38	8.23
adj P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.359	0.001	0.012	0.004
Autocorrelation Correction	1.45	1.29	1.15	1.47	1.03	1.12	1.09	1.38	1.00
Model DF	2	3	2	2	2	2	3	1	1
Error DF	33	41	35	57	57	57	56	60	60
Days Sampled	36	45	38	60	60	60	60	62	62
					Adj z-ratios (z-ratios $\geq$ 1.95 are significant, $P \leq 0.05$)				
Solar Open	-1.48	-2.30	--	--	--	-0.83	-2.80	--	--
Wind Open	--	0.57	2.18	2.58	4.87	--	1.50	--	--
Temp Open	-3.16	-5.60	-11.44	-2.64	-1.86	--	-1.02	--	--
Gust Forested	--	--	--	--	--	1.05	--	2.15	2.87
Intercept	3.75	5.62	8.46	1.49	-0.58	-1.27	1.34	-1.65	-7.00
					Model Coefficients				
Solar Open	-0.0046	-0.0055	--	--	--	-0.0007	-0.0038	--	--
Wind Open	--	0.0738	0.2391	0.3304	0.3560	--	0.2405	--	--
Temp Open	-0.1166	-0.1433	-0.2956	-0.0650	-0.0249	--	-0.0195	--	--
Gust Forested	--	--	--	--	--	0.0964	--	0.2993	0.2962
Intercept	9.1080	10.0587	19.1319	3.4585	-0.6663	-0.9359	2.0527	-0.5124	-2.8100
					Model Predictions				
Temp Reduction	-5.55	-7.51	-6.52	-1.07	-1.49	-1.42	-2.14	-0.06	-2.37
					Afternoon Mean Differences				
Wind Reduction	-99.6%	97.5%	-100.0%	-99.3%	-94.8%	99.8%	93.1%	-99.4%	89.5%
RH Increase	34.9%	36.7%	44.5%	11.8%	6.7%	3.7%	8.0%	-0.1%	4.7%

Table 3. Bootstrap models corrected for autocorrelation effects are presented for difference in mean daily afternoon air temperatures (degrees Fahrenheit) between non-forested open sites and nearby forested sites relative to the mean daily solar radiation (Watts/m²), wind speed (miles/hour), and air temperatures (^{o}F) at the open sites during October and November 2014. Model predictions are given for a solar radiation of 700 Watts/m² and a wind speed of 3 miles/hour at the open sites. The mean reduction in wind speed and relative humidity for afternoon conditions in October and November are also presented.

	Caswell 1	Caswell 2	ACOE	SJR Cottonwood	SJR Mixed	Site 3 RB	Site 3 For-A	Site 3 For-B	Site 7 RB	Site 7 For-A	Site 7 For-B
adj-R^2	0.499	0.575	0.680	0.699	0.689	0.651	0.671	0.423	0.550	0.288	0.253
adj χ^2	53.57	83.44	77.82	59.58	85.98	105.15	138.05	47.70	58.46	45.43	16.58
adj P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.000
Autocorrelation Correction	1.24	1.60	1.64	0.88	0.85	1.61	1.34	1.57	1.01	1.31	1.33
Model DF	2	2	2	2	2	2	2	2	1	2	2
Error DF	58	58	58	48	48	58	58	58	31	58	30
Days Sampled	61	61	61	51	51	61	61	61	33	61	33
Adj z-ratios (z-ratios $\geq$ 1.95 are significant, $P \leq 0.05$)											
Solar Open	-6.53	-7.16	-6.16	-2.01	1.37	-6.95	-9.58	-5.47	-7.61	-4.95	-2.58
Wind Open	1.87	2.60	0.26	7.63	7.99	4.53	5.18	1.59	--	2.64	1.09
Intercept	-1.95	-2.50	1.34	-2.97	-3.72	-1.25	-1.60	-0.74	4.05	-1.62	0.20
Model Coefficients											
Solar Open	-0.0048	-0.0055	-0.0078	-0.0019	0.0011	-0.0044	-0.0047	-0.0034	-0.0089	-0.0027	-0.0046
Wind Open	0.0857	0.1755	0.0263	0.3396	0.2920	0.2502	0.2323	0.0692	--	0.1665	0.1277
Intercept	-0.5620	-1.0112	0.5960	-1.0984	-1.2628	-0.4106	-0.3953	-0.2056	2.7096	-0.5434	0.1991
Model Predictions											
Temp Reduction	-3.68	-4.34	-4.80	-1.38	0.39	-2.71	-3.00	-2.35	-3.53	-1.96	-2.65
Afternoon Mean Differences and Wind Direction											
Wind Reduction	-98.6%	-97.9%	-100.0%	-75.6%	-66.3%	-99.0%	-93.4%	-96.7%	-91.9%	-94.9%	-93.3%
RH Increase	10.4%	12.2%	13.8%	-3.5%	-5.2%	5.9%	5.2%	3.3%	9.2%	8.3%	8.2%
Wind Direction	262.4	258.6	--	200.0	147.6	--	--	--	--	--	--

Table 4. Bootstrap models corrected for autocorrelation effects are presented for difference in mean daily afternoon air temperatures (degrees Fahrenheit) between non-forested open sites and nearby forested sites relative to the mean daily solar radiation (Watts/m²), wind speed (miles/hour), and air temperatures (°F) at the open sites during April and May 2014. Model predictions are given for an air temperature of 85°F, solar radiation of 850 Watts/m², and a wind speed of 3.75 miles/hour at the open sites. The mean reduction in wind speed and relative humidity for afternoon conditions in October and November are also presented.

	Caswell 1	Caswell 2	Caswell 3	SJR Cottonwood	SJR Mixed	Site 3 RB	Site 3 For-A	Site 3 For-B	Site 7 RB	Site 7 For-A
adj-R^2	0.758	0.829	0.752	0.750	0.667	0.429	0.771	0.520	0.194	0.171
adj χ^2	142.90	164.17	128.85	219.63	78.50	29.4	101.37	36.98	11.49	7.70
adj *P*	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0007	0.0213
Autocorrelation Correction	1.09	1.21	1.16	1.02	1.33	1.68	0.88	0.98	1.57	1.52
Model DF	2	2	2	2	2	3	3	2	1	2
Error DF	58	58	56	58	58	57	57	58	59	58
Days Sampled	61	61	59	61	61	61	61	61	61	61
Adj *z*-ratios (*z*-ratios $\geq$ 1.95 are significant, $P \leq 0.05$)										
Temp Open	-10.49	-10.11	-8.31	--	--	-1.17	-3.10	-2.00	-2.70	-2.15
Wind Open	4.81	5.53	4.80	14.60	5.88	2.14	4.99	--	--	--
Solar Open	--	--	--	2.95	6.18	-1.64	-4.11	-1.97	--	1.77
Intercept	3.65	-3.58	2.71	-5.19	-4.34	1.41	3.40	2.74	2.58	1.02
Model Coefficients										
Temp Open	-0.1201	-0.1324	-0.1100	---	--	-0.0525	-0.0465	-0.0388	-0.1056	-0.0658
Wind Open	0.2302	0.2606	0.2247	0.4558	0.2394	0.1920	0.2031	--	--	--
Solar Open	--	--	--	0.0020	0.0044	-0.0037	-0.0051	-0.0038	--	0.0044
Intercept	3.3197	3.7897	2.9954	-2.9820	-2.7276	3.7165	3.3072	3.031	7.7729	2.1384
Model Predictions										
Temp Reduction	-6.03	-6.49	-5.51	0.40	1.90	-3.15	-4.19	-3.50	-1.20	0.26
Afternoon Mean Differences and Wind Direction										
Wind Reduction	-99.6%	-98.3%	-99.5%	-66.9%	-44.7%	-96.6%	-98.5%	-95.0%	-83.6%	-68.2%
RH Increase	14.5%	12.4%	12.1%	-3.4%	-5.6%	18.0%	13.2%	13.9%	-2.3%	-5.0%
Wind Direction	238.2	284.3	--	264.4	197.2	252.9	252.9	252.9	260.6	260.6

1.4 Discussion

The results of this study suggest that mature riparian forests on the valley floor may not reduce water temperatures as much as forests in the upper watersheds. In the upper watersheds, a 30-meter wide riparian tree canopy would be expected to reduce above stream air temperatures by 8.6^{o}F, reduce wind speed by about 15%, and increase relative humidity by about 12.5% (Moore et al. 2005). Reduced air temperatures should reduce water temperatures, but the effect of air temperature on water temperature may interact with a reduction in wind speed and an increase in relative humidity. Using these upper watershed forest microhabitat conditions, the SJRRP HEC-5Q analysis suggested that water temperatures in Reach 4B would be reduced by about 6^{o}F in early-April, 5^{o}F in late-April, and 4.5^{o}F in mid-May. In contrast, the large mature riparian forests at Caswell 2 and Caswell 3 reduced air temperatures by 6.0 ^{o}F to 6.5^{o}F, reduced wind speed by 98 to 100%, and increased relative humidity by 12 to 15% during the spring, which is the most important migratory period for adult and juvenile spring-run Chinook salmon in the Restoration Area. Reductions in air temperatures by valley floor forests were greater during the summer (6.5 to 7.5 ^{o}F) but less pronounced during the fall (4.3 to 4.8 ^{o}F) and winter compared to the spring. Furthermore, valley floor forests need to cover large areas to substantially lower air temperatures. The 55-meter to 65-meter wide forests in Reach 4B2 reduced air temperatures to a much smaller degree than did the large forests at Caswell and the ACOE Park which were at least 200 meters wide. Furthermore, the low density canopies at the recently replanted forests at the San Joaquin River National Wildlife Refuge did not reduce air temperatures during spring 2015. As a result, canopy density is important and should be considered when planning habitat restoration projects.

1.5 Recommendations

In regard to salmon survival, the spring air temperature models are important for the SJRRP because they reflect the period when juvenile and adult spring-run salmon migrate. The fall models are the next most important because they reflect the period when adult fall-run salmon typically migrate. The results of this study suggest that the microclimate data from the upper watersheds (Moore et al. 2005) do not reflect in air temperature, wind speed, or relative humidity as previously documented in the Restoration Area. Therefore, the HEC-5Q model should be recalibrated to reflect the valley floor microclimate associated with a large and mature riparian forest like the study sites at Caswell Memorial State Park (SJRRP 2014; SJRRP *in press*). Future HEC-5Q analyses should consider (1) evaluating or including the effects of restoring a large and mature riparian forest on water temperatures and (2) comparing these effects with those associated with a narrowing of the river channel in place of or in combination with riparian forest restoration (SJRRP 2008b; SJRRP 2014; SJRRP *in press*).

1.6 References

Dale, M. and M. Fortin. 2009. Spatial autocorrelation and statistical tests: some solutions. Journal of Agricultural Biological and Environmental Statistics 14(2):188-206.

Efron, B. and R. Tibshirani. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science 1(1):54.77.

Gill, G. C. 1983. Comparison testing of selected naturally ventilated radiation shields. NOAA Data Buoy Office Rep., Bay St. Louis, MS, in partial fulfillment of Contract NA-82-0A-A-266, 38 pp. [Available from NOAA/National Data Buoy Center, Bay St. Louis, MS 39529.]

Good, P. 2005. Permutation, parametric, and bootstrap tests of hypotheses. Third edition. Springer, New York. 315 p.

Moore, R. D., D. L. Spittlehouse, and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review. Journal of the American Water Resources Association, 41(4): 813-834.

SJRRP (San Joaquin River Restoration Program). 2008a. Temperature Model Sensitivity Analyses Sets 4 & 5. Draft Technical Memorandum, October 2008.

SJRRP (San Joaquin River Restoration Program). 2008b. Temperature Model Sensitivity Analyses Sets 1 & 2. Draft Technical Memorandum, February 2008.

SJRRP (San Joaquin River Restoration Program). 2012. SJRRP temperature model SJR5Q Evaluation in Post-Settlement Conditions. Draft Technical Memorandum, October 2012.

SJRRP (San Joaquin River Restoration Program). 2014. Reducing spring water temperatures below Sack Dam. 2014 Mid-Year Technical Report. July 2014.

SJRRP (San Joaquin River Restoration Program). *in press*. Effects of a riparian forest on water temperatures in the Restoration Area. Annual Technical Report.

van Belle, G. 2008. Statistical Rules of Thumb. John Wiley and Sons, Inc. 2nd Ed. Hoboken, New Jersey. 272 p.

1.7 Appendix: Study Sites

Table A1. Sampling dates, GPS coordinates, minimum canopy diameter, and mean canopy density at Sites 3 and 7 in the San Luis National Wildlife Refuge, Caswell and ACOE Park sites on the Stanislaus River, and Cottonwood and Mixed Tree Species revegetation sites on the San Joaquin River National Wildlife Refuge. Some weather stations were located near the riverbank (RB) whereas some were located near the middle of the forested areas (FOR).

Site	Launch Date	Status - End Date	Latitude	Longitude	Minimum Canopy Diameter (m)	Canopy Density
3-RB	7/01/2014	Logging	37°15'44.0"N	120°49'51.4"W	60	--
3 FOR-A	6/30/2014	Logging	37°15'43.8"N	120°49'52.5"W	60	86.9%
3 FOR-B	6/30/2014	Logging	37°15'32.7"N	120°49'47.6"W	65	--
3 Open	7/03/2014	Logging	37°16'18.4"N	120°49'50.1"W	0	0%
7 RB	7/03/2014	Logging	37°13'00.9"N	120°46'57.9"W	63	--
7 FOR-A	7/01/2014	Logging	37°13'00.7"N	120°46'58.7"W	63	58.3%
7A FOR-B	7/01/2014	Logging	37°12'56.0"N	120°46'59.2"W	55	--
7 Open	6/30/2014	Logging	37°13'36.4"N	120°48'04.6"W	0	0%
Caswell 1	7/16/2014	8/22/2014	37°41'30.6"N	121°11'30.6"W	200	--
Caswell 1	9/16/2014	Logging	37°41'30.1"N	121°11'29.2"W	200	88%
Caswell 2	7/18/2014	Logging	37°41'21.4"N	121°10'58.1"W	200	82%
Caswell 3	4/08/2015	Logging	37°41'27.6"N	121°11'04.6"W	360	85%
ACOE Park	7/25/2014	1/26/2015	37°43'37.5"N	121°06'54.6"W	215	>90%
Ripon Open 2	7/18/2014	Logging	37°43'45.7"N	121°06'42.9"W	0	0%
SJR Cottonwood	10/8/2014	Logging	37°43'37.5"N	121°06'54.6"W	470	49%
SJR Mixed	10/8/2014	Logging	37°36'27.2"N	121°10'38.8"W	340	32%
SJR Open	10/8/2014	Logging	37°35'50.8"N	121°10'10.4"W	0	0%

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