IN PRESS *California Agriculture* – April/June 2005

Statistical Analysis of Monitoring Data to Examine Factors Influencing Stream Temperature – A Watershed Scale Case Study

Kenneth W. Tate[1*], David F. Lile[2], Donald L. Lancaster[2], Marni L. Porath3, Julie A. Morrison2, and Yukako Sado[1]

[1] University of California, Agronomy and Range Science, Davis, CA

[2] University of California Cooperative Extension

[3] Oregon State University, Cooperative Extension

[*] Corresponding Author. kwtate@ucdavis.edu

Declines in cold water habitat and fisheries have generated stream temperature monitoring efforts across northern California and the western United States. In this paper we demonstrate a statistical analysis approach to facilitate the interpretation and application of these datasets to achieve monitoring objectives. Specifically we demonstrate an approach to identify and quantify relationships which might exist between stream temperature and factors such as streamflow, stream canopy cover, and air temperature.

Concern about long-term reductions in salmonid populations and loss of cold water stream habitat has resulted in significant stream temperature monitoring efforts across rangeland and forest watersheds (Tate et al. 2005). Stream temperature monitoring is being conducted by various groups and individuals in order to fill both watershed specific and regional information gaps. Specific monitoring objectives often include: 1) evaluation of compliance with stream temperature criteria; 2) determination of temperature changes above and below a land use activity, through a given stream reach, or across an entire stream network; and 3) examination of watershed specific relationships between stream temperature and factors such as air temperature, streamflow, and riparian canopy cover.

In our previous paper in this issue (Tate et al. 2005) we utilize a 3 year stream temperature dataset collected from Lassen and Willow Creek Watersheds in northeastern Modoc County, CA to demonstrate some graphical analysis approaches to reduce, display, and interpret a typical large raw stream temperature dataset to achieve monitoring objectives 1 and 2 listed above. The objective of this paper is to report the results of statistical analysis conducted on this same dataset to identify and quantify relationships between stream temperature, air temperature, streamflow, stream order and riparian canopy cover for Lassen and Willow Creek Watersheds (objective 3 listed above). The presentation of this statistical analysis is intended to demonstrate a statistical approach to facilitate understanding of the basic factors associated with stream temperature, and to compliment graphical analysis presented in our previous paper.

Lassen and Willow Creek Watershed Dataset

Lassen and Willow Creek watersheds and the dataset used in this paper are described in our previous paper in this issue (Tate et al. 2005). We refer the reader there for information about the: 1) stream temperature – fisheries related issues which motivated the collection of this dataset; 2) criteria for selecting the 22 monitoring locations monitored throughout the summers of 1999, 2000, and 2001; 3) methods used to collect stream temperature, air temperature, streamflow, and stream canopy cover data; and 4) graphical presentation of the raw data used for the analysis presented this paper.

Statistical Analysis Approach

Monitoring efforts typically produce datasets composed of temperature observations (*e.g.*, hourly, daily, etc.) from a set of discrete locations across a stream system through time (*i.e.*, cross-sectional, longitudinal surveys). We will make the case in this paper that in order to optimize the analysis and interpretation of such stream temperature datasets, the collection of associated data on air temperature, streamflow, and stream canopy for each location is critical. For the purposes of identifying and quantifying relationships between stream temperature (dependent variable), air temperature, streamflow, and stream canopy cover (primary independent variables) we propose a regression based analysis approach. Regression analysis leads to the development of a linear equation (model) which displays the estimated effect of a set of independent variables on the dependent variable. The simple form of the equation is $y = a +$

$b_1*X_1 + b_2*X_2 + \ldots + b_i*X_i$; where y is the dependent variable, a is the intercept of the equation, b_1 is a coefficient which estimates the relationship between the independent variable (X_1) and the dependent variable y given that the other factors ($X_{2,\,3,\,\ldots\,,\,i}$) are also present in the model. The model coefficients (b_i) thus represent the best estimate identification and quantification of the relationships between stream temperature (y) and the factors of interest (X_i), within the limitations of the particular dataset.

This approach does not lead to definitive test of cause and effect as expected in a controlled experiment. However, the lack of "replicate" streams and experimental control over variables such as streamflow generally negate the use of a balanced, experimental approach to test the effect of air temperature, streamflow, etc. on stream temperature, particularly at the watershed scale. Caution must of course be taken in the development and interpretation of regression models examining relationships between y and X_i. As with any analysis, the results are only as good as the data used in the analysis. The appropriateness of monitoring location selection (*e.g.*, are the locations representative of the stream system, the watershed, or the region?) and data collection methods must be considered in interpretation of any analysis. It is important to confine conclusions drawn from regression analysis only to the factors which were examined for inclusion into the final significant model (*e.g.*, conclusions about the importance of streamflow relative to air temperature can only be drawn if both factors were examined simultaneously). A good rule when evaluating relationships identified in regression analysis is to examine if the relationships make sense in light of existing knowledge and basic principles. If the relationship is not readily explained, then additional research or monitoring is warranted to refute or confirm.

Regardless of the analysis approach used, one must account for the potential effect introduced by repeatedly measuring temperature at each monitoring location. A basic assumption of many statistical analysis techniques is that each observation in the dataset is independent of all other observations in the dataset. It is unlikely that the maximum daily temperature realized at monitoring location W1 (Figure 1 in Tate et al. 2005) on June 15 is independent of the maximum daily temperature at this location on July 1. This problem is typical of most longitudinal datasets (repeated measurement at a fixed site through time). The co-dependence introduced by repeated measurements of a single site through time can be addressed using a linear mixed effects regression analysis (Pinheiro and Bates 2000) which we employ in this paper, or other approaches such as a repeated measures analysis of variance.

Analysis of the Lassen and Willow Creek Watershed Dataset

For this paper we selected daily maximum stream temperature (F^o) at fixed dates across the summer at fixed sites across Lassen and Willow Creek Watersheds (Figure 1 in Tate et al. 2005) as the dependent variable for analysis. We selected daily maximum as an example because it is a simple and biologically important measure of cold water habitat; however, the same analysis could be conducted on other metrics of interest defined in Tate et al. (2005) (*e.g.*, 7-day running average of daily maximum temperature, change in maximum temperature per stream mile). The maximum temperature for each 24 – hour time period from June 15 through September 15 of 1999 – 2001 was extracted from the 0.5 hour time series of data at each of the 22 monitoring locations (Figure 1 in Tate et al. 2005). To further reduce the dataset, we elected to use the daily maximum temperature at each site for the dates June 15, July 1, July 15, August 1, August 15, September 1, and September 15 from each year as the dependent variable in our analysis (n=462 stream temperature observations). Graphical analysis of this dataset in Figures 2 and 3 from Tate et al. (2005) clearly illustrates that stream temperature increases to a peak in July-August and decreases in September. We selected bi-monthly data from the larger continuous daily maximum temperature dataset in an effort to capture the evident seasonal pattern in temperature while reducing the amount of redundant data included in the analysis. Depending upon the monitoring and analysis objectives, alternative approaches could be the use of weekly or monthly calculations (*e.g.*, average, maximum) across the summer or the use of all daily maximum temperature records.

The linear mixed effects analysis (Pinheiro and Bates 2000) conducted on bi-monthly daily maximum stream temperature from locations on Lassen, Willow, and Cold Creek contained the following fixed effect independent variables: date (June 15, July 1, etc.), maximum daily air temperature (F^o), streamflow (cfs), and stream canopy cover (%) of the 1000 feet reach upstream of the site. Additional terms introduced in the initial model included all possible interactions between independent variables as well as the quadratic form of all continuous variables (air temperature, streamflow, and canopy cover). Maximum daily air temperature for each date from the nearest air temperature monitoring location was matched to each stream temperature observation. Stream order (1^{st}, 2^{nd}, 3^{rd}) of each monitoring location was introduced as an independent variable to account for each location's position in the watershed. A first order stream is a headwater channel, a 2^{nd} order stream is formed by the merger of two 1^{st} order channels, and a 3^{rd} order stream is formed by the merger of two 2^{nd} order channels. Monitoring location ID and year (1999, 2000, 2001) were treated as random effects to account for repeated measures and the random effect of annual weather, respectively. A backwards stepwise approach was followed until only significant ($P \leq 0.05$) factors remained in the model. Insignificant main effects were left in the model if interaction terms containing the main effect were significant. Evaluation of residual error plots indicated that assumptions of normality, independence and constancy were met.

A Statistical Model Predicting Stream Temperature

Evaluation and interpretation of statistical models requires the display of several important model outputs including: 1) the final statistical model with coefficients, coefficient confidence intervals, and significance levels for all variables included in the final model; 2) display of the "fit" of the model, or how model predictions compare with observed data; and 3) graphical display of relationships between the independent and dependent variables reported in the final statistical model. Evaluation and interpretation of the statistical model and the relationships implied by the model should always be coupled with local knowledge of the system modeled and application of basic scientific principles.

Table 1 presents the final statistical model developed to predict daily maximum stream temperature (F^o) at stream locations on Lassen and Willow Creek Watersheds. Table 1 reports the significance (P-Value) and 95% confidence intervals of the coefficient estimated for each independent variable associated with daily maximum stream temperature. The coefficient value indicates the estimated effect (positive or negative) and magnitude of the relationship between each variable and daily maximum stream temperature. For continuous variables (canopy cover, daily maximum air temperature, and streamflow) the coefficient indicates the change in maximum daily stream temperature expected with each incremental change in the variable given that all other factors in the model are held constant. For example, a 1% increase in canopy cover is associated with an estimated 0.19 F^o reduction in stream temperature. For categorical variables (stream, date, stream order) the coefficient represents the estimated difference between the referent level for the variable and other levels of the variable, given that all other variables are held constant. The coefficient for the referent level (stream = Willow Creek, date = June 15, stream order = 1st) are set to 0.0. The coefficients for other levels represent the estimated difference in daily maximum stream temperature between each level and the referent level. For example, the referent level for "stream" is Willow Creek, and Lassen and Cold Creek are estimated to be 4.43 F^o and 10.16 F^o colder than Willow Creek, respectively (Table 1).

Equation 1. The coefficients reported in Table 1 can perhaps be more easily conceptualized in an equation format. It follows as:

Daily Maximum Stream Temperature (F^o) = -41.68 + [0.00 if *Willow Cr., -4.43* if *Lassen Cr., -10.16* if *Cold Cr.] + [0.00* if *June 15, 3.17* if *July 1, … , -2.92* if *September 15] + [0.00* if *1st order stream, 13.32* if *2nd order stream, 14.05* if *3rd order stream] + 0.19*Canopy Cover (%) + 2.29*Daily Max. Air Temp. (F^o) – 0.012* [Daily Maximum Air Temperature (F^o)]^2 – 1.64*Streamflow (cfs) – 0.004*[Daily Maximum Air Temperature (F)*Canopy Cover (%)]*

The fit of the statistical model reported in Table 1 can be evaluated graphically in Figure 1. Figure 1 is a plot of the observed daily maximum stream temperatures used to develop the model in Table 1 versus the daily maximum temperatures predicted by the model. We used simple linear regression of the form *predicted = a + b*observed* to evaluate the fit of the model. If the model perfectly predicted observed stream temperature, the slope (*b*) of the regression would equal 1.0 with an R^2 of 1.0. Figure 1 indicates the model in Table 1 is not perfect, but with a slope of 0.88 and an R^2 of 0.89, it certainly is a reasonable fit.

Interpreting and Presenting the Statistical Model

Table 1 and Equation 1 report the results of the statistical analysis, thus simultaneously identifying and quantifying the estimated relationships between daily maximum stream temperature, air temperature, streamflow, and canopy cover through the summer period across these watersheds. There is opportunity to use simple graphical display of this statistical model in order to facilitate interpretation and presentation of these results to audiences with limited statistical background. Without adequate translation and interpretation, the results of statistical analysis will not lead to achievement of monitoring or restoration objectives. Figures 2 and 3 illustrate the use of the statistical model reported in Table 1 and Equation 1 to "predict" or display the relationships identified to exist between daily maximum stream temperature and significant environmental and management factors on these streams. These figures also illustrate the potential to use Equation 1 to examine "what if" scenarios such as the benefit of increasing canopy cover v. streamflow on 2^{nd} order streams. Care must be taken in limiting such speculation within the range of the data used to develop the model.

Relationship between Stream and Stream Temperature. Figure 2a displays the relationship identified to exist between stream (Lassen, Willow, and Cold Creek) and daily maximum stream temperature over the course of the summer season. This relationship was identified and quantified given that all other significant variables (Table 1) are constant and accounted for. Thus, in order to generate Figure 2a we set stream order at 1^{st}, canopy cover at 25 %, daily maximum air temperature at 85 F^{o}, and streamflow at 1 cfs. We then used Equation 1 (the statistical model) to estimate daily maximum stream temperature for each stream at each date (Figure 3). Figure 2a is in agreement with raw data presented in Figures 2 and 3 in Tate et al. (2005) which illustrate that Willow Creek is warmer (4.43 F^{o} on average for daily maximum) than Lassen Creek. Potential reasons for this difference are discussed in Tate et al. (2005). It is also clear that Cold Creek is aptly named, being on average 10.16 F^{o} cooler than Willow Creek for daily maximum temperature. The seasonal pattern from June through September is also captured with this statistical model.

Relationship between Stream Order and Stream Temperature. Figure 2b displays the relationship identified between stream order (1^{st}, 2^{nd}, 3^{rd}) and maximum daily stream temperature over the course of the summer. It is no surprise that 1^{st} order, headwater stream locations are significantly cooler than 2^{nd} and 3^{rd} order stream locations in the mid to lower reaches of these watersheds. In general, stream temperature will progressively increase from the upper to lower reaches of a stream system, as is the case for all but one reach of Willow Creek (Figures 2 and 3, Tate et al. 2005). Maximum daily stream temperature is not different between 2^{nd} and 3^{rd} order stream locations, given all other factors are equal. It is clear that the primary sources of cold water habitat within these streams, as with most, are in headwater locations.

Relationship between Stream Flow and Stream Temperature. Figure 3a displays the relationship identified between streamflow (cfs) and maximum daily stream temperature for the Lassen and Willow Creek watersheds, which have summer streamflow ranging from 1 to 5 cfs. For every 1 cubic foot per second increase in streamflow at a site there is an estimated 1.64 F^{o} decrease in maximum daily stream temperature (Table 1). This is an important result, given that one of the suspected sources of elevated stream temperatures is the diversion of streamflow for irrigation. This result provides local irrigation managers and water resources professionals with tangible evidence that investments to reduce streamflow withdrawal demands (*e.g.*, improved irrigation delivery efficiency, matching irrigation amount and timing to plant water demand and current soil moisture status) will result in reduced daily maximum temperatures, as well as reasonable expectations of the likely magnitude of these reductions. The lack of significance of the interaction term for streamflow and stream order ($P>0.05$) in this model indicates that the relationship between streamflow and daily maximum temperature is constant from the upper to lower reaches of these streams. This is interesting, given that the sources of increased streamflow in the upper reaches are likely natural phenomena (return of subsurface streamflow to the surface, diffuse springs, etc.) while increased streamflow in the lower reaches (where irrigation occurs) is likely in part due to warm irrigation water returns. One might expect increased streamflow in the lower reaches to be associated with increased stream temperatures. However, if a significant portion of irrigation return flow is reaching the stream as cool subsurface flow, then the relationship identified in this analysis is feasible (Stringham et al. 1998). These statistical results agree with our graphical analysis, reporting relatively low rates of change in stream temperature across lower reaches of Willow and Lassen Creeks (Figure 4 and 5, Tate et al. 2004).

Relationship between Stream Canopy Cover and Stream Temperature. Figures 3b and 3c display the relationships identified between stream canopy cover (%) and maximum daily stream temperature. For every 1% increase in canopy cover in the 1000 ft reach above a site there is an estimated 0.19 F^{o} reduction in daily maximum stream temperature at that site (Table 1). This relationship is logical, given that a reduction in the amount of solar energy reaching a stream's surface should result in a reduction in the temperature of that stream. Another interesting result is that there is a significant interaction between stream canopy cover and maximum daily air temperature (Table 1). As daily maximum air temperature increases, the cooling effect of canopy cover increases (Figure 3c) with the implication that increased canopy cover is more effective at reducing daily maximum stream temperature as air temperature increases. This is an important result because it provides evidence that management and restoration efforts to increase riparian vegetation and thus stream canopy cover can be expected to reduce daily maximum stream temperature. Most importantly, these results provide local managers with information about the expected reductions that could occur by using vegetation management as a restoration tool allowing realistic expectations to be placed on the potential to create cold water habitat simply by increasing canopy cover alone.

Relationship between Air Temperature and Stream Temperature. Figure 3c illustrates the relationship between daily maximum stream temperature and daily maximum air temperature. The interacting relationship between air temperature, canopy cover and stream temperature was discussed above. For every 1 F^o increase in daily maximum air temperature there is an expected 2.29 F^o increase in daily maximum stream temperature. This relationship is not constant however, as air temperature increases as is indicated by the significance of the term [max. air temp.]^2 in the final model (Table 1). This relationship is displayed in the slight curve in the relationships plotted in Figure 3c. This is a complex but logical relationship, and an important one in determining the background, or natural, temperature regime for streams in the arid, hot regions of the western United States.

Summary

While little concern about the relative temperature of Willow, Lassen, and Cold Creeks may exist outside of northeastern Modoc County, the ability to clearly and defensively identify warm or cold streams within a region of concern is of significant broader importance in the determination of possible regulatory action, allocation of limited restoration funds, and other controversial local decisions across northern California and the western United States. This analysis approach facilitates the incorporation of monitoring data into that determination.

Stream temperature monitoring efforts can provide a significant amount of information required to make informed decisions about management changes and restoration projects to increase and/or improve existing cold water habitat in streams. On a watershed or regional scale, information about the relationships existing between stream temperature and factors such as stream canopy cover, streamflow, and watershed position are important to identify and quantify the expected benefits of practices to reduce stream temperature. For instance, monitoring data presented in this paper clearly indicate that a combination of management practices to increase instream flow and increase canopy cover can be expected to reduce stream temperature on Lassen and Willow Creek Watersheds. Such practices (modification of irrigation and riparian grazing management, etc.) come with real costs to managers, and decisions to implement such practices should be based on a reasonable expectation of the return on that investment in terms of cold water habitat improvement. Monitoring data presented here also place constraints on the expected extent of cold water habitat given seasonal patterns, air temperature and the position of the stream in the watershed, regardless of increases in canopy cover and streamflow. Collectively these results provide local information required for watershed groups to reach a balance between restoration desires, management possibilities, and inherent environmental constraints.

In order for monitoring data to be interpreted and integrated into restoration plans, regulatory processes, and land use management decisions there must be appropriate collection and analysis of that data. In our previous paper we illustrate the value of simple graphical analysis to address certain typical stream temperature monitoring objectives. In this paper we illustrate the potential to use relatively simple statistical analysis to achieve additional monitoring objectives and informational needs, as described above. It is important to examine and plan for data analysis options during the initial development of the monitoring plan *prior* to data collection, not only *after* the data has been collected. While most individuals and groups planning and conducting monitoring may not have the statistical expertise to conduct the analysis described in this paper, there is statistical analysis support available within many of the state and federal agencies and organizations (regulatory and non-regulatory) to assist with monitoring plan development, implementation, and analysis.

Literature Cited

California Department of Fish and Game. 1998. California salmonid stream habitat restoration handbook. Appendix M.

Pinheiro, J.C., and D.M. Bates. 2000. Mixed effects models in S and S-Plus. Springer. 528 pp.

Stringham, T.K., J.C. Buckhouse, W.C. Krueger. 1998. Stream temperatures as related to subsurface waterflows originating from irrigation. J. Range Management. 51:88-90.

Tate, K.W., D.F. Lile, D.L. Lancaster, M.L. Porath, J.A. Morrison, and Y. Sado. 2005. Graphical analysis of monitoring data to evaluate stream temperature – a watershed scale case study. California Agriculture. April/June.

Table 1. Results of linear mixed effects analysis predicting maximum daily stream temperature (F^{o}) at monitoring locations on Willow, Lassen, and Cold Creeks in northeast Modoc County, CA during June – September of 1999-2001. Random effects in the analysis were year (1999, 2000, and 2001) to account for random annual weather patterns and monitoring location ID to account for repeated measures.

Fixed Variable	Coefficient[a]	P-value[b]	95% Low CI[c]	95% Up CI[c]
Intercept	-41.68	<0.001	-63.79	-19.50
Stream				
Willow Creek[d]	0.00	--	--	--
Lassen Creek	-4.43	0.003	-6.99	-1.86
Cold Creek	-10.16	0.000	-14.46	-5.86
Date				
June 15[e]	0.00	--	--	--
July 1	3.17	<0.001	2.02	4.31
July 15	3.15	<0.001	1.99	4.29
August 1	3.30	<0.001	2.05	4.54
August 15	1.55	0.014	0.31	2.77
September 1	-0.92	0.179	-2.25	0.42
September 15	-2.92	<0.001	-4.07	-1.76
Stream Order				
1st[f]	0.00	--	--	--
2nd	13.32	<0.001	8.51	18.12
3rd	14.05	<0.001	9.07	19.02
Stream Canopy Cover (%)	0.19	0.100	-0.04	0.42
Daily Max. Air Temp. (F)	2.29	<0.001	1.75	2.82
Daily Max. Air Temp.^{2} (F)	-0.012	<0.001	-0.009	-0.016
Streamflow (cfs)	-1.64	<0.001	-2.50	-0.78
Daily Max. Air Temp. (F) X Stream Canopy Cover (%)	-0.004	0.004	-0.006	-0.001

[a] Coefficient for each significant fixed variable in the linear model. Coefficient value indicates the effect (+ or -) and the magnitude of the relationship between each variable and maximum

daily stream temperature. For continuous variables (canopy cover, max. air temp., and streamflow) the coefficient indicates the change in maximum daily stream temperature associated with each incremental change in the variable.

[b] P-value associated with each fixed variable.

[c] Upper and lower 95% confidence interval for the coefficient of each fixed variable.

[d] Referent condition for the categorical variable “stream”. The coefficient for the referent condition (Willow Creek) is set to 0.0. The coefficients for Lassen Creek and Cold Creek represent the estimated difference in daily maximum stream temperature between these streams and Willow Creek (e.g. Lassen Creek is estimated to be 4.43 F^{o} colder than Willow Creek given that all other variables are held constant).

[e] Referent condition for the categorical variable “date”. The coefficient for the referent condition (June 15) is set to 0.0. The coefficients for other levels (July 1, July 15, etc.) represent the estimated difference in daily maximum stream temperature between each subsequent date and June 15 (e.g. July 1 is estimated to be 3.17 F^{o} warmer than June 15 given that all other variables are held constant).

[f] Referent condition for the categorical variable “stream order”. The coefficient for the referent condition (1^{st} Order) is set to 0.0. The coefficients for other levels (2^{nd} and 3^{rd} Order) represent the estimated difference in daily maximum stream temperature between each stream order and a 1^{st} order stream (e.g. 2^{nd} order stream is estimated to be 13.32 F^{o} warmer than a 1^{st} order stream given that all other variables are held constant).

List of Figures

Figure 1. Plot of the observed daily maximum stream temperatures versus the daily maximum temperatures predicted by the linear mixed effects model containing independent variables of streamflow, stream canopy cover, maximum daily stream temperature, and stream order. The model was developed with data from 1999-2001 from 22 stream locations in Lassen, Willow, and Cold Creek in northeastern Modoc County, CA.

Figure 2a. Relationship of daily maximum stream temperature and stream (Willow, Lassen, Cold) across the summer season developed from mixed effects analysis of data from 1999-2001 from stream locations in Lassen, Willow, and Cold Creek in northeastern Modoc County, CA. Other significant factors are set to fixed values [stream order = 1^{st}, stream canopy cover =25%, daily maximum air temperature = 85 F^{o}, and streamflow = 2 cfs].

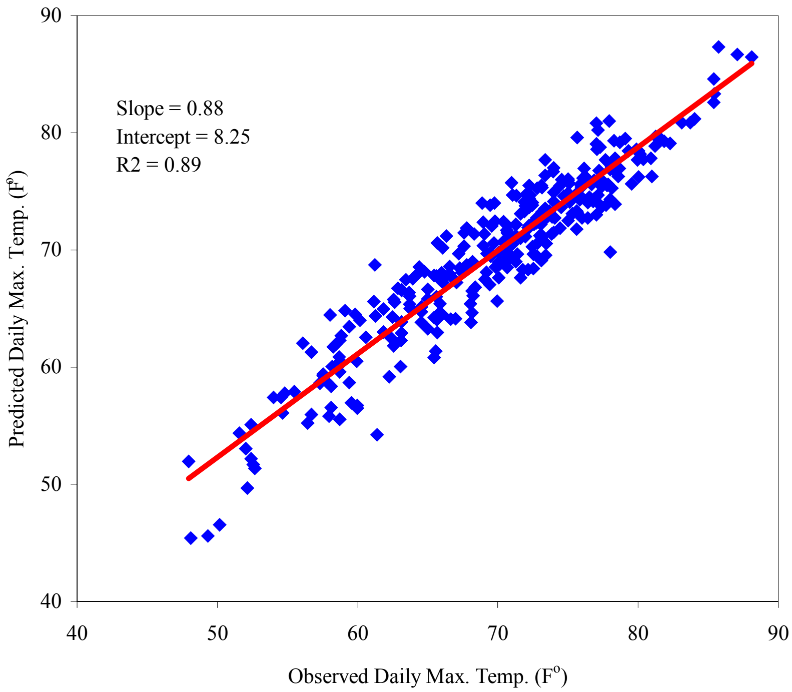
Figure 2b. Relationship of daily maximum stream temperature and stream order (1^{st}, 2^{nd}, 3^{rd}) across the summer season developed from mixed effects analysis of data from 1999-2001 from stream locations in Lassen, Willow, and Cold Creek in northeastern Modoc County, CA. Other significant factors are set to fixed values [stream = Lassen, stream canopy cover = 25 (%), daily maximum air temperature = 85 F^{o}, and streamflow = 2 cfs].

Figure 3a. Relationship of daily maximum stream temperature and streamflow (cfs) across the summer season developed from mixed effects analysis of data from 1999-2001 from stream locations in Lassen, Willow, and Cold Creek in northeastern Modoc County, CA. Other significant factors are set to fixed values [stream = Willow, date = August 1, stream order = 1^{st}, and daily maximum air temperature = 85 F^{o}].

Figure 3b. Relationship of daily maximum stream temperature and stream canopy cover (%) across the summer season developed from mixed effects analysis of data from 1999-2001 from stream locations in Lassen, Willow, and Cold Creek in northeastern Modoc County, CA. Other significant factors are set to fixed values [stream = Willow, date = August 1, stream order = 2^{nd}, and daily maximum air temperature = 85 F^{o}].

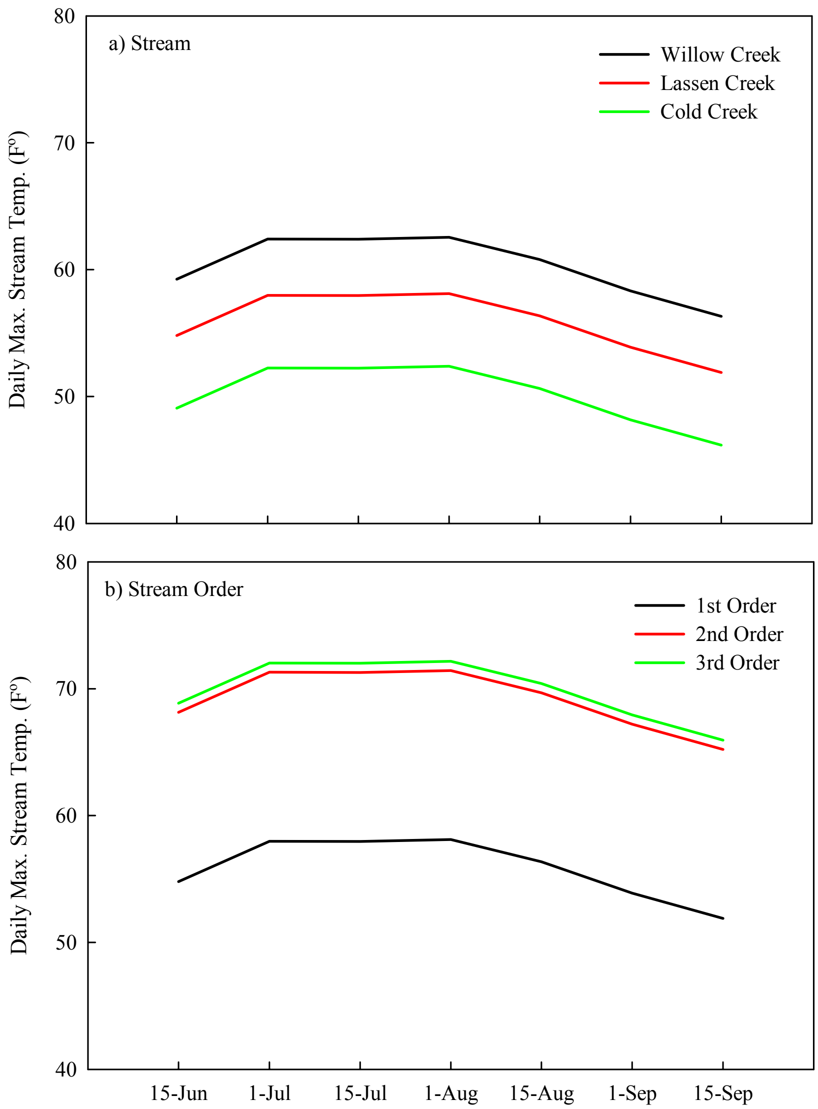
Figure 3c. Relationship of daily maximum stream temperature and daily maximum air temperature (F^o) across the summer season developed from mixed effects analysis of data from 1999-2001 from stream locations in Lassen, Willow, and Cold Creek in northeastern Modoc County, CA. Other significant factors are set to fixed values [stream = Willow, date = August 1, stream order = 1^{st}, and streamflow = 2 cfs].

Figure 1.



Slope = 0.88
Intercept = 8.25
R2 = 0.89
Predicted Daily Max. Temp. (F°)
Observed Daily Max. Temp. (F°)
90
80
70
60
50
40
40
50
60
70
80
90

Figure 2a, 2b.



a) Stream
Willow Creek
Lassen Creek
Cold Creek
Daily Max. Stream Temp. (F°)
80
70
60
50
40
b) Stream Order
1st Order
2nd Order
3rd Order
Daily Max. Stream Temp. (F°)
80
70
60
50
40
15-Jun
1-Jul
15-Jul
1-Aug
15-Aug
1-Sep
15-Sep

Figure 4a, 4b, 4c.