A CASE STUDY OF RIVER TEMPERATURE RESPONSE TO AGRICULTURAL LAND USE AND ENVIRONMENTAL THERMAL PATTERNS

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ABSTRACT: Water temperature standards, which may impact agricultural land management, are being implemented in various states. This case study was conducted on irrigated hay (meadow and wet meadow ecological sites) and pasture (sodic meadow ecological site) land in northeastern Oregon. Shading over the river channel (approximately 40-feet channel width) was estimated at 1 to 5% based on site characteristics. We evaluated the association between river temperature patterns, existing agricultural land uses, and the thermal equilibrium condition of the surrounding environment (e.g. air and soil temperatures). Daily mean and maximum stream temperature increases along approximately 1.0 mile reach lengths were 0 to 0.18 and 0.18 to 0.36°F, respectively, and were not different between existing land uses/ecological sites. Mean air and water temperatures were approximately 2°F apart indicating that an equilibrium condition existed during the study. Weather conditions were dominant when compared to existing land use influence on river temperature, which is expected as temperatures approach equilibrium.

Water temperature has become a water quality issue where designated beneficial uses are deemed sensitive to temperature. In Oregon, anadromous fish passage, spawning, and rearing habitat have been declared limited beneficial uses sensitive to temperature. Oregon Department of Environmental Quality (web page www.deq.state.or.us/wq/wqrules/wqrules.htm - Fact Sheets - DEQ's Temperature Standards - last visited April 23, 2002) has established statewide water temperature standards, which directly impact forest and agricultural management. As a result, it is important to improve our understanding of water temperature response to natural events and to land-management activities.

Water temperature patterns develop within streams and rivers because of energy imbalances that exist between the water and surrounding thermal sources (e.g. air and soil temperatures). In general, stream temperature patterns from headwater sources to mouth begin with a transient period of temperature change, as a result of an imbalance with surrounding thermal sources, until an equilibrium condition is achieved (Adams and Sullivan 1989, Hopkins 1971). As equilibrium is approached, stream temperature becomes increasingly independent of headwater conditions and daily mean air and water temperatures converge to within a few degrees of each other (Adams and Sullivan 1989). Edinger et al. (1968) described this aspect of stream temperature change as a function of 1) temperature difference between the stream and the equilibrium temperature of the surrounding environment, and 2) the amount of time that the water body is exposed to energy imbalance.

Research relating land management influences to stream temperature has mostly occurred in forested systems. Several authors have concluded that clearcut harvesting results in greater diurnal variation and higher maximum stream temperatures than patch-cutting or non-harvested controls (Brown and Krygier 1967, Lee and Samuel 1976, Lynch et al. 1984). Zwieniecki and Newton (1999) found that clearcut harvesting along low-elevation western Oregon streams resulted in little direct effect on water temperature when forest buffers of 28 to 100 feet were left and that streams had a tendency to warm in the downstream direction, even under full forest cover. They concluded that this natural warming trend in streams necessitates inclusion of a warming trend line when evaluating the net temperature effect of management practices. With the exception of one case study relating grazing to increased stream temperatures (Claire and Storch 1983), we have not found other studies relating agricultural practices to water temperature. Claire and Storch (1983) compared vegetation composition and water temperature within and downstream from an un-replicated exclosure on a small entrenched stream in semiarid eastern Oregon. They reported that maximum stream temperatures and daily fluctuations were greater below the exclosure.

The purpose of our study was to evaluate the association between river temperature patterns, existing agricultural land uses, and the thermal equilibrium condition of the surrounding environment.

METHODS AND MATERIALS

EXISTING ENVIRONMENT OF THE STUDY AREA

The main stem of Burnt River in northeastern Oregon is formed from the combined flows of tributaries into Unity Reservoir (constructed in 1939), which releases water to supply the main stem (Mangelson 2001). The Burnt River basin encompasses about 1100 miles^2, ranging in elevation from about 7970 feet above sea level in the headwaters to 2115 feet at its mouth where it joins the Snake River. The study was conducted at an approximate elevation of 3610 feet, 10 miles below the reservoir, and extended 20 miles downstream. Unity Reservoir influence on in-stream temperature is limited to 5 to 10 miles downstream of Unity Dam (Mangelson 2001).

Nearly 85% of the Burnt River watershed snowmelt plus rainfall occurs during the months of March through June. Very low stream flows occur during the remainder of the year (Mangelson 2001). Normal Unity Dam in-stream flow releases to Burnt River are 90 to 130 ft^{3}s^{-1} during the irrigation season (May 1 to October 1) and 15 to 40 ft^{3}s^{-1} for the remainder of the year (Mangelson 2001).

Climatic records at Unity, Oregon have been maintained for 38 years (Table 1) and are representative of the area around the reservoir. Average daily maximum temperatures greater than 79, 88 and 90°C will occur 2 years in 10 during June, July, and August, respectively.

Table 1. Daily mean, maximum, and minimum temperature (°F) for Unity, Oregon compiled over a 38-year period.

	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Mean	22.3	28.8	35.2	42.4	50.2	57.2	64.2	63.3	54.9	44.8	33.3	24.3
Maximum	31.5	39.7	47.7	57.2	66.4	75.2	85.3	83.8	75.0	62.2	45.0	34.2
Minimum	12.2	17.8	22.6	27.5	33.6	39.2	43.0	42.3	35.1	27.5	21.7	14.5

The vegetation/soil complex within the study area (Laird 1987) is varied with three ecological sites dominating the irrigated lands below the reservoir (wet meadow, meadow, and sodic meadow). Representative soils for the wet meadow, meadow, and sodic meadow sites are fine-silty, mixed (calcareous), mesic Cumulic Haplaquolls; fine-silty, mixed, mesic Pachic Haploxerolls; and coarse-silty, mixed (calcareous), mesic Typic Haplaquepts, respectively. Wet meadow and meadow communities generally occur over fine sediment deposits approaching a 3.3-feet depth and are dominated by sedges, rushes, and grasses. Soils associated with sodic meadow contain significant amounts of lime and alkalinity and can have a pH of 9.6. Alkali-grass (*Puccinellia lemmonii* (Vasey) Scribn.) and saltgrass (*Distichlis stricta* (Torr.) Rydb.) typically dominate sodic meadow communities. The meadow floodplain width averages approximately 2300 feet. Soils and flooding patterns limit establishment of trees and shrubs thereby reducing the shade potential for the river to less than 10%. Shading over the river channel (approximately 40-feet channel width) was estimated to be between 1 and 5% and is derived from the channel banks (< 3-feet height), grass (< 5-feet height), and patches of mid-story willow species (< 13-feet height).

Irrigated lands are used for pasture and grass-hay production with a small amount of land dedicated to alfalfa production (Mangelson 2001). Hay management is generally practiced on meadow and wet meadow sites. Fields are flood irrigated in the spring and early summer to extend the period of soil saturation and maximize hay production (4000 lb acre^{-1}). Irrigation is curtailed partway through the growing season, allowing the soil profile to drain in preparation for harvest. Buffer or leave strips of 10 to15 feet are typical along the river channel at the time of harvest. Post-harvest irrigation initiates growth for fall and winter pasturage.

A rotation grazing system during the growing season is typical on sodic meadows and to a lesser extent on some meadow ecological sites, which are generally in grass-hay production. Depending on water rights, these lands may be irrigated to increase forage production. Sodic meadows are not suitable for hay production.

FIELD SAMPLING STRATEGIES

This study contains both experimental and survey designs. Experimental design was used to detect thermal change associated with existing land use, which was associated with vegetation/soil complex. River segments containing 1-hour flow periods (approximately 1 mile of river length) were monitored for temperature change. Land uses were used as treatments and were replicated. They consisted of 1) grazing in a summer rotation pattern and 2) hayproduction followed by fall/winter grazing. The summer rotation grazing treatment was on the sodic meadow ecological site. The shade estimate for these reaches was 1%. The hay production followed by fall/winter grazing treatment was concentrated on wet-meadow and meadow ecological sites. Shade estimates for these reaches were 3 to 5%. The buffer or leave strips in the grass-hay meadows serve as a natural barrier to cattle and physically restrict river access to water gaps. Woody vegetation structure and development was considered to be at or near site potential along significant portions of the river segments under grass-hay management.

Water temperatures were measured at the upstream and downstream ends of each treatment replication during July and August, 1998 and 1999. Air and soil temperatures were measured near the middle of each replicate. StowAway® data loggers were used to record temperature data sets. Data loggers were tested for accuracy and precision at 0, 50, and 68°F at the beginning and end of the 1998 field season, and at 50 and 68°F for the 1999 field season. StowAway® data loggers have an accuracy of ± 0.36°F for the range of temperatures encountered in this study. The data loggers recorded temperature hourly and were enclosed in waterproof submersible cases. Data sets consisted of temperature data for air (3.5 feet above ground in shaded, well ventilated areas), soil (1-foot depth at stream side in a nonsaturated area), and water (measured in the free-flowing thalweg). Treatments within the study were replicated twice in 1998 and three times in 1999. Data were collected during 30 days each in July and August during both years. Two treatments by 60 days by two (1998) and three (1999) replications yielded 240 and 360 observations in 1998 and 1999, respectively.

River segment comparisons were made using analysis of variance (Stat Graphics 7.0) with mean separation (least significant difference) procedures. Changes in daily maximum and mean temperature within each treatment replicate were determined by subtracting up-stream from down-stream values. Similarly, changes in daily temperature range were determined by comparison of the temperature differences between the daily maximum and minimum temperatures at the up- and down-stream endpoints for each replicate.

The survey component of the study was conducted without statistical (treatment) control. Air, water, and soil temperatures were measured at two locations near the middle of the study area. Data from the two locations were averaged together over the July through August period for each year to represent environmental thermal patterns.

The analysis of thermal patterns included the use of analysis of variance and chi-square comparisons. Chi-square analysis was used to evaluate the pattern of air and water heating between 5:00 a.m. and 5:00 p.m. on a daily basis. The heating period was partitioned into three equal time periods (5:00-9:00 a.m., 9:00 a.m.-1:00 p.m. and 1:00-5:00 p.m.) and comparisons among those periods were made to detect differences in temperature change. Analysis of variance with LSD mean separation was used to partition yearly and monthly differences in air, water, and soil thermal patterns. Year and month comparisons of daily maximum and mean temperatures, and of temperature ranges were made for air, water, and soil temperatures.

RESULTS AND DISCUSSION

RIVER SEGMENT COMPARISONS

River segments were compared to determine if differences in water temperature accumulation could be observed at daily maximum and mean temperatures or within the daily temperature range. The analysis (Table 2) indicates that water flowing through each river segment had similar amounts of temperature change and daily temperature range. Values reported in Table 2 reflect mathematical differences of daily values between upper and lower ends of treatment reaches. Thermister technology limits data collection accuracy to ± 0.36°C.

Table 2. Change[1] in water temperature (°F) (daily maximum, mean, and temperature range) associated with river segment/land use treatments during July and August of 1998 and 1999.

	Hay meadows/fall-winter grazing (meadow and wet meadow sites)	Summer rotation grazing (sodic meadow sites)	P
		Daily Maximum Temperature	
July 1998	0.36	0.36	NS[2]
August 1998	0.18	0.18	NS
July 1999	0.36	0.36	NS
August 1999	0.18	0.18	NS
		Daily Temperature Range	
July 1998	0.36	0.18	NS
August 1998	0.36	0.36	NS
July 1999	0.36	0.36	NS
August 1999	0.36	0.36	NS
		Daily Mean Temperature	
July 1998	0.18	0.18	NS
August 1998	0.18	0.00	NS
July 1999	0.18	0.18	NS
August 1999	0.18	0.18	NS

[1] Change is the mathematical difference of daily mean temperatures between the upper and lower ends of treatment reaches.

[2] NS = no significant difference between data pairs (P 0.05).

These results suggest that existing land use, vegetation structure, and other channel characteristics within the flow segments are temperature neutral at the scale tested in this study and that other factors are more strongly associated with the existing temperature patterns. Our results appear similar to the results of Zwieniecki and Newton (1999) where water temperatures in a lower-elevation forest harvest study seemed to reflect the influence of equilibrium conditions and exhibited a warming trend in the downstream direction regardless of forest cover.

Our results are different from forest harvest studies by Brown and Krygier (1967), Lee and Samuel (1976) and Lynch et al. (1984) who found vegetation management affected stream temperatures. There are at least two potential reasons for the different results between our study and the three noted above. 1) There is a large contrast among the different studies with regard to vegetation structure. The potential for woody vegetation structure is great within the western

Oregon forest zone and the difference in vegetation structure contrasted by the forest-harvest treatments was substantial. The three forest studies compared clearcut versus intact forest in a temperate oceanic climate. By comparison the potential for woody vegetation on the sites used in this study (steppe climate) was minimal and the range of treatments do not reflect a comparable level of vegetation manipulation. The harvest treatments in the forest studies may have contributed to a substantial increase in the equilibrium temperature at the stream surface. Unfortunately the forest studies did not estimate changes in the equilibrium temperature and none reported a commonly used surrogate, air temperature. Equilibrium temperature, as estimated by air temperature, was not different between treatments in our study (data not shown). 2) The three forest studies were conducted on small-volume streams with flow rates ranging from 0.25 to 1.0 ft^3s^{-1}. Our study was conducted on a river with substantially larger volume than the streams in the forested studies. During July and August outflow from Unity Reservoir into Burnt River was approximately 106 ft^3s^{-1}. Zwieniecki and Newton (1999) noted that the magnitude of the warming trend was inversely related to discharge on streams they studied. The setting for our study would reflect common river situations in low-elevation agricultural settings. This combination of factors suggests that results from water temperature studies reflect site specific conditions and are not directly comparable.

Our analysis of river temperature patterns suggested an association between river temperature and weather, which influences the surrounding thermal environment (e.g. air and soil temperatures). To illustrate this point, temperature patterns for the seasonal grazing treatment are provided for July and August in 1998 and 1999 (Table 3). Temperature increases were similar regardless of the month studied. However, the daily range and monthly mean data contained differences among time periods. These differences appear to be weather related. Mean air temperature in the summer of 1998 (July and August temperatures combined; Table 4) was 5.4°F warmer than in 1999. July and August of 1999 had seven and five daily air temperature means that were below 59°F compared to no days during the same time period in 1998. The pattern reflected in these results was repeated in the other treatment data sets (data not shown). Water temperature patterns followed the pattern of weather and the resulting thermal environment (Table 4).

Table 3. Change in water temperature associated with a grazed/sodic meadow river treatment segment. Attributes are daily temperature range, mean temperature increase within the grazed treatment, and monthly mean temperature. Values reported are monthly means for July 1998 to August 1999.

	Water temperature (°F)		
	Daily Range	Temp. Increase[1]	Monthly Mean
July 1998	14.0 ab[2]	0.18 a	65.7 b
August 1998	14.0 ab	0.18 a	68.2 d
July 1999	14.9 b	0.18 a	64.4 a
August 1999	13.0 a	0.18 a	66.5 c

[1] Treatment temperature increases averaged for each month.

[2] Means with different letters within a column are significant at P 0.05.

Table 4. Observed air, water, and soil thermal patterns (averages of daily maximums, means, and temperature ranges) during the July - August period in 1998 and 1999. Data tabulated by combining a hay and grazed river segment in the center of the study area.

	July/August Mean Temperature (^oF)	
	1998	1999
	Air	
Maximum	88.0 b[1]	81.9 a
Mean	68.9 b	63.5 a
Temperature range	68.2 a	70.2 a
	Water	
Maximum	73.8 b	72.7 a
Mean	66.9 b	65.5 a
Temperature range	14.0 a	14.0 a
	Soil	
Maximum	64.9 a	64.6 a
Mean	61.5 a	61.5 a
Temperature range	2.0 a	1.8 a

[1] Different letters between years denote significance at $P \leq 0.05$.

THERMAL PATTERNS

Table 4 contains the July through August averages of maximum, mean, and daily temperature ranges for air, water, and soil that were recorded during 1998 and 1999. Differences between the two years were observed in the maximum and mean temperature of air and water. Soil temperature means and the temperature range of air, water, and soil were constant. Within each year, mean air, water, and soil temperatures were within a few degrees of each other. Mean air and water temperatures were approximately 2°F apart indicating that an equilibrium condition existed during the study. Edinger et al. (1968) and Adams and Sullivan (1989) indicated that the influence of atmospheric conditions increases as the stream temperature approaches an equilibrium condition. At or near equilibrium, energy transfer to and from the water body will most likely be strongly associated with stream and air temperature differences (Adams and Sullivan 1989). Adams and Sullivan (1989) also noted that mean daily water and air temperatures will be very similar as water temperatures come into balance with the daily pattern of the thermal environment.

Peak air and water temperatures occurred daily between 3:00 and 4:00 p.m., unless climatic conditions disrupted the daily cycle of heating, which was several hours after peak solar angles. Chi-square comparisons indicated that air typically heated most rapidly (29°F) during the first 8 hours (5:00 a.m.-1:00 p.m.) of the day ($p \leq 0.05$). Water heated most rapidly between 9:00 a.m. and 1:00 p.m. ($p \leq 0.05$), with average increases of 6.8°F. Water continued to heat until 3:00 or 4:00 p.m., but these later heat accumulations occurred at a slower rate. When air temperature accumulation during the first 4 hours of the day (5:00 a.m.-9:00 a.m.) did not approach an 14°F increase, then daily water temperature patterns lacked a strong pattern of heating. On a typical day, the river temperature pattern had a daily range roughly one-third the range of air. Soil temperature at 1-foot depth was relatively constant, peaking near midnight. The midnight peak reflects the rate at which heat transfers between the soil surface, with fluctuating temperatures, and soil at depth, with more stable temperatures (Miller and Donahue 1990). We conclude from these data that weather was strongly associated with river temperature patterns and that the mean river temperature will be near mean air temperature in this segment of the river and downstream. A number of researchers have observed that stream temperature patterns closely follow and lag behind air temperature patterns (Edinger et. al 1968, Walker and Lawson 1977, Stefan and Preud'homme 1993, McRae and Edwards 1994, Mohseni and Stefan 1999, Larson and Larson 2001), and that air heating lags behind peak solar radiation (Hidore and Oliver 1993). The strength of the association between air and water temperatures has led several researchers to describe local air temperature as the single most important parameter associated with daily mean stream temperature (Bartholow 1989, Sinokrot and Stefan 1994, Lewis et al. 2000).

CONCLUSIONS

Results from this study indicate that river temperature patterns within the study area were at or near an equilibrium condition. Weather conditions were dominant when compared to river segment/existing land use influence on river temperature. Mean air and water temperatures were nearly equivalent. Water flowing through river segments receiving hay-meadow and summer-grazing treatments showed similar amounts of temperature change during the heating cycle of the day and accumulated minimal amounts of energy through the 1-mile reach lengths. No attempt was made to partition the sources of variation contained within the minimal (non-significant) temperature difference.

This research should be repeated at locations where the temperature of the headwater source influences the stream temperature profile. Under those conditions, potential temperature differences associated with land use, vegetation structure, and channel morphology may have a greater likelihood of detection.

A major change in management practices is not likely to occur in this valley because of economic and environmental constraints. Current management practices reflect ecological constraints (i.e., grazing on sodic meadows sites, and irrigated hay production on meadow and wet meadow sites) and adaptive management continues to take place within the valley. Although it was not possible in this study to provide an unmanaged control the practice of grass-hay management provided segments of stream buffer that were at or near site potential. Results from this study suggest that the land uses evaluated in the study area are temperature neutral with regard to the thermal pattern of Burnt River. The setting for our study would reflect common river situations in low-elevation agricultural settings. However, results from water temperature studies can reflect site-specific conditions and may not be directly comparable.

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