United States Department of Agriculture

Forest Service

Pacific Northwest Research Station

General Technical Report PNW-GTR-459
April 1999

Influence of Stream Characteristics and Grazing Intensity on Stream Temperatures in Eastern Oregon

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Abstract

Maloney, S.B.; Tiedemann, A.R.; Higgins, D.A.; Quigley, T.M.; Marx, D.B. 1999. Influence of stream characteristics and grazing intensity on stream temperatures in eastern Oregon. Gen. Tech. Rep. PNW-GTR-459. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 19 p.

Stream temperatures were measured during summer months, 1978 to 1984, at 12 forested watersheds near John Day, Oregon, to determine temperature characteristics and assess effects of three range management strategies of increasing intensity. Maximum temperatures in streams of the 12 watersheds ranged from 12.5 to 27.8 °C. Maximum stream temperatures on four watersheds exceeded 24 °C, the recommended short-term maximum for rainbow trout (*Oncorhynchus mykiss)* and chinook salmon (*O. tshawytscha*). Streams with greater than 75 percent stream shade maintained acceptable stream temperatures for rainbow trout and chinook salmon. Lowest temperatures were observed in streams from ungrazed watersheds. Although highest temperatures were observed in the most intensively managed watersheds (2.8 hectares per animal unit month), the effect of range management strategy was not definitive. It was confounded by watershed characteristics and about 100 years of grazing use prior to initiation of this study.

Keywords: Forested watersheds, grazing management strategies, grazing intensity, fisheries, fish habitat, chinook salmon, steelhead trout, cutthroat trout, Dolly Varden trout.

Summary

Stream temperatures were measured during the summer months from 1978 to 1984 on 12 forested watersheds near John Day, Oregon, to determine the temperature characteristics of streams in the watersheds and to assess the effects of three range management strategies. Maximum temperatures in streams of the 12 watersheds ranged from 12.5 to 27.8 °C. Daily ranges within the streams were as great as 12.8 °C. Maximum mean weekly temperatures ranged from 10.9 to 17.8 °C. On four of the watersheds, maximum stream temperatures exceeded 24 °C, the recommended short-term maximum for rainbow trout (*Oncorhynchus mykiss*) and chinook salmon (*O. tshawytscha*). Percentage of stream shade, week of the year, weekly flow, stream width, year, travel time, elevation, and aspect explained 67 percent of the variation in stream temperatures. Streams with greater than 75 percent stream shade maintained acceptable stream temperatures for rainbow trout and chinook salmon. Streams from watersheds with range management strategy A (no grazing) had significantly lower ($p < 0.05$) maximum temperatures than those from strategy D watersheds (intensively managed at 2.8 hectares per animal unit month). Temperatures of streams managed at strategy C (7.7 hectares per animal unit month) were intermediate and not significantly different from those of either strategy A or D. The effect of range management strategy in this study was not definitive, however, because it was confounded by watershed characteristics and about 100 years of grazing use prior to initiation of this study. The dominant vegetative habitat (ecosystem) on a watershed significantly influenced stream temperatures. Temperatures were lower with the larch/Douglas-fir (*Larix occidentalis* Nutt./*Pseudotsuga menziesii* (Mirbel) Franco) and fir/spruce (*Abies lasiocarpa* (Hook.) Nutt./*Picea engelmannii* Parry ex Engelm.) ecosystems than with ponderosa pine (*Pinus ponderosa* Dougl. ex. Laws.) and mountain meadow ecosystems. Stream temperatures for lodgepole pine (*Pinus contorta* Dougl. ex Loud.) were intermediate. A strong first-order autocorrelation was found for stream temperature measurements within all watersheds. This indicated that the stream temperature of one time period was significantly related to the temperature of the previous period. Data were analyzed to account for autocorrelation.

Contents

Introduction

The headwaters of the John Day River provide spawning and rearing habitat for one of the few remaining wild runs of chinook salmon (*Oncorhyncus tshawytscha*) and steelhead (*O. mykiss*) in the Columbia River basin (State of Oregon 1986a). These streams also support resident populations of rainbow trout (*O. mykiss*), cutthroat trout (*Salmo clarki*), and Dolly Varden char (*Salvelinus malma*). Stream temperature plays an important role in determining the survival, distribution, and productivity of these species because salmonids have a low thermal tolerance (Bjornn 1971). Rainbow trout prefer temperatures between 14 and 18 °C and have an upper lethal temperature tolerance of about 27 °C (Ames 1977, Bowers and others 1979, Cherry and others 1977, Gariside and Tait 1958). Chinook salmon fry prefer temperatures between 12 and 14 °C and have an upper lethal temperature tolerance of 25 °C (Bjornn 1971). As stream temperatures increase above the optimum for salmonids, warm water species compete more effectively with salmonids for available space.

Water quality criteria established to protect aquatic life include two upper limiting temperatures: a short-term maximum for survival, and a maximum weekly mean for growth. For both adult and juvenile rainbow trout (including steelhead trout), the short-term maximum is 24 °C; the maximum mean weekly is 19 °C (U.S. Environmental Protection Agency 1986). For embryo rainbow trout during the spawning season, short-term maximum and maximum mean weekly stream temperatures are 13 and 9 °C, respectively. Oregon State water quality standards (State of Oregon 1986b) reflect these criteria and the needs of salmonids by establishing permissible limits on water temperature increases. These criteria indicate that when stream temperature is 20 °C, activities influencing stream temperature will be regulated such that no further temperature increases occur. In our study, we used hourly maxima and weekly mean maximum stream temperatures so that comparisons could be made to Oregon State standards. We also used 20 °C as the threshold for comparison.

Shade provided by riparian vegetation is one of the most important regulators of temperature in small streams where solar radiation is the predominant energy source. When riparian vegetation is removed by harvest, grazing, road construction, and mining, the stream surface is exposed to direct solar radiation, and stream temperatures increase (Gibbons and Salo 1973, Levno and Rothacher 1969, Rishel and others 1982, Swift and Messer 1971). Complete harvest of riparian vegetation increased the mean monthly maximum temperature as much as 7.8 °C in one Pacific Northwest stream (Brown 1970). Levno and Rothacher (1969) showed that removal of stream shade by tree harvesting and slash burning of residues caused an increase of 7.8 °C in average maximum stream temperature; however, when buffer strips of riparian vegetation 15 to 30 meters wide were left adjacent to streams, temperatures did not increase (Brown 1970).

Elimination of streamside vegetation and removal of overhanging streambanks are two of the leading causes for decline of native trout in Western streams (Behnke and Zarn 1976). Domestic livestock such as cattle are one of the major causes of this problem because they tend to concentrate in riparian zones for the high-quality forage and readily available water (Bryant 1982, Roath and Krueger 1982). They consume grasses, forbs, and new growth from many shrubs and small trees (Ames 1977). Severe alteration of composition, structure, and productivity of vegetation in riparian zones has been a common result (Kauffman and Krueger 1984). Protracted heavy grazing use can eventually eliminate shrubs and small trees. Cattle may crush overhanging streambanks and physically disturb the streambed, causing increases in sediment, turbidity, and water temperature (Clary and Webster 1989). Protection of streams from livestock grazing has resulted in improvement in abundance of riparian vegetation, stream surface shade, and channel morphology (Platts 1981, Winegar 1977). Improvements in vegetation and stream channel morphology have generally taken 10 or more years after exclusion of cattle. In some areas, however, past grazing use has caused sufficient damage that recovery may be a long-term process—even with reduced grazing (Clary et al. 1996). Although numerous studies have related grazing to water quality and watershed condition (Blackburn 1984; Gaither and Buckhouse 1981; Gifford and Hawkins 1978; Meehan and Platts 1978; Moore and others 1979; Tiedemann and Higgins 1989; Tiedemann and others 1988, 1989), studies relating grazing systems to water temperature are lacking (Gaither and Buckhouse 1981, Gifford and Hawkins 1978).

The Oregon Range Evaluation Project (EVAL) was established in 1976 to implement present understanding of range management techniques and evaluate their effects on range and associated resources (Quigley and others 1989, Sanderson and others 1988). Water quality was one of the major associated resources studied (Tiedemann and Higgins 1989).

As part of this project, 12 small watersheds, ranging from 1.2 to 18.1 square kilometers, were established and implemented with three range management strategies; they provided an opportunity to examine the effects of increasing intensity of management on stream temperature.

Specific objectives of stream temperature studies on these watersheds were to establish summer stream temperature characteristics for the 12 study watersheds; determine relations among stream characteristics (including the dominant ecosystem) and summer stream temperatures; determine the influence of increasing intensity of range management strategy on summertime stream temperature characteristics; characterize changes in stream temperatures along the profile of one stream as shade and other characteristics change; and compare stream temperatures with criteria established for tolerances of rainbow trout and chinook salmon.

Location and Characteristics of Watersheds

The studies described here were carried out near John Day in Grant County, Oregon. The EVAL project area encompassed about 140 000 hectares on 19 Forest Service grazing allotments and 21 private ranches. The 12 study watersheds were in the northern part of the Malheur National Forest within EVAL grazing allotments. In most cases, the study watersheds were part of a larger, fenced pasture within a defined range management strategy. Cattle control was therefore not specific to the riparian area or watershed, but to a much larger area.

Range management strategies of increasing intensity applied to the 12 watersheds were:

A. Control—no grazing.
C. Management of grazing to attain uniform livestock distribution throughout a pasture by using fencing and water developments. Stocking rate averaged 7.7 hectares per animal unit month for this strategy.
D. Management of grazing to emphasize livestock production with multiple use considerations. Management included practices such as fencing, watering, and salting to attain uniform livestock distribution. Practices to improve forage production included

seeding, fertilization, shrub and tree removal, and forest thinning. Stocking rate was 2.8 hectares per animal unit month for this strategy.

More than one grazing system (i.e., deferred rotation, rest rotation, no use, and season-long use) was used to achieve a given strategy. Strategy A was implemented on four watersheds; strategy C on five watersheds; and strategy D on three watersheds (table 1).

Table 1—Range management strategy and characteristics of study watersheds of the Oregon Range Evaluation Project near John Day, Oregon, 1978-84

Watershed	Range management strategy	Ecosystem[a]	Drainage area	Stream					Drainage density	7-day low-flow
				Elevation	Aspect	Shade	Width	Travel		
			Km^2	*Meters*	*Degrees*	*Percent*	*Meters*	*Hours*	*$Km \bullet km^{-2}$*	*$L \bullet sec^{-1} \bullet km^{-2}$*
Big	A	F/S	5.2	1903	340	67.8	0.82	14.7	2.8	1.54
Blackeye	A	LA/DF	2.3	1768	265	87.0	.67	3.2	1.5	1.36[b]
Caribou	C	PP	6.3	1440	195	54.7	.49	17.1	3.0	.17
East Donaldson	C	LA/DF	4.1	1403	335	89.7	.55	5.9	2.9	.93
East Little Butte	C	LA/DF	3.0	1415	360	83.1	.94	6.8	2.4	1.53[b]
Flood Meadow	D	LP/MM	18.1	1615	360	35.0	1.00	14.7	3.1	.67
Keeney Meadow	D	MM/PP	12.7	1655	360	6.1	.52	4.4	2.6	.08
Lake	A	LA/DF	1.2	1585	155	75.9	.27	3.3	1.4	.33
Little Boulder	C	LA/DF	6.0	1648	200	79.2	.73	12.5	2.2	1.42
Ragged	A	LA/DF	8.8	1425	25	87.8	.67	24.4	2.6	.75
Tinker	D[c]	LA/DF	4.4	1615	155	64.0	.52	15.5	4.4	.50
West Donaldson	C	LA/DF	3.9	1390	360	87.5	.40	12.5	2.7	1.03

[a] F/S = fir/spruce; LA = larch; MM = mountain meadow; PP = ponderosa pine; LP = lodgepole pine; DF = Douglas-fir.
[b] Estimated values.
[c] Strategy D at Tinker was attained in water year 1981; all other strategies were attained in water year 1979.

Because strategies were assigned to watersheds as a consequence of their inclusion in larger treatment areas, the experimental design was not random. Also, strategy D watersheds were in areas that were selected for their potential for implementing practices resulting in sufficient forage production to support grazing at stocking rates of 2.8 hectares per animal unit month.

A detailed description of the watersheds and hydrologic characteristics is provided by Higgins and others (1989) and Tiedemann and Higgins (1989). Predominant ecosystems (vegetative habitats) as described by Garrison and others (1977) were mountain meadow, western larch/Douglas-fir (*Larix occidentalis* Nutt./*Pseudotsuga menziesii* (Mirbel) Franco), subalpine fir/Engelmann spruce (*Abies lasiocarpa* (Hook.) Nutt./*Picea engelmannii* Parry ex Engelm.), ponderosa pine (*Pinus ponderosa* Dougl. ex. Laws.), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.). Each watershed is characterized in table 1 by the predominant vegetative habitat or ecosystem. Data from Austin, Oregon (1280 meters elevation), indicates that the study area receives 51 to 127 centimeters of precipitation, with about 70 percent occurring as snow between November and April (National Oceanographic and Atmospheric Administration 1984). The mean monthly air temperature at Austin is -6.7 °C in January and 16.7 °C in July, with annual extremes of -26 to 38 °C common. Summer relative humidities range from 15 to 30 percent during the daytime. Summer cloud cover averages 3 to 6 percent. The annual hydrograph is dominated by snowmelt runoff that begins at low-elevation watersheds in March and at high-elevation watersheds in mid-May. Peak discharge ranges from 5.7 to 634 liters per second per square kilometer and occurs from mid-April to early June, depending on elevation and aspect of the watershed. Flows diminish through the summer with the lowest in August and September. Runoff patterns are similar to those reported for other watersheds in eastern Oregon and Washington (Fowler and others 1979, Helvey and others 1976).

Methods

Stream Temperature

Stream temperatures were continuously recorded at the mouth of each watershed during the summers of 1978 through 1984 by using Ryan model "J" and "G" (Ryan Instruments, Inc., Kirkland, Washington)[1] thermographs. Recorders were placed near the center of the pool behind control structures (weirs) used for measurement of water yield. Accuracy was ± 2 percent for temperature and timing. Charts were digitized and reduced to 1-hour values. Only complete days from June 21 to September 19 were used in the analysis. All analyses were based on the hourly datum point. Daily analysis was based on the mean of 24 hourly values. Weekly analysis was based on the mean of 7 daily means, starting the first week on June 21.

Determination of Stream Characteristics

Streams of each watershed were divided into reaches for purposes of determining stream characteristics. Reaches ranged from 75 to 2590 meters long. Reach length was determined by uniformity of the measured characteristics, percentage of shade, azimuth (aspect), and gradient. All stream characteristics were measured at the start of the study. Stream shade was measured at several systematically spaced points within each reach by using a Solar Pathfinder. It was used to determine the percentage of potential solar radiation reaching the measurement point in mid-August. The number of sample points differed among reaches, depending on the variation in stream shade, and were selected to produce an estimated mean within 5 percent of the true mean at the 80-percent confidence level. The mean stream shade for each reach was determined from a simple arithmetic average; means for entire streams were weighted by reach lengths. Stream widths also were measured at the shade measurement points and means determined by the same procedure.

Stream gradients and aspects were measured from 7.5-minute topographic maps. Streamflow travel times were estimated by using tracer dye over short sections of some reaches during the low-flow period in August 1983. Reach lengths were determined by pacing in the field and verified on topographic maps.

Intensive Analysis of Temperature Change Along One Stream

To determine the relations among stream temperature and characteristics of individual stream reaches, an intensive analysis was conducted for six reaches of Caribou Creek from July 10 through September 13, 1984. Thermographs were placed at the end of each of six stream reaches on Caribou Creek. These reaches encompassed all but the uppermost kilometer of the perennial stream and were the same reaches defined for analysis of stream characteristics that were used in the broader part of the watershed study. Analysis of stream temperature was based on daily maximum values. Shade cover, reach length, aspect, gradient (slope), and elevation were the same values used in the general watershed study described above. The day with the highest maximum (July 26, 1984) was used for discussion purposes. Multiple regression analysis with all

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

observations was used to determine the amount of variation in stream temperature that was accounted for by stream characteristics, air temperature, and cloud cover. Estimates of air temperature and cloud cover were determined from air temperature data from Long Creek, Oregon, and cloud cover data from Meacham, Oregon, by using procedures of Satterlund (1981).

Data Analysis

Cumulative frequency-distribution curves for the percentage of time a stream temperature was exceeded were developed for the period of record for each watershed. To compensate for missing data, the study period was arbitrarily divided into critical and noncritical periods selected by examining temperature plots for a 6-week period when most watersheds reached yearly maxima (table 2). The critical period was July 10 to August 21, and the noncritical period included June 21 to July 9 and August 22 to September 19. The percentage of time a temperature was exceeded (actual hours exceeded divided by hours observed) was weighted by the proportion of possible hours within the study period that occurred in each period (46.2 percent in critical and 53.8 percent in noncritical). Values for critical and noncritical periods were then added to form data points for that temperature. This procedure was repeated for each year and temperature. The annual weighted values were averaged to produce a cumulative frequency distribution curve for the period of record.

Statistical analyses were performed by using the general linear model procedure of the Statistical Analysis System (1985). Autocorrelation of weekly means within years and watersheds was tested by following the procedure of Abraham and Ledolter (1983) for small sample size. All analyses were conducted after adjustment for observed autocorrelation. Stepwise and multiple regression and correlation procedures were used to determine significant ($p < 0.05$) differences among relations of stream temperatures and stream characteristics. Analysis of variance models, with and without shade as a covariate, were used to test the significance of range management strategy on mean weekly stream temperature and the amount of time stream temperature exceeded 20 ^{o}C. Analysis of variance also was used to test for significance of ecosystem (dominant vegetative habitat) on mean weekly stream temperature. Flood Creek watershed was not included in the analysis of time that temperature exceeded 20 ^{o}C because of insufficient data.

Results and Discussion

Stream Temperature Characteristics

Maximum temperatures in streams of the 12 watersheds ranged from 12.5 to 27.8 ^{o}C (table 3). Minimum temperatures (not shown in table) ranged from 3.5 to 5.0 ^{o}C and were similar on all watersheds. Daily ranges (not shown in table) within the streams were as great as 12.8 ^{o}C. Maximum mean weekly temperatures ranged from 10.9 to 17.8 ^{o}C (table 3). Dates of maximum temperatures differed from year to year, but more than 88 percent of the maximum temperatures were observed during weeks 29 to 33 (July 16 to August 19) (fig. 1).

Autocorrelation analysis showed a strong first-order correlation over time, which was approximately constant among watersheds (table 4). Significant autocorrelation indicates that the stream temperature of one time period was significantly related to the temperature of a previous period. Average autocorrelations differed more from year to year but were relatively strong in all years. The overall average autocorrelation for all watershed-year combinations was 0.36. The relatively small sample size may explain some of the large variability in autocorrelation among watersheds and years. Results suggest that an uncorrelated error model would not be appropriate and that the true variance of the weekly temperature analyses may have been underestimated by less than 10 percent.

Table 2—Percentage of hours of stream temperature data present in the critical (C) and noncritical (NC) periods of study watersheds of the Oregon Range Evaluation Project near John Day, Oregon, 1978-84[a]

		Year						
Watershed	Period	1978	1979	1980	1981	1982	1983	1984
		Percent						
Big	NC	48	9	16	33	33	ID	31
	C	41	22	34	19	40	ID	33
Blackeye	NC	ID	54	23	35	54	ID	ID
	C	ID	32	46	46	46	ID	ID
Caribou	NC	ID	47	49	52	45	ID	53
	C	ID	23	46	46	37	ID	46
East Donaldson	NC	ID	33	ID	26	45	54	38
	C	ID	45	ID	45	46	46	46
East Little Butte	NC	ID	ID	47	45	51	54	ID
	C	ID	ID	46	46	46	43	ID
Flood	NC	ID	ID	ID	ID	ID	33	53
	C	ID	ID	ID	ID	ID	11	46
Keeney	NC	ID	51	53	33	45	ID	50
	C	ID	27	46	31	46	ID	24
Lake	NC	52	33	53	33	20	54	10
	C	42	20	46	30	46	46	44
Little Boulder	NC	36	41	37	54	4	33	13
	C	37	23	46	46	23	34	24
Ragged	NC	ID	54	49	45	32	ID	53
	C	ID	33	46	46	26	ID	46
Tinker	NC	ID	41	35	46	16	ID	40
	C	ID	46	12	46	46	ID	37
West Donaldson	NC	ID	24	53	ID	54	42	53
	C	ID	46	46	ID	46	13	46

ID = insufficient data (total hours < 650 or critical hours < 240).

[a] Total possible hours in the noncritical period = 1176 hours (54 percent); total possible hours in the critical period = 1008 hours (46 percent); and total possible hours in the study period = 2184 hours.

Table 3—Stream temperature characteristics for study watersheds of the Oregon Range Evaluation Project near John Day, Oregon 1978-84

Watershed	Maximum hourly	Maximum mean weekly	Range[a]	Mean[b]
		^oC		
Big	15.7	12.6	7.9	9.0
Blackeye	12.5	10.9	5.5	7.8
Caribou	26.1	17.8	10.5	14.0
East Donaldson	15.2	13.2	5.5	10.3
East Little Butte	18.1	14.1	6.9	10.7
Flood	24.0	16.6	6.6	13.5
Keeney	27.8	17.7	9.1	14.1
Lake	16.6	11.9	6.2	9.2
Little Boulder	18.0	14.2	7.9	10.3
Ragged	19.1	14.4	7.6	11.1
Tinker	25.8	16.8	8.3	13.0
West Donaldson	15.8	13.5	5.9	10.1

[a] Range = maximum mean weekly - minimum mean weekly.
[b] Mean = mean of the mean weekly.

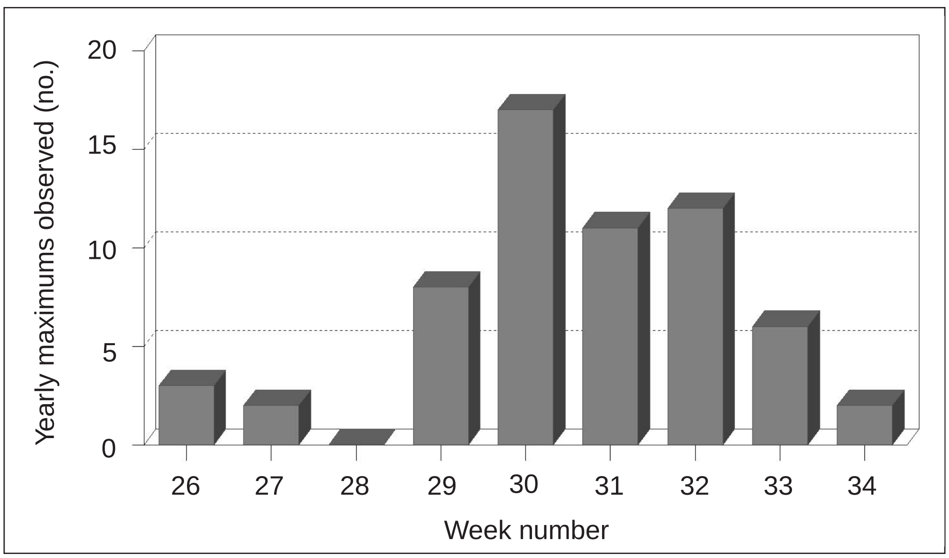

Figure 1–Timing of yearly maximum stream temperatures.

Table 4—First-order autocorrelations and sample sizes for study watersheds of the Oregon Range Evaluation Project near John Day, Oregon, 1978-84

	Year							
Watershed	1978	1979	1980	1981	1982	1983	1984	Average
Big	0.602	ID	-0.172	-0.076	0.325	ID	0.321	0.274
	11		6	6	9		7	
Blackeye	ID	0.588	0.054	0.561	0.607	ID	ID	0.487
		10	8	10	13			
Caribou	ID	0.292	0.236	0.514	0.498	ID	0.454	0.402
		8	12	12	9		12	
East Donaldson	ID	0.111	ID	-0.001	0.298	0.712	0.313	0.333
		10		7	11	13	10	
East Little Butte	ID	ID	-0.563	0.270	0.596	0.711	ID	0.385
			6	11	12	12		
Flood	ID	ID	ID	ID	ID	ID	0.639	0.639
							12	
Keeney	ID	0.431	0.310	0.115	0.452	ID	-0.025	0.271
		9	10	8	11		9	
Lake	ID	-0.253	-0.027	0.206	0.336	0.724	-0.332	0.204
		6	10	8	7	13	6	
Little Boulder	-0.154	0.379	0.277	0.525	ID	0.259	ID	0.290
	8	8	10	13		8		
Ragged	ID	0.638	0.518	0.451	-0.024	ID	0.623	0.499
		11	12	11	6		13	
Tinker	ID	0.525	-0.238	0.394	0.172	ID	0.427	0.319
		11	6	11	7		9	
West Donaldson	ID	0.036	0.432	ID	0.591	0.308	0.596	0.431
		9	13		13	7	13	
Average	0.291	0.344	0.169	0.345	0.431	0.598	0.405	0.363

ID = insufficient data (sample size < 5).

Relations of Stream Temperature to Stream Characteristics

Maximum and mean weekly stream temperatures were regressed against stream characteristics to help explain stream temperature variation. Our best model from stepwise regression analysis explained 67 percent of the variation in stream temperatures and contained eight factors in declining order of F-value (shade, week, weekly flow, width, year, travel time, elevation, and aspect). These variables were significant at $p < 0.001$, except for aspect at $p < 0.03$. Our results were similar to those of Schloss (1985). Schloss's critical variables were shade, elevation, and channel length (related to our variable of travel time).

Visual examination of cumulative frequency distribution curves of the percentage of time a temperature was exceeded for individual watersheds revealed that there were three potential groups. We conducted a cluster analysis to determine if there was a statistical basis for grouping watersheds. Based on maximum hourly temperatures, three significantly different ($p < 0.05$) temperature ranges emerged from this analysis (fig. 2, table 5). Characteristics of individual watersheds explained some of the variability in stream temperatures within strategies. Group 1 watersheds had the lowest temperatures, the highest mean percentage of shade, the highest 7-day low flow, the highest mean elevation, and the shortest mean travel time. Within group 1, Big Creek watershed had the lowest percentage of shade and the longest travel time; however, it maintained low stream temperatures because of low air temperatures common at higher elevations and because about 85 percent of the flow originates in the lower two reaches where stream shade averages 80 percent. All group 1 watersheds were within range management strategies A and C. Group 3 watersheds, all in C and D strategies, had the highest temperatures, the lowest mean percentage of shade, the lowest 7-day low flow, and the longest mean travel time. Short travel time of Keeney Creek was more than compensated by a small amount of shade (6.1 percent). Flood Creek had both relatively long travel time and a small amount of stream shade that resulted in high temperatures. Caribou and Tinker Creeks had relatively long travel times with low to moderate amounts of shade. The maximum stream temperatures observed in group 3 were more than twice as great as the maxima observed by Helvey and others (1976) and Fowler and others (1979). Group 2 watersheds (A and C range management strategies) were intermediate in temperature response and characteristics to those of groups 1 and 3.

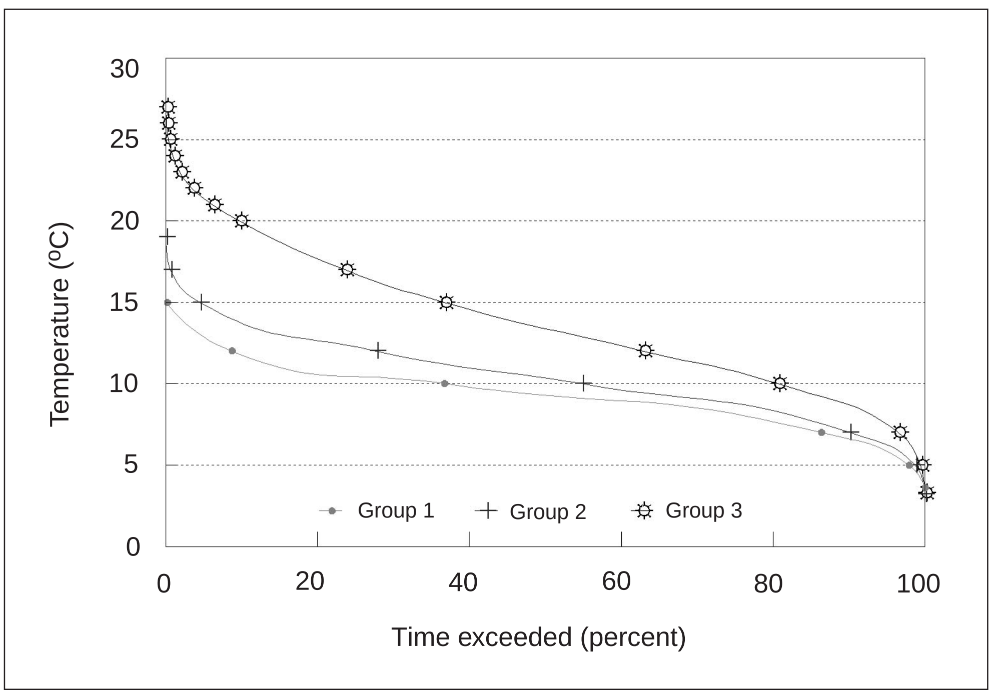

Figure 2–Cumulative frequency-distribution curves for stream temperature groups.

Table 5—Stream temperature groups of study watersheds of the Oregon Range Evaluation Project near John Day, Oregon, 1978-84

Group[a]	Maximum temperature range	Strategy	Mean Elevation	Travel time	Shade	7-day low flow
	°C		*Meters*	*Hours*	*Percent*	*L•sec^{-1} •km^{-2}*
1	12.5-15.8	A/C	1616	9.1	83.0	1.22
2	16.6-19.1	A/C	1518	11.8	81.5	1.01
3	24.0-27.8	D/C	1581	12.9	40.0	0.36

[a] Group 1 contains Big, Blackeye, East and West Donaldson; group 2 contains East Little Butte, Lake, Little Boulder, and Ragged; and group 3 contains Caribou, Flood, Keeney, and Tinker.

Slopes of cumulative frequency curves were greatest in group 3 and least in group 1 (fig. 2). The steepest slopes are associated with the highest temperatures of group 3, and the flattest slopes with the lowest temperatures of group 1. The steep slopes of group 3 indicated responsiveness to sunlight. Group 1 streams, with more protective shade, were less responsive to sunlight. The higher temperature ranges for each group were the primary element separating groups from one another, because ranges for lower temperatures were similar in all three groups.

The dominant ecosystem on a watershed (table 1) had a significant effect ($p < 0.05$) on mean weekly stream temperatures (fig. 3). Mean weekly stream temperatures were significantly greater ($p < 0.05$) for mountain meadow and ponderosa pine than for larch/Douglas-fir and fir/spruce ecosystems, but there were no significant differences between larch/Douglas-fir and fir/spruce or mountain meadow and ponderosa pine. Stream temperatures for the lodgepole pine ecosystem were not significantly different from streams of the other ecosystems. Differences among ecosystems can be explained by differences in amount of overstory shade and elevation. Overstory shade was greatest for larch/Douglas-fir and fir/spruce ecosystems and least for mountain meadow. Mountain meadow and ponderosa pine were at low elevations; larch/Douglas-fir and fir/spruce were at higher elevations.

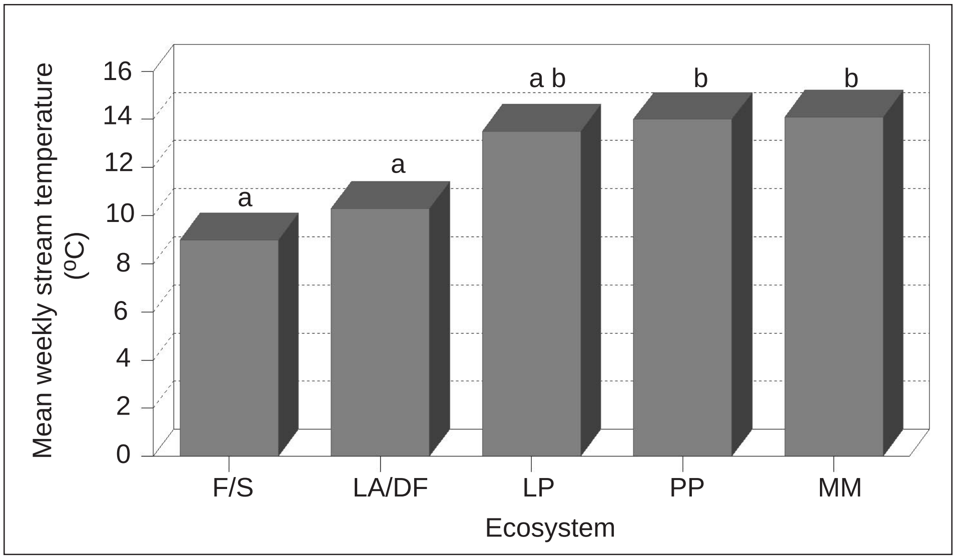

Figure 3–Mean weekly stream temperatures among ecosystems. Ecosystems with the same lower case letter are not significantly different ($p < 0.05$). F/S = fir/spruce; LA/DF = western larch/Douglas-fir; LP = lodgepole pine; PP = ponderosa pine; MM = mountain meadow.

Stream Temperature Along the Profile of Caribou Creek

Stream temperature varied with time of day along all six stream reaches of Caribou Creek (fig. 4). The maximum daily stream temperature on most reaches occurred at 1300 hours. Reach 6, at the origin of the stream, had the greatest amount of stream shade (73 percent) and the lowest maximum stream temperatures (16 °C) (table 6). In reach 5, the next reach downstream, shade decreased to 62 percent and the maximum temperature increased to 19 °C. Daily maximum stream temperatures continued to increase downstream as stream shade decreased and exposure of stream to sun-light increased. There was a slight reduction of maximum stream temperature (1.5 °C) with increased stream shade (26 to 64 percent) between reaches 3 and 1.

In a multiple regression analysis, 88 percent of the variation in temperature from reach to reach could be accounted for by slope, air temperature, length of reach, cloud cover, shade, elevation, and aspect. Partial r^2 values for each factor are shown in table 7. Slope and air temperature accounted for about 82 percent of the variation in stream temperatures. A second-order polynomial model explained 85 percent of the variation along a stream with watershed, climatic, and time variables. Input variables were the same as those for the long-term watershed study with the addition of climatic variables (cloud cover, air temperature, and precipitation).

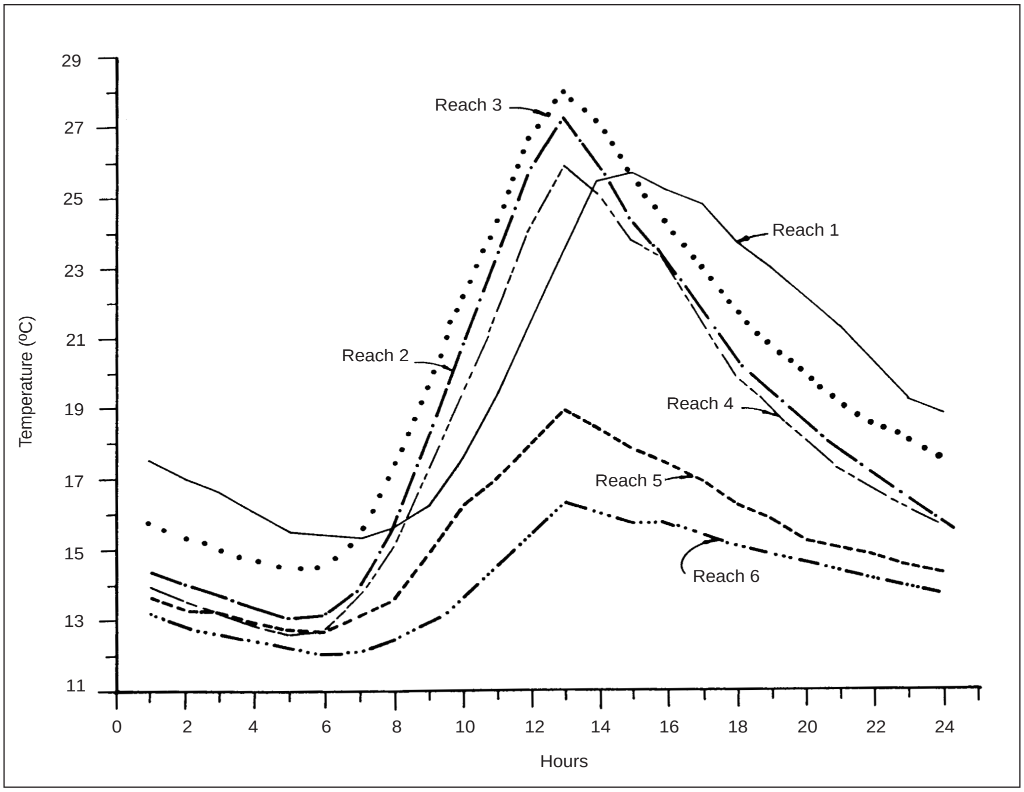

Figure 4–Stream temperatures along six reaches of Caribou Creek during the day with the highest maximum (July 26, 1984).

Table 6—Stream reach characteristics of Caribou Creek watershed of the Oregon Range Evaluation Project near John Day, Oregon, September 1984

Stream reach	Shade	Length	Aspect	Gradient	Maximum temperature
	Percent	*Meters*	*Degrees*	*Percent*	*°C*
Reach 1	64	400	196	5.4	26.5
Reach 2	35	245	186	4.0	27.0
Reach 3	26	610	224	4.4	28.0
Reach 4	44	1220	197	5.0	26.0
Reach 5	62	580	221	7.1	19.0
Reach 6	73	1465	175	10.6	16.0

Table 7—Partial r^2, cumulative r^2, and significance of F-test for relations of stream reach characteristics and stream temperatures for Caribou Creek watershed of the Oregon Range Evaluation Project near John Day, Oregon, July 10 through September 13, 1984

Variable	Partial r^2	Cumulative r^2	Probability > F
Slope	0.606	0.606	0.0001
Air temperature	.213	.819	.0001
Reach length	.022	.841	.0001
Cloud cover	.018	.859	.0001
Shade	.006	.865	.0001
Elevation	.014	.879	.0001
Aspect	.003	.882	.0009

Effect of Range Management Strategy on Stream Temperatures

Maximum hourly and mean weekly temperatures were significantly different ($p < 0.05$) among range management strategies (fig. 5). Maximum hourly temperatures and mean weekly temperatures for streams from strategy D watersheds were significantly greater than for those from strategy A watersheds; streams from strategy C watersheds were intermediate and not statistically different from either strategy A or D. Analysis for effect of the EVAL range management strategy was confounded by watershed characteristics and pre-EVAL management strategies. The temperature difference was attributable to differences in stream shade; when shade was used as a covariate, range management strategy was not significant. Streams from the three strategy D watersheds have open meadows with little tree or shrub cover. Caribou Creek, strategy C, also has an open stream channel and stringer meadows that are associated with high stream temperatures. These meadow areas are highly susceptible to temperature increases from grazing because once streambank vegetation (herbaceous, shrubby, and tree) is removed and stream banks are rounded, there is nothing to shade the stream. This problem is aggravated by the long travel time for water through the meadows. Nearly 100 years of grazing use and logging activities likely had a strong influence on stream temperatures of these watersheds through removal of streamside shrubby vegetation and caving of overhanging stream banks. Streams from strategy A watersheds, in contrast, were more heavily forested and had probably received less previous grazing use. Except for Caribou Creek, strategy C watersheds are more forested than strategy D watersheds and likely have had less previous gazing use.

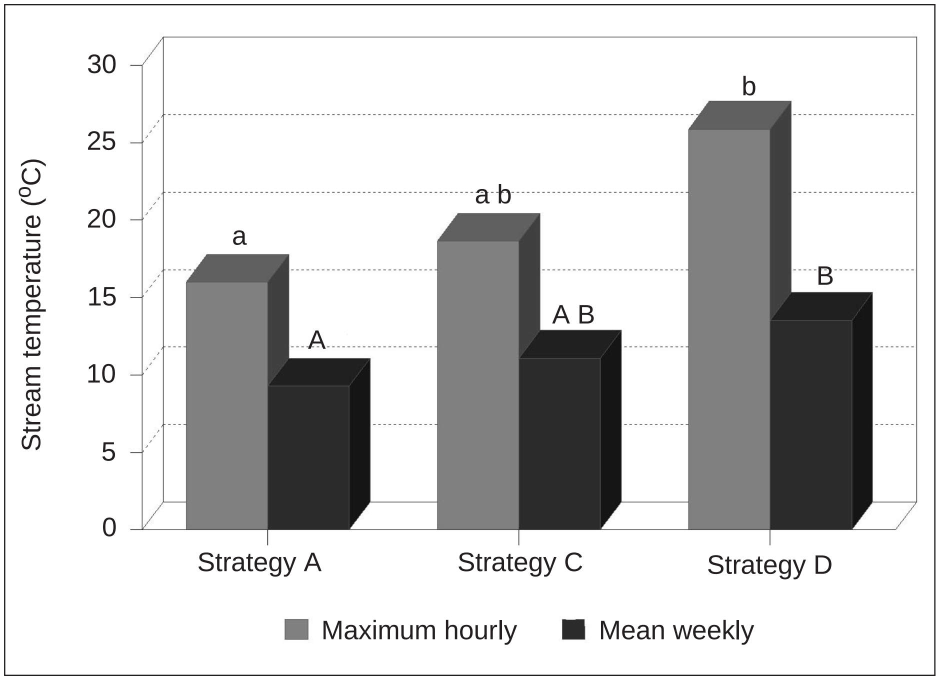

Figure 5–Maximum hourly and mean weekly stream temperatures among range management strategies. Strategies with the same lower case letter are not significantly different ($p < 0.05$) for maximum hourly temperature. Strategies with the same upper case letter are not significantly different ($p < 0.05$) for mean weekly stream temperature. Strategy A = no grazing; strategy C = 7.7 hectares per animal unit month; strategy D = 2.8 hectares per animal unit month.

Range management strategy did not have a significant effect on the percentage of time the temperature was above 20 °C. Keeney Creek was above 20 °C the greatest amount of time, about 17 percent (fig. 2). Keeney Creek also had the least streamside shade and has a northern aspect that restricts shading from the streambanks. Again, the strong influence of watershed characteristics likely masked the effect of range management strategy.

Comparisons of Maximum Stream Temperatures and Established Fish Tolerances

Maximum hourly stream temperatures on Keeney, Flood, Tinker, and Caribou Creeks all exceeded the short-term (maximum hourly) standard for rainbow trout of 24 °C (U.S. Environmental Protection Agency 1986) because shade cover was limited on these streams. Streams of these watersheds had the lowest percentage of shade, ranging from 6.1 to 64.0 percent. The principal source of heat for small forest streams is solar energy striking the stream surface (Brown 1983). A minimum of 75 percent of the stream surface must be shaded from 1100 to 1600 hours from June to September to control maximum stream temperatures (Brown 1969). All watersheds with greater than 75 percent effective stream shade had maximum hourly stream temperatures within acceptable limits. Big Creek had less than 75 percent effective stream shade but its high elevation and the contributing flows from shaded reaches resulted in acceptable stream temperatures.

Although fish populations survive in these streams, they are likely stressed by high stream temperatures in summer. The trout most likely move to a colder reach of the stream to help them through these periods. Caribou Creek had the highest density of age 0 (first year) trout and, yet, had the highest maximum stream temperatures (Grimes 1980). Caribou and Tinker Creeks had the highest biomass of trout per square meter, during 1978-80 (Grimes 1980). Age 0 trout correlated positively with shallow riffles over spawning-size gravel and aquatic vegetation, and negatively with elevation and water depth (Grimes 1980). Caribou and Tinker Creeks offer all these stream characteristics. Keeney Creek does not have a trout population because of a physical barrier, lethal stream temperatures, and ephemeral stream sections. The trout population of Flood Creek is lower than that of Caribou and Tinker Creeks, but the trout are larger because Flood Creek lacks spawning-size gravel. Flood Creek, however, offers some physical cover of logs and streambanks for larger trout.

Conclusions

Maximum stream temperatures as high as 28 ^{o}C occurred in streams in the study area. Streams can be classified into temperature groups by watershed and environmental parameters (elevation, travel time, stream shade, and 7-day low flow). Increasing intensity of range management strategy did have a significant effect on stream temperature resulting in temperatures that exceeded limits for fish. This was not definitive, however, and likely was due to the strong influence of watershed characteristics and effects of prior grazing and management. Ecosystem had a significant ($p < 0.05$) effect on mean weekly stream temperature. Larch/Douglas-fir and fir/spruce had similar mean weekly stream temperatures, but they were significantly lower than those of ponderosa pine and mountain meadow. Mean weekly temperatures of the lodgepole pine ecosystem were intermediate between the other ecosystems. Watershed characteristics that had a significant ($p < 0.001$) effect on stream temperature were shade, stream elevation, travel time, and flow. A strong first-order autocorrelation was found on stream temperature measurements within all watersheds.

Streamside vegetation is essential in providing shade that keeps stream temperatures from reaching lethal levels. Watersheds with less than 75 percent surface stream shade can exceed stream temperature standards for rainbow trout and chinook salmon. All three strategy D watersheds and one strategy C watershed exceeded this standard because sufficient streamside shade from vegetation was lacking within the riparian areas of these watersheds. Once the streamside vegetation was removed, little protective shade remained in the meadow ecosystem. Revegetation of the streamside areas with shrubs or small trees likely would result in reduced stream temperatures and an improved environment for rainbow trout and chinook salmon.

Management practices within the riparian zone could be implemented to reduce adverse impacts on the streams and their dependent trout populations. Streamside vegetation is probably the most easily manipulated variable. Maintenance of the integrity of the riparian zone could be achieved by using buffer strips and by more stringent control of animal use of riparian areas.

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Stream temperatures were measured during summer months, 1978 to 1984, at 12 forested watersheds near John Day, Oregon, to determine temperature characteristics and to assess effects of three range management strategies of increasing intensity. Maximum stream temperatures on four watersheds exceeded 24 °C, the recommended short-term maximum for rainbow trout and chinook salmon. Although highest temperatures were observed in the most intensively managed watersheds, the effect of range management strategy was not definitive. It was confounded by watershed characteristics and about 100 years of grazing use prior to initiation of this study.

Keywords: Forested watersheds, grazing management strategies, grazing intensity, fisheries, fish habitat, chinook salmon, steelhead trout, cutthroat trout, Dolly Varden trout.

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