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Density and biomass of redband trout relative to stream shading and temperature in southwestern Idaho

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DENSITY AND BIOMASS OF REDBAND TROUT RELATIVE TO STREAM SHADING AND TEMPERATURE IN SOUTHWESTERN IDAHO

Bruce W. Zoellick[1]

ABSTRACT.—Density and biomass of redband trout (*Oncorhynchus mykiss gairdneri*) relative to stream temperature were examined in headwater reaches of Big Jacks and Little Jacks Creeks in southwestern Idaho. Stream shading was greater (mean of 80% versus 46%) and solar insolation was lower (mean of 7.9 versus 15.1 mJ $\cdot$ m^{-2} $\cdot$ day^{-1}) in Little Jacks Creek ($P < 0.04$); otherwise the 2 streams were similar (e.g., width, depth, gradient, median substrate size). Maximum water temperatures increased with distance from headwater springs in both streams ($P \le 0.07$) but increased more rapidly and to higher levels (24°–26°C) in Big Jacks Creek. Daily maximum water temperatures (23 km downstream of headwater springs) during July 1996 were lower in Little Jacks Creek (ranged from 18° to 22°C) than in Big Jacks Creek (20.2° to 26°C, $P < 0.001$). Daily temperature fluctuations also differed between streams, averaging 3.6°C for Little Jacks Creek and 7.8°C for Big Jacks Creek ($P < 0.001$). Redband trout density and biomass were greater in Little Jacks Creek (means of 0.8 fish $\cdot$ m^{-2} and 25.0 g $\cdot$ m^{-2}) compared to Big Jacks Creek (0.3 fish $\cdot$ m^{-2} and 8.9 g $\cdot$ m^{-2}, $P = 0.01$). Trout density was negatively correlated with increases in water temperature ($P = 0.03$) and solar insolation ($P = 0.09$) in both streams. Trout biomass increased with stream shading and was negatively correlated with solar insolation ($P < 0.1$). Warmer water temperatures in Big Jacks Creek were likely due to historical summerlong livestock grazing, which drastically reduced riparian shading.

Key words: redband trout, Oncorhynchus mykiss gairdneri, *water temperature, density, biomass, stream shading, solar insolation, desert streams, southwest Idaho.*

Platts and Nelson (1989) hypothesized that summer water temperature increases limit salmonid populations in open-canopied streams in the Great Basin and that deleterious effects of elevated temperatures offset increases in invertebrate abundance generated from greater primary production. Li et al. (1994) tested this hypothesis in streams inhabited by interior rainbow (redband) trout (*Oncorhynchus mykiss gairdneri*) in eastern Oregon. Trout biomass was negatively correlated with solar insolation and maximum stream temperature in streams in the John Day River basin, but was not correlated with invertebrate biomass. Near-lethal water temperature levels in open-canopied streams likely impose high metabolic costs on redband trout, offsetting higher food availability (Li et al. 1994).

Persistence of redband trout in warm-temperature stream reaches in the John Day River basin did not necessarily require physiological adaptations to temperature extremes; trout were thought to behaviorally thermoregulate by moving to cold-water microhabitats when temperatures approached 23°–25°C (Li et al. 1994). However, redband trout stocks in low-elevation desert streams in the Snake River basin in southwestern Idaho and northern Nevada have probably evolved adaptations to temperature extremes (Behnke 1992). In particular, redband trout inhabiting tributary streams to the Snake and Owyhee Rivers tolerate maximum stream temperatures of 28°–29°C (Behnke 1992, Zoellick 1999). Adaptations to extremes in temperature and flow undoubtedly have allowed populations in desert basins to persist through time even in extreme drought conditions when flows become intermittent (Behnke 1992). While increased stream temperatures may not limit distribution of desert-adapted populations of redband trout to the extent of other trout stocks, their abundance likely declines with temperature increases because of increased metabolic costs (Li et al. 1994).

To ascertain whether redband trout populations in lower-elevation sagebrush desert basins respond similarly to temperature increases compared with populations in the John Day River basin, I studied relationships between trout

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abundance and stream shading, solar insolation, and stream temperature in Big Jacks and Little Jacks Creeks in southwestern Idaho. These streams support redband trout stocks tolerant of extreme fluctuations in temperature (Zoellick 1999). Headwater reaches are physically similar (elevation, geomorphology, stream flows, and channel types) with the exception of the amount of stream shading provided by riparian shrubs. I hypothesized fewer trout were present in Big Jacks Creek per unit area than in Little Jacks Creek because of elevated stream temperatures due to lower levels of stream shading in Big Jacks Creek. Objectives were to (1) compare redband trout abundance (density and biomass) in reaches of Big Jacks and Little Jacks Creeks that differed only in amount of stream shading from riparian shrubs, (2) quantify solar insolation and water temperatures of the 2 streams, and (3) relate abundance of redband trout in the 2 streams to stream temperature, solar insolation, and stream shading.

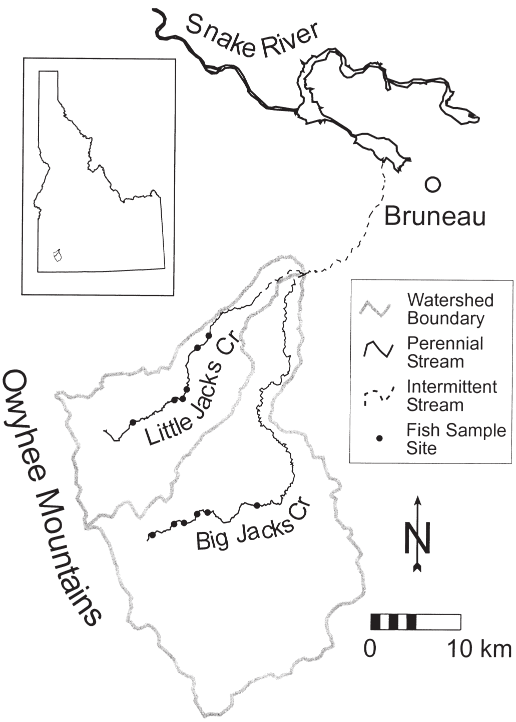

Fig. 1. Location of Big Jacks and Little Jacks Creeks in southwestern Idaho, their watershed boundaries, study reaches (shaded), fish sample sites, and area map (inset).

STUDY SITE

Big Jacks and Little Jacks Creeks flow northeasterly from the Owyhee Mountains to C.J. Strike Reservoir on the Snake River near the town of Bruneau in southwestern Idaho (Fig. 1). Drainage basins of Big Jacks and Little Jacks Creeks are 633 km^2 and 260 km^2, respectively. Elevations range from 750 m to 1920 m, and the basins are predominantly vegetated with big sagebrush (*Artemisia tridentata*) shrub-steppe communities. The upper perennial segments of the 2 streams are located in canyons 30–270 m deep, carved through ryholite lava, with narrow floodplains and stream substrates dominated by cobble-sized rocks. Flows in both streams were intermittent at downstream ends of the watersheds (Zoellick 1999; Fig. 1), and surface flows were not connected during 1995–96. Stream channels were moderately confined by side valley slopes and had gradients of 1.5%–4% (B stream types; Rosgen 1994). I conducted the study on the upper 23 km of each stream (Fig. 1), starting at the headwater springs.

Livestock grazing has been excluded from Little Jacks Creek since 1976, and stream banks were densely vegetated with riparian shrubs. In contrast, Big Jacks Creek was grazed summerlong by cattle from at least the 1970s through 1995, resulting in annual removal of 80%–100% of the current year's growth of young shrubs and herbaceous vegetation. Mean vertical cover of young shrubs (<2 m tall) was unchanged from 1984 to 1994; median residual stubble heights of herbaceous vegetation ranged from 2.5 cm to 3.8 cm during 1993–1995 (U.S. Bureau of Land Management unpublished data). Approximately one-half or more of the riparian shrubs on Big Jacks Creek were replaced with herbaceous vegetation because of livestock eliminating or preventing the reestablishment of shrubs after their removal by beaver (*Castor canadensis*) or scouring flows.

Upstream, steeper gradient (2%–4%) segments of both study reaches were dominated by red-twig dogwood (*Cornus sericea*). Lower segments (>11 km downstream of headwater springs) of the Little Jacks Creek study reach were predominantly vegetated with arroyo willow (*Salix lasiolepsis*), and other willow species (*S. lasiandra, S. exigua, S. amygdaloides*) were present. Middle to lower segments (>8 km downstream of headwater springs) of Big Jacks

Creek were vegetated with remnant stands of willows (primarily *S. lasiolepsis* and *S. exigua*) and herbaceous plant communities dominated by Kentucky bluegrass (*Poa pratensis*), goldenrod (*Solidago* spp.), and scouring rush (*Equisetum arvense*).

METHODS

The 2 study reaches were stratified into 5 segments each (3–8 km long), based on stream gradient and composition and canopy cover of riparian plant communities determined from 7.5-minute topographic maps and 1:24,000 scale color aerial photographs. I measured canyon width, depth, steepness of side slopes, and valley bottom widths on 7.5-minute topographic maps at 1 randomly selected site per segment. Canyon aspect was calculated as the compass bearing of the line connecting upstream and downstream ends of study reaches. Average stream gradient for each segment was calculated from topographic maps. In August 1995 and August 1996, I walked the length of each segment to verify that stream types (Rosgen 1994) did not change within a segment. I then measured stream (bankfull) and floodplain dimensions at 1 reference site per segment to classify the stream type of each segment (Rosgen 1996).

Redband trout density (number $\cdot$ m^{-2}) and biomass (g $\cdot$ m^{-2}) were estimated with an electrofisher at 1 site per stream segment. An exception was the downstream-most segment of the Big Jacks Creek study reach because initial stratification indicated the gradient of this segment (0.01) was lower than other segments. Therefore, I compensated by sampling fish abundance at 1 randomly selected site in Little Jacks Creek study reach and 2 randomly selected sites in Big Jacks Creek study reach, so that 6 sites were sampled per study reach. Not sampling fish abundance in the downstream-most segment (and thus the segment with likely the warmest stream temperatures) of Big Jacks Creek probably decreased the power to detect differences in fish abundance relative to temperature, but ensured all fish sites were located in similar stream types.

Most systematically placed fish sites were located at the downstream ends of each study segment. Access was limited in the upper half of each canyon, and sample sites for 1 segment of each study reach were established in the middle of those segments. Selecting sample sites at the lower ends of study segments was not as rigorous a statistical approach as randomly selecting sample sites within study reaches, but it allowed for maximizing the effect of upstream riparian canopy on water temperature (Li et al. 1994).

Fish sample sites were 61–82 m long and were composed of multiple habitat units (pools, runs, and riffles). I sampled Little Jacks Creek in August of both 1995 and 1996 (3 sites each year) and Big Jacks Creek in August–September 1996. Trout were captured during 2 to 3 electrofishing passes, and population sizes were estimated using the Zippin capture-removal model (Zippin 1958). All trout were weighed.

Stream (wetted channel) width and average depth were measured at fish sample sites on 10 cross-section transects located 6.1 m apart. I calculated average depth for each cross section transect by the method of Overton et al. (1997). Individual transect widths and depths were treated as subsamples, and means of the widths and depths for the 10 transects were the sample units. Stream flows of Little Jacks Creek were similar between years; base flows measured at the lower end of the study reach in September were 0.07 m^3 $\cdot$ s^{-1} in 1995 and 0.09 m^3 $\cdot$ s^{-1} in 1996 (Zoellick 1999).

Wolman (1954) pebble counts were used to sample substrate composition at fish sample sites. Ten pebbles were sampled on each of 10 cross-section transects that were located 6.1 m apart, for a total of 100 pebbles per site. I calculated the median (50th) particle size for each sample site.

A Solar Pathfinder (Platts and Nelson 1989, Li et al. 1994) was used to measure solar insolation where fish were sampled. For the downstream-most segment of Big Jacks Creek, which did not have a fish sample site, solar insolation was measured at the downstream end of the segment. The Solar Pathfinder identifies the amount of solar insolation intercepted by local shade-producing objects (streamside shrubs and trees, canyon walls, etc.) and estimates the average daily thermal input falling on the stream surface for each month of the year by integrating the effects of azimuth, topographic altitude, height of vegetation, aspect, latitude, hour angle, and time of year (Platts et al. 1987, Tait et al. 1994). I calculated the mean percent of solar input unimpeded by shade from riparian shrubs and topographic features (i.e., canyon walls) for 10

TABLE 1. Watershed characteristics and geomorphology of Big Jacks and Little Jacks Creeks study reaches, southwestern Idaho.

Feature	Little Jacks Creek	Big Jacks Creek
Geologic parent material	rhyolite lava	rhyolite lava
Elevation of headwater spring (m)	1673	1670
Elevation of downstream end of reach (m)	1079	1286
Aspect of canyon (degrees)	41	70
Mean canyon width[a] (m)	974 ± 111	490 ± 77
Mean canyon depth[a] (m)	271 ± 14	152 ± 14
Canyon side slopes (%)	>60	>60
Mean width of valley bottom[a] (m)	19 ± 4	24 ± 7

[a]Mean ± $s_{\bar{x}}$, $n = 5$ for each study reach.

points (starting at the downstream end of a fish site and spaced 6.1 m apart up the stream and at the center of the channel) per site, and by determining the number of cloud-free days each month for the study area (calculated for the nearby city, Boise, ID; Platts et al. 1987). The height of the solar pathfinder above the stream surface was standardized at 0.3 m. To avoid pseudoreplication, insolation levels at each of the 10 points per site were treated as subsamples. I calculated insolation as megajoules per square meter per day, averaged for the months of June through September, and calculated the percentage of insolation shaded by riparian shrubs and topographic features of each site for those months. For stream segments with 2 fish sample sites, insolation for that segment was estimated from the downstream-most fish site.

Temperature recorders (Stowaways; Onset, Inc.) were placed in the streams at the lower end of the 2 study reaches and within 100 m of headwater springs in late June 1996, which monitored water temperatures through September. Water temperatures were recorded every 1.6–2 hours. In June 1997, I placed maximum-registering thermometers at each of the 1995 and 1996 fish sample sites, and also placed temperature recorders in headwater springs and at the lower end of the 2 study reaches. Stream temperatures were monitored through September 1997; the maximum thermometers were read once (at the end of the monitoring period).

Differences between study reaches in redband trout abundance (density and biomass), physical habitat parameters, percent shading, stream temperatures, and solar insolation levels were examined using *t* tests and analysis of variance. I combined data sets from both streams to examine correlations among stream shading, solar insolation, water temperature, and trout abundance. Measurements of maximum temperature at fish sample sites in 1997 were used as indices of stream temperatures during 1995–96. Correlations were also used to examine change in maximum stream temperature with distance from headwater springs.

RESULTS

Geomorphology, Shading, and Solar Insolation

Watershed characteristics and geomorphology of the 2 streams were similar with the exception of some differences in canyon size and aspect (Table 1). All segments of the study reaches comprised B stream types (Rosgen 1994), with cobble-dominated substrates (Table 2). Diameters of 50th particle size of substrate materials were similar between Big Jacks and Little Jacks Creeks (Table 2). Bankfull channel dimensions and stream gradients were similar between the 2 study reaches. Additionally, wetted channel widths and depths were similar between streams (Table 2). Little Jacks Creek canyon was deeper, but wider, than that of Big Jacks Creek (Table 1). Consequently, stream shading from topographic features (primarily canyon walls) did not differ between the 2 streams (Table 3).

Stream shading and insolation levels were similar for the upstream, most confined, steep-gradient segments of the study reaches (Fig. 2). Stream shading from riparian shrubs increased in the less confined, downstream segments of the Little Jacks Creek reach, while shading decreased and insolation greatly increased in the lower segments of the Big Jacks study reach. Solar insolation was significantly greater and

TABLE 2. Stream channel and floodplain measurements of Big Jacks and Little Jacks Creeks study reaches, southwestern Idaho, 1996.

	Big Jacks Creek		Little Jacks Creek			
Channel dimension	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	n[a]	P-value
BANKFULL CHANNEL						
Width (m)	6.5	0.7	6.8	0.6	5	0.73
Maximum depth (m)	0.52	0.04	0.54	0.06	5	0.76
Average depth (m)	0.27	0.02	0.27	0.03	5	0.96
Entrenchment ratio[b]	1.8	0.09	1.8	0.2	5	0.94
Width/depth ratio	23.8	1.8	26.0	3.1	5	0.54
Flood-prone width[b] (m)	11.9	1.5	11.8	1.2	5	0.95
WETTED CHANNEL						
Stream width (m)	4.2	0.2	4.2	0.5	6	0.95
Stream depth (m)	0.16	0.02	0.12	0.01	5	0.14
Diameter 50th particle (mm)	62	10.5	67	2.9	6	0.26
GRADIENT[c]	0.017	0.003	0.021	0.002	5	0.37

[a]Sample size per study reach; t tests were used to examine for differences between means.
[b]Rosgen (1994) channel classification system; all segments of the 2 study reaches were classified as B channel types.
[c]Gradients of segments of study reaches were calculated from USGS 7.5-minute topographic maps.

TABLE 3. Insolation (mJ · m^{-2} · day^{-1}), percent stream shade (total from topographic features and vegetation), and shading from deciduous vegetation and topographic features for study reaches of Big Jacks and Little Jacks Creeks, southwestern Idaho, 1995–96.

	Big Jacks Creek		Little Jacks Creek			
Parameter	$\bar{x}$	$s_{\bar{x}}$	$\bar{x}$	$s_{\bar{x}}$	n[a]	P-value
Insolation	15.1	2.4	7.9	0.9	5	0.04
Stream shading	46.4	10.9	80.4	4.5	5	0.03
Shading from deciduous vegetation	26.7	7.9	57.0	11.4	5	0.06
Shading from topographic features	19.7	4.6	23.4	9.1	5	0.73

[a]Number of sites (1 per segment of each study reach) where insolation and shading were measured; t tests were used to examine for differences between means.

total shade and deciduous vegetation shade were lower in the Big Jacks study reach compared with Little Jacks Creek (Table 3).

Stream Temperature

Stream temperatures measured within 100 m of headwater springs averaged 11.4 ± 0.08°C (± $s_{\bar{x}}$, n = 300) and 11.4 ± 0.02°C (n = 516) during July 1996 in Little Jacks and Big Jacks Creeks, respectively. Maximum temperatures of 10°C were measured at Big Jacks and Little Jacks Creeks headwater springs in 1997. Maximum stream temperatures and temperature fluctuations at the lower ends of the study reaches in 1996 were significantly greater in Big Jacks Creek (Table 4). Daily maximum temperatures in Big Jacks Creek were consistently 2°–4°C higher than Little Jacks Creek temperatures (Fig. 3). The effect of solar heating is shown by maximum temperatures occasionally converging for the 2 streams, probably during days with cloud cover or thunderstorms. Streamside vegetation on Little Jacks Creek also apparently buffered drops in minimum temperatures by intercepting heat reradiating from the stream surface at night. Daily minimum temperatures in Little Jacks Creek were slightly higher than those for Big Jacks Creek and remained higher than those in Big Jacks Creek during a drop in overall temperatures over several days (Fig. 3).

Maximum temperatures increased with distance from headwater springs for both Big Jacks (r = 0.67, n = 8, P = 0.07) and Little Jacks (r = 0.77, n = 7, P = 0.03) Creeks, but increased more quickly and to greater temperatures in Big Jacks Creek. In 1997 maximum temperatures observed at fish sample sites in

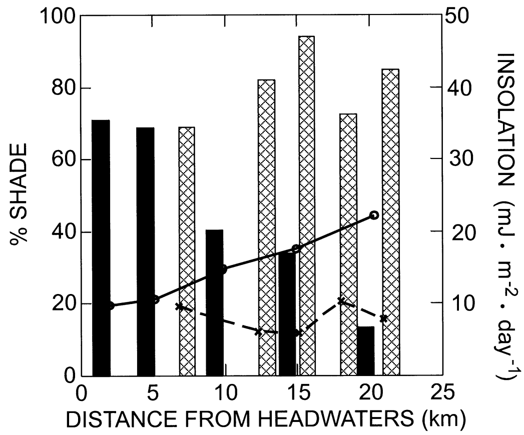

Fig. 2. Stream shading (bars) and solar insolation (lines) relative to distance from headwater springs for Big Jacks Creek (solid bar, line) and Little Jacks Creek (hatched bar, dashed line), southwestern Idaho, 1995–96.

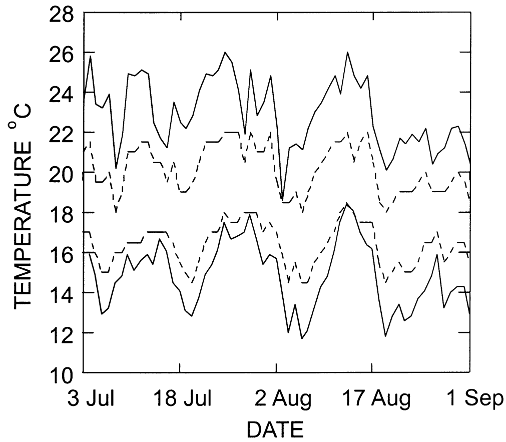

Fig. 3. Daily maximum and minimum stream temperatures at the downstream end of the Big Jacks Creek (solid lines) and Little Jacks Creek (dashed lines) study reaches, southwestern Idaho, July–August 1996.

Little Jacks Creek did not exceed 22°C, while maximum temperatures in Big Jacks Creek increased to 24.5°C by 8.3 km from headwater springs and remained at or above 24°C to the lower end of the study reach. Mean daily maximum temperatures in July 1997 at the lower end of Big Jacks (21.8°C) and Little Jacks (18.8°C) study reaches were about 2°C lower than in 1996 ($F_{1,108} = 58.88$, $P < 0.001$).

Trout Abundance

Redband trout density was significantly greater in Little Jacks Creek (0.8 ± 0.1 fish · m^{-2}, $n = 6$) than in Big Jacks Creek (0.3 ± 0.1 fish · m^{-2}, $n = 6$; $t = 3.16$, $P = 0.01$). Density ranged from 0.6 to 1.3 fish · m^{-2} in Little Jacks Creek and 0.1 to 0.8 fish · m^{-2} in Big Jacks Creek. Trout biomass was also greater in Little Jacks Creek (25.0 ± 1.9 g · m^{-2}, $n = 6$) than in Big Jacks Creek (8.9 ± 1.8 g · m^{-2}, $n = 6$; $t = 6.22$, $P < 0.001$). Biomass ranged from 18.0 to 30.7 g · m^{-2} in Little Jacks Creek and 6.1 to 17.7 g · m^{-2} in Big Jacks Creek.

Trout density in Little Jacks and Big Jacks Creeks was negatively correlated with maximum stream temperature ($r = -0.76$, $P = 0.03$; Fig. 4) and solar insolation ($r = -0.68$, $n = 12$, $P = 0.09$), and increased with stream shading, but the correlation was not significant ($r = 0.62$, $n = 12$, $P = 0.19$). Redband trout biomass was negatively correlated with solar insolation ($r = -0.71$, $n = 12$, $P = 0.06$) and increased with stream shading ($r = 0.68$, $P = 0.09$). Trout biomass decreased with maximum stream temperature, but the correlation was not significant ($r = -0.53$, $P = 0.47$).

Discussion

Platts and Nelson (1989) showed that salmonid biomass in desert streams in the Great Basin is negatively related to solar insolation levels. They hypothesized that trout abundance in desert streams is limited by the deleterious effects of increased stream temperatures and temperature fluctuations. In this study density and biomass of redband trout were significantly greater in a well-shaded stream than in a stream with significantly higher maximum stream temperatures and insolation levels. Trout density was negatively correlated with increases in maximum stream temperature and solar insolation in both streams. Biomass also declined with increasing temperature, but the relationship was not significant because several Big Jacks Creek sites had lower trout biomass than expected. Density and biomass were greatest in a stream reach with 80% stream shading and maximum temperatures ≤22°C. Similarly, Li et al. (1994) found that high-desert streams in eastern Oregon with greater riparian canopy had higher standing crops of interior rainbow (redband) trout

TABLE 4. Stream temperatures and daily temperature fluctuations (°C) at the lower end of the Big Jacks and Little Jacks Creeks study reaches, southwestern Idaho, July 1996.

Parameter	Big Jacks Creek	Little Jacks Creek	n^a	P-value
Maximum temperature	26.0	22.0	1	—
Maximum daily fluctuation	10.7	5.0	1	—
Average maximum ($\pm s_{\bar{x}}$)	23.7 ± 0.3	20.6 ± 0.2	28	<0.001
Average daily fluctuation	8.3 ± 0.3	4.0 ± 0.2	28	<0.001
Average minimum	15.3 ± 0.3	16.6 ± 0.2	28	<0.001

[a]Sample size per stream; t tests were used to examine for differences between means.

and lower daily maximum temperatures (range 16°–23°C compared with 26°–31°C).

In this study riparian shrub cover on Big Jacks Creek was removed by historical summerlong cattle grazing. Livestock grazing impacts on instream habitat would add to the negative impact of elevated stream temperatures on trout. However, because the streams were dominated by cobble substrates and had confined flood plains with most pools formed by lateral scouring at bedrock or boulders, livestock impacts to trout habitat other than changes in vegetation composition were minor. Stream banks and channels were stable as evidenced by similar channel shape and form and median substrate particle size between grazed and ungrazed streams. One possible difference between habitats of the 2 streams was the amount of near-bank vegetative cover that provided feeding and security cover for trout, but this difference was unlikely the major causative factor for the almost threefold difference in trout density and biomass between the shaded and open-canopy (grazed) streams.

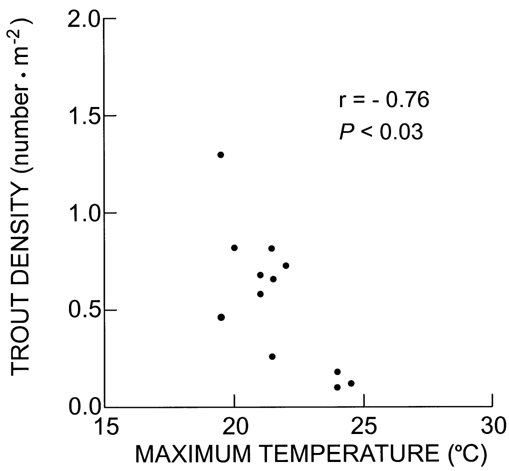

Fig. 4. Correlation of redband trout density with maximum daily temperature for all reaches of Big Jacks and Little Jacks Creeks combined (maximum daily temperatures were measured in 1997).

Redband trout populations in this study responded to temperature increases similarly to populations in the John Day River basin in eastern Oregon, despite the fact that redband trout from this study (inhabiting sagebrush desert basins) are thought to have evolved adaptations to temperature extremes (Behnke 1992). Redband trout stocks in both streams in this study have been documented to survive short-term exposure to maximum temperatures of 29°C, temperatures of >26°C for up to 4.4 hours, and daily temperature fluctuations of up to 11°C (Zoellick 1999). Behnke (1992) observed redband trout foraging in a pool with no flow at a temperature of 28.3°C in northern Nevada. In contrast, Li et al. (1994) thought trout in the John Day basin behaviorally thermoregulated when temperatures approached 23°–25°C by moving to coldwater microhabitats, and that persistence of redband trout in warm-temperature stream reaches in the John Day River basin did not necessarily require physiological adaptations to temperature extremes.

In desert streams in the John Day River basin, primary productivity increased in open-canopy reaches as did invertebrate abundance (Li et al. 1994, Tait et al. 1994). However, trout abundance was not correlated with increased invertebrate abundance. In these open-canopy streams, maximum temperatures were elevated to 26°–31°C, imposing higher metabolic costs on trout than could be offset by increases in food supply (Li et al. 1994). Elevated stream temperatures also may have affected the availability of prey. Tait et al. (1994) found open-canopy reaches of streams in eastern Oregon supported greater periphyton abundance and invertebrate biomass, but much of the increased invertebrate biomass was that of a large-bodied caddisfly (*Dicosmoecus*), which was less available to and infrequently eaten by trout and other small fish.

In contrast, removal of riparian canopy on streams in the Cascade and Coast Ranges of the Pacific Northwest has been associated with increases in salmonid abundance (Murphy et al. 1981, Murphy and Hall 1981, Hawkins et al. 1982, 1983). In these nondesert streams, canopy removal increased primary productivity and biomass of invertebrates without elevating maximum stream temperatures above 22°C (Murphy et al. 1981, Hawkins et al. 1982, 1983). Similarly, removal of canopy cover on small streams in southeast Alaska increased primary productivity along with invertebrate and salmonid biomass (Hetrick et al. 1998a, 1998b, Keith et al. 1998). However, during periods of low stream flows and sunny weather, increased solar input associated with open-canopy reaches of southeastern Alaska streams was predicted to increase stream temperatures beyond the optimum for growth of juvenile coho salmon (*Oncorhynchus kisutch;* Hetrick et al. 1998b). Thus, the effect of riparian canopy (removal or restoration) on trout production must be examined relative to the stream temperatures that are attained.

Decreased abundance of redband trout in warmer stream reaches in desert basins may be due in part to competition with warm-water fishes. Reeves et al. (1987) found that redside shiner (*Richardsonius balteatus*) and juvenile steelhead trout (*Oncorhynchus mykiss*) competed for habitat and warm water favored redside shiners. Production of trout decreased in warm water (19°–22°C) when redside shiners were present. Similarly, Baltz et al. (1982) showed that competition for cover in riffles between speckled dace and riffle sculpin (*Cottus gulosus,* a cold-water species) was mediated by temperature. Tait et al. (1994) found that warm-water fishes (cyprinids and suckers) increased in abundance in warmer, unshaded reaches of streams in the John Day River basin. Similarly, redside shiner, speckled dace (*Rhinichthys osculus*), and bridgelip suckers (*Catostomus columbianus*) were common in the warmer, open-canopy reach of Big Jacks Creek that was examined in this study (U.S. Bureau of Land Management unpublished data). These species were absent from the cooler, closed-canopy study reach of Little Jacks Creek but were present in warmer, downstream reaches of Little Jacks Creek.

Implications for Salmonid Management in Desert Streams

To maintain and ultimately improve habitat for trout in the Great Basin and desert portions of the Columbia Basin, streams should be managed to preserve riparian shrubs and trees and increase their canopy cover to provide suitable stream temperatures for salmonids. Brook trout (*Salvelinus fontinalis*) in southern Ontario (Barton et al. 1985), desert-adapted redband trout from this study, and redband trout from the south central portion of the Columbia Basin (Li et al. 1994, Tait et al. 1994) declined in abundance with increasing stream temperatures resulting from open canopies. Probable causes were higher metabolic costs imposed by temperature elevations, competition with warm-water fishes, and changes in prey availability (Li et al. 1994, Tait et al. 1994).

The importance of maintaining riparian shading of desert streams is further illustrated by heating and cooling of streams relative to amount of riparian canopy. Keith et al. (1998) demonstrated that even relatively short (20–76 m long) open-canopy reaches can substantially increase water temperatures (up to 6°C) in small streams in southeast Alaska (average widths of 1.6–2.8 m). Presence of open-canopy reaches does not necessarily result in elevated stream temperatures through all downstream reaches. Water warmed by solar input in open-canopy reaches can cool when it flows through downstream reaches with closed canopies (Li et al. 1994, Hetrick et al. 1998b, Keith et al. 1998). Cooling (when air temperatures exceed stream temperatures) occurs when heat loss to hyporheic or groundwater exchange exceeds heat gained from low insolation in closed-canopy reaches.

Idaho water quality regulations designated to protect cold-water aquatic life prescribe that water temperatures not exceed 22°C, with a maximum daily average of ≤19°C (Idaho Department of Environmental Quality 2000). During 1996–97, water temperatures in Little Jacks Creek met these criteria, while they were not met in the lower reaches of Big Jacks Creek. Differences in temperature and trout abundance between the 2 streams indicate

Idaho's cold-water criteria were appropriate for protecting redband trout populations.

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