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ASSESSMENT OF NATIVE SALMONIDS ABOVE HELLS CANYON DAM, IDAHO

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Assessment of Native Salmonids Above Hells Canyon Dam, Idaho

Project Progress Report

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PART #1: COMPARING FACTORS RELATED TO REDBAND TROUT DISTRIBUTION AND ABUNDANCE IN DESERT VERSUS MONTANE STREAMS

ABSTRACT

Redband trout *Oncorhynchus mykiss gairdneri* in the Columbia River basin occupy a variety of stream habitats, from desert streams in arid landscapes to montane streams in forested settings. In general, desert streams are lower in gradient and elevation, contain less large substrate and more silt substrate, are less shaded by overhead vegetation, and have higher summer water temperature. Such disparities suggest that limiting factors for redband trout would differ between settings. We assessed this by relating redband trout distribution and abundance to several stream conditions at 615 study sites in small- to medium-sized streams (i.e. <25 m mean width, <0.7 m mean depth). Redband trout occupancy was more likely in both desert and montane streams as the percentage of silt substrate decreased and the percentage of cobble/boulder substrate increased. In desert streams, redband trout occupancy was also more likely as gradient and stream shading increased, whereas in montane streams, occupancy was more likely at sites with lower gradients and at lower elevations. At a subsample of sites with mean summer (Jun-Aug) water temperature (Tempsmr) data (n = 51), occupancy was less likely in desert streams at Tempsmr >16°C. For montane streams, occupancy was more likely at Tempsmr >9°C, though the sample size was small for the montane comparison. At sites that contained redband trout, stream shading was correlated with redband trout density in montane (r = 0.37) and desert streams (r = 0.48); stream order (r = -0.49) was also correlated with density in desert streams. For the subsample of sites with temperature data, Tempsmr was negatively correlated to redband trout density in desert streams (r = -0.64), but the relationship was weak for montane streams (r = -0.16). These results suggest that stream conditions affect redband trout distribution and abundance differently in desert versus montane streams.

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INTRODUCTION

Redband trout *Oncorhynchus mykiss gairdneri* are native to much of the Columbia River basin east of the Cascade Range, occupy a variety of habitats from small streams to large rivers and lakes, and include anadromous and nonanadromous (i.e. resident) life history forms. Stream-dwelling forms themselves live in a variety of habitats, ranging from high-desert streams in arid landscapes to montane streams in forested settings. Evolving in such a wide range of habitats may help explain why redband trout remain the most widely distributed native salmonid in the Columbia River basin (Thurow et al. 1997). Nevertheless, declines in distribution and abundance have occurred, due largely to anthropogenic disturbances resulting in habitat fragmentation, alteration, and desiccation. Such declines led to a petition in 1995 to list redband trout in the Snake River basin, the largest tributary of the Columbia River, for protection under the Endangered Species Act (ESA), but the petition was deemed unwarranted at that time (USOFR 1995).

In the interior Columbia River basin, numerous studies have been conducted in streams regarding redband/rainbow trout habitat preferences at the macrohabitat scale. In montane streams, redband trout have been positively related to the abundance of pools and negatively related to stream gradient (Muhlfeld et al. 2001). In contrast, redband trout in desert settings generally are more closely associated with shaded reaches of stream that allow less solar radiation and produce cooler stream temperatures (Li et al. 1994; Zoellick 1999, 2004). In a cursory comparison of these two settings, Platts and Nelson (1989) found that thermal input was a much better predictor of salmonid biomass in Great Basin desert streams than in Rocky Mountain montane streams, but generalizations that can be drawn from this study are limited because they used a number of salmonid species (including redband trout), each with unique habitat preferences. Moreover, sample sizes have been limited in most of the aforementioned studies on redband trout habitat preferences, leaving it difficult to speculate fully on the relationship between habitat conditions and redband trout abundance in desert and montane settings.

Establishing a relationship between stream-dwelling fish and their habitat has been the focus of many studies. Previous work on fish/habitat models in streams that predicted standing stock of fish has typically focused on specific small-scale attributes of streams (e.g., McFadden and Cooper 1962; Binns 1982; Chisholm and Hubert 1986; Kozel and Hubert 1989). Such efforts tend to lack generality because sample sizes are often insufficient to fully characterize relationships, or the studies are focused on small areas not necessarily representative of other areas of the species' range (Fausch et al. 1988). In addition, one environmental condition is often not the only limiting factor for a population (Terrell et al. 1996), and the influence of environmental conditions on ecological response variables are often not linear (Huston 2002). Huston (2002) listed three primary obstacles to developing models that accurately conceptualize relations between ecological patterns and the factors that produce them, including: 1) mismatches between spatial and temporal dimensions of ecological measurement and the dimensions at which hypothesized processes operate; 2) misunderstanding of ecological processes; and 3) use of inappropriate statistics to quantify ecological patterns and processes.

OBJECTIVES

1. Assess what habitat conditions that we measured were most strongly related to redband trout distribution and abundance.

2. Examine whether different environmental factors appeared to be important in desert versus montane settings.

STUDY AREA

The Snake River flows through southern Idaho from east to west, flowing 1,674 km from the headwaters in Yellowstone National Park to its confluence with the Columbia River. The 83,892 km^2 study area included nearly all tributaries of the Snake River from Hell's Canyon Dam along the Oregon-Idaho border upstream to Shoshone Falls, a 65 m natural waterfall that stopped upstream colonization by redband trout (Figure 1). We excluded the Burnt River, Powder River, Malheur River, and Pine Creek drainages in Oregon because they lie entirely outside of Idaho. For all other drainages, stream surveys were conducted mostly in Idaho but also within the state boundaries of Oregon and Nevada where the upper portions of river drainages mostly within Idaho lay outside the state of Idaho. Discharge in much of the study area is heavily influenced by snowmelt and peaks between April and June. Elevation within the basin ranges from up to 3,300 m at mountain peaks to 514 m at Hell's Canyon Dam.

The historical range of redband trout in Idaho included all of the Snake River and its tributaries below Shoshone Falls, except the Coeur d'Alene River drainage in northern Idaho (Behnke 2002). Chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon *O. nerka*, and steelhead trout, the anadromous form of *O. mykiss*, were native to the study area but were blocked upstream access in the Snake River and a number of the major tributaries by a series of dams which culminated with the construction of Brownlee Dam in 1958 (rkm 460), then by Oxbow Dam in 1961 (rkm 440), and finally by Hell's Canyon Dam in 1967 (rkm 398). Bull trout *Salvelinus confluentus* and mountain whitefish *Prosopium williamsoni* are also native to the Snake River basin below Shoshone Falls, as are a number of nongame fish species. Nonnative trout, including rainbow trout *O. mykiss* of hatchery origin and coastal descent, brook trout *Salvelinus fontinalis*, and brown trout *Salmo trutta* were previously introduced in the basin and have established some self-sustaining populations in streams within the study area.

We divided study sites into desert or montane streams somewhat arbitrarily in that we grouped all streams within the major river drainages north of the Snake River (i.e. the Weiser, Payette, Boise, and Big Wood rivers) into the montane category, whereas streams in all the remaining drainages were grouped into the desert category. However, this division also corresponds well with differences in geology, vegetation, and precipitation differences. In the montane drainages, the topology is dominated by mountainous terrain typical of the Rocky Mountains, with the geology dominated by the Idaho Batholith and younger Tertiary granitic intrusions (Orr and Orr 1996). Upland vegetation is largely composed of mixed conifer forest intermixed with sagebrush *Artemesia spp*. and mesic forbs, with streamside vegetation also consisting of willow *Salix spp*. Mean annual precipitation in the montane drainages ranges from about 35 cm at lower elevations to over 125 cm at higher elevations. In the desert drainages, the topology is dominated by broken plateaus, barren rocky ridges, cliffs, and deep gulches and ravines within rhyolite and basalt geologic formations (Orr and Orr 1996). Upland vegetation is dominated by sagebrush and western juniper *Juniperus occidentalis*, while streamside vegetation is dominated by willows and mesic forbs. Mean annual precipitation ranges from less than 25 cm at low elevations to over 76 cm at higher elevations.

It should be noted that some streams in the montane category were near the valley floors and were thus more desert-like, and some desert study sites occurred at high elevation in somewhat of an alpine setting and appeared to be more montane-like. However, we deemed the classification to be reasonably accurate based on the fact that stream conditions differed significantly between desert and montane streams in nearly every stream characteristic for which we had measurements (Table 1). In fact, desert streams tended to be lower in gradient and elevation, were less shaded by overhead vegetation, had more unstable streambanks, were higher in conductivity and summer water temperature, contained more silt and gravel substrate and less cobble/boulder substrate, and contained fewer nonnative salmonids (Table 1).

METHODS

Data collection occurred between 1999 and 2005. Spatially balanced randomly selected study sites were generated from a standard 1:100,000 hydrography layer with the help of the Environmental Protection Agency's Environmental Monitoring and Assessment Program (see Stevens and Olsen 2004). Sampling occurred during base flow conditions (usually late June to early October) to minimize 1) differences in fish capturability, and 2) seasonal changes in stream habitat. We included only those streams small enough that fish and habitat measurements could be made at the study sites (i.e. <25 m average width and 0.7 m average depth).

Fish sampling

At each study site that contained enough water to support fish, we typically used depletion electrofishing (n = 579) to determine abundance of salmonids, using one or more backpack electrofishers (Smith-Root Model 15-D) with pulsed DC. Fish were identified, enumerated, measured to the nearest millimeter (total length, TL) and gram, and eventually released. The few hatchery rainbow trout (which are sterilized in Idaho) that were encountered were easy to differentiate from wild redband trout based on fin condition and were not included in this study. Block nets were installed at the upper and lower ends of the sites to meet the population estimate modeling assumption that the fish populations were closed. Depletion sites averaged 88 m in length (range 20–170 m). Maximum-likelihood abundance and variance estimates were calculated with the MicroFish software package (Van Deventer and Platts 1989). When all trout were captured on the first pass, we estimated abundance to be the total catch. Because electrofishing is known to be size selective (Sullivan 1956; Reynolds 1996), trout were separated into two length categories (<100 mm TL and ≥100 mm TL) and abundance estimates were made separately for each size group. Depletions were attempted only for salmonids, whereas relative abundance was recorded for all nongame species.

Snorkeling was used at sites too large to perform backpack electrofishing (i.e. ≥10 m wide; n = 36), and sampling followed the protocol of Thurow (1994). We counted all salmonids ≥100 mm, and total counts were used as minimal abundance estimates with no correction for any sightability bias. From the above data, we estimated for each study site the presence/absence and abundance of redband trout with abundance being standardized to redband trout/100 m^2.

Habitat sampling

Several stream conditions were measured to assess their relationship to redband trout distribution and abundance (Table 2). Selection of the stream conditions we measured was based on their presumed ecological importance, on previous research of fish/habitat relationships, and on their ease of collection. At each study site, we determined elevation (m) from U.S. Geological Survey (USGS) 1:24,000 scale topographic maps using Universal Transverse Mercator (UTM) coordinates obtained at the lower end of the reach with a Global Positioning System unit. Stream order (Strahler 1964) was determined from a 1:100,000 scale stream hydrography layer. Gradient (%) was determined using the software package All Topo Maps Version 2.1 for Windows (iGage Mapping Corporation, Salt Lake City, Utah); the distance (in meters) between the two contour lines that bounded the study site was traced (average traced distance was about 1 km), and gradient was calculated as the elevational increment between those contours divided by the traced distance. Conductivity (μS/cm) was measured with a calibrated hand-held conductivity meter accurate to ± 2%.

Ten equally spaced transects were established throughout the sample site from which the remaining measurements took place. Stream wetted width (m) was calculated from the average of all transect readings. Across the transects, depth was measured at 1/4, 1/2, and 3/4 distance across the channel, and the sum of the measurements was divided by four to account for zero depths at the stream margins for trapezoidal-shaped channels (Platts et al. 1983; Arend 1999). From these measurements we calculated the width:depth ratio. Percent substrate composition was visually estimated as the percent of stream bottom within one meter of each transect that was comprised of silt (<0.06 mm), sand (0.06–1.99 mm), gravel (2-63 mm), cobble (64-249 mm), boulder (250-3,999 mm), or bedrock (>4,000 mm). Percent unstable banks and stream shading were also visually estimated within one meter of each transect. All visual estimates were averaged across all transects for an overall mean for each study site. Abundance of nonnative trout was also included as an independent variable that might influence redband trout distribution and abundance in montane streams but was excluded from similar analyses in desert streams because the occurrence of nonnative salmonids was rare (i.e. <5% of the study sites).

At a subsample of study sites (n = 51), electronic temperature loggers that record continuous water temperature were deployed in the spring and retrieved in the fall in the year in which the site was sampled. Once retrieved, we calculated mean temperature throughout what we deemed to be the growing season (June-August; hereafter termed Tempsmr). This period also typically includes the highest water temperatures experienced by stream-dwelling fish in Idaho, which when at elevated levels has been shown to influence redband trout distribution and abundance (Ebersole et al. 2001; Zoellick 2004).

Data analyses

We assessed whether any stream conditions that we measured were correlated to redband trout distribution and abundance, separating our analyses into montane settings (n = 342) and desert settings (n = 273). We first plotted the independent variables (stream conditions) against distribution and abundance data (Figure 2) to look for data abnormalities and assess whether any stream attributes appeared to have a nonlinear relationship with abundance, especially looking for wedge-shaped distributions of data (Terrell et al. 1996). No obvious nonlinearity, wedge-shaped patterns, or data abnormalities were clearly apparent except for unequal error variance when comparing many of the habitat conditions to redband trout density, which we alleviated with a log transformation of redband trout density. Multicollinearity between independent variables was assessed with correlation analyses, but no bivariate correlations were greater than 0.70, suggesting collinearity was acceptably low in our dataset (Tabachnick and Fidell 1989). To minimize the number of independent variables being analyzed we included width:depth ratio instead of each variable separately, and we only included three of the six substrate categories (silt, gravel, and a combined category of cobble and boulder).

We compared the means and 95% confidence intervals (CIs) of the stream conditions at sites with and without redband trout to assess their relationship to redband trout distribution, and formally tested the relationships using logistic regression, using a binary dependent variable (0 = absent, 1 = present). Stepwise methods were used for including independent variables in the model, and we used Akaike's Information Criteria (AIC) to assess the best models. Akaike's Information Criteria is an extension of the maximum likelihood principle with a bias correction term that penalizes for added parameters in the model (Akaike 1973), with lower AIC values indicating better-fitting models. For comparison, we also calculated an adjusted R^2 for discrete models (hereafter termed R^2a; Nagelkerke 1991) to assess the amount of variation explained by the models. Only first order interactions were tested for significance and were removed from the models if they were not significant. The Hosmer and Lemeshow goodness-of-fit statistic (Hosmer and Lemeshow 1989) was used to determine whether a particular logistic regression model adequately fit the data, and models not satisfying the goodness-of-fit test were discarded. We used similar logistic regression analyses to relate Tempsmr alone to redband trout occupancy for the subsample of study sites for which continuous summer water temperature data were available, and as above we separated our analyses into montane (n = 14) and desert streams (n = 37).

For the 366 sites where redband trout were present, we assessed the amount of variation in redband trout abundance (fish/100 m²) that could be explained by stream conditions using multiple regression models. Analyses were similarly divided between desert (n = 159) and montane (n = 207) streams, and the adjusted coefficient of variation (R^2a) was used to judge the best models. We used least squares regression to relate Tempsmr alone to redband trout abundance for the subsample of sites with water temperature data (montane streams n = 12; desert streams n = 30).

To control for the inclusion of multiple independent variables in our analyses, we used a Bonferroni-corrected P-value of P = 0.05/21 = 0.002, where 21 is the total number of variables considered for the desert (n = 10) and montane (n = 11) models, whether they be logistic or multiple regression models. Water temperature models were analyzed separately and thus a Bonferroni correction of P = 0.05/2 = 0.025 was used since models were developed for montane and desert settings. As above, a log transformation was made to redband trout density for this comparison.

RESULTS

There were differences in many stream conditions between sites that did and did not contain redband trout (Table 1). For both desert and montane environments, redband trout occupancy increased as the percentage of silt substrate decreased and the percentage of cobble/boulder substrate increased (Table 1). In desert streams, redband trout occupancy also increased as gradient and stream shading increased, whereas in montane streams, redband trout occupancy increased at lower gradients and lower elevations (Table 1).

For desert streams, shading (P <0.0001), percent silt substrate (P = 0.0003), and percent cobble/boulder substrate (P = 0.0098) were all statistically significant or nearly significant coefficients in a logistic regression model, and their inclusion gave the best AIC and R^2a scores (AIC = 309.2; R^2a = 0.28). For montane streams, gradient (P = 0.0019), elevation (P <0.0001), and percent cobble/boulder substrate (P <0.0001) were all statistically significant coefficients in a logistic regression model, and their inclusion gave the best AIC and scores (AIC = 402.5; R^2a = 0.23).

Redband trout occupancy was also related to Tempsmr (Figure 3). For desert streams, a statistically significant logistic regression model was formed (R^2a = 0.39; P = 0.0096; n = 37), with redband trout occupancy decreasing rapidly at temperatures above 16°C; at Tempsmr above 20°C, the probability of redband trout being present was less than 0.50. For montane streams, redband trout occupancy increased sharply at 9°C and were always present above 10°C, but the sample size was much smaller and thus the model was not statistically significant despite a high R^2a value (R^2a = 0.74; P = 0.44; n = 14). Combining all temperature data and removing the three data points below 10°C, a statistically significant logistic regression model was formed (R^2a = 0.31; P = 0.0110; n = 48).

At sites that contained redband trout (n = 366), there was little correlation between stream conditions and redband trout density (log [fish/100 m²]) in either montane or desert streams (Table 2). In montane streams, only stream shading was correlated with redband trout density at a statistically significant level (P <0.0001; r^2 = 0.13) after the Bonferroni correction. For desert streams, only stream shading and stream order were correlated with redband trout density at a statistically significant level (P <0.0001 for both variables; r^2 = 0.36). For the subsample of sites with temperature data, Tempsmr was negatively related to redband trout density in desert streams (Figure 4), and explained 41% of the variation in the log of redband trout density in a least squares regression model ($y = -0.216x + 1.884$; n = 30; P = 0.0002); adding width:depth ratio increased the amount of variation explained to 58%. For montane streams, Tempsmr showed no relationship with redband trout density, and explained only 3% of the variation in the log of redband trout density ($y = -0.040x – 0.884$; n = 12; P = 0.62).

DISCUSSION

Our results indicate that summer water temperature was strongly related to redband trout distribution in southwestern Idaho. In fact, redband trout were always present when Tempsmr was between 10-16°C, and were much less likely to be present at temperatures outside this range, regardless of whether the stream was in a desert or montane setting. This pattern may in part be an artifact of our sampling design, since no desert study sites and only three montane sites had Tempsmr <10°C, and no montane study sites had Tempsmr >18°C. Nevertheless, occupancy did steadily decline in desert streams as Tempsmr increased from 16°C (always present) to 22°C (present 33% of the time). A Tempsmr of about 22°C in the desert streams translated to an average daily maximum temperature of about 26°C, and a summer absolute maximum temperature of about 30°C. We found redband trout at six study sites with maximum water temperatures over 28°C, and two study sites with maximum values over 30°C. However, only two of these six fish surveys occurred within 21 days of the warmest temperature day recorded. Thus, although unlikely, we cannot rule out that redband trout may have moved out of the study area when temperatures were at their maximum, seeking thermal refugia (Ebersole et al. 2001), and returned when temperatures receded. If redband trout remained present at temperatures exceeding 30°C, our results would concur nicely with Zoellick (1999), who found redband trout in maximum stream temperatures of 29°C. However, Cassinelli (2007) found that in lab experiments, all redband trout fry died when 10°C-diel fluctuations peaked at 30°C. At the lower end of the temperature spectrum, our finding that redband trout were absent at two of the three montane streams with Tempsmr <10°C concurs with Harig and Fausch (2002), who found that re-establishing native cutthroat trout populations was much more likely at streams with Tempsmr >10°C because successful spawning and recruitment was unlikely to occur below this temperature threshold.

In addition to its correlative relationship with redband trout distribution, stream temperature also explained much of the variation in redband trout density in desert streams (Figure 4). In our study, redband trout density in desert streams approached zero at Tempsmr of 26-27°C. Ebersole et al. (2001) and Zoellick (2004) found similar negative relationships between stream temperature and redband trout density in the desert streams they studied in the western US. For montane streams, our results suggest that factors other than water temperature were limiting redband trout density, although few of the habitat conditions we measured showed a strong relationship with redband trout density except shading.

Redband trout are known to seek thermal refugia at summer water temperatures of 18-25°C (Ebersole et al. 2001), but refugia are patchy in arid streams (Ebersole et al. 2003), and the majority of fish may not have refugia available to them (Ebersole et al. 2001). Alternatively, redband trout often may simply tolerate higher temperatures using heat shock proteins, a crucial cellular response mechanism that prevents and repairs the damaging effects of high temperature (see review in Feder and Hoffman 1999). Both desert and montane populations of redband trout appear to have the ability to withstand daily exposure to fluctuating water temperatures that exceed 26°C (Cassinelli 2007). However, our results suggest that in southwestern Idaho, elevated summer water temperatures currently are restricting redband trout distribution only in desert streams, as has been previously demonstrated (Zoellick 1999, 2004), and that montane populations rarely experience such high temperatures.

Although stream shading was also strongly related to redband trout distribution and abundance in both desert and montane streams, shading has been shown to be correlated to water temperature (Rutherford et al. 1997; Isaak and Hubert 2001). Stream shading in montane streams was positively correlated to redband trout density, but temperature was not, which suggests that shading in montane streams was providing benefits other than lowered stream temperature, such as improved trout cover or increased invertebrate food supply (Glova and Sagar 1994; Saunders and Fausch 2007).

Nearly all the habitat conditions we measured were different between desert and montane streams, especially gradient, percent shading, nonnative trout occupancy and density, and water temperature (Table 1). However, such differences did not always translate to differences in the relationships between redband trout and associated stream conditions (Table 2). For example, redband trout occupancy was negatively related to silt substrate and positively related to cobble/boulder substrate in both montane and desert streams (Table 1). Conversely, gradient was positively related to redband trout occupancy in desert streams but negatively related to occupancy in montane streams. Although habitat conditions differed between desert and montane settings, redband trout that occupy desert and montane streams of southwestern Idaho appear similar in terms of physiology and stress response (Cassinelli 2007) and genetic population structure (C. Kozfkay, IDFG geneticist, unpublished data).

Our results suggest that, in general, habitat conditions were more suitable for redband trout in desert streams than montane streams. Indeed, where redband trout were present, densities were almost double in desert streams (0.123 fish/m^2; n = 159) compared to montane streams (0.065 fish/m^2; n = 207). Similarly, Platts and Nelson (1989) found that salmonid biomass was over three times higher in Great Basin streams compared to Rocky Mountain streams.

A large portion of the total variation in redband trout occupancy or density was left unexplained by the habitat conditions we measured, despite the fact that our analyses identified a number of statistically significant relationships between redband trout metrics and habitat conditions. This suggests that the limiting factors for redband trout in our study area varied widely, especially in montane environments. Habitat conditions were more highly correlated to redband trout occupancy than to density, although occupancy and abundance are often related (Gaston and Lawton 1990; Wright 1991). Other factors we did not measure may have been more closely related to redband trout occupancy and density, such as abundance of pools (Muhlfeld et al. 2001), invertebrate biomass (Li et al. 1994), or overhead cover (Keller and Burnham 1982). Limiting factors are dynamic and interactive, and rarely does one factor limit a population (Terrell et al. 1996; Zoellick and Cade 2006), especially across vast landscapes such as in our study. Clearly, further work is needed to more fully characterize what affects redband trout distribution and abundance in desert and montane streams.

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Table 1. Average stream conditions at sites with and without redband trout in desert and montane environments in southwestern Idaho. Asterisks indicate 95% confidence intervals (CIs) that do not overlap between absent and present sites only, and does not include all sites.

	Desert streams						Montane streams					
			Redband trout occupancy						Redband trout occupancy			
	All sites		Absent		Present		All sites		Absent		Present	
Variable	Mean	95% CIs	Mean	95% CIs	Mean	95% CIs	Mean	95% CIs	Mean	95% CIs	Mean	95% CIs
Stream order	2.5	0.1	2.8	0.3	2.3	0.2	1.9	0.1	1.7	0.2	2.0	0.1
Elevation (m)	1508	48	1488	65	1523	69	1671	39	1782	71	1579	43*
Gradient (%)	2.1	0.3	1.6	0.4	2.4	0.3*	5.1	0.5	6.2	1.1	4.4	0.5*
Conductivity (µS/cm)	156.1	21.2	186.6	38.3	133.8	23.4	89.2	10.1	92.2	21.3	87.7	10.6
W:D ratio	28.4	2.0	27.4	3.3	29.2	2.4	29.3	2.1	27.5	4.5	30.5	1.9
Percent silt substrate	13.6	1.8	18.9	3.5	9.9	1.8*	7.2	1.4	9.7	3.0	5.5	1.1*
Percent gravel substrate	30.9	1.9	30.7	3.0	31.1	2.4	26.3	1.7	25.1	2.8	27.2	2.1
Percent cobble/boulder substrate	23.5	2.1	17.6	3.1	27.4	2.8*	29.8	2.3	24.2	3.8	33.5	2.9*
Percent shading	19.2	2.4	13.0	3.2	23.8	3.3*	29.2	3.2	30.9	5.9	28.0	3.7
Percent unstable banks	9.7	2.2	13.1	3.7	7.3	2.6	5.4	1.4	6.1	2.6	5.0	1.8
Nonnative trout density (No./100m²)	0.01	0.10	0.08	0.13	0.16	0.14	1.50	0.40	1.94	0.74	1.20	0.45

Table 2. Correlations (*r*) between stream attributes and redband trout density (log [fish/100 m²]) at study sites surveyed in southwestern Idaho.

	Redband trout density	
Stream attribute	Desert	Montane
Gradient (%)	0.30	0.01
Stream order	-0.49	-0.19
Elevation (m)	0.08	-0.07
Conductivity (µS/cm)	-0.12	0.08
Width:depth ratio	-0.24	-0.21
Percent silt substrate	-0.19	0.03
Percent gravel substrate	0.07	0.13
Percent cobble/boulder substrate	0.24	-0.05
Percent unstable banks	0.10	0.22
Percent shading	0.48	0.37
Mean summer water temperature (°C)	-0.64[a]	-0.16[a]
Nonnative trout density	-[b]	-0.08

[a]Includes only subsample of sites where temperature loggers were located (see text).

[b]Nonnative trout density was not included in desert streams since they were rarely present.

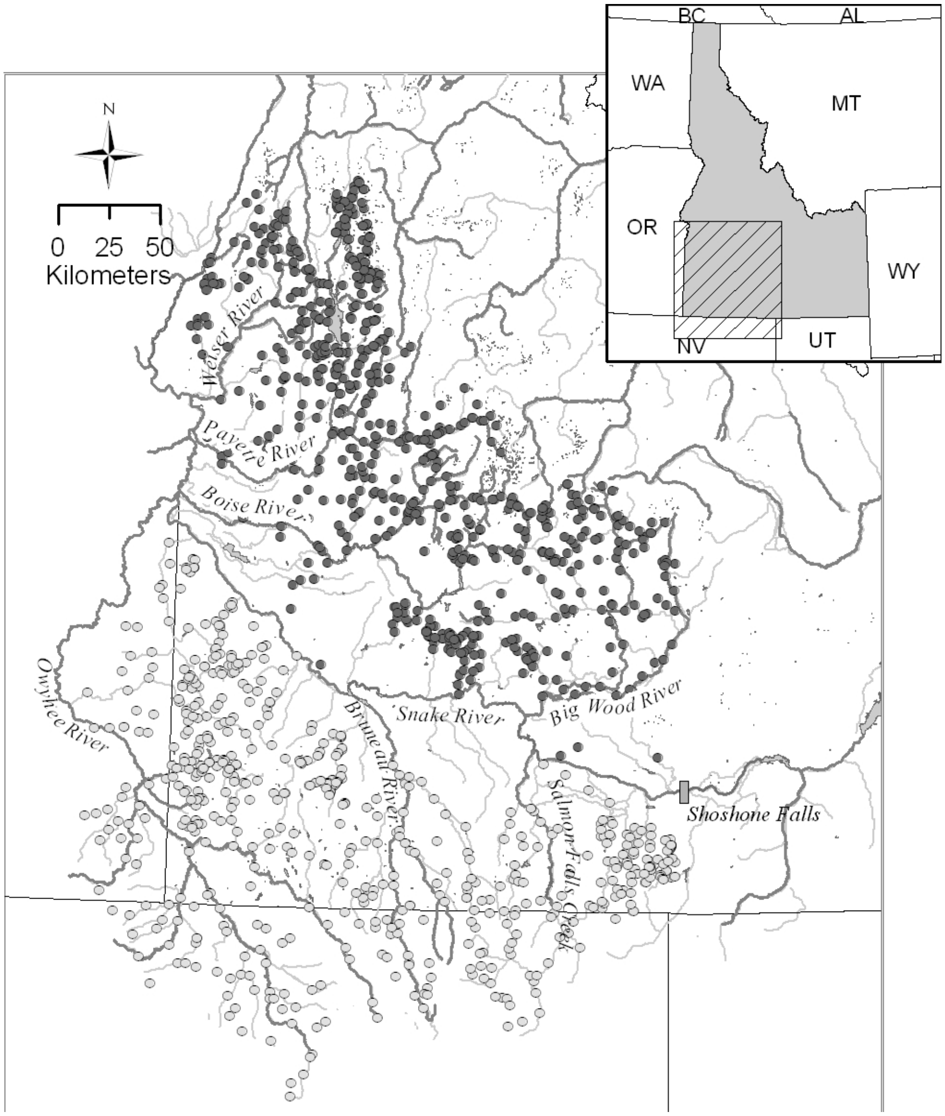

Figure 1. Distribution of desert (light circles) and montane (dark circles) study sites throughout southwestern Idaho and adjacent states.

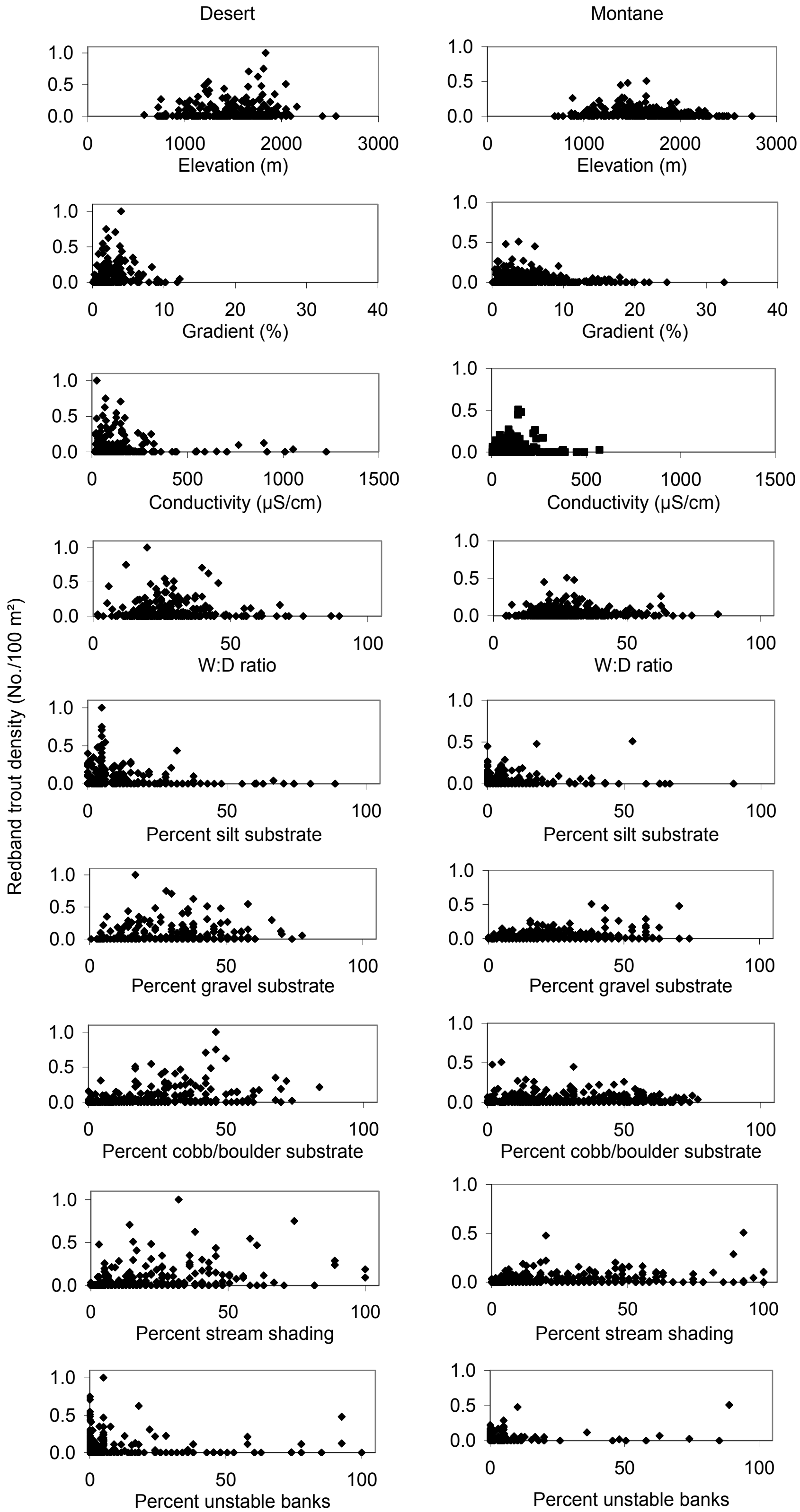

Figure 2. Scatterplots of stream conditions and redband trout densities (No./m²) in desert and montane streams in southwestern Idaho.

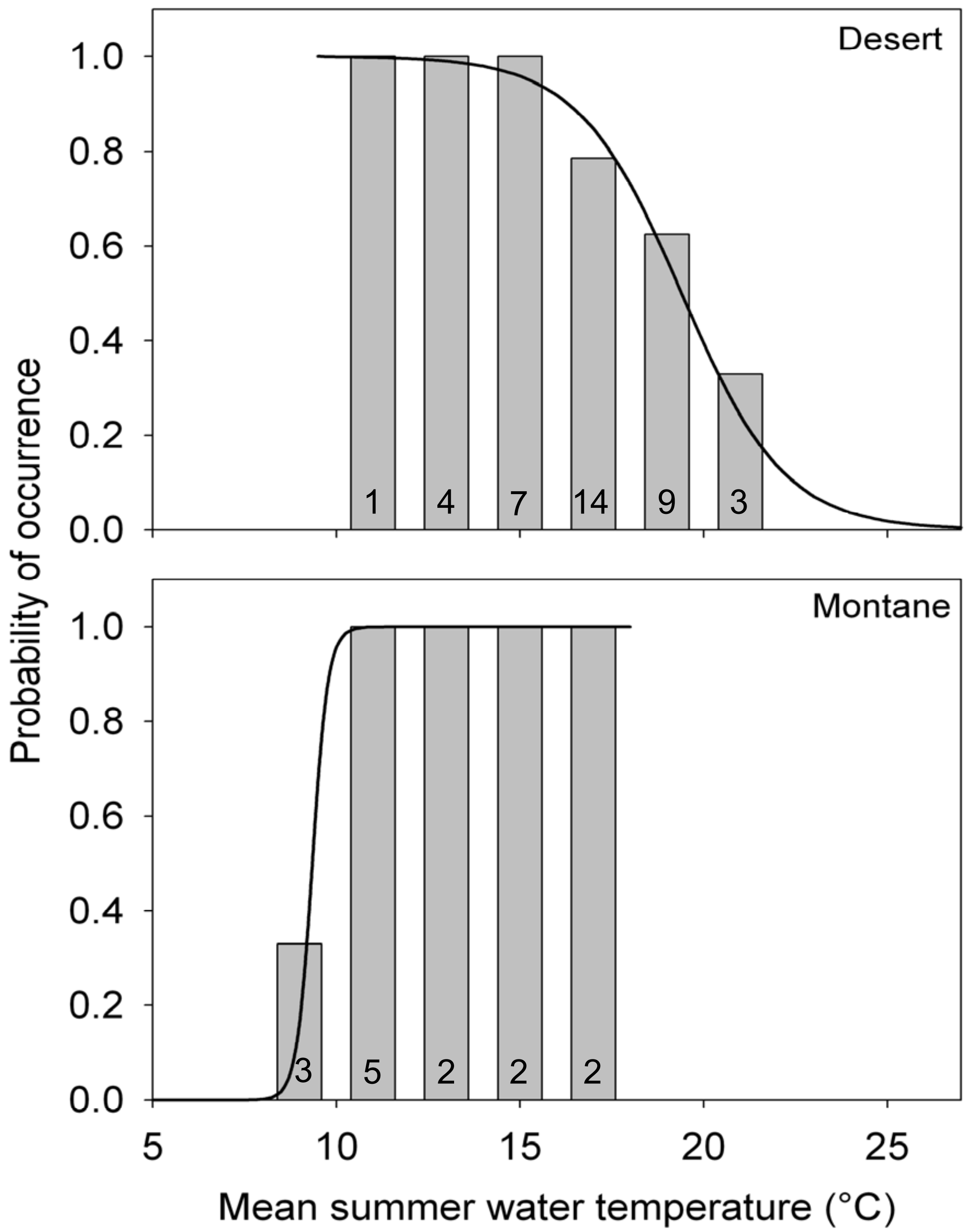

Figure 3. Observed frequency of occurrence (histograms) and probability of occurrence predicted from logistic regression models (lines) for redband trout against mean summer (Jun-Aug) water temperature in desert and montane streams in southwestern Idaho. The centers of the histograms are the mid-points of the bins used in the frequency distributions. Sample sizes appear within each bar.

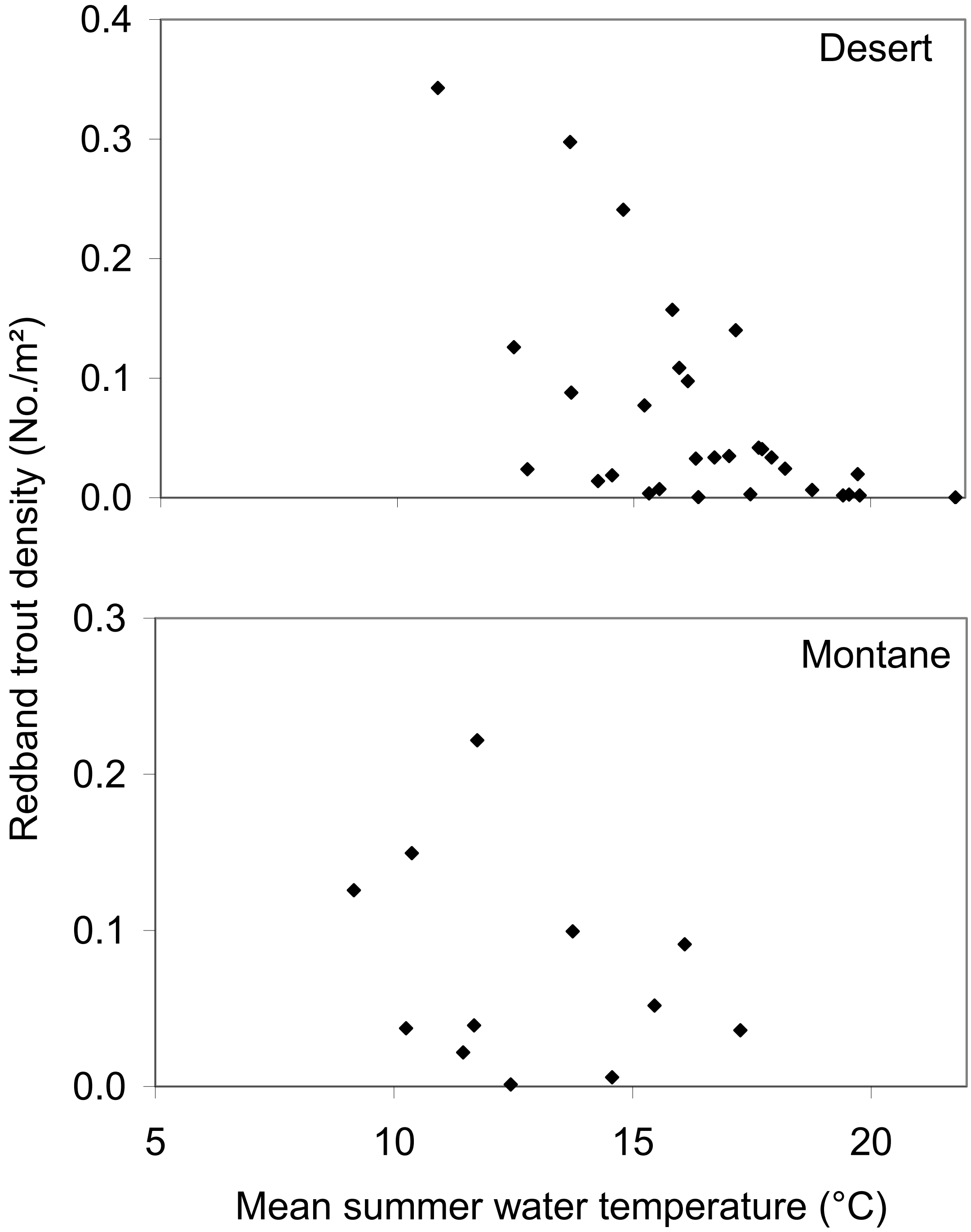

Figure 4. Scatterplot of mean summer (Jun-Aug) water temperature and redband trout density in desert and montane settings of southwestern Idaho.

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