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[Article]

Evaluating Redband Trout Habitat in Sagebrush Desert Basins in Southwestern Idaho

BRUCE W. ZOELLICK
U.S. Bureau of Land Management, 3948 Development Avenue, Boise, Idaho 83705, USA

BRIAN S. CADE
U.S. Geological Survey, Fort Collins Science Center, 2150 Centre Avenue, Building C, Fort Collins, Colorado 80526, USA

Abstract.—We estimated abundance quantiles of redband trout *Oncorhynchus mykiss gairdneri* relative to five site-specific habitat variables (stream shading, bank cover, bank stability, fine sediment in the stream substrate, and cover for adults) and one landscape variable (distance from stream headwaters) on 30 streams in southwestern Idaho during 1993–1998. In addition, the five site-specific habitat variables were used to calculate a habitat suitability rating (HSR) used by the U.S. Bureau of Land Management to determine habitat quality of sagebrush desert streams for redband trout. Variation in abundance increased significantly with increasing HSR; the highest abundances were only found with high HSRs, indicating that the HSR model correctly predicted habitat quality for redband trout. However, a model that consisted of stream shade, distance from stream headwaters, and their interaction best predicted redband trout density, explaining 36% of the variation in adult density in sagebrush desert basin streams; stream shade explained most of the variation in redband trout density. When habitat quality was modeled on shade alone, the precision in predicting adult redband trout density was similar to that of the HSR model, as evaluated with tolerance intervals that contained 80% of future observations of redband trout density with 95% confidence. Increasing stream shade in the uppermost 50 km of a stream would result in the greatest increase in redband trout density. We recommend that land managers primarily evaluate the habitat quality of sagebrush desert streams by quantifying the amount of stream shade provided by riparian shrubs and trees. Use of a multivariable habitat model should be retained for desert streams where shade from riparian plant communities is limited.

Most of the habitat for redband trout *Oncorhynchus mykiss gairdneri* in sagebrush desert basins in southwestern Idaho is located on lands managed by the U.S. Bureau of Land Management (BLM). About 70% of the Bruneau River watershed and 74% of the upper Owyhee River watershed are comprised of BLM-managed lands. Under the Federal Lands Policy Management Act of 1976, the BLM must manage public lands for multiple uses, including providing habitat for fish and wildlife species. Redband trout are considered a sensitive species by the BLM, and their habitats are managed to maintain and recover these populations. Objectives are often included in land use plans (LUPs) that direct the BLM to manage particular streams or basins for the benefit of listed fish (state species of special concern, BLM-designated sensitive species, or federally threatened or endangered species).

In the early 1980s, the BLM prepared LUPs that identified streams in the Snake River basin in southwestern Idaho where habitat improvements for redband trout were needed (USDI 1983). The BLM also developed a habitat evaluation system for use in determining whether habitat objectives were being met (USDI 1983). Six stream habitat variables were used to determine habitat quality for redband trout: stream shading, bank cover, bank stability, channel stability, amount of fine sediment in the stream substrate, and cover for adult redband trout. Numerical scores were assigned to each individual habitat parameter (Table 1) and were summed to provide a habitat suitability rating (HSR) of excellent, good, fair, or poor (USDI 1983).

Numerous habitat models have been developed that relate fish abundance to physical habitat conditions (Fausch et al. 1988). The BLM HSR system incorporates many of the habitat variables that have been found to be important factors limiting abundances of salmonid species, particularly rainbow trout *O. mykiss* (Raleigh et al. 1984). Additionally, habitat variables included in the model (Table 1) are all potentially impacted by livestock grazing, which is the primary land use authorized by the BLM on public lands in southwestern Idaho.

Recent ecological research has identified the importance of examining the landscape effects of flowing streams on fish abundance (Fausch et al. 2002). In sagebrush desert areas of the Columbia River basin,

* Corresponding author: bruce_zoellick@blm.gov

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TABLE 1.—Rating system used to evaluate redband trout habitat in streams managed by the U.S. Bureau of Land Management in sagebrush desert basins in southwestern Idaho. Numerical scores for each habitat parameter were summed to calculate the overall habitat rating (excellent = 22–24, good = 16–21, fair = 10–15, and poor = 6–9; USDI 1983).

Habitat variable	Condition rating (numerical score)			
	Excellent (4)	Good (3)	Fair (2)	Poor (1)
Stream shading	>80%	>60–80%	40–60%	<40%
Bank cover	No bare soil; stubble height >20 cm	<10% bare soil; stubble height >10 cm	<20% bare soil; stubble height <7.5 cm	>20% bare soil
Bank stability	<5% erosion	5–10% erosion	>10–20% erosion	>20% erosion
Channel stability[a]	≤1% channel movement	1–5% channel movement	6–10% channel movement	>10% channel movement
Fine sediment (<2 mm)	<10%	10–15%	>15–25%	>25%
Cover[b]	>50% of channel	>25–50%	10–25%	<10%

[a]Little lateral movement, bank erosion, scouring, and redeposition of channel materials.
[b]Pools (>45 cm deep), undercut streambanks, instream aquatic vegetation, instream rocks or boulders, woody debris, overhanging vegetation (within 30 cm of water surface), velocity breaks, and surface turbulence.

stream temperature increases with increasing distance from stream headwaters (Fausch et al. 2002). Stream temperature and abundance of redband trout at a given site along a stream are dependent on the extent of riparian canopy at and upstream of that site (Li et al. 1994; Tait et al. 1994; Zoellick 2004). Thus, while the abundance of redband trout at a local stream site is dependent on the quality of the physical habitat at that site, abundance is also affected by stream temperature increases related to the distance from stream headwaters and the extent of riparian canopy along that distance. Additionally, local stream temperature heterogeneity resulting from upwelling of groundwater can also alter fish distribution and abundance longitudinally along streams (Nielsen et al. 1994; Torgersen et al. 1999; Fausch et al. 2002; Ebersole et al. 2003).

Our first objective was to determine whether streams rated as excellent or good habitat under the BLM HSR system were providing higher-quality habitat and a greater abundance of redband trout. A second objective was to evaluate whether a subset of habitat variables in the BLM HSR could be used to more efficiently model and monitor habitat quality for redband trout in southwestern Idaho streams. Our third objective was to evaluate the landscape effect of distance from stream headwaters on redband trout abundance. We hypothesized that distance from stream headwaters would explain additional variation in the relationship between redband trout abundance and stream habitat characteristics by acting as a surrogate measure for increases in stream temperature with increasing distance from headwaters.

Study Area

We sampled 30 streams in the Owyhee River, Bruneau River, and Snake River basins in southwestern Idaho. Streams ranged in size from first- to sixth-order streams (Bruneau, Owyhee, and Jarbidge rivers) and included 15 Owyhee River tributaries, 4 tributaries to the Bruneau River, and 9 Snake River tributaries. Most streams were moderately confined by side valley slopes with stream gradients of 1.0–4.0% (B and C stream types: Rosgen 1994). Elevations of the stream basins ranged from 750 to 2,560 m, and the basins were predominantly vegetated with shrub-steppe communities that included big sagebrush *Artemesia tridentata*. Sites sampled at elevations less than 1,650 m were in big sagebrush–bunchgrass communities. Seven sites at 1,650–1,975-m elevations were in a mix of juniper *Juniperus occidentalis*, Douglas-fir *Pseudotsuga menziesii*, big sagebrush *Artemisia* spp., and bunchgrass communities (primarily Idaho Fescue *Festuca idahoensis* and bluebunch wheatgrass *Pseudoroegneria spicata*. Streamside vegetation was dominated by riparian shrubs, primarily willows *Salix* spp. In areas of historically heavy livestock grazing, streambanks were predominantly vegetated with Kentucky bluegrass *Poa pratensis*, creeping bentgrass *Agrostis stolonifera*, and forbs such as clovers *Trifolium* spp.

Methods

Sampling.—During 1993–1998, we evaluated redband trout density and biomass relative to habitat condition at 78 sites on 30 streams. To minimize differences resulting from seasonal population changes, sampling was conducted during base flow conditions in summer and early fall (i.e., mid-July to late October). All sites sampled were located in stream segments known to historically support populations of redband trout. Snake River tributaries (18 sites on 9 streams) and streams in the Owyhee River basin (29 sites on 16 streams) were randomly sampled during a reexamina-

tion of redband trout abundance in streams originally sampled in the late 1970s. Streams in the Bruneau River basin (31 sites on 5 streams) were sampled as part of evaluations of habitat condition relative to BLM-authorized livestock grazing of public land. We used topographic maps and National Wetland Inventory maps to stratify stream segments in the Bruneau River basin by gradient and composition of riparian plant communities. Each stream segment was 3–8 km long and was generally comprised of one stream type (Rosgen 1994). To quantify habitat condition and sample redband trout density and biomass, we selected a 61-m-long sample site that was representative of the stream segment.

At each site, we measured five of six habitat variables that were included in the HSR: percent stream shading, bank cover (percentage of bank that was vegetated), bank stability (percent stable bank), percent fine sediment in the stream substrate, and percent cover for adult redband trout. We did not include the sixth habitat variable (channel stability) in the HSR because at the scale of measurement in our study (61-m-long reaches), channel stability was approximately equal to our measure of bank stability. Each habitat parameter was assigned a numerical score of 1–4 (Table 1). We summed the five individual parameter scores to calculate an overall HSR. We used ArcView (ESRI 2003) to measure the length of stream (km) from the start of each sample site to the headwaters of the stream based on 7.5-min or 1:100-scale topographic map coverages.

We used a solar pathfinder (Platts and Nelson 1989; Li et al. 1994) to measure percent stream shading from riparian shrubs and topographic features at 10 points (spaced 6.1 m apart and situated at the center of the stream) per site. The height of the solar pathfinder above the stream surface was standardized at 0.3 m. We calculated the average percent shading for the 10 points per site and then calculated the average shading for each site for the months of June–September.

We measured percent bank cover by designating each 0.3 m of streambank (for both streambanks on the 61-m-long site) as vegetated or bare soil. The summed length of bank composed of bare soil was then divided by the total length of bank examined and the resulting number was multiplied by 100. We did not measure stubble height of herbaceous vegetation; therefore the habitat rating for bank cover (Table 1) was solely based on percent bare bank.

We calculated bank stability by assigning each 0.3 m of streambank to one of four categories: (1) vegetated (>50% of bank surface with vegetation) and stable, (2) unvegetated and stable (armored with rock or woody debris), (3) vegetated and unstable (bank that was breaking down or eroding or that had tension cracks, shearing, or slumping), and (4) unvegetated and unstable (IDEQ 1992). The two unstable categories were summed and divided by the total length of bank examined on the 61-m-long transect to determine the percentage of eroding bank.

The percentage of the stream substrate composed of fine sediment (<2 mm in diameter) was calculated either by use of the Wolman (1954) pebble count method (34 of 78 sites) or by ocular estimation of the percentage of each substrate size-class, similar to the method of Overton et al. (1997). For sites sampled by the pebble count method, 10 pebbles were sampled on each of 10 cross-sectional transects that were located 6.1 m apart, for a total of 100 pebbles per site.

Stream width was measured at sample sites on 10 cross-sectional transects located 6.1 m apart. Average stream width and transect length were multiplied to give the total area of stream sampled. We estimated percent cover for adult redband trout by determining the width of each cross-sectional transect that provided cover and then dividing by the total channel width for the 10 cross-sectional transects. We defined the following channel and vegetation features as providing cover: pools, runs, or glides (>45 cm deep), undercut streambanks, instream aquatic vegetation, instream rocks or boulders, woody debris, overhanging vegetation (within 30 cm of water surface), velocity breaks, and surface turbulence.

We used a backpack-mounted electrofisher to capture redband trout at each site. At least two electrofishing removal passes were made. Additional passes were made if necessary until the catch per pass declined by 50% or more between successive passes. We measured total lengths of all redband trout captured, and weighed the fish at most sites ($n = 60$). Redband trout that exceeded 100 mm in length were considered to be adults (≥1 year of age). Maximum likelihood estimates of abundance for all redband trout and adult redband trout and associated 95% confidence intervals (CIs) were estimated by use of the Zippin removal model (Zippin 1958). Capture probabilities estimated with the Zippin removal model averaged 74%. Removal estimators tend to overestimate capture probabilities (Peterson et al. 2004), and we cannot rule out the potential for negative bias in abundance estimates. We calculated redband trout density (number of adults per m^2) by dividing the maximum likelihood estimate of adult abundance by the area of stream sampled. For sites where fish were weighed, we also calculated redband trout biomass (g/m^2) by dividing biomass (of the maximum likelihood estimate of abundance for all redband trout) by the area of stream sampled.

Data analysis.—We used linear regression quantiles (Koenker and Bassett 1978, 1982) to estimate the relationships between adult redband trout density, habitat and landscape variables, and the HSR. Quantile regression was used because conventional analyses that estimate mean density can overlook or misrepresent the effects of habitat variables that limit fish abundance (Terrell et al. 1996; Dunham et al. 2002). Regression quantiles estimate rates of change in the dependent variable as a function of independent variables for all quantiles (τ; range = 0.0–1.0) of a distribution, rather than just estimating changes in means (Cade et al. 1999, 2005). This facilitates the examination of boundaries of fish–habitat relationships for upper or lower limits imposed by limiting factors (Terrell et al. 1996; Cade et al. 1999, 2005; Dunham et al. 2002). We estimated quantile regression models with Blossom (www.fort.usgs.gov/products/software/blossom.asp) and the Quantreg library of R (http://lib.stat.cmu.edu/R/CRAN). Models were selected based on quantile regression coefficients of determination (R^1) and a small-sample-adjusted Akaike's information criterion (AIC) modified for quantile regression estimates (Cade et al. 2005). Confidence intervals around slope and intercept parameters were estimated in R by inverting a quantile rank-score test for each value of τ (0.05, 0.10, 0.15, ..., 0.90, 0.95); weights were based on a local bandwidth of quantiles to adjust for heterogeneous error distributions (Koenker and Machado 1999; Cade et al. 2005). Conceptually, CIs and R^1 can be computed for estimates of all possible τ-values. However, CIs for the regression coefficients (intercepts and slopes) for values of τ equal to 0.05, 0.10, 0.15, ..., 0.90, and 0.95 were sufficient to characterize sampling variation for all quantiles and were plotted as a step function of coefficient estimates (ordinate) by τ (abscissa). We performed several supplementary analyses to examine how unequal sampling of within-stream variation might be affecting our estimates (see Appendix).

After selecting models, we estimated tolerance intervals (TIs) with 95% confidence on 80% of the population for selected values of independent variables. This was done by computing upper 95% CI endpoints for a τ-value of 0.90 and lower 95% CI endpoints for a τ-value of 0.10 for estimates of the intercept (b_0) after shifting the origin of the independent variable to the selected value by subtraction (Cade et al. 2005). We compared TIs of predicted redband trout density for the HSR model and models comprised of a reduced set of site-specific variables and the landscape variable (stream distance).

Results

Adult redband trout density had wedge-shaped patterns of variation relative to both individual habitat variables (Figure 1) and the HSR (Figure 2). Adult redband trout density increased with stream shading and decreased with distance from stream headwaters, percent bare bank, percent eroding bank, and percent fines in substrate (Figure 1). Both methods of sampling percent fines yielded a similar pattern of redband trout density response. Adult density decreased with increasing amounts of cover for most regression quantiles.

Variation in the density of adult redband trout increased with HSR (Figure 2). Sites with low HSRs consistently had low densities of redband trout. Rates of change in density were near zero for τ-values less than 0.20 and became increasingly positive with higher quantiles. Most regression slopes for τ-values over 0.50 differed from zero ($P < 0.05$). Although biomass was not measured for all sample sites, quantile regression estimates for the 60 sites where it was measured had a relationship to HSR similar to that of adult density.

Stream shading explained the greatest proportion of variation in redband trout density, as indicated by AICs and quantile regression R^1 values (Figure 3A). Distance from stream headwaters explained the second-largest proportion of variation in redband trout density, although the linear model is clearly a crude approximation of what appears to be a nonlinear relation (Figure 1). Of the four other habitat variables that made up the HSR, cover explained the next-greatest proportion of variation in redband trout density for τ-values less than 0.85. Percent fines in substrate, eroding streambank, and bare streambank explained a small proportion of the variation in redband trout density for τ-values greater than 0.80.

The density of adult redband trout and variance in the density increased with stream shading (Figures 1, 4). Sites with low levels of stream shade (<20%) had consistently low densities of redband trout. Rates of change in redband trout density increased successively with increasing τ (Figure 4). Slopes of regression τ-values differed from zero ($P < 0.05$) for the regression of redband trout density versus shade for all values of τ except 0.05 and 0.95. Among-stream variation and within-stream variation in the effect of stream shade on redband trout density were similar (Appendix). Addition of percent eroding streambank, fines in the substrate, and bare streambank did not improve estimates at any quantile based on hypothesis tests ($P > 0.10$), AIC, or increased R^1 values.

The multiple-regression model relating redband trout density to stream shade and cover explained a slightly

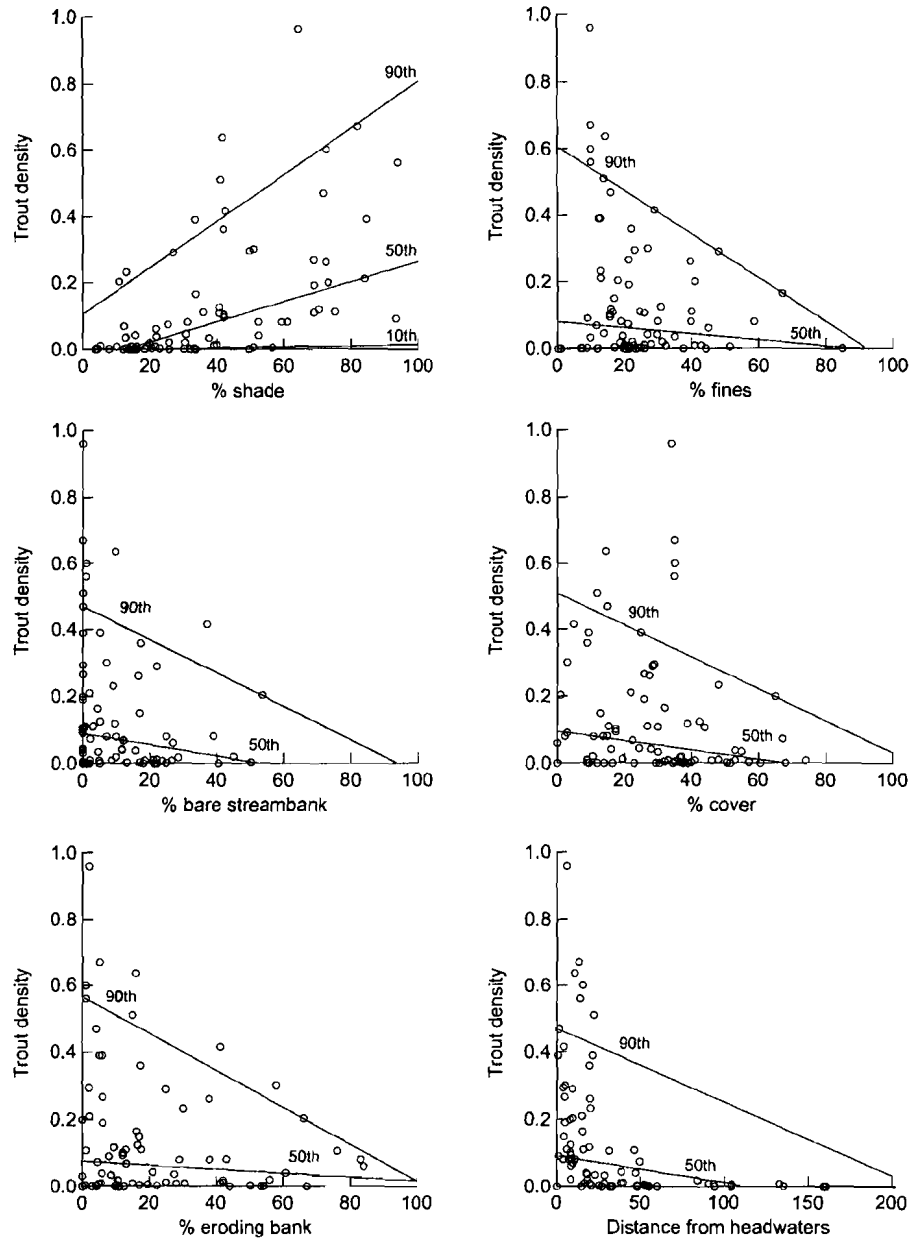

FIGURE 1.—Density of adult redband trout (fish/m^2) by site-specific habitat variables (percent stream shade, percent bare ground on streambank, percent eroding streambank, percent fines in substrate, and percent cover for adult redband trout) and an additional landscape variable of distance from stream headwaters for 78 sites on 30 streams in southwestern Idaho. The 0.10 (10th), 0.50 (50th), and 0.90 (90th) linear regression quantile estimates are plotted for each graph.

larger amount of variation in density than the single-parameter shade model for τ-values greater than 0.75 (Figure 3B). The primary effect of the addition of cover to the shade model was to slightly reduce the sampling variation in density estimates at the lowest and highest quantiles of the shade parameter. Redband trout abundance exhibited a weak negative relation to cover for upper quantiles and a zero effect at lower quantiles. The effect of cover on redband trout density barely differed from zero ($P = 0.05$) at higher values of τ (0.80–0.85).

An interaction model of shade and distance from

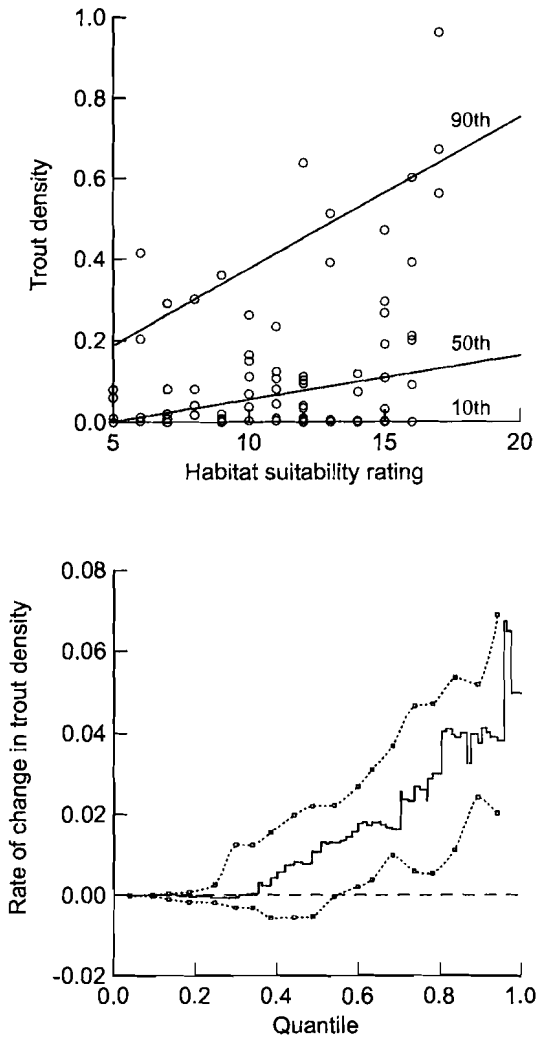

FIGURE 2.—The upper panel shows the density of adult redband trout (fish/m^2) relative to the habitat suitability rating and the 0.10 (10th), 0.50 (50th), and 0.90 (90th) linear regression quantile (τ) estimates for 78 sites on 30 streams in southwestern Idaho. In the lower panel, estimated rates of change (b_1) for the linear model for all τ-values (range = 0.0–1.0) are plotted as a step function (solid line); the dotted lines represent the 95% confidence interval formed by inverting the quantile rank-score test at τ-values of 0.05, 0.10, 0.15, . . ., 0.90, and 0.95.

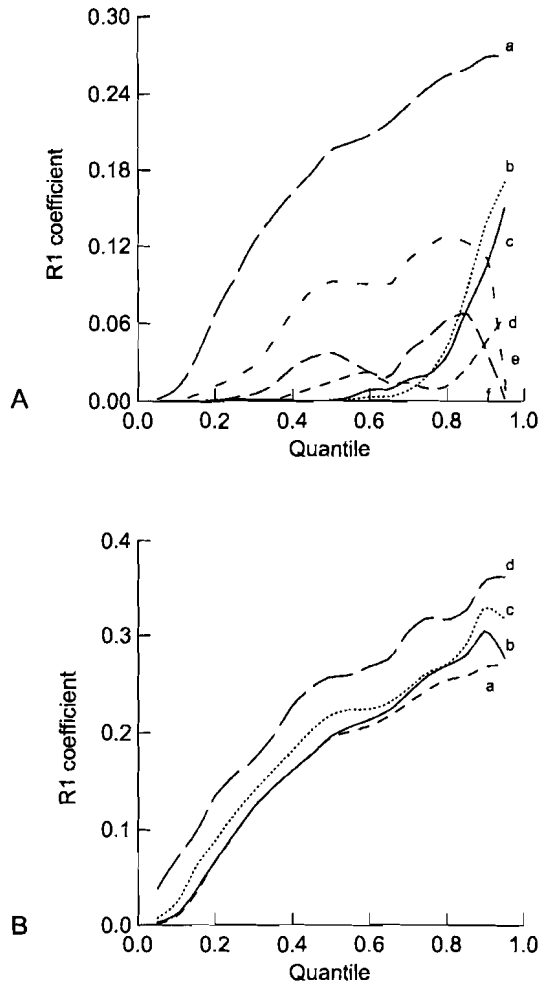

FIGURE 3.—Coefficients of determination (R^1) for linear regression quantiles (τ) where Y is the density of adult redband trout. In panel (**A**), the X_i values are (a) percent stream shade, (b) percent fines in substrate, (c) percent eroding streambank, (d) percent bare ground on bank, (e) distance from stream headwaters, and (f) percent cover for adult redband trout. In panel (**B**), the values of X_i are (a) stream shade, (b) stream shade and cover, (c) stream shade and distance from headwaters, and (d) stream shade, distance from headwaters, and stream shade × distance. The lines plotted are linear interpolations between adjacent R^1 values for τ-values of 0.05, 0.10, 0.15, . . ., 0.90, and 0.95 based on data from 78 sites sampled on 30 streams in southwestern Idaho.

headwaters (the landscape effect of increasing stream temperature with increasing distance) explained a significantly greater proportion of variation in redband trout density across all quantiles (an additional 5–10%) than did other multiple-regression models, as indicated by AIC and R^1 values (Figure 3B). Increases in redband trout density with stream shade were conditional on distance from stream headwaters (Figure 5). Within 50 km of stream headwaters, redband trout density increased with stream shading. At distances over 50 km from stream headwaters, stream shading had a lesser positive effect on density.

Rates of change in redband trout density with stream shading (b_1) for the shade and distance interaction model were near zero for τ-values less than 0.15 and

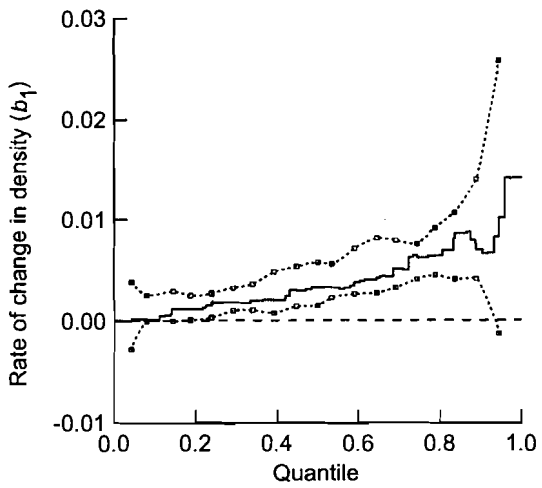

FIGURE 4.—Estimated rates of change in redband trout density with stream shade (b_1) for linear regression quantiles (τ) relating adult density and stream shade at 78 sites on 30 streams in southwestern Idaho. All τ-values (range = 0.0–1.0) are plotted as a step function (solid line); the dotted lines represent the 95% confidence interval formed by inverting the quantile rank-score test at τ-values of 0.05, 0.10, 0.15, . . ., 0.90, and 0.95.

increased successively with increasing values of τ (Figure 6). Slopes of regression quantiles differed from zero ($P < 0.05$) for the shade parameter (b_1) for all τ-values except 0.05 and 0.95. The effect of distance from stream headwaters (b_2) was not easily assessed by CIs on individual parameters of this interaction relation (b_2 and b_3). Rank-score hypothesis tests on the joint effect of the linear (b_2) and interaction (b_3) terms indicated a nonzero effect ($P < 0.05$) of the distance to stream headwaters for τ-values less than 0.85. Density was negatively related to the interaction between shade and distance to headwaters (b_3). Rates of change in density became increasingly negative for larger quantiles, and the effect of the interaction parameter differed from zero ($P < 0.05$) for most τ-values greater than 0.40. Variation within streams appeared to differ from the variation among streams in the effect of the interaction of stream shade and distance to headwaters on redband trout density (Appendix).

The 80% TIs of redband trout density were similar between the HSR model and the reduced-parameter model consisting of only stream shade. Upper endpoints of the TIs of redband trout density more than doubled with an increase in stream shading from 20% to 60% ($TI_{20\%}$ 0–0.42; $TI_{60\%}$ = 0–0.90), similar to the results obtained by increasing the HSR from 7.5 to 15.0 ($TI_{HSR=7.5}$ = 0–0.39; $TI_{HSR=15.0}$ = 0–0.92). The TIs for the interaction model of shade and distance from headwaters also approximately doubled as stream shade increased from 20% to 60%; TIs were similar to those for the shade model (distance = 0 km; Table 2). At 80% shading, the upper bound of the TI for the interaction model was about 0.2-fish/m^2 greater than that of the shade model and exceeded our maximum redband trout density (0.94 fish/m^2). The decrease in redband trout density with increasing distance from headwaters for the interaction model was small relative to the decrease in density with decreasing amounts of shade (Table 2).

Discussion

Redband trout density was best predicted by the interaction between stream shade and distance from stream headwaters; stream shade explained most of the variation in density. Increases in stream shade in the uppermost 50 km of a stream resulted in the greatest increase in redband trout density. The wedge-shaped distribution of redband trout density and corresponding quantile regression estimates were consistent with the idea that stream shade limited, but was not the sole determinant of, redband trout abundance (Terrell et al. 1996; Cade et al. 1999; Dunham et al. 2002). Redband trout abundance was always lower at low levels of shading, but abundance varied from low to high with increasing levels of stream shade. Density was not always greater at higher levels of stream shading because other ecological factors both within and outside of the sample site also determined redband trout abundance.

We hypothesize that stream shade explained the majority of the variation in density of redband trout largely because sagebrush desert streams shaded by mature riparian shrub and tree communities maintain suitable water temperatures for trout (Li et al. 1994; Tait et al. 1994; Zoellick 2004). Open-canopy streams in sagebrush deserts of the Columbia River basin are heated by insolation to temperatures of 26°C or greater, at which redband trout are rare to absent (Li et al. 1994; Zoellick 2004). Salmonid biomass in Great Basin streams is also limited by solar input into open-canopy streams (Platts and Nelson 1989). In particular, the distribution of Lahontan cutthroat trout *O. clarkii henshawii* in the eastern Lahontan Basin is delineated by large-scale elevation and climatic temperature gradients (Dunham et al. 1999). At the local scale of individual streams, Lahontan cutthroat trout occur most frequently in streams with temperatures less than 26°C (Dunham et al. 2003).

We believe that much of the unexplained variation in redband trout density in the shade and distance interaction model is the result of fish density's being lower than that predicted by the limiting effect of

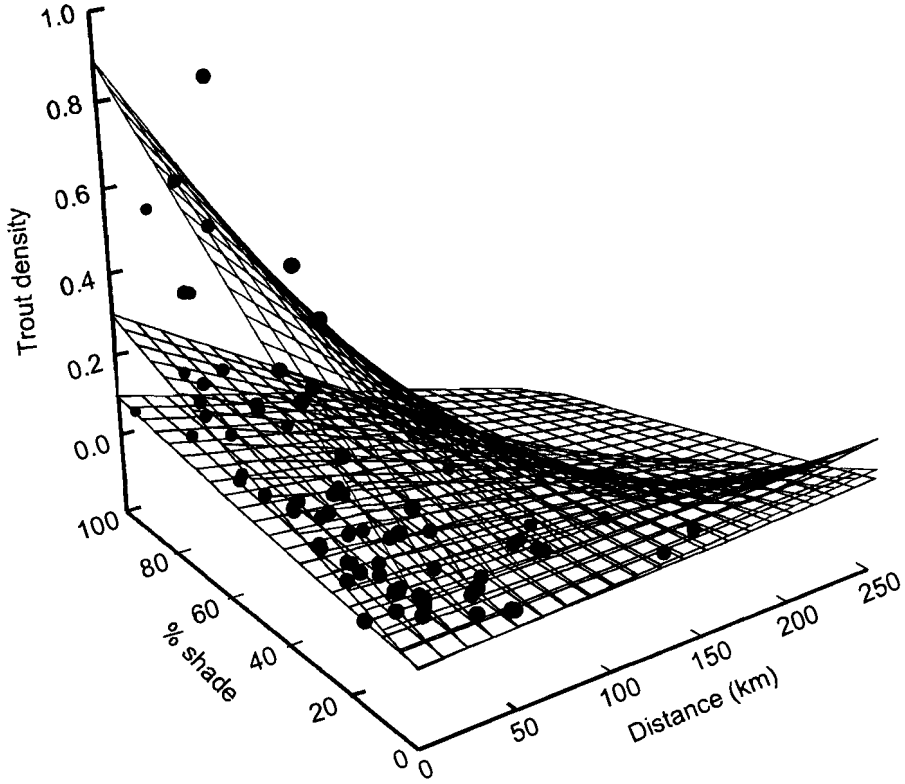

FIGURE 5.—Redband trout density (adults/m^2) relative to percent stream shade and distance from stream headwaters for 78 sites on 30 streams in sagebrush desert basins of southwestern Idaho. The response surfaces from top to bottom are the 0.90, 0.50, and 0.10 quantile regression estimates for a model that included percent shade, distance from headwaters, and the shade × distance interaction.

stream shade because of elevated stream temperatures. The amount of shade at a local site (61-m sample sites) will not always accurately reflect stream temperature and redband trout abundance. Extensive riparian canopy removal upstream of a local site can lead to warmer stream temperatures even though shade levels are high at the site (Li et al. 1994). Additionally, reaches with hyporheic upwelling or water exchanges with groundwater can provide coldwater habitat patches that cannot be predicted from the general increase in temperature with stream distance or from the amount of riparian canopy and shade in that stream reach (Torgersen et al. 1999; Fausch et al. 2002; Ebersole et al. 2003). Inclusion of stream distance and its interaction with shade in the quantile regression model partly incorporated the effect of stream temperature on redband trout density. Stream distance acted as a surrogate measure of stream temperature because stream temperature increases with linear stream distance in sagebrush desert streams (Ebersole et al. 2001; Fausch et al. 2002; Zoellick 2004).

Most shading of desert basin streams is provided by canopy cover of riparian shrubs and trees (Platts and Nelson 1989; Li et al. 1994; Zoellick 2004). Mature willows *Salix* spp., which are 5–8 m in height and width on desert streams in southwestern Idaho (Brunsfeld and Johnson 1985), also have a large volume of roots that stabilize streambanks and channels (Beeson and Doyle 1995), allowing the formation of complex habitat features such as high-quality pools and undercut banks (Micheli and Kirchner 2002). Well-vegetated streambanks also reduce erosion (Beeson and Doyle 1995; Micheli and Kirchner 2002), thereby minimizing the amount of fine-sediment deposition in stream substrates. Streams vegetated with riparian shrub communities in forests of ponderosa pine *Pinus ponderosa* in the interior Columbia River basin had more box-like cross sections, lower width–depth ratios, more pools, and more undercut banks (Liquori and Jackson 2001).

In addition to shade, cover was the other site-specific habitat variable that contributed significantly to the

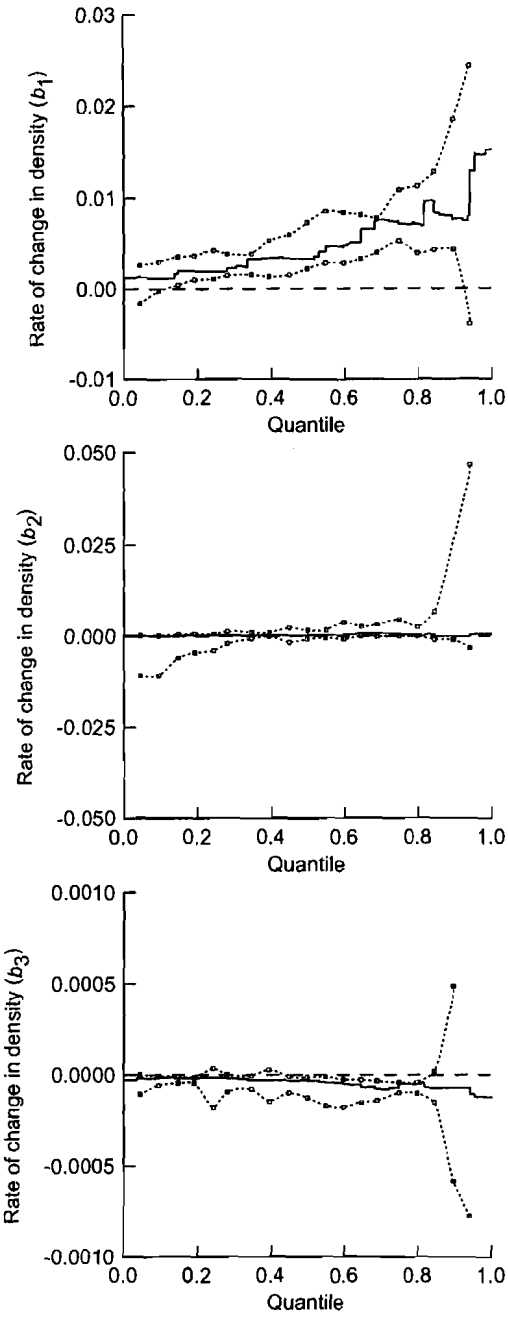

FIGURE 6.—Estimated rates of change in adult redband trout density with percent stream shade (b_1, upper panel), distance (km) from headwaters (b_2, middle panel), and the shade × distance interaction (b_3, lower panel) for the multiple linear regression quantile model where $Y = b_0 + b_1X_1 + b_2X_2 + b_3X_1X_2$. All quantiles ($\tau$; range = 0.0–1.0) are plotted as a step function (solid line); the dotted lines represent the 95% confidence interval formed by inverting the quantile rank-score test for τ-values of 0.05, 0.10, 0.15, . . ., 0.90, and 0.95 based on 78 sites on 30 streams in southwestern Idaho.

prediction of redband trout abundance. Redband trout density was weakly and negatively related to percent cover only for upper quantiles, and the primary contribution of cover to the shade model was a slight reduction of variation in density estimates for the lowest and highest quantiles of the shade parameter. Intuitively, redband trout density would be expected to increase with increasing amounts of cover, except perhaps for large amounts of cover provided by pools deeper than 45 cm. The habitat suitability information model for rainbow trout predicts that habitat suitability decreases as the percentage of pools increases from 65% to 100% (Raleigh et al. 1984). Our measure of cover included pools and areas of stream with depths greater than or equal to 0.45 m. The positive effect of cover was possibly captured by the shade parameter at low to moderate levels of cover, as riparian shrubs provide both stream shade and cover for fish. Levels of cover in excess of 60% were provided predominantly by pool and run habitats deeper than 45 cm. A decline in habitat suitability was associated with the predominance of deep areas rather than with other aspects in our broad definition of cover.

Our best explanatory habitat model (shade and distance from headwaters) explained 36% of the variation in redband trout abundance at 78 sites that were widely distributed across southwestern Idaho. Increasing sample size, particularly to increase the applicability of habitat models to broader geographic areas, decreases model precision (Fausch et al. 1988; Terrell et al. 1996). Recently published fish–habitat models with sample sizes corresponding to degrees of freedom less than 22 explained less than 60% of the variation in abundance of populations studied (Terrell et al. 1996). Model precision might be improved by relating redband trout abundance to stream temperature rather than to surrogate measures of temperature, such as stream shade and distance from headwaters. However, surrogates of elevated stream temperature may provide more guidance to managers for corrective measures to take to reduce water temperature. Indicators or surrogates for elevated temperature may not be limited to stream shade. For example, loss of wetlands and decreased groundwater input resulting from channel degradation also contribute to elevated stream temperature (Poole and Berman 2001).

Inclusion of additional variables, such as stream gradient and size, would probably explain additional variation in redband trout abundance (Muhlfeld et al. 2001). Other factors that may be contributing to some of the unexplained variation in redband trout density relative to habitat condition include temporal effects of drought or flood flows on density (Platts and Nelson 1988; Pearsons et al. 1992; Dunham et al. 1997),

TABLE 2.—Tolerance intervals (95% confidence intervals on central 80% of the population delineated by the 0.1 and 0.9 quantile regression estimates) for adult redband trout density (fish/m^2) in southwestern Idaho streams. Tolerance intervals were calculated with the interaction model of stream shade and distance from headwaters (Y = constant + b_1 [shade] + b_2 [distance] + b_3 [shade × distance].

Stream shading	Distance from stream headwaters (km)			
	0	5	10	25
20%	0.0–0.49	0.0–0.49	0.0–0.49	0.0–0.47
40%	0.003–0.65	0.002–0.62	0.001–0.60	0.006–0.56
60%	0.0–0.98	0.0–0.97	0.001–0.93	0.0–0.85
80%	0.004–1.41	0.004–1.34	0.0–1.22	0.001–1.11

connectivity to migratory habitats, and presence of nonnative fishes (Dunham et al. 2002). Introduced smallmouth bass *Micropterus dolomieu* were present in some streams that we sampled in the Owyhee River basin and probably affected redband trout abundance in those streams. Habitat availability and distribution of redband trout in desert basin streams can vary greatly from one year to another as a result of changes in streamflow related to the size of winter snowpacks. During greater streamflows, redband trout are distributed to lower elevations and over greater lengths of stream (Zoellick 1999).

The primary land use affecting riparian and aquatic habitats in southwestern Idaho sagebrush desert basins is livestock grazing (Hann et al. 1997). To be useful for analyzing land management alternatives, habitat models must include variables affected by management (Fausch et al. 1988). The BLM HSR and derivations of it include habitat parameters directly affected by livestock grazing practices: stream shade, bank stability, bank cover, and fish cover provided by streamside vegetation. Inclusion of additional habitat variables may increase model precision, yet such models may have limited management application if the added variables cannot be manipulated or improved through changes in land use management.

The reliability of the CIs that we estimated for regression quantiles of redband trout density for the various models considered here would be improved by having a better probability-based sample of stream reaches. Ideally, it would be desirable to have replication within each stream (e.g., stratified random sample) and to have the number of replicate reaches proportional to stream length. Because the formal probability linkage of our sample to the population of reaches within the 30 streams is weak, the intervals we computed must be interpreted and accepted with caution. Nevertheless, these CIs will be more useful than those associated with mean redband trout densities. Additionally, with improved sample design, quantile regression would provide additional insights into fish–habitat relationships (Dunham et al. 2002). Replication within each stream would allow us to examine redband trout density in relation to shade and distance from headwaters for individual drainages and to compare densities among drainages. Replication over time would allow the use of regression quantiles for examining temporal patterns in redband trout abundance relative to habitat characteristics, similar to work by Dunham et al. (2002).

Management Implications

A major limitation to habitat models that examine the mean response of fish populations to habitat variables is the assumption that fish populations are only limited by the set of habitat variables included in the model (Fausch et al. 1988). To attempt to address this assumption and increase the precision of habitat models (Fausch et al. 1988; Terrell et al. 1996), authors often recommend (1) limiting the geographic area of model usage and (2) repeated building of models for different geographic areas (e.g., McClendon and Rabeni 1987; Wesche et al. 1987). Use of quantile regression (Terrell et al. 1996; Cade et al. 1999, 2005; Dunham et al. 2002) to examine the limiting effects of habitat variables on redband trout density provided useful models for guiding management actions over a broad geographic area of southwestern Idaho without necessitating the development of site-specific least-squares regression habitat models for separate stream basins.

We recommend that land managers evaluate the habitat quality of southwestern Idaho streams for redband trout primarily by examining stream shade because density predictions (TIs) were similar for the shade and HSR models but the single-shade variable requires less time and labor to monitor. An advantage of the HSR model is that it provides guidance about which habitat features to manage for (e.g., bank stability and bank cover) on streams with soil types or channel confinement that limit the development of riparian shrub communities. For desert streams in which ecological factors limit the amount of shade from riparian canopy, we recommend retaining the use of a multiple-variable model like the HSR model to evaluate habitat quality.

We could not precisely predict changes in redband trout abundance with increases in stream shade, as indicated by the width of the TIs associated with models that included shade. Managers should not be surprised to see low densities of redband trout even when shade has been improved to levels that can support higher densities. The TIs were wide because

stream shade is not the only habitat variable limiting redband trout abundance. When shade was the active limiting factor (i.e., as modeled by the upper bound of the 80% TI), redband trout density approximately doubled from 0.42 to 0.90 fish/m^2 as shading increased from 20% to 60%. The TIs for the shade and distance interaction model at high levels of stream shading should be used with caution. Upper bounds of the TI at 80% stream shading were 0.2–0.45 fish/m^2 greater than our maximum redband trout density and that previously observed in Idaho (Schill 1991). Platts and McHenry (1988) reported density estimates greater than 1.0 fish/m^2 for portions of the western USA; however, these estimates probably included both juvenile (<100 mm in length) and adult redband trout. Upper bounds of TIs for the shade model appear to represent more realistic maximum densities.

The shade and stream distance interaction model provides management guidance regarding where to prioritize canopy restoration efforts. Restoration of riparian canopy within the first 50 km of stream headwaters would result in the greatest increase in redband trout abundance. Similarly, the greater the distance from stream headwaters, the greater the amount of stream shade is needed to obtain a similar increase in redband trout abundance. However, there may be important conservation reasons to improve habitat in middle to lower reaches of a stream or basin, such as to increase redband trout numbers in a population that maintains connectivity among several otherwise isolated headwater populations (Dunham et al. 1997; Thurow et al. 1997).

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Appendix Follows

Appendix: Influence of Within- and Among-Stream Variation for Models Relating Redband Trout Density to Stream Shade and Distance to Headwaters

Our sample of 78 stream reaches included variation within and among streams, but variation within streams was not reflected equally among the 30 streams, as 16 streams had only a single reach sampled and 14 streams had 2–16 reaches sampled. We performed several analyses to explore how this unequal within-stream variation might be affecting our estimates. First, we recomputed CIs for parameter estimates for the full data set ($n = 78$) by using reduced degrees of freedom for determining CI endpoints associated with 30 independent samples (df = 30 – p, where p = number of parameters) corresponding to streams. We then estimated parameters for the models by taking random samples of stream reaches ($n = 30$) with the constraint that each stream always occurred in the sample and every reach within a stream was included in a sample at least once. This resulted in 16 resamples with 30 replicated reaches, preserving among-stream variation but eliminating within-stream variation. The quantile regression models were estimated for each of the 16 random samples, and parameter estimates were graphed by quantile relative to the CIs computed based on the reduced degrees of freedom.

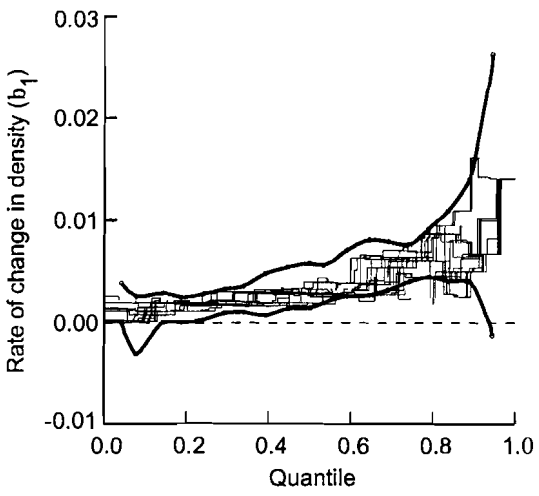

FIGURE A.1.—Estimated 95% confidence intervals based on reduced degrees of freedom (30 – 2) for rates of change in redband trout density with percent stream shade parameter estimates (thick solid lines; b_1) for the model with a sample size of 78 stream reaches for quantiles (τ) equal to 0.05, 0.10, 0.15, . . ., 0.90, and 0.95. The τ estimates for 16 random samples of 30 reaches are plotted as step functions (thin solid lines).

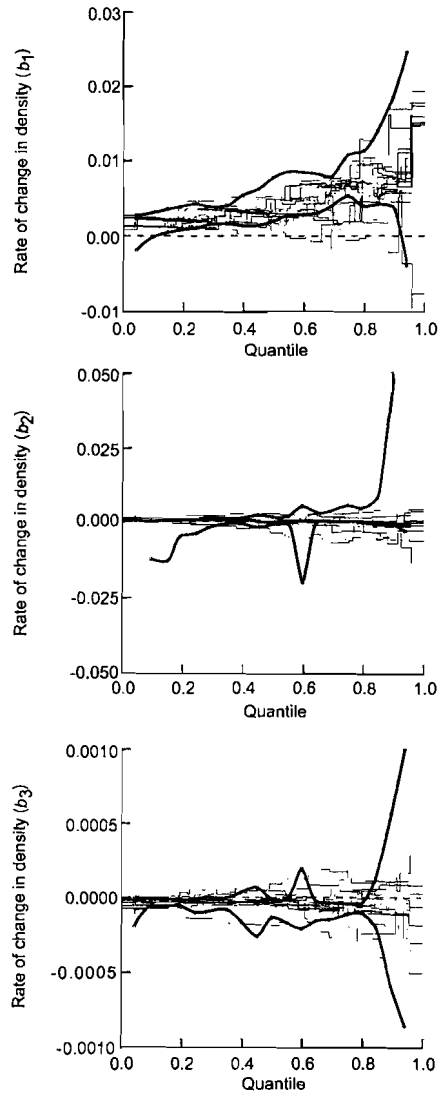

FIGURE A.2.—Estimated 95% confidence intervals based on reduced degrees of freedom (30–4) for rates of change in redband trout density with stream shade (b_1, upper panel), distance from headwaters (b_2, middle panel), and the shade × distance interaction (b_3, lower panel) parameter estimates (thick solid lines) for the model with a sample size of 78 stream reaches for quantiles (τ) equal to 0.05, 0.10, 0.15, . . ., 0.90, and 0.95. The τ estimates for 16 random samples of 30 reaches are plotted as step functions (thin solid lines).

For the model of density as a function of stream shade, 95% CIs based on reduced degrees of freedom (30 – 2) for the rate of change in density (b_1) increased 0–122% in length depending on quantile; most CIs increased by less than 2%. Estimates for the 16 random samples of

30 reaches were well contained within the 95% confidence band across quantiles (Figure A.1). This indicates that the CIs formed for the full sample of 78 reaches (Figure 6) were primarily reflecting among-stream variation, and the replicate samples within streams primarily improved precision of estimates because of larger sample size rather than adding substantially to variation.

For the model of density as a function of stream shade, distance from headwaters, and their interaction, 95% CIs based on reduced degrees of freedom (30 – 4) for the rate of change in density increased in length by 0.4–16% (most <2%) for stream shade (b_1), 1–113% (most <9%) for distance from headwaters (b_2), 1–96% (most <8%) for the shade × distance interaction (b_3), depending on quantile. Estimates for the 16 random samples of 30 replicated reaches were reasonably well contained within the 95% confidence band across quantiles for stream shade (b_1) but were slightly more variable for the distance to headwaters (b_2) and the interaction (b_3); however, estimates followed the trend indicated by the confidence bands (Figure A.2). This suggests that unequal contribution to within-stream variation in distance to headwaters may be biasing the estimated interval lengths for these two variables more than for stream shade.