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Proposed Standard Weight (W_s) Equations for Interior Cutthroat Trout

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Abstract.—We developed standard weight (W_s: length-specific standard weight for the species) equations for inland cutthroat trout *Oncorhynchus clarki* using the regression-line-percentile technique. Length and weight data from samples of 117 cutthroat trout populations (48 lentic and 69 lotic) over the interior range of the species were used. Separate W_s equations were developed for lentic and lotic populations, as well as an overall equation. Relative weight (W_r: individual weight/W_s) values did not change systematically with increasing fish length. No significant differences in mean W_r were found among subspecies of cutthroat trout. Differences between lotic and lentic populations suggested the need for two separate equations.

The cutthroat trout *Oncorhynchus clarki* attained the broadest distribution of any native trout species in North America. It is the only native trout in Colorado, Wyoming, Utah, and Alberta (Canada) and the dominant native trout species in Nevada, Idaho, and Montana (Behnke 1988). Thirteen interior and one coastal subspecies are generally recognized; of these, 2 subspecies are believed extinct, 10 have suffered catastrophic reductions throughout their historic range, and 2 have remained constant, neither replaced nor hybridized (Behnke 1992). Because of declining numbers, the future of native cutthroat trout populations is of concern to managers, and a reliable measure of body condition could be an important component in population assessments and management.

Condition indices are widely used to assess robustness or physiological well-being of fishes (Murphy et al. 1990; Brown and Murphy 1991; Piccolo et al. 1993). Fulton-type condition factors (K) were introduced by Lagler (1956); however, these indices have inherent length-related and species-related biases (Neumann and Murphy 1991; Willis et al. 1991). More recently, Wege and Anderson (1978) proposed that the relative weight (W_r) index avoids bias associated with increasing length and allows comparison among fish populations across the geographic range of a species. Relative weight is the ratio of a fish's weight to the standard weight (W_s), the length-specific weight predicted by a weight-length regression constructed to represent the species as a whole. Subsequently, W_r has been applied to assess condition in fish stocks when W_s equations are available for target species (Murphy et al. 1991; Willis et al. 1991; Piccolo et al. 1993). The first W_s equations were based on pooled weight–length data (Wege and Anderson 1978; Murphy et al. 1991) from Carlander (1977), but these did not provide a realistic standard because larger fish often had higher W_r values than smaller fish (Murphy et al. 1991). To avoid this problem, Murphy et al. (1990) proposed use of the regression-line-percentile (RLP) technique when developing W_s equations. The RLP technique formulates the 75th percentile W_s equation based on $\log_{10}$weight–$\log_{10}$length regression equations from each sample included in the analysis (Murphy et al. 1991).

While W_s equations have been developed for many warmwater and coolwater species (see Anderson and Neumann 1996), equation development for coldwater species is relatively recent. Presently, only inland chinook salmon *Oncorhynchus tshawytscha* (Halseth et al. 1990), lake trout *Salvelinus namaycush* (Piccolo et al. 1993), mountain whitefish *Prosopium williamsoni* (Rogers et al. 1996), and rainbow trout *O. mykiss* (Simpkins and Hubert 1996) have W_s equations that were developed with the RLP technique. Our objective was to use the RLP technique to develop a standard weight equation for inland cutthroat trout (excluding coastal cutthroat trout *O. c. clarki*) that considered sources of variation associated with differences between lentic and lotic populations and subspecies.

Methods

Cutthroat trout length and weight data were solicited from fisheries management agencies throughout the western United States for development of a standard weight equation following Murphy et al. (1990). Samples included seven in-

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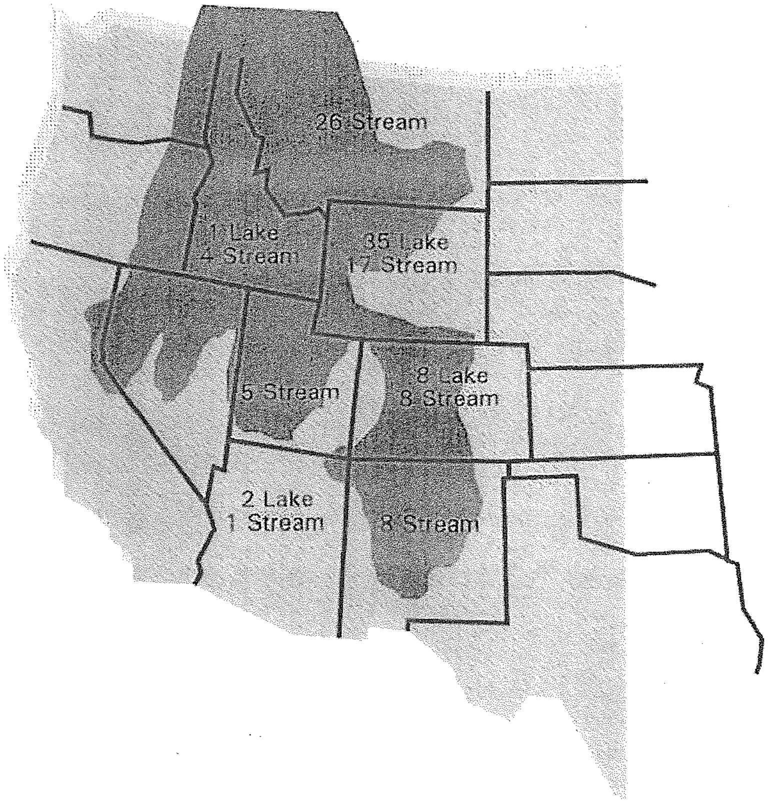

FIGURE 1.—Geographic locations from which cutthroat trout length and weight data were summarized to develop proposed standard weight equations. The number of lotic and lentic samples received from each state are noted. The estimated historic range of inland cutthroat trout is highlighted by the darker shading.

land cutthroat trout subspecies (Yellowstone *O. c. bouvieri*, westslope *O. c. lewisi*, Lahontan *O. c. henshawi*, Bonneville *O. c. utah*, Colorado River *O. c. pleuriticus*, greenback *O. c. stomias*, and Rio Grande *O. c. virginalis*) and their hybrids from both lakes and streams (Figure 1).

Total (TL), standard (SL), and fork length (FL) are three measures of fish length commonly used by management agencies (Anderson and Gutreuter 1983), and data were recorded in all three measures. However, we developed W_s equations using only measurements of total length. We calculated simple linear regression equations from a sample of 810 cutthroat trout from Wyoming for which all three length measurements were available to convert FL ($r = 0.996$, $P < 0.0005$) and SL ($r = 0.997$, $P < 0.0005$) measurements to TL (all measurements in millimeters):

$$\text{TL} = (\text{FL} + 1.850)/0.977;$$

$$\text{TL} = (\text{SL} + 3.340)/0.910.$$

Linear regressions of $\log_{10}$weight as a function of $\log_{10}$length were calculated for each sample. The variance : mean ratios for $\log_{10}$weight of the pooled data sets were plotted by length-groups to determine the minimum total length at which weights were sufficiently reliable to include in the analysis (Murphy et al. 1991). For each population, estimated weights were generated for fish 130–670 mm TL at 10-mm intervals with the back-transformed regression equation calculated for that population. The estimated 75th-percentile weight in each length increment was calculated and regressed against length to provide the parameters for the W_r equation. Standard weight equations were developed for lentic and lotic samples separately, and an overall W_s equation was developed from all samples combined.

To reduce potential bias to the W_s equations caused by unusual samples, we plotted weight–length relationships and eliminated outlying points to reduce influence on individual sample weight–length regressions. Additionally, we plotted predicted W_s for the two extreme length categories

(130 and 670 mm) and the two most outlying population samples in each length category were removed from equation development. Similar to Pope et al. (1995) and Fisher et al. (1996), population samples with extreme slope values were eliminated from the data set. Data sets with less than 10 individuals were removed from analysis.

The maximum length (670 mm) for inclusion in development of the W_s equation was based on the largest cutthroat trout in the 117 samples used to calculate the equations. Previous W_s equations (Brown and Murphy 1991; Neumann and Murphy 1991; Piccolo et al. 1993) have used the world record length, as recorded by the National Freshwater Fishing Hall of Fame, of the species as the maximum length. However, we felt the discrepancy between the largest cutthroat trout in our samples (670 mm) and the world record cutthroat trout (990 mm) was too large to extrapolate.

Length categories (stock, quality, preferred, memorable, and trophy) of cutthroat trout were established according to Gabelhouse (1984) by identifying the midpoint of the suggested length category and rounding down to the nearest 50-mm increment. Therefore, based on a 990-mm world record fish, the total length categories were: stock–quality (S–Q; 200–349 mm), quality–preferred (Q–P; 350–449 mm), preferred–memorable (P–M; 450–599 mm), memorable–trophy (M–T; 600–749 mm), and trophy ($\geq$750 mm).

To determine whether W_r values from the proposed W_s equations were independent of fish length, we regressed W_r values for individual fish in each sample on length and determined the number of significant correlations (positive or negative). The numbers of significant correlations were compared with chi-square analysis (Krebs 1989) to determine if the proportion of positive slopes was significantly greater or less than the proportion of negative slopes. Fish populations were stratified, and the mean W_r was calculated separately for lotic or lentic samples and among length categories with all three W_s equations. Mean W_r was compared among length categories, disregarding sample location, with a one-way analysis of variance (Hubert and Gibson 1994). Individual sample *t*-tests were used to evaluate differences between lotic and lentic populations within length categories (Krebs 1989).

Analysis of covariance (ANCOVA; Tripple and Hubert 1990), with lotic and lentic samples as treatments and length as a covariate, was used to test whether the separate lotic and lentic equations produced distinctly different W_s values. Additionally, 95% confidence intervals were calculated for predicted W_s values for fish 130–670 mm from both individual equations (lotic and lentic). The confidence levels were compared to determine if predicted values were significantly different (i.e., nonoverlapping).

To assess the influence of the proportion of lotic to lentic samples on an overall (containing both lotic and lentic samples) W_s equation, we developed five W_s equations with a subset of 50 randomly chosen lotic populations and differing numbers of lentic populations (N = 5, 12, 24, 36, and 43) randomly selected from all populations available. Equation parameters from these five overall equations were compared with the slope and intercept of the overall equation developed with all of the samples from lotic and lentic populations.

Subspecies differences among habitat types were determined with a two-way analysis of variance (Krebs 1989). Differences in mean W_r between lentic and lotic samples of the same and different subspecies were assessed to determine whether genetic (evolutionary) differences or habitat type (lotic or lentic) was a more probable explanation for significant differences in mean W_r. All statistical analyses were performed with SPSS/PC+ (SPSS 1991). Significance was determined at $P \leq 0.05$ for all tests.

Results

Weight–length regressions were developed for 117 separate samples (N = 18,599 cutthroat trout) from seven states (Figure 1). Only 7 of the 117 regressions models had correlation coefficients less than 0.9. The inflection point where the variance : mean ratio for $\log_{10}$weight stabilized was 130 mm (Figure 2). Therefore, only cutthroat trout 130 mm or longer were used in W_s equation development (Murphy et al. 1991).

Regression-line-percentile analysis yielded the following proposed standard weight equations.

Overall (N = 117),

$$\log_{10} W_s = -5.139 + 3.072 \log_{10}\text{TL}.$$

Lotic (N = 69),

$$\log_{10} W_s = -5.189 + 3.099 \log_{10}\text{TL}.$$

Lentic (N = 48),

$$\log_{10} W_s = -5.192 + 3.086 \log_{10}\text{TL}.$$

In these equations, N is the number of populations, W_s is weight in grams, and TL is total length in millimeters.

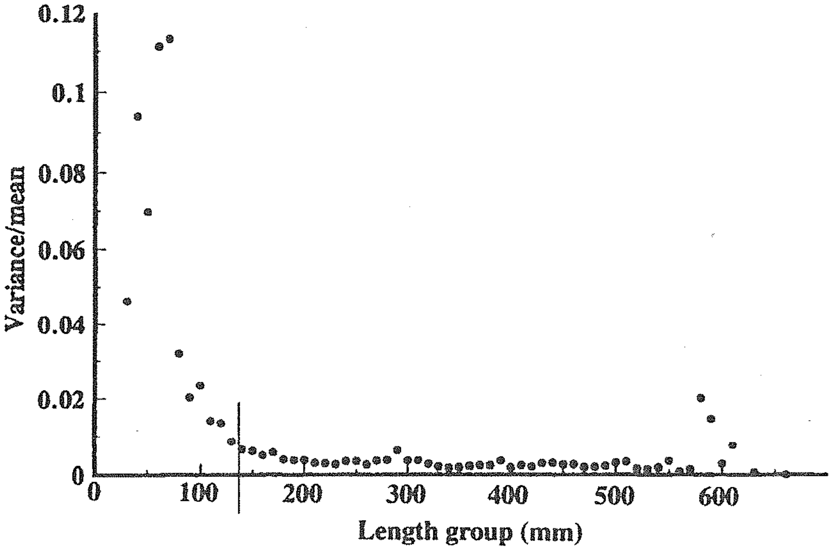

FIGURE 2.—Variance : mean ratio for $\log_{10}$weight by 10-mm length-group for cutthroat trout. The vertical line represents the minimum applicable length of fish for use in the standard weight equations for cutthroat trout.

TABLE 1.—Mean relative weights (W_r) among five length categories of cutthroat trout from 117 samples. The grand mean is an average of sample means. Length categories are abbreviated as follows: stock to quality (S–Q), quality to preferred (Q–P), preferred to memorable (P–M), and memorable to trophy (M–T). Each category (overall, lotic, lentic) is based on its respective equation.

Length category	Number of population samples with fish in the category	Mean W_r		
		Grand mean	Range	SD
		Overall equation		
S–Q	113	93	67–120	10.4
Q–P	44	91	73–106	8.4
P–M	21	91	77–108	8.9
M–T	1	91	91–91	
All	117	92	67–120	9.8
		Lotic equation		
S–Q	66	93	65–116	11.2
Q–P	14	91	71–101	7.0
P–M	7	86	74–103	9.7
M–T	1	86	86–86	
All	69	92	65–116	10.6
		Lentic equation		
S–Q	47	93	74–119	7.7
Q–P	30	93	76–110	8.7
P–M	14	95	79–112	8.7
M–T	0			
All	48	93	74–119	8.1

The English-unit equations, where W_s is in pounds, and TL is in inches, were also developed.

Overall,

$$\log_{10} W_s = -3.480 + 3.072 \log_{10}\text{TL}.$$

Lotic,

$$\log_{10} W_s = -3.492 + 3.099 \log_{10}\text{TL}.$$

Lentic,

$$\log_{10} W_s = -3.514 + 3.086 \log_{10}\text{TL}.$$

With all three proposed standard weight equations, W_r of individual cutthroat trout was calculated and regressed on total length for each sample. The number of positively and negatively correlated slopes was not significantly different for any of the three W_s equations. For example, with the overall equation, significant correlations of TL with W_r were found for 41 of the 117 sampled populations; 14 of the significant correlations were positive and 27 were negative ($\chi^2 = 4.1$, $P = 0.142$).

The range of means, grand mean, and number of samples with fish in each length category, for lotic and lentic populations (separately and in combination) are presented in Tables 1 and 2. No significant difference in grand mean W_r averaged across length categories was observed for any of the three W_s equations individually (Table 1). Mean W_r values for cutthroat trout from streams were significantly higher than those from lakes for the S–Q and Q–P length categories when calcu-

TABLE 2.—Comparison of mean relative weights (W_r; sample grand mean) between lotic and lentic cutthroat trout samples for individual length categories. Length categories are abbreviated as follows: stock to quality (S–Q), quality to preferred (Q–P), and preferred to memorable (P–M).

Length category	Sample	Number of samples	Mean W_r	SD	P
		Overall equation			
S–Q	Lotic	66	95.5	11.58	
	Lentic	47	89.3	7.26	0.001
Q–P	Lotic	14	95.3	7.23	
	Lentic	30	89.2	8.36	0.023
P–M	Lotic	7	89.0	10.14	
	Lentic	14	92.0	8.34	0.487
Overall	Lotic	69	94.9	10.88	
	Lentic	48	89.7	7.79	<0.001
		Separate equations			
S–Q	Lotic	66	92.5	11.16	
	Lentic	47	93.0	7.65	0.787
Q–P	Lotic	14	91.1	6.95	
	Lentic	30	92.7	8.66	0.546
P–M	Lotic	7	84.6	9.70	
	Lentic	14	95.3	8.70	0.019
Overall	Lotic	69	91.6	10.57	
	Lentic	48	93.2	8.11	0.234

lated with the overall W_s equation (Table 2); however, when separate equations were used for the lotic and lentic samples, cutthroat trout from lakes and streams had similar mean W_r values in the two length categories. Lotic and lentic samples were not significantly different within the P–M length category with the overall equation. Only one sample contained memorable-length fish, and none had trophy-length cutthroat trout; thus these results are not reported. Overall, cutthroat trout from lakes had significantly lower W_r values than those from streams when the overall equation was used to calculate relative weights, but no overall difference was apparent when separate W_s equations were used (Table 2).

The analysis of covariance showed that lotic and lentic equations were significantly ($P < 0.0001$) different. No overlap in confidence intervals calculated around predicted W_s values for fish from 130 to 670 mm was seen. For example, confidence intervals for 130-mm cutthroat trout was 22.9–23.2 g among lotic populations and 21.0–21.9 g among lentic populations. Similarly, 670-mm cutthroat trout had confidence intervals of 3,697–3,723 g among lotic populations and 3,326–3,419 among lentic populations. These results indicate that W_s equations for lotic and lentic populations were distinctly different.

Varying the proportion of lentic samples in an overall equation (with a constant proportion of 50 randomly chosen lotic samples) resulted in significantly different ($P \leq 0.05$) equation parameters. The form of the overall equation was a function of the proportion of lotic to lentic samples used to develop the equation and varied from parameters that were near those of the lotic equation when 9% (5 of 55) of the samples were lentic to closer to those of the lentic equation when 46% (43 of 93) of the samples were lentic.

Analysis of variance indicated no consistent differences in mean W_r between subspecies but significant differences between fish from lotic and lentic habitats. With the overall equation, Colorado River cutthroat trout (mean W_r = 91.4) and Yellowstone cutthroat trout from the Snake River drainage in Wyoming (mean W_r = 91.4) had similar W_r values. However, two-way analysis of variance showed a significant difference between samples from lotic and lentic populations ($P < 0.0001$) but no significant difference between the two subspecies and no interaction. Yellowstone cutthroat trout from lakes (mean W_r = 92.1) and those from streams (mean W_r = 89.2) showed a significant difference ($P < 0.0001$) in mean W_r as did Colorado River cutthroat trout ($P = 0.019$) from lakes (mean W_r = 93.4) and streams (mean W_r = 90.6).

Discussion

None of the three W_s equations showed a consistent relationship to fish length. These results suggest that there is not a consistent change in W_r with increasing cutthroat trout length, supporting the use of the RLP technique. Standard weight equations that have been developed with techniques other than the RLP method have produced length-biased W_r values (Neumann and Murphy 1991).

Differences in mean W_r between lotic and lentic fish populations have been found for other species such as burbot *Lota lota* (Fisher et al. 1996), spotted bass *Micropterus punctulatus* (Wiens et al. 1996), and rainbow trout (Simpkins and Hubert 1996). Fisher et al. (1996) and Wiens et al. (1996) elected to present a single W_s equation with different mean target ranges for lotic and lentic populations; however, Simpkins and Hubert (1996) proposed dual W_s equations to address differences found between lotic and lentic rainbow trout populations.

We propose that separate equations for lotic and lentic cutthroat trout should be used. The two equations were shown to be significantly different when ANCOVA was applied and the 95% confidence intervals did not overlap through the target range of 130–670 mm. The lentic equation predicted lower W_s values (higher W_r values) than the lotic equation for fish of similar length and weight. This difference suggests that fish of a given length should weigh more in the lotic environment than in lentic habitats. We expected cutthroat trout in lakes to show higher body condition, paralleling faster growth rates among lentic populations (Varley and Gresswell 1988; Young 1995) because of a more energetically benign environment. Several explanations are plausible for this difference, including evolutionary or body form differences between fish in the two habitats. Cutthroat trout evolved predominately in coldwater lotic environments and may be more suited to this environment.

We considered the application of one equation with two target ranges, but the lotic and lentic W_s equations were not parallel. Therefore, the difference in mean W_r was different for each length category. For example, the lentic equation produced standard weights that were 7.5 and 10% lower at 130 and 670 mm, respectively. Depending on the application, this 2.5% difference may or may not be important.

Springer et al. (1990) and Murphy and Willis (1992) suggested multiple W_s equations may lead to confusion and misapplication when used in fisheries management. However, we believe that the discrepancy in mean W_r between lotic and lentic populations predicted by an overall equation will likely lead to misunderstanding and miscommunication among fishery professionals applying W_r to cutthroat trout. The difference in body shape between lotic and lentic populations and the simplicity when interpreting results from separate W_s equations for lotic and lentic populations warrants the use of two W_s equations.

Due to potential genetic and evolutionary differences between subspecies, it is possible that pooling weight–length data across subspecies may mask natural diversity in body form among the subspecies. However, we found no consistent differences in mean W_r between two cutthroat trout subspecies for which we had adequate samples from both lotic and lentic populations within a similar region (state of Wyoming) to make an assessment. Colorado River cutthroat trout and Yellowstone cutthroat trout, two of the subspecies with a wide evolutionary divergence (Behnke 1992), showed little difference in mean W_r between subspecies, but large differences between lotic and lentic habitats. Whereas these data do not conclusively eliminate the effect of genetic differences between subspecies, they indicate that habitat differences are an overriding factor leading to differences in W_r between lotic and lentic populations.

The differences shown between samples from lotic and lentic populations of cutthroat trout, as well as those shown in other species (Fisher et al. 1996; Simpkins et al. 1996; Wiens et al. 1996), leads to concerns regarding previously developed standard weight equations. We feel that all newly proposed standard weight equations should include inquiry into differences in body form between lotic and lentic populations. Checks of current standard weight equations may also be warranted.

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