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ARTICLE

Proposed Standard Weight (W_s) Equation and Length Categories for Utah Chub

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Abstract
Condition indices, such as relative weight (W_r), provide a simple method for comparing length–weight relationships among populations. However, no standard weight (W_s) equation has been developed for Utah Chub *Gila atraria*, a species of important management focus in the Intermountain West. We obtained length–weight data for 30,541 Utah Chub from 24 populations in Idaho, Montana, Utah, and Wyoming. We used the regression line percentile (RLP), linear empirical percentile (EmP), and quadratic EmP methods to develop average (50th percentile) and above average (75th percentile) W_s equations. Additionally, Froese's method was used to develop another W_s equation for Utah Chub. Length-related biases were detected in W_s equations developed using the RLP, 50th percentile quadratic EmP, and Froese methods. The linear EmP W_s equations did not exhibit length-related biases for the 50th and 75th percentiles. We propose using the 75th percentile linear EmP W_s equation for Utah Chub between 90 and 410 mm TL. The EmP 75th percentile equation was $\log_{10}(W_s) = -4.938 + 3.031 \cdot \log_{10}(\text{TL})$, where W_s is weight in grams and TL is in millimeters. The English equivalent of this equation is $\log_{10}(W_s) = -3.335 + 3.031 \cdot \log_{10}(\text{TL})$, where W_s is weight in pounds and TL is in inches for 4–16-in Utah Chub. Additionally, we propose that minimum TLs of 100 mm (4 in; stock), 200 mm (8 in; quality), 250 mm (10 in; preferred), 300 mm (12 in; memorable), and 380 mm (15 in; trophy) be used to calculate proportional size distribution (PSD) indices. Better understanding Utah Chub populations using W_r and PSDs will aid managers in assessing management strategies (e.g., biological controls) focused on Utah Chub.

Utah Chub *Gila atraria* is a nongame cyprinid species native to the Snake River and Lake Bonneville basins. Its distribution has expanded to other waters in the western United States through intentional and unintentional releases (e.g., bait fish introductions; Sigler and Sigler 1987; Rahel 2004). In systems where it is nonnative, it has

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the ability to expand its population quickly once established (Page and Burr 1991; Winters et al. 2017). Typically, Utah Chub are found in lentic systems, where they often compete with salmonids for prey resources (Teuscher and Luecke 1996; Winters and Budy 2015). Utah Chub is a particularly good competitor with salmonids in unnatural or disturbed systems, such as reservoirs (Johnson and Belk 2007). In systems with high Utah Chub densities, salmonid growth, abundance, and survival often decrease (Schneidervin and Hubert 1987; Teuscher and Luecke 1996; Winters and Budy 2015; Winters et al. 2017). A better understanding of the ecology of Utah Chub will aid fishery managers in monitoring trends in Utah Chub populations and in evaluating management actions (e.g., Ward et al. 2008; Roth et al. 2020).

Fisheries assessment tools were originally developed for sport fish populations (Gabelhouse 1984), but the same indices are being applied to nongame species with the goal of providing insight on their population dynamics (Bister et al. 2000; Didenko et al. 2004; Ogle and Winfield 2009). Condition indices provide a simple measure of comparing length–weight relationships among populations and provide insight on the body condition of fish (Brown and Murphy 1991). A commonly used index to assess the condition of fish is relative weight (W_r; Wege and Anderson 1978; Neumann et al. 2012). To calculate W_r, a standard weight (W_s) equation must be developed for the particular species. Once a W_s equation is available, W_r is calculated as

$$W_r = (W/W_s) \times 100,$$

where W is the weight of the fish and W_s is the standard weight for a fish of the same length (Wege and Anderson 1978). Standard weight equations are estimated using various techniques, particularly the regression line percentile (RLP) and empirical percentile (EmP) methods (Murphy et al. 1990; Gerow et al. 2005). The RLP has been the most widely used method for developing W_s equations and uses the 75th percentile of the mean weights estimated among populations as the basis for the W_s equation (Murphy et al. 1990). However, Gerow et al. (2005) found that length-related biases can occur with the development of W_s equations using the RLP method and suggested that the EmP method may be a more appropriate alternative. The EmP technique is based on the 75th percentile of the observed weights by 10-mm length increments as opposed to the RLP technique, which uses weights estimated from regression models. Selection of the most appropriate method (i.e., RLP versus EmP) for development of the W_s equation has not entirely been resolved (Gerow 2010; Ranney et al. 2010). Another option for developing a W_s equation is the method proposed by Froese (2006). Froese's method uses the geometric mean and mean produced from all available weight–length estimates to represent the mean weight for the focal species.

The objective of this study was to develop a W_s equation for Utah Chub based on the RLP, EmP, and Froese methods and to establish minimum TLs that can be used to estimate length structure following the five-cell system described by Gabelhouse (1984). This information will provide managers with the necessary tools to effectively monitor Utah Chub populations.

METHODS

Data summarization and standard weight equation.— Length–weight data for Utah Chub were acquired from state, federal, and university biologists across the known geographic distribution of Utah Chub. Personnel providing data were asked to include the TL, weight, sex, date sampled, and sampling gear used. Data sets were screened and evaluated prior to analysis. First, data collected during June were excluded to minimize length–weight discrepancies associated with the development of mature gonads and spawning (Graham 1961; Ogle and Winfield 2009). Next, outliers were removed by plotting Utah Chub $\log_{10}$(TL) against $\log_{10}$(weight) across years for each water body (Bister et al. 2000; Ogle and Winfield 2009). Individual fish that exceeded the 99% prediction interval from each water body were considered outliers and removed from the data set (Bister et al. 2000; Ogle and Winfield 2009). Utah Chub that were one of a few individuals (i.e., three or less) that were substantially shorter or longer than the majority of individuals in the data set were also considered outliers and removed from the analysis (Ogle and Winfield 2009). This resulted in 0.25% of the total number of individuals being removed and had no effect on the number or composition of length categories used in subsequent analyses. After removing outliers, water bodies with less than 20 fish were removed from the data set. Furthermore, water bodies with a log-transformed length–weight regression with a coefficient of determination less than 0.90 or with a slope (b) beyond 2.5–3.5 were removed from the analysis (Ogle and Winfield 2009). We further analyzed the estimated intercepts ($\log_{10}[a]$) regressed against the estimated slopes for each water body to evaluate any divergent patterns among populations. No additional data were excluded from analysis.

The data were then randomly separated into "developmental" and "validation" data sets. The developmental data set was used to compute the W_s equation, whereas the validation data set was used to evaluate the proposed W_s equation and examine any length-related bias (Gerow et al. 2005; Ogle and Winfield 2009). The developmental data set contained 18,130 individuals representing 24 populations. Populations assigned to the developmental data set had 1–9 years of data and varied from 24 to 7,709 individuals (Table 1). Populations assigned to the validation data set had large samples (≥500 fish) and at least 2 years of data. These criteria were used to identify populations that were large enough to be further partitioned into the developmental or validation data sets. Nine of the 24 populations met these criteria. Years within populations were randomly assigned to either the developmental or validation data set. Consecutive years placed in a data set were avoided while still assigning a large proportion to the developmental data set (Ogle and Winfield 2009). For example, Blackfoot Reservoir, Idaho, contained 3 years of data and 500 fish. Therefore, Blackfoot Reservoir met the requirements for inclusion in the validation data set. Three-hundred eighty-three Utah Chub were sampled in 2009 and 2012 from Blackfoot Reservoir; years were combined and included in the developmental data set. The remaining year was assigned to the validation data set (Table 1). At the end of this process, the validation data set contained 12,280 individuals representing nine populations. Populations assigned to the validation data set had 1–8 years of data and varied from 117 to 5,733 individuals (Table 1). Hereafter, "population" refers to the combined population-years of a water body. For example, data from 2009 and 2012 in Blackfoot Reservoir were combined to represent a single "population" in the developmental data set. Differences in mean slope and mean intercept values between the developmental and validation data sets were tested using a two-sample *t*-test (Ogle and Winfield 2009). The number of populations required for a robust W_s equation from the developmental data set was estimated using a bootstrap technique (Brown and Murphy 1996). Specifically, slopes from $\log_{10}$(TL) against $\log_{10}$(weight) regressions (by population) were used as modeling parameters and were randomly selected with replacement for 300 iterations. Sample variance of the slope was calculated for each incremental sample size ($n = 2$–24 populations). A sample variance of less than 0.002 was selected as the decision criterion for the minimum number of populations required for the W_s equation (Brown and Murphy 1996).

Following the compilation of the data sets, an estimate of a suitable length distribution was developed prior to the derivation of W_s equations, given that measurements from small fish tend to have low precision and accuracy (Rypel and Richter 2008; Neumann et al. 2012). The minimum and maximum TLs were established using the developmental data set. Minimum TL was established for the RLP method by plotting the variance-to-mean ratio for $\log_{10}$(weight) by 10-mm intervals and described when the ratio fell below 0.01 (Murphy et al. 1990; Figure 1). Maximum TL was established for the EmP method when at least three populations contained the largest size-class (Gerow et al. 2005; Table 2).

Standard weight equations were estimated using the RLP, EmP, and Froese methods (Murphy et al. 1990; Gerow et al. 2005; Froese 2006). For RLP and EmP methods, the 50th (W_{s50}) and 75th (W_{s75}) percentiles were estimated using the mean of the predicted weights in each 10-mm length interval from individual populations produced from the weight–length relationships (Brown and Murphy 1996). Using quadratic regression, the third quartile of mean weight by TL was used to develop the W_s equation (Gerow et al. 2005). Froese's method ($W_{s\text{mean}}$) was assessed by calculating mean intercept and mean slope from length–weight regressions for each population in the developmental data set (Froese 2006).

Length-related biases of the W_s equations were assessed using the residual analysis, Willis method (Willis et al. 1991), and empirical quartiles (EmpQ) method (Gerow et al. 2004). For the residual analysis, residuals of the W_s equation were visually examined for evident patterns. The Willis method used a chi-square test to identify whether the proportion of populations with a significant positive slope (i.e., TL versus W_r using the validation data) was equal to the proportion with a significant negative slope. To assess the length-related bias of the quadratic EmP equations, the EmpQ method used the validation data set to evaluate whether the slope of the third quartile of the mean weight (standardized by W_s midpoint length intervals of 10 mm) was zero. We used the Fisheries Stock Assessment package (version 0.0-14; Ogle 2009) using R software (version 4.0.3; R Core Team 2020) for all analyses.

Length categories for stock size distribution indices.— We used the criteria developed by Gabelhouse (1984) to establish a minimum TL of Utah Chub for each of the five-cell length categories (i.e., stock, quality, preferred, memorable, and trophy). For development of the minimum TL categories, we excluded all Utah Chub from Jackson Lake, Wyoming. The longest specimen from Jackson Lake was over 115 mm larger than the next largest specimen from any other population, and Jackson Lake contained the 12 largest individuals in the data set. Using the largest specimen from Jackson Lake would have resulted in minimum TLs that are too large for most Utah Chub populations.

RESULTS AND DISCUSSION

Data were obtained from 24 Utah Chub populations that spanned over 40 years (1977–2017) from four states—Idaho, Montana, Utah, and Wyoming. All populations were from lentic systems except for a population in Billingsley Creek, Idaho. The entire data set included 30,410 Utah Chub that varied in length from 65 to 612 mm (mean ± 95% CI = 232 ± 0.7 mm) and from 3 to 2,168 g (mean ± 95% CI = 202 ± 1.9 g; Table 1). For all populations used in the developmental and validation data sets, mean slope was 3.127 (95% CI = 3.072–3.182). When

TABLE 1. Populations used to develop standard weight equations for Utah Chub in Idaho (ID), Montana (MT), Utah (UT), and Wyoming (WY) by gear type used (EF = electrofishing; GN = gill net; MNT = minnow trap; TN = trap net; UNK = unknown sampling gear), data set use (D = developmental; V = validation), years, sample size (*n*), minimum (min) and maximum (max) TL and weight, and estimated intercept ($\log_{10}[a]$) and slope (*b*) of the $\log_{10}$ transformed length–weight data.

						TL (mm)		Weight (g)		Length–weight equation		
State	Population	Use	Gear	Years	*n*	Min	Max	Min	Max	$\log_{10}(a)$	*b*	R^2
ID	American Falls Reservoir	D	GN	1997	129	137	406	30	1,000	−4.706	2.950	0.989
	Billingsley Creek	D	EF	2006	60	65	285	3	277	−4.928	3.012	0.995
	Blackfoot Reservoir	D	GN, TN	2009, 2012	383	135	495	32	1,780	−5.029	3.078	0.993
		V	GN	2015	117	120	435	28	1,118	−4.561	2.886	0.991
	Henrys Lake	D	GN	2005, 2007, 2010, 2014, 2015, 2017	7,709	120	373	18	758	−4.998	3.044	0.981
		V	GN	2004, 2006, 2008, 2009, 2012, 2013, 2016	5,733	92	370	9	654	−5.099	3.089	0.983
	Island Park Reservoir	D	GN	2008, 2016	146	82	360	5	626	−5.398	3.206	0.991
	Ririe Reservoir	D	GN	2013, 2016	299	150	422	37	890	−4.823	2.971	0.963
		V	UNK	2012, 2014	240	145	390	40	635	−5.045	3.063	0.912
ID/WY	Palisades Reservoir	D	UNK	2012	189	150	391	36	885	−5.698	3.329	0.974
MT	Hebgen Lake	D	UNK	1998, 2006, 2007, 2012, 2015	1,857	127	404	23	835	−4.976	3.037	0.971
		V	UNK	1999, 2002, 2009, 2011	1,939	145	406	27	816	−5.202	3.127	0.972
UT	Fish Lake	D	GN	2014, 2015	85	107	285	15	319	−5.145	3.111	0.969
	Lost Creek Reservoir	D	GN	2012, 2014	842	132	283	26	303	−4.996	3.062	0.94
		V	GN	2011, 2013	626	133	265	29	257	−5.999	3.491	0.90
	Minersville Reservoir	D	GN	2015	30	162	278	41	305	−5.806	3.383	0.91
	Otter Creek Reservoir	D	GN	2015	24	140	340	42	511	−4.688	2.934	0.99
	Piute Reservoir	D	GN	2010, 2011, 2014	31	138	283	33	312	−5.203	3.110	0.97
	Rockport Reservoir	D	GN	2012, 2015	70	158	334	45	599	−5.396	3.241	0.96
	Scofield Reservoir	D	GN, MNT	2012	1,084	94	336	8	543	−5.404	3.219	0.98
		V	GN, MNT	2011	745	94	325	9	469	−5.436	3.233	0.99
	Strawberry Reservoir	D	UNK	2002, 2006, 2008, 2009, 2012, 2013, 2016	2,216	92	435	9	1,150	−5.495	3.269	0.99
		V	UNK	2000, 2001, 2005, 2008, 2009, 2013, 2014	1,666	95	361	9	860	−5.532	3.280	0.99
	Woodruff Reservoir	D	UNK	1997	356	150	328	36	540	−5.789	3.385	0.99
UT/WY	Flaming Gorge Reservoir	D	UNK	2001, 2003, 2009	208	191	361	86	662	−5.527	3.265	0.95

TABLE 1. Continued.

State	Population	Use	Gear	Years	n	TL (mm) Min	TL (mm) Max	Weight (g) Min	Weight (g) Max	Length–weight equation $\log_{10}(a)$	b	R^2
WY	Fontenelle Reservoir	D	UNK	1998, 1991, 1993, 2004	271	107	285	14	771	−5.085	3.085	0.98
		V	UNK	1984, 1992, 1997, 2009	314	104	366	9	671	−5.515	3.261	0.99
	Jackson Lake	D	UNK	1978, 1990, 1993, 1995–1997, 2000, 2002, 2004, 2006, 2007, 2009	1,273	127	612	27	2,168	−4.992	3.024	0.99
		V	UNK	1977, 1979, 1980, 1998, 1999, 2003, 2005, 2008	900	132	475	32	1,139	−4.902	2.989	0.99
	Lower Slide Lake	D	UNK	1998–2000, 2002–2007, 2009–2012	302	135	422	27	776	−4.566	2.838	0.92
	Naughton Plant Pond	D	UNK	2009	107	124	323	23	376	−4.860	2.944	0.98
	Two Ocean Lake	D	UNK	1981, 1995, 2009	153	135	376	32	549	−5.236	3.110	0.99
	Viva Naughton Reservoir	D	UNK	1981, 1983, 1989, 1993	306	137	328	27	553	−5.290	3.173	0.96

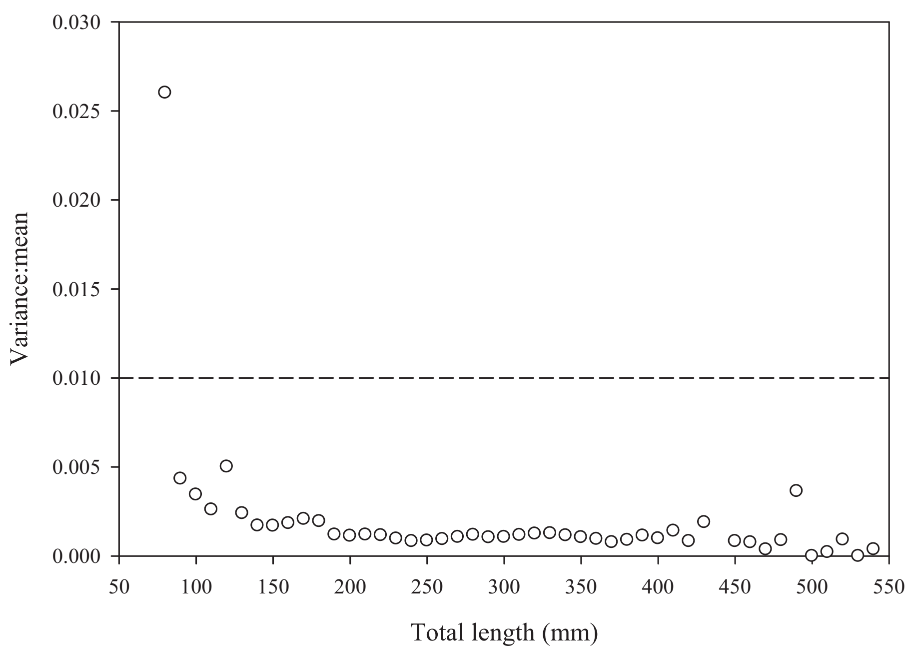

FIGURE 1. Variance-to-mean ratio of $\log_{10}$(weight) by TL at 10-mm intervals for Utah Chub used in the developmental data set. Dashed line indicates the value of 0.01.

b was regressed on $\log_{10}(a)$ for the populations in the developmental data set ($\log_{10}[a] = -2.319[b] + 2.058$; $r^2 = 0.98$) and populations in the validation data set ($\log_{10}[a] = -2.323[b] + 2.081$; $r^2 = 0.99$), no obvious outliers were observed. Also, differences in mean slope ($t = 0.684$, df = 31, $P = 0.50$) and mean intercept ($t = -0.607$, df = 31, $P = 0.55$) between the developmental and validation data sets were not significant. Proportions between the

TABLE 2. Number of populations and number of individual Utah Chub in the developmental data set used to develop the standard weight (W_s) equation per 10-mm length-class (TL). Length-classes marked with an asterisk were not used in estimating the W_s equation of the linear empirical percentile due to low sample size ($n < 3$).

Length-class (mm)	Populations	Individuals	Length-class (mm)	Populations	Individuals
70*	1	2	330	17	359
80*	2	3	340	14	225
90	3	3	350	12	206
100	3	36	360	12	206
110	6	52	370	10	167
120	5	31	380	7	140
130	10	70	390	5	94
140	15	545	400	3	42
150	20	1,331	410	3	43
160	22	1,340	420	4	17
170	20	1,088	430*	1	10
180	17	715	440	3	7
190	22	911	450*	1	3
200	23	1,120	460*	1	7
210	22	1,274	470*	1	4
220	21	1,046	480*	1	1
230	22	869	490*	1	4
240	24	763	500*	2	2
250	23	718	510*	1	2
260	24	640	520*	1	2
270	21	640	530*	1	1
280	23	734	540*	1	1
290	18	691	550*	1	2
300	16	756	560*	1	1
310	17	728	570*	1	1
320	19	476	610*	1	1

TABLE 3. Parameter estimates for Utah Chub standard weight (W_s) equation using regression line percentile (RLP), linear empirical percentile (EmP), quadratic EmP, and Froese methods (W_{s50} = 50th percentile; W_{s75} = 75th percentile; EmpQ = empirical quartiles).

	Parameters			Willis test			EmpQ test	
Equation	$\log_{10}(a)$	b_{linear}	$b_{\text{quadratic}}$	Negative	Positive	P	P_{linear}	$P_{\text{quadratic}}$
RLP W_{s50}	−5.1454	3.1220	NA	3	4	1.0000	0.0078	0.0015
EmP W_{s50}	−6.4431	4.2338	−0.2442	3	5	0.7266	0.2682	0.0471
EmP W_{s50}	−5.1337	3.0987	NA	3	4	1.0000	0.0773	0.0008
RLP W_{s75}	−5.1454	3.1220	NA	3	4	1.0000	0.0373	0.5710
EmP W_{s75}	−4.4103	2.5728	0.0985	2	6	0.2891	0.4697	0.0858
EmP W_{s75}	−4.9386	3.0308	NA	2	6	0.2891	0.3561	0.2217
Froese $W_{s\text{mean}}$	−5.1681	3.1158	NA	3	4	1.0000	0.0022	0.0005

developmental and validation data sets with a slope statistically less than, equal to, or greater than 3.0 were not significantly different ($\chi^2 = 0.060$, df = 2, $P = 0.97$). Based on the bootstrap analysis, variability among slopes was low and the minimum number of populations necessary for the developmental data set (sample variance < 0.002) was eight populations. The minimum TL for the W_s equation was 90 mm based on the variance-to-mean ratio for RLP (Figure 1) and 90 mm for EmP due to the low sample size ($n < 3$ populations; Table 2). Due to the low number of populations with fish in the 450-mm interval ($n < 3$), the maximum TL for the W_s equation was 440 mm for

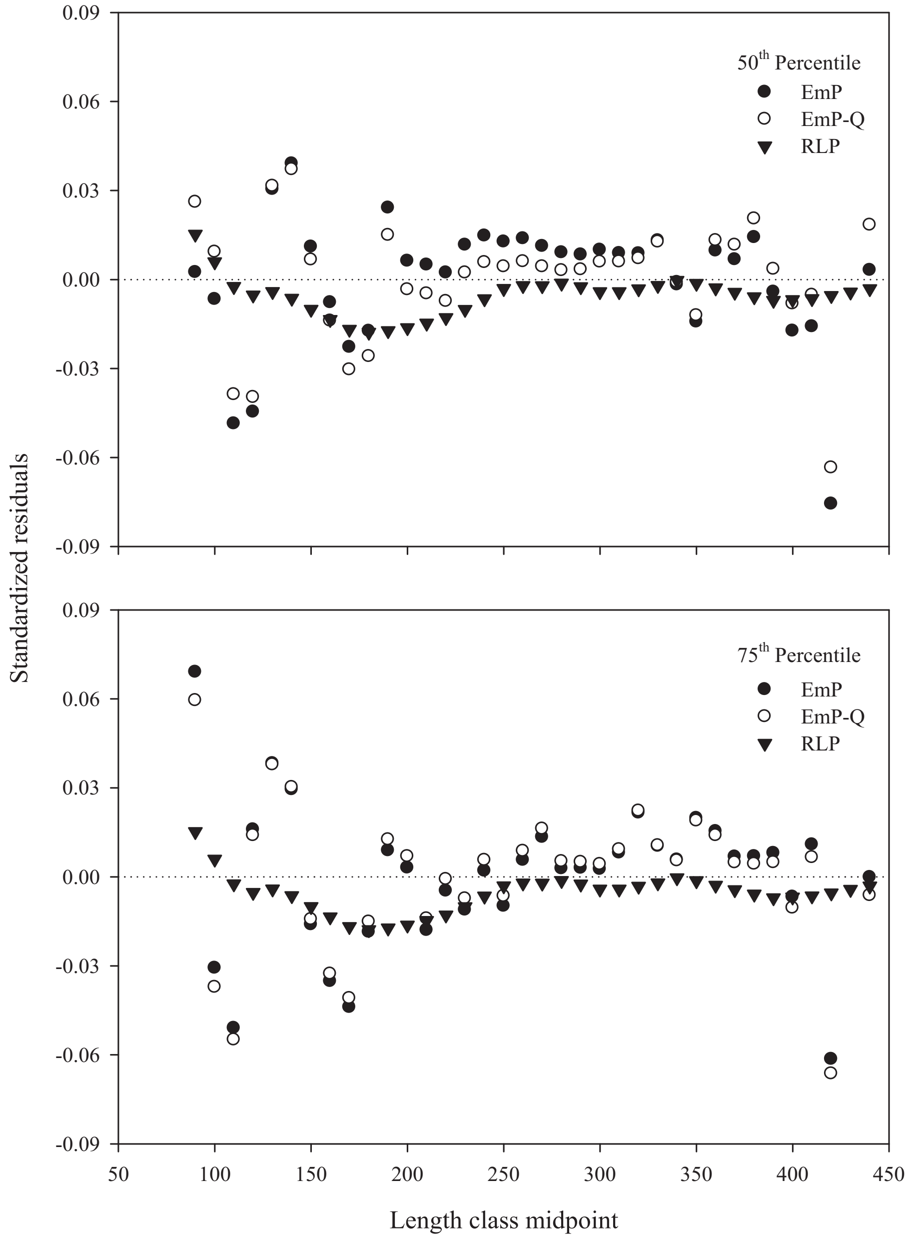

FIGURE 2. Distribution of standardized residuals of the regression plotted against TL category midpoints of Utah Chub obtained by model fit of the 50th and 75th percentiles for the linear empirical percentile (EmP), quadratic empirical percentile (EmP-Q), and regression line percentile (RLP) methods.

EmP. The maximum TL for the W_s equation was 440 mm for the RLP to match that used in the EmP. Although the developmental data set included fish from 90 to 440 mm, the W_s equation is only applicable to 90–410-mm fish due to the availability of size-classes present in the validation data set.

The RLP W_{s50} equation exhibited significant length-related bias when evaluated with the EmpQ method (Table 3) and overpredicted the W_r across all lengths. Residuals of the RLP W_{s50} equation also exhibited nonlinearity (Figure 2). Residuals from the linear EmP W_{s50} equation exhibited no obvious pattern, and a slight length-related bias was detected with the EmpQ method. The quadratic EmP W_{s50} exhibited a length-related bias (Table 3). Residuals of the RLP W_{s75} equation exhibited nonlinearity (Figure 2), and length-related bias was detected with the EmpQ method (Table 3). The RLP W_{s75} equation tended to overpredict W_r with length (Figure 3). The EmP W_{s75} equation showed no

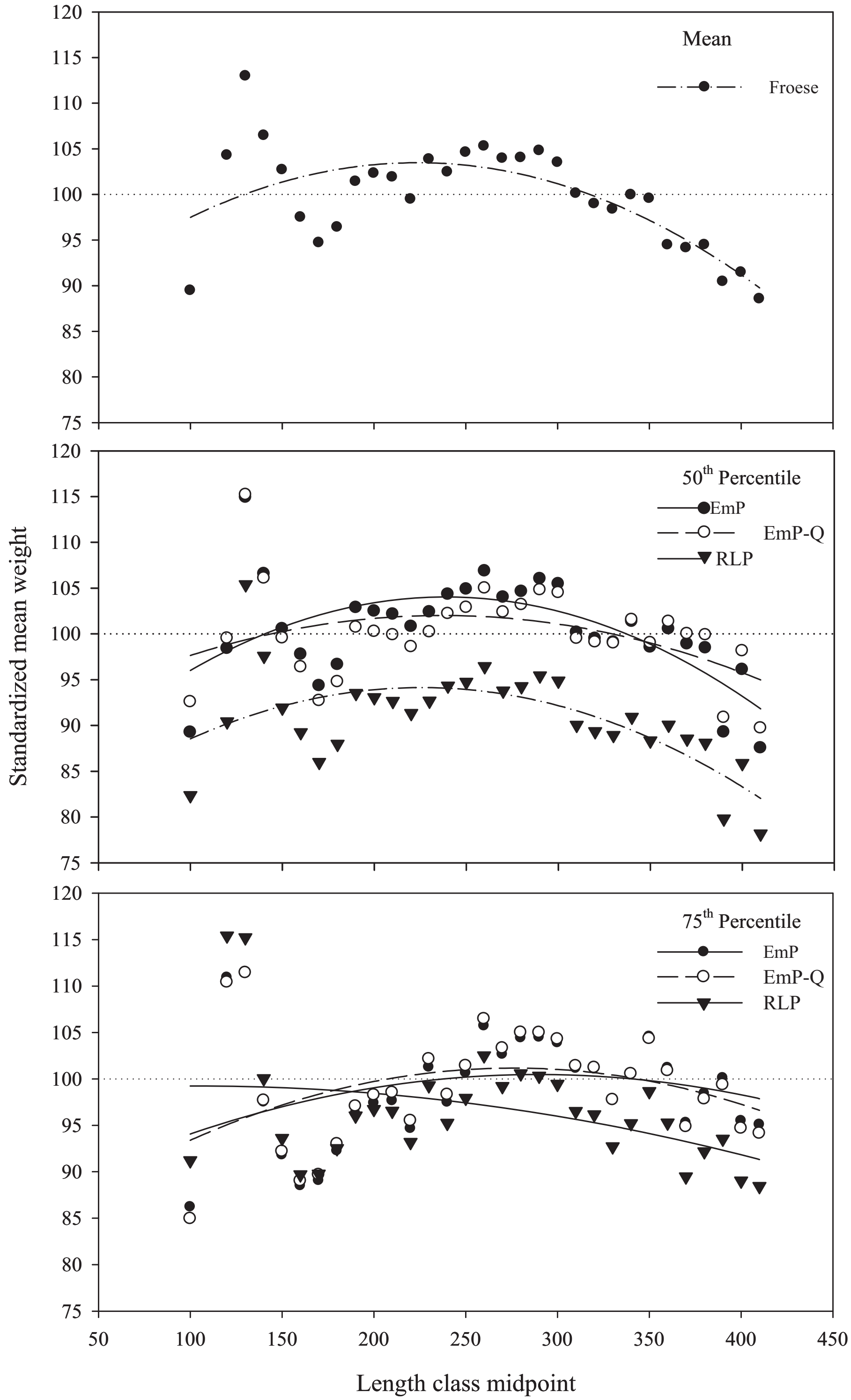

FIGURE 3. Standardized mean Utah Chub weights compared to TL category midpoints with the weighted quadratic fit for the Froese method and 50th and 75th percentiles for the linear empirical percentile (EmP), quadratic empirical percentile (EmP-Q), and regression line percentile (RLP) methods for establishing standard weight equations.

length-related bias with the Willis or EmpQ method for the linear and quadratic terms. Froese W_{smean} exhibited significant length-related bias with the EmpQ method (Table 2) and overpredicted the W_r with increasing length (Figure 3).

The longest fish observed in the data set excluding Jackson Lake was a 495-mm individual from Blackfoot Reservoir, Idaho. Using this length, the proposed minimum TLs are 100 mm (4 in; stock), 200 mm (8 in; quality), 250 mm (10 in; preferred), 300 mm (12 in; memorable), and 380 mm (15 in; trophy).

Length–weight data are rarely collected for nongame species, and Murphy et al. (1990) suggested 50 populations for the development of a W_s equation. We did not collect data from the suggested 50 populations but were successful in obtaining data across the geographical distribution of the species. Variance among populations was low, suggesting that 50 populations were not needed. The linear EmP equation(s) provided the best fit to the data and did not result in length-related bias. We propose using the 75th percentile linear EmP W_s equation for 100–410-mm Utah Chub: $\log_{10}(W_s) = -4.938 + 3.031 \cdot \log_{10}(\text{TL})$, where W_s is weight in grams and TL is in millimeters. The English equivalent of this equation is $\log_{10}(W_s) = -3.335 + 3.031 \cdot \log_{10}(\text{TL})$, where W_s is weight in pounds and TL is in inches for 4–16-in Utah Chub. The linear EmP W_{s75} equation showed no length-related bias and can be a valuable tool for monitoring Utah Chub populations.

Despite the potential negative influence Utah Chub may have on sport fish populations (Teuscher and Luecke 1996; Winters and Budy 2015; Roth et al. 2020), limited information exists regarding their life history and population dynamics. Relative weights coupled with other population metrics (e.g., age structure, growth; Griffin et al. 2017; Roth et al. 2020) of Utah Chub could increase basic knowledge on their population dynamics and ultimately improve sport fish management. The use of the proposed length categories in conjunction with W_r could be useful for providing additional information on factors influencing Utah Chub populations. Relative weights could be used as a simple, less invasive tool to monitor changes in Utah Chub populations (e.g., compared to growth evaluations) and evaluate management strategies across the geographical range of Utah Chub. Temporal trends of W_r for a specific population may also provide understanding of the abiotic (e.g., temperature, oxygen) and biotic (e.g., intraspecific and interspecific competition, predation) factors potentially regulating their populations. The W_r values estimated for this nongame species provide an additional tool for management efforts aimed at enhancing or reducing densities.

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