North American Journal of Fisheries Management 24:697–703, 2004

Standard Weight (W_s) Equations for Four Rare Desert Fishes

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Abstract.—Standard weight (W_s) equations have been used extensively to examine body condition in sport fishes. However, development of these equations for nongame fishes has only recently been emphasized. We used the regression-line-percentile technique to develop standard weight equations for four rare desert fishes: flannelmouth sucker *Catostomus latipinnis*, razorback sucker *Xyrauchen texanus*, roundtail chub *Gila robusta*, and humpback chub *G. cypha*. The W_s equation for flannelmouth suckers of 100–690 mm total length (TL) was developed from 17 populations: $\log_{10}W_s = -5.180 + 3.068 \log_{10}\text{TL}$. The W_s equation for razorback suckers of 110–885 mm TL was developed from 12 populations: $\log_{10}W_s = -4.886 + 2.985 \log_{10}\text{TL}$. The W_s equation for roundtail chub of 100–525 mm TL was developed from 20 populations: $\log_{10}W_s = -5.065 + 3.015 \log_{10}\text{TL}$. The W_s equation for humpback chub of 120–495 mm TL was developed from 9 populations: $\log_{10}W_s = -5.278 + 3.096 \log_{10}\text{TL}$. These equations meet criteria for acceptable standard weight indexes and can be used to calculate relative weight, an index of body condition.

Relative weight (W_r), introduced by Wege and Anderson (1978), is used widely by North American inland fisheries managers as a measure of body condition of fish. Before computing W_r for individual fish and populations, a standard weight (W_s) equation must be developed for the species. Relative weight has been used primarily to assess the status of sport fishes. However, the often strong relation between fish growth and environmental quality suggests that relative weight might also have value in assessment of populations of native, nongame fishes, especially those threatened and endangered. Therefore, recent emphasis has been placed on developing these equations for nongame species (Bister et al. 2000).

Flannelmouth suckers *Catostomus latipinnis*, razorback suckers *Xyrauchen texanus*, roundtail chub *Gila robusta*, and humpback chub *G. cypha* occupy the Colorado River basin (Minckley 1973). Roundtail chub are found in several southwestern states and are listed under the U.S. Endangered Species Act as a species of concern. Humpback chub are most abundant at the confluence of the Colorado and Little Colorado rivers and are listed as endangered under federal legislation (Holden and Minckley 1980; Douglas and Marsh 1996; Meretsky et al. 2000). Flannelmouth sucker are listed as a species of concern under the U. S. Endangered Species Act. Within Grand Canyon, flannelmouth suckers occur in greatest abundance in the Little Colorado River and its confluence with the main stem of the Colorado River. Razorback suckers are listed under the U. S. Endangered Species Act as endangered. Natural reproduction is rare and young fish are seldom found. Currently, most fish collected in nature were produced by hatcheries. All four of these species have declined during the past century. The primary reasons for the reduced range and abundance of these species are habitat alterations and the introduction of nonnative fishes (Cross 1978; Bestgen and Propst 1989; McElroy and Douglas 1995; Marsh and Douglas 1997; Tyus and Saunders 2000). Our objective was to develop standard weight equations for these four, rare species.

Methods

Weight–length data for flannelmouth suckers, razorback suckers, roundtail chub, and humpback chub were obtained from biologists from fisheries agencies and universities of southwestern states and represent the full geographic range of these species. Currently, most W_s equations are estimated by the regression-line-percentile (RLP) technique developed by Murphy et al. (1990). The

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Received July 26, 2002; accepted June 6, 2003

TABLE 1.—Populations used to develop a W_s equation and parameters for $\log_{10}$(weight)–$\log_{10}$(length) regressions for flannelmouth suckers, razorback suckers, roundtail chub, and humpback chub in Arizona (AZ), Colorado (CO), Nevada (NV), New Mexico (NM), Utah (UT), and Wyoming (WY).

Populations	State	Sample size	Regression parameters		
			Intercept	Slope	r^2
Flannelmouth sucker					
Tapeats Creek	AZ	11	−4.617	2.861	0.950
Spencer Creek	AZ	32	−5.138	3.012	0.980
Shinumo Creek	AZ	162	−5.185	3.072	0.958
Havasu Creek	AZ	776	−5.325	3.114	0.983
Kanab Creek	AZ	1,165	−5.248	3.091	0.987
Paria Creek	AZ	1,566	−5.155	3.025	0.925
Colorado River	AZ	5,001	−5.254	3.096	0.990
Little Colorado River	AZ	6,187	−5.521	3.181	0.990
San Juan River	UT	32,358	−5.241	3.068	0.973
Green River	UT	179	−5.103	3.027	0.968
Burnt Lake	WY	11	−5.331	3.126	0.995
Halfmoon Lake	WY	88	−4.707	2.884	0.990
Willow Lake	WY	10	−5.825	3.308	0.995
Gunnison River	CO	3,132	−5.259	3.100	0.976
Colorado River	CO	810	−5.027	3.004	0.982
White River	UT, CO	298	−4.961	2.972	0.992
Yampa River	CO	398	−5.537	3.195	0.967
Razorback sucker					
Lake Mohave	AZ, NV	3,670	−4.893	2.988	0.834
Lake Mead, Las Vegas Bay	NV	101	−4.863	2.997	0.890
Lake Mead, Echo Bay	NV	128	−5.280	3.127	0.933
Granite Creek	AZ	27	−5.139	3.061	0.981
Upper Verde River	AZ	162	−4.807	2.913	0.976
Middle Verde River	AZ	398	−5.049	3.024	0.962
Workman Creek	AZ	17	−4.668	2.856	0.979
Carrizo Tank	AZ	13	−4.469	2.853	0.915
Stehr Lake	AZ	12	−4.453	2.833	0.924
San Juan River	UT	72	−5.146	3.064	0.841
Green River	UT	218	−5.130	3.059	0.975
Yampa River	CO	27	−5.036	3.013	0.815
Roundtail chub					
Upper Verde River	AZ	1,426	−4.870	2.932	0.980
Middle Verde River	AZ	38	−5.041	3.005	0.927
Lower Verde River	AZ	660	−5.071	3.000	0.948
Cherry Creek	AZ	14	−5.748	3.332	0.981
Upper Salt River	AZ	17	−5.113	3.034	0.935
Lower Salt River	AZ	53	−5.440	3.170	0.981
West Clear Creek	AZ	78	−5.076	3.004	0.976
Bill Williams River	AZ	41	−4.923	2.952	0.973
Fremont Lake	WY	26	−4.899	2.994	0.969
Halfmoon Lake	WY	114	−4.948	2.946	0.960
Willow Lake	WY	68	−5.032	2.994	0.967
San Juan River	UT	24	−5.092	3.026	0.979
Green River	UT	79	−5.209	3.038	0.922
White River	UT, CO	43	−4.830	2.927	0.960
Lower Colorado River	UT	42	−4.545	2.802	0.965
Westwater Canyon	UT	2,157	−5.025	2.995	0.915
Black Rocks Canyon	CO	832	−5.001	2.953	0.923
Upper Colorado River	CO	213	−5.112	3.014	0.953
Gunnison River	CO	1,932	−4.757	2.879	0.977
Yampa River	CO	80	−5.519	3.190	0.968
Fossil Creek[a]	AZ	79	−4.872	2.963	0.926
Spring Creek[a]	AZ	98	−4.860	2.968	0.972
East Fork of Gila River[a]	NM	10	−4.760	2.921	0.980
Humpback chub					
Colorado River	AZ	3,728	−5.141	3.044	0.986
Little Colorado River	AZ	34,609	−5.627	3.208	0.975
Havasu Creek	AZ	60	−5.845	3.330	0.972

TABLE 1.—Continued.

Populations	State	Sample size	Regression parameters		
			Intercept	Slope	r^2
Shinumo Creek	AZ	27	−5.450	3.173	0.978
Green River	UT	230	−4.789	2.868	0.945
Cataract Canyon	UT	26	−4.452	2.718	0.893
Westwater Canyon	CO	1,833	−4.733	2.835	0.906
Black Rocks Canyon	CO	865	−4.393	2.700	0.948
Yampa River	CO	215	−4.974	2.926	0.958

[a] Roundtail chub populations were recently reclassified as headwaters chub; they were not used in development of the W_s equation.

RLP technique is based on $\log_{10}$(weight)–$\log_{10}$(length) regressions developed for different populations of the same species. The fish in our data sets were separated into distinct populations. When the Universal Transverse Mercator (UTM) coordinates of sample locations were available, they were overlaid on a map of southwestern water bodies to detect clusters of sample sites in different rivers or clusters separated by some distance on the same river. More commonly, UTM coordinates were not available, and in these cases all fish sampled at the same sampling site or water body were considered to belong to one population. Razorback suckers from Lake Mead were separated into two populations: Las Vegas Bay and Echo Bay. According to local biologists (Paul Holden, Bio-West Inc., personal communication), these two populations do not interbreed.

We obtained data for 17 populations of flannelmouth suckers, 23 populations of roundtail chub, 9 populations of humpback chub, and 12 populations of razorback suckers, each with 10 or more individuals in the samples (Neumann and Flammang 1997; Rogers and Koupal 1997; Hyatt and Hubert 2000; Table 1). The taxonomy of roundtail chub and relatives is complicated, and some fish recorded as roundtail chub in Fossil Creek, Spring Creek, and the East Fork of the Gila River were recently reclassified as a new species, the headwater chub *G. nigra* (Minckley and DeMarais 2000). Thus, these 3 tributaries were eliminated from our analysis of roundtail chub, leaving us with 20 populations.

Southwestern rivers are characterized by variable conditions over years, and data were scarce for these fishes. Therefore, we pooled data from one population over all years to develop each W_s equation. Including weight–length data for all available years represents the maximum possible range of condition for a population. Because fish sex was not indicated in all samples, we pooled weight–length data for males and females by population. To detect outlier values, log(weight) was plotted against log(length) for each population. Evident outliers (mean ± 0.5 SD) were not used in development of the W_s equation.

Developers of W_s equations recommend using minimum lengths in these equations because weight measurements of small fish tend to have low precision and accuracy (Anderson and Neumann 1996). The minimum total lengths for our W_s equations were found by plotting the ratio of the variance to the mean for $\log_{10}$(weight) by 1-cm intervals; the length at which this ratio exceeded 0.01 was designated as the minimum length for the equations (Murphy et al. 1990).

The RLP technique was applied as suggested by Murphy et al. (1990). Fish weight and length values were $\log_{10}$ transformed. For each population, $\log_{10}$(weight)–$\log_{10}$(length) regressions were developed and mean $\log_{10}$(weights) were predicted for each 10-mm length increment. These predicted $\log_{10}$(weights) were back-transformed to weights in grams. Slopes of $\log_{10}$(weight)-$\log_{10}$(length) regressions of individual populations were plotted against *y*-intercepts to detect population samples that could be outliers (Brown and Murphy 1996). The 75th percentile of expected weight in each 10-mm length interval was computed based on all populations. These 75th percentile expected weights were then $\log_{10}$ retransformed and regressed on $\log_{10}$(length) to determine slope and *y*-intercept for the W_s equation.

We used the bootstrap technique of Brown and Murphy (1996) to determine if the number of populations used was sufficient to generate a robust W_s equation. Slopes from $\log_{10}$(weight)-$\log_{10}$(length) regressions for a population were used as modeling parameters. Slopes were randomly selected with replacement (300 iterations). Arithmetic mean and sample variance of slopes were computed for each incremental sample size ($N = 2$–17 for flannelmouth sucker; $N = 2$–20 for roundtail chub; $N = 2$–9 for humpback chub; and

$N = 2–12$ for razorback sucker). Next, we plotted variance in slope values against increasing sample size. The number of populations needed to produce a sample variance of less than 0.002 was used for our decision criterion (Brown and Murphy 1996).

Results and Discussion

We found no population outliers for any species when we regressed the slope of $\log_{10}$(weight)–$\log_{10}$(length) regressions on the *y*-intercept for all populations. Minimum total lengths were 100 mm for flannelmouth suckers, 110 mm for razorback suckers, 100 mm for roundtail chub, and 120 mm for humpback chub (Figure 1). Within razorback sucker populations, we often had few fish of the same length, which created a problem using the variance:mean ratio as a criterion for identifying useful data. For example, for some length intervals (especially for large fish) there were only two records. If weights of two fish with the same length were considerably different, the resulting variance: mean ratio was much greater than 0.01. Three fish longer than 600 mm TL had variance:mean ratios greater than 0.01 (Figure 1). Also, in most razorback sucker populations, fish less than 300 mm TL were absent and length ranges were relatively narrow. Few population data sets contained data for small fish (about ≤100 mm TL). Because the variance:mean ratio for razorback suckers of about 110 mm was less than 0.01, we accepted a minimum length of 110 mm. Maximum total lengths, set at lengths of the largest individual fish in our samples, were 688 mm for flannelmouth sucker, 881 mm for razorback sucker, 522 mm for roundtail chub, and 492 mm for humpback chub.

The W_s equation for flannelmouth sucker from 17 populations (Table 1) is

$$\log_{10}W_s = -5.180 + 3.068 \log_{10}\text{TL},$$

where W_s is weight in grams, and TL is total length in millimeters. Variability among slope and intercept values for flannelmouth sucker populations was relatively low, and the minimum level of precision (sample variance <0.002) was achieved with 9 of the 17 populations. The W_s equation developed for flannelmouth suckers satisfied necessary conditions because our data covered the entire geographic range for the species and the minimum level of precision was achieved. Therefore, the standard weight equation developed for flannelmouth suckers should be acceptable for use by fisheries biologists.

The W_s equation based on 20 populations of roundtail chub is

$$\log_{10}W_s = -5.065 + 3.015 \log_{10}\text{TL}.$$

Variability among slope and intercept values for roundtail chub was also low, and the minimum level of precision (sample variance <0.002) was achieved for 11 of 20 populations. Mean W_r values exceeded 120 in Fossil Creek, Spring Creek, and East Fork of the Gila River, being much higher than all other populations (Table 1). According to Minckley and DeMarais (2000), roundtail chub inhabiting these water bodies were recently reclassified as headwater chub. Thus, these populations were correctly removed from the analysis. The W_s equation for roundtail chub might be useful for identifying headwater chub populations because headwater chub seem to have a higher W_r. We had few weight–length data for headwater chub. More weight–length data from more populations of this species are needed to conclude that headwater chub have higher W_r values than roundtail chub. The W_s equations developed for roundtail chub satisfied necessary conditions because our data covered the entire geographic range for the species and the minimum level of precision was achieved. The standard weight equation developed for roundtail chub should also be acceptable for use by fisheries biologists.

The W_s equation for humpback chub from 9 populations is

$$\log_{10}W_s = -5.278 + 3.096 \log_{10}\text{TL}.$$

Using all nine populations of humpback chub, the minimum level of precision was not achieved. The variance of slopes for this species was 0.005. Weight–length relationships of humpback chub from different populations were more variable across their geographic range than those of the other three species we studied (Table 1), which explains why the minimum level of precision of sample variance was not achieved. Although few data were available for humpback chub, we used almost all available data across the geographic range of the species in developing the W_s equation. Therefore, the W_s equation developed is representative for humpback chub, even though variance is somewhat higher than the 0.002 threshold.

The W_s equation for razorback sucker from 12 populations (Table 1) is

$$\log_{10}W_s = -4.886 + 2.985 \log_{10}\text{TL}.$$

Variability among slope and intercept values for razorback sucker populations was relatively low and the minimum level of precision (sample var-

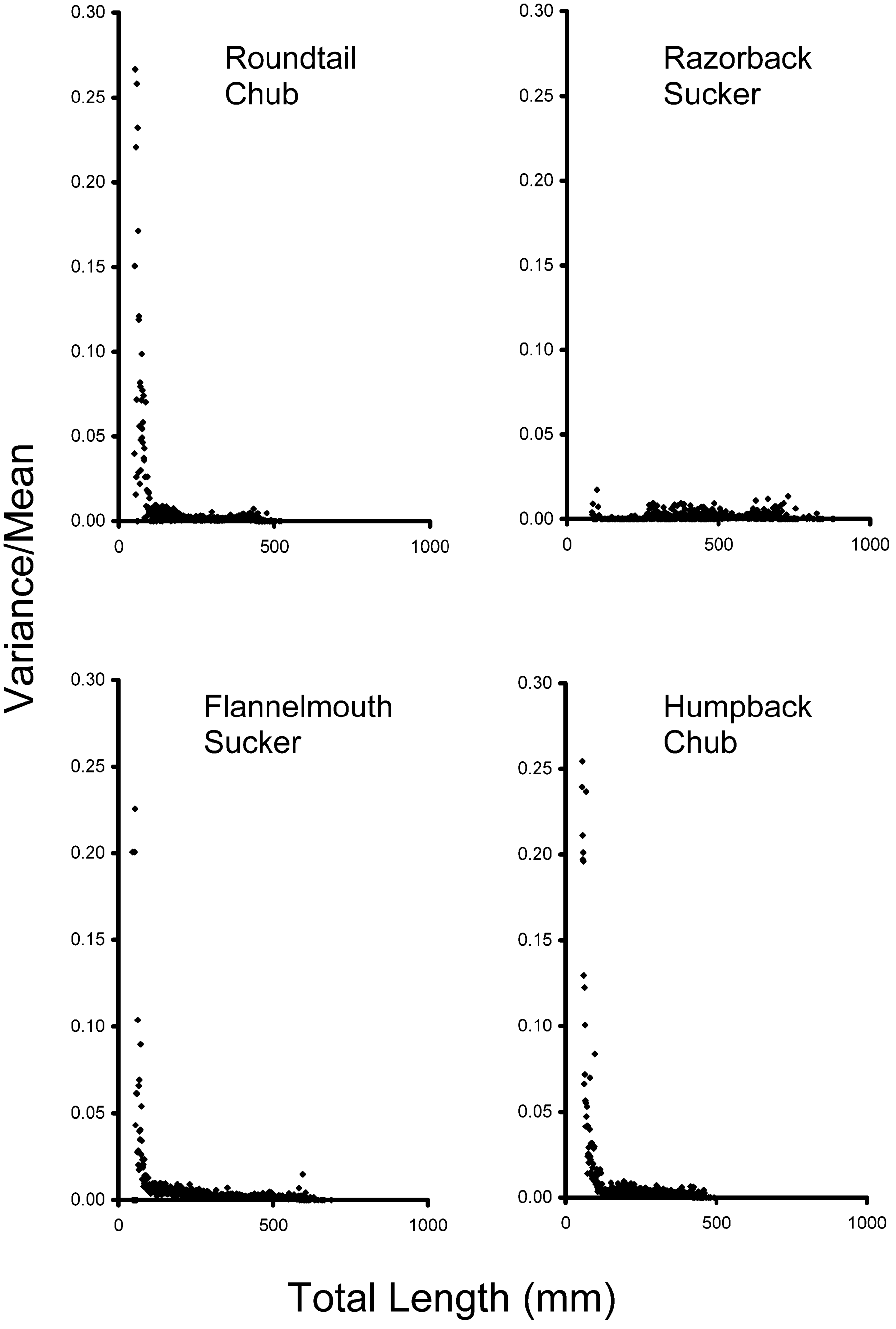

FIGURE 1.—Variance:mean ratio for log10(weight) by 1-cm total length increments for roundtail chub, razorback suckers, flannelmouth suckers, and humpback chub.

iance <0.002) was achieved in 6 of 12 populations of razorback sucker. The slope for the W_s equation for razorback sucker is less than 3.0. Murphy et al. (1991) indicated that slopes less than 3.0 may be unsuitable for W_s equations for most species because such a slope indicates that the species becomes progressively thinner with length. Slopes less than 3.0 may indicate populations in crowded or stunted condition. Low slopes also may be a result of including small fish in the regression (Carlander 1969). However, according to Blackwell et al. (2000), many W_s equations currently accepted for use have slopes less than 3.0. In addition, slopes of weight–length regressions of different populations of razorback suckers were similar. Therefore, our analysis suggests that the W_s equation for razorback suckers is appropriate.

The goal of our study was similar to that of Bister et al. (2000), who were interested in encouraging expanded use of W_r outside of traditional sport fish management. Many of the indices and analysis techniques used for years to successfully assess sport fish populations would also be useful for nongame fish management with little modification. We suggest that standardization of nongame fish survey techniques, for example using indicies such as W_r, would benefit managing entire aquatic ecosystems.

Acknowledgments

We gratefully acknowledge those who contributed data sets and information used in this study: Robert Bettaso, Mark Brouder, William Persons, Jeremy Voeltz, David Ward, Chris Flaccus, Scott Bryan, and David Weedman from Arizona Game and Fish Department; Paul Marsh from Arizona State University; Paul Holden and T. Welker from the Bio-West Inc.; Chris Kitcheyan from U.S. Fish and Wildlife Service in Utah; R. Brunson and Ann McLuckie from Utah Division of Wildlife Resources; William Elmblad from Colorado Division of Wildlife; C. McAda and Dale Ryden from the Colorado River Fishery Project, U.S. Fish and Wildlife Service; and P. Cavalli from Wyoming Game and Fish Department. Research for this study was supported by the Arizona Cooperative Fish and Wildlife Research Unit of the U. S. Geological Survey and the Edmund S. Muskie and Freedom Support Act Graduate Fellowship Program of the Bureau of Educational and Cultural Affairs (ECA), U.S. Department of State under authority of the Fulbright–Hays Act of 1961 as amended, and administered by the Open Society Institute (OSI). The opinions expressed herein are the author's own and do not necessarily express the view of either ECA or OSI.

References

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447–482 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Bestgen, K. R., and D. L. Propst. 1989. Distribution, status, and notes on the ecology of *Gila robusta* (Cyprinidae) in the Gila River drainage. The Southwestern Naturalist 34:402–412.

Bister, T. J., D. W. Willis, M. L. Brown, S. M. Jordan, R. M. Neumann, M. C. Quist, and C. S. Guy. 2000. Proposed standard weight (W_s) equations and standard length categories for 18 warmwater nongame and riverine fish species. North American Journal of Fisheries Management 20:570–574.

Blackwell, B. G., M. L. Brown, and D. W. Willis. 2000. Relative weight (W_r) status and current use in fisheries assessment and management. Reviews in Fisheries Science 81:1–44.

Brown, M. L., and B. R. Murphy. 1996. Selection of a minimum sample size for application of the regression-line-percentile technique. North American Journal of Fisheries Management 16:427–432.

Carlander, K. D. 1969. Handbook of freshwater fishery biology, volume 1. Iowa State University Press, Ames.

Cross, J. N. 1978. Status and ecology of the Virgin River roundtail chub, *Gila robusta seminunda* (Osteichthyes, Cyprinidae). Southwestern Naturalist 23: 519–528.

Douglas, M. E., and P. C. Marsh. 1996. Population estimates/population movements of *Gila cypha*, an endangered cyprinid fish in the Grand Canyon region of Arizona. Copeia 1996:15–28.

Holden, P. B., and W. L. Minckley. 1980. *Gila cypha* Miller, humpback chub. Page 165 *in* D. S. Lee, C. R. Gilbert, C. H. Hocutt, R. E. Jenkins, D. E. McAllister, and J. R. Stauffer Jr., editors. Atlas of North American freshwater fishes. North Carolina Museum of Natural History, Raleigh.

Hyatt, M. H., and W. A. Hubert. 2000. Proposed standard weight (W_s) equations for kokanee, golden trout, and bull trout. Journal of Freshwater Ecology 15:559–563.

Marsh, P. C., and M. E. Douglas. 1997. Predation of introduced fishes on endangered humpback chub and other native species in the Little Colorado River, Arizona. Transactions of the American Fisheries Society 126:343–346.

McElroy, D. M., and M. E. Douglas. 1995. Patterns of morphological variation among endangered populations of *Gila robusta* and *Gila cypha* (Teleostei: Cyprinidae) in the upper Colorado River basin. Copeia 1995:636–647.

Meretsky, V. J., R. A. Valdez, M. E. Douglas, M. J. Brouder, O. T. Goreman, and P. C. Marsh. 2000. Spatiotemporal variation in weight-length relationships of endangered humpback chub: implications for conservation and management. Transactions of the American Fisheries Society 129:419–428.

Minckley, W. L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix.

Minckley, W. L., and B. D. DeMarais. 2000. Taxonomy of chubs (Teleostei, Cyprinidae, genus *Gila*) in the

American Southwest with comments on conservation. Copeia 2000:251–256.

Murphy, B. R., M. L. Brown, and T. A. Springer. 1990. Evaluation of the relative weight (W_r) index, with new applications to walleye. North American Journal of Fisheries Management 10:85–97.

Murphy, B. R., D. W. Willis, and T. A. Springer. 1991. The relative weight index in fisheries management: status and needs. Fisheries 16(2):30–38.

Neumann, R. M., and M. K. Flammang. 1997. Relative weight as a body condition index for chain pickerel. Journal of Freshwater Ecology 12:19–26.

Rogers, K. B., and K. D. Koupal. 1997. Standard weight equation for tiger muskellunge (*Esox lucius* × *Esox masquinongy*). Journal of Freshwater Ecology 12: 321–327.

Tyus, H. M., and J. F. Saunders III. 2000. Nonnative fish control and endangered fish recovery: lessons from the Colorado River. Fisheries 25(9):17–24.

Wege, G. D., and R. O. Anderson. 1978. Relative weight (W_r): a new index of condition for largemouth bass. Pages 79–91 *in* G. D. Novinger and J. G. Dillard, editors. New approaches to the management of small impoundments. American Fisheries Society, Symposium 4, Bethesda, Maryland.