The Effect of Stomach Contents on the

Relative Weight (*Wr*) of Smallmouth Bass and Walleye

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<A>Abstract

Relative weight (*Wr*) is commonly used to characterize fish condition. As a short-term indicator of fish condition, *Wr* could be biased high by the mass of recently ingested prey items. We estimated the maximum stomach volume of smallmouth bass *Micropterus dolomieu* and walleye *Sander vitreus* from the Midwestern United States and calculated the *Wr* of fish with empty stomachs (*Wr*E), filled stomachs (*Wr*MAX), and with observed stomach contents (*Wr*). No statistically significant difference existed between *Wr* and *Wr*E of smallmouth bass or walleye in substock, stock-quality, quality-preferred, preferred-memorable, or memorable-trophy length categories. Significant differences existed between *Wr*E and *Wr*MAX in all five length categories of smallmouth bass but only in the quality-preferred length category of walleye. Significant differences existed between *Wr* and *Wr*MAX in only the substock, stock-quality, and quality-preferred length categories of smallmouth; no significant differences existed between *Wr* and *Wr*MAX of any length categories of walleye. The greatest difference between *Wr*MAX and *Wr*E of smallmouth bass was 4.4 in the substock length category. Because most management target ranges for *Wr* are 10 units wide, fisheries managers need not consider the stomach contents of smallmouth bass and walleye when setting target *Wr* ranges.

<A>Introduction

Length and weight data are important for fisheries management (Neumann et al. 2012) and are often used in combination (i.e., relative weight, *Wr*) to evaluate fish condition and the success of management actions (Blackwell et al. 2000); moreover, *Wr* is a concept that is easily communicated by fisheries managers to anglers. Relative weight is simple to calculate provided a species has a standard weight (*Ws*) equation (Anderson and Neumann 1996; Pope and Kruse 2007). The optimal *Wr* target was established as 100 *Wr* units, indicating a fish in “above average” condition (Wege and Anderson 1978; Pope and Kruse 2007). However, recently ingested food may affect *Wr*, inflating the estimated conditions of individual fish and affecting management decisions. We therefore evaluated the effect of stomach contents on *Wr* values of smallmouth bass *Micropterus dolomieu* and walleye *Sander vitreus* from the Midwestern United States by comparing *Wr* values of fish without stomach contents, with stomach contents, and with estimated-maximum stomach volumes.

<A>Methods

We solicited length (mm), weight (g), and stomach contents weight (g; weighed to a minimum accuracy of 0.01 g) data of individual smallmouth and walleye from fisheries scientists and managers across the Midwestern and Western United States. We collected total length, total weight, and stomach-contents weight data from 1,133 smallmouth bass individuals from four impoundments in eastern South Dakota. For walleye, we collected length, total weight, and stomach-contents weight data from 953 individuals from six populations including impoundments in eastern South Dakota (*n* = 3), Nebraska (*n* = 1), Kansas (*n* = 1), and the Missouri River upstream of Ft. Peck Reservoir in Montana (*n* = 1). We calculated relative weight of each fish (Murphy et al. 1990; Kolander et al. 1993) with three different values of body weight: including stomach contents (*Wr*), excluding stomach contents (*Wr*E), and including the estimated maximum stomach capacity (*Wr*Max).

To calculate *Wr*Max, we first estimated the maximum stomach capacity of smallmouth bass and walleye at a given body weight with ordinary least squares (OLS) regression and quantile regression at the 95th quantile. We based our estimates of maximum stomach capacity (*W*StMax) on a filtered data set. For both species, we selected the individuals with the highest observed stomach contents weight in each length category [substock (SS), stock – quality (S-Q), quality – preferred (Q-P), preferred – memorable (P-M), memorable – trophy (M-T), and greater than trophy (>T); Gabelhouse 1984] by population. This resulted in four individuals in all length categories for smallmouth bass and six individuals in each of the substock, S-Q, Q-P, and P-M categories and five individuals in the M-T category for walleye. One South Dakota population did not have any walleye in the M-T length category. With species-specific populations reduced to the individuals with the maximum observed stomach contents in each length category by population, we modeled observed stomach contents weight (*W*­St) as a function total weight minus observed stomach contents weight (*W*E) for each species. We used linear regression because visual examination of the relationship of *W*St to *W*E appeared linear.

For OLS and quantile regression, we fit a linear model

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where *W*St is the observed maximum stomach contents (g) of a fish at a given empty weight (*W*E; g) and *a* and *b* are derived from the linear model. Given that our OLS model minimizes the sum of the squared residuals, the “best-fit” line in 50% of the cases was less than the actuals, thus returning estimated maximum stomach contents values that were less than the observed values. Because of this we chose to also use quantile regression to estimate the 95th quantile of *W*St as a function of *W*E. Quantile regression can estimate the functional relationships between variables for any portions of a distribution (Koenker and Basset 1978; Cade and Noon 2003). We modeled the 95th quantile of *W*St as a function of *W*E with the quantreg package in R 3.3.0 (Koenker 2017; R Development Core Team 2017). To evaluate goodness of fit of the models, we used R2 for OLS and R1 for quantile regressions (Koenker and Machado 1999).

We estimated *W*StMax of each individual with the derived regression lines by species. We then calculated *Wr*Max by adding the maximum stomach contents weight (g) to the total empty weight of each individual (*W*E). Because we have two estimators of maximum *Wr*, we refer to the estimator derived from OLS as *Wr*Max and that derived from 95th quantile regression as *Wr*MaxQ.

We tested for normality of our *Wr*E, *Wr*, *WrMax*, and *Wr*MaxQ data by each species x population x length category with a Shapiro-Wilk test because *Wr* dataare often non-normally distributed (Brendan et al. 2003; Pope and Kruse 2007). When data were distributed non-normally, we compared differences in the median values of *Wr*, *Wr*E, *Wr*Max, and *Wr*MaxQ by length category and population with Wilcoxon two-sample tests (Pope and Kruse 2007). Alpha for all statistical tests was set equal to 0.05. Statistical analyses were conducted using R version 3.3.0 (R Development Core Team 2017).

We calculated the percent difference among *Wr*, *Wr*E, and *Wr*Max, and *Wr*MaxQ values using the equation

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where *z* = the experimental value (i.e., *Wr*E, *Wr, Wr*Max, *Wr*MaxQ) and *z*1 = the observed value (*Wr, Wr, WrMax,* or *Wr*MaxQ), depending on the comparison made.

<A>Results

Ordinary least squares linear regression of *W*St as a function of *W*Eprovided a good fit for smallmouth bass (n = 22; R2 = 0.76; Figure 1) and an adequate fit for walleye (n = 29; R2 = 0.56; Figure 1). Quantile regression of *W*St as a function of *W*E at the 95th quantile provided good fits for smallmouth bass (n = 22; R1 = 0.78; Figure 1) and walleye (n = 29; R1 = 0.74; Figure 1)

Median *Wr* for smallmouth bass was 98.2 [1st Quantile (Q1) = 89.9; 3rd Quantile (Q3) = 106] *Wr* units across all length categories. Median *Wr*E for smallmouth was 97.2 (Q1 = 89.3; Q3 = 105.3) *Wr* units across all length categories. Median *Wr*MAX for smallmouth bass was 100.8 (Q1 = 92.8; Q3 = 109.0) *Wr* units across all length categories. For smallmouth bass, median *Wr*, *Wr*E, and *Wr*MAX were greater in the S-Q length category than in other length categories (Figure 2). Relative weight, *WrE*, and *WrMAX* decreased through the P-M length category, but increased in the M-T length category (Figure 2).

Median *Wr* for walleye was 94.6 (Q1 = 87.2; Q3 = 101.5) *Wr* units across all length categories. Median *Wr*E for walleye was 94.0 (Q1 = 86.7; Q3 = 100.6) *Wr* units across all length categories. Median *Wr*MAX for walleye was 95.5 (Q1 = 88.4; Q3 = 102.2) *Wr* units across all length categories. For walleye, condition was lowest in the S-Q length category (Figure 2). Relative weight, *Wr*E, and *Wr*MAX were higher in the substock length category, and increased in the Q-P, P-M, and M-T length categories.

Shapiro-Wilk tests on *Wr*, *Wr*E, and *Wr*MAX data indicated departures from normality for both smallmouth bass and walleye (p < 0.0001). Wilcoxon two-sample test comparisons of *Wr* and *Wr*E by length category indicated that there was no statistical difference in fish condition with and without stomach contents for smallmouth bass or walleye in either the substock, S-Q, Q-P, P-M, or M-T length categories (Table 1). Wilcoxon two-sample test comparisons of *Wr*E and *Wr*MAX indicated that there were statistically significant differences between *Wr*E and *Wr*MAX for smallmouth bass (p < 0.05) in all five of the length categories (Table 1). The percent differences here represent differences in weight of -3.3 g, -11.2 g, -20.5 g, -36.0 g, and -55.6 g for smallmouth that weighs 180 g, 280 g, 3250 g, 430 g, and 510 g, respectively. For walleye, *Wr*E was statistically different from *Wr*MAX in only the Q-P length category (Table 1). For a 420 mm walleye, the percent different indicated here is a difference of -14.4 g. When we compared *Wr* to *Wr*MAX, we found significant differences in the substock, S-Q, and Q-P length categories for smallmouth and no significant differences for walleye (Table 1). For smallmouth, the percent differences here represent differences of -2.4 g, -8.8 g, and -15.0 g for a smallmouth that weighs 180 g, 280 g, 3250 g, 430 g, and 510 g, respectively.

<A>Discussion

The most common method of calculating *Wr* includes the stomach contents of fish. For our smallmouth bass data set, the differences among predictions of condition were less than 5 *Wr* units within a length category, though the differences between *Wr* and *Wr*MAX were statistically significant in all length categories. For walleye, the only statistically significant difference was between *Wr*E and *Wr*MAX in the Q-P length category. Though statistically significant differences are present in our data set, we do not believe that there are any biologically significant differences that would affect fisheries management.

Relative weight is a widely used tool to manage fish populations (Blackwell et al. 2000). Standard weight equations have been developed for over 60 species, many of which are targeted by anglers. Additionally, some *Ws* equations have also been developed for rare and nongame fishes (Bister et al. 2000; Richter, T. J. 2007; Rypel and Richter 2008; Ogle and Winfield 2009). Fisheries managers rely on condition factors in monitoring and managing fish populations and the results herein suggest that although stomach contents increase estimates of *Wr*, the increase is negligible. For example, though estimates of *Wr*MAX were significantly larger than estimates of *Wr*E in smallmouth bass, these differences were less than 5 *Wr* units, suggesting that even at maximum stomach capacity stomach contents of fishes would have little impact on management related decisions.

Stomach fullness is limited by rates of digestion or prey encounter (Breck 1993). Thus, stomach fullness for an individual fish at a given time will range from empty to full (Gosch et al. 2009). Predicting the likelihood at which an individual fish will be at maximum stomach capacity would be almost impossible because prey are patchily distributed (Gosch et al. 2009). The difference in the exponent, *b*, for smallmouth (*b* = 2.69) and walleye (*b* = 4.12) indicate that walleye have a higher rate of change in stomach capacity than smallmouth (Gosch et al. 2009). Thus, walleye experience a greater rate of change in stomach capacity with increasing length. This difference is likely a result of feeding strategies for these species. Walleye are considered specialist piscivores from hatch (Graeb et al. 2005) whereas smallmouth experience greater ontogenetic shifts in prey items: zooplankton to insects and small fish, culminating in crayfish and larger fish (Coble 1975). Another possible explanation are the potential morphological differences in digestive systems between smallmouth and walleye. Though we did not investigate stomach morphology, walleye and smallmouth may have a dissimilar number of pyloric caeca, which could affect digestion rates and stomach fullness.

Developers of *Ws* equations have not accounted for the influence of stomach-contents on total fish mass (i.e., Murphy et al. 1990; Gerow et al. 2005). Wege and Anderson (1978) discuss several factors that could influence *Wr* in largemouth bass *Micropterus salmoides* (e.g., population density, prey abundance, etc.) but do not discuss how stomach contents could affect *Wr*. Though the stomach contents of fishes is a measurement error and population density and prey abundance are physiological mechanisms, measurement error should be taken into account when collecting data that will be used in management-related decisions. However, our analyses suggest that there are little management-related differences among *Wr*E, *Wr*, and *Wr*MAX.

Nonlinear regression of observed stomach contents on length provided adequate fits for both smallmouth and walleye. The values for *R2* are both greater than 0.50, suggesting that 50% of the observed variation in the amount of observed stomach contents can be explained by fish length (Gotelli and Ellison 2004). This is reasonable, as larger fish would generally have higher numbers and sizes of stomach contents. However, the regression estimate for walleye was likely affected by several outliers in the M-T length category. Two fish in this length category had less than 20 ml of stomach contents which biased the regression downward. As a result, all of the observed stomach contents in the substock length category were higher than the estimated values, leading to estimates of *Wr*MAX being lower than estimates of *Wr* in the substock length category. We used a high density conversion factor (i.e., 1.05 g/ml) to estimate the “maximum of the maximum,” giving us a broader range of *Wr*, *Wr*E, and *Wr*MAX to compare. However, the small deviation between *Wr*MAX and *Wr* in substock walleye may not be a pragmatic concern for fisheries managers.

The data we analyzed were non-normal, thus we used non-parametric tests to compare *Wr* values among groups. Brenden et al. (2003) suggest that their *R*-test is the most appropriate for testing *Wr* data, but the statistical merit of *Wr* data continues to be debated (Pope and Kruse 2007). The *R*-test is likely the most appropriate and conservative method to compare *Wr* values, but the difficulty of computing the *R*-statistic and its associated significance value outweighs the only moderate improvement in testing power (Pope and Kruse 2007). Our study investigated the potential management concerns related to the effects of fish stomach contents on *Wr* values and was not an attempt to make any definitive conclusions regarding patterns in smallmouth or walleye condition. Thus, using non-parametric statistical analyses was an acceptable alternative to the *R*-test. However, results derived from the *R*-test may provide additional insight into the affects that fish stomach contents has on *Wr*.

To our knowledge, there has been no investigation into the lowest resolution of *Wr* at which fisheries managers can manage a population. Fish with *Wr* “close to” 100 are considered to be “in balance” with their food supply while fish with *Wr* less than 85 are underweight and fish with *Wr* greater than 105 are “more plump than necessary” (Flickinger et al. 1999). Most fisheries managers consider fish with a *Wr* value between 95 and 105 to be in good condition because *Wr* is a model of the 75th percentile of fish population weight as a function of length (Wege and Anderson 1978). When *Wr* target ranges are given for a species, the range encompasses 10 *Wr* units, suggesting that the lowest *Wr* resolution at which a fish population can be managed is 10 (see Blackwell et al. 2000). The maximum difference we found between *Wr*MAX and *Wr*E was 4.4 in the substock length category of smallmouth bass. As a result, we do not believe that fisheries managers should consider the stomach contents of the fishes in their populations when setting *Wr* target ranges.

<A>Acknowledgments

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Table 1. Sample size, p-value from Wilcoxon two-sample comparison test (e.g., *Wr*E X *Wr*), and % difference in *Wr* calculated from whole individuals (*Wr*), individuals minus stomach contents (*Wr*E), and individuals at estimated maximum stomach capacity (*Wr*MAX) by five-cell length category. Asterisks (\*) indicate comparisons that were significantly different.

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| --- | --- | --- | --- | --- | --- | --- |
| Species | Statistic | Length category | | | | |
| Substock | S-Q | Q-P | P-M | M-T |
| Smallmouth bass | n | 274 | 410 | 205 | 151 | 93 |
| *Wr*E X *Wr* | 0.36 | 0.25 | 0.35 | 0.54 | 0.49 |
| % difference | -1.14 | -0.80 | -0.87 | -0.66 | -0.75 |
| *Wr*E X *Wr*MAX | < 0.005\* | < 0.005\* | < 0.05\* | 0.01\* | 0.049\* |
| % difference | -4.22 | -3.54 | -3.16 | -2.87 | -2.57 |
| *Wr* X *Wr*MAX | 0.012\* | < 0.005\* | 0.016\* | 0.057 | 0.17 |
| % difference | -3.11 | -2.76 | -2.30 | -2.22 | -1.84 |
| Walleye | n | 86 | 234 | 522 | 74 | 36 |
| *Wr*E X *Wr* | 0.31 | 0.38 | 0.46 | 0.66 | 0.58 |
| % difference | -1.25 | -0.80 | -0.53 | -0.78 | -1.25 |
| *Wr*E X *Wr*MAX | 0.46 | 0.09 | 0.009\* | 0.28 | 0.24 |
| % difference | -0.86 | -1.54 | -1.86 | -2.31 | -2.74 |
| *Wr* X *Wr*MAX | 0.71 | 0.39 | 0.059 | 0.44 | 0.53 |
| % difference | 0.40 | -0.74 | -1.33 | -1.54 | -1.50 |

<A>Figure Legends

Figure 1. Plots of observed stomach contents weight (*W*St; g) as a function of total weight minus stomach contents (*W*E; g) for smallmouth bass *Micropterus dolomieu* and walleye *Sander vitreus*. Each point represents the maximum total prey mass (g) observed in an individual stomach for each five-cell length category (Gabelhouse 1984) from each population. Note different scales on the x-axis.

Figure 2. Box plot of relative weight with (*Wr*) and without stomach contents (*Wr*E) and at estimated maximum stomach capacity from two linear estimators (*Wr*Max= ordinary least squares regression; and *Wr*MaxQ = 95th quantile regression) by length category (Gabelhouse 1984) and population for smallmouth bass *Micropterus dolomieu*. The box describes the median value (heavy line) and the upper and lower edges of the box are the 25th and 75th percentiles. The whiskers of the box extend to 1.5 ∙ the interquartile range (Wickham 2009). Outliers beyond the whiskers are not shown.

Figure 2. Box plot of relative weight with (*Wr*) and without stomach contents (*Wr*E) and at estimated maximum stomach capacity from two linear estimators (*Wr*Max= ordinary least squares regression; and *Wr*MaxQ = 95th quantile regression) by length category (Gabelhouse 1984) and population for walleye *Sander vitreus*. The box describes the median value (heavy line) and the upper and lower edges of the box are the 25th and 75th percentiles. The whiskers of the box extend to 1.5 ∙ the interquartile range (Wickham 2009). Outliers beyond the whiskers are not shown.

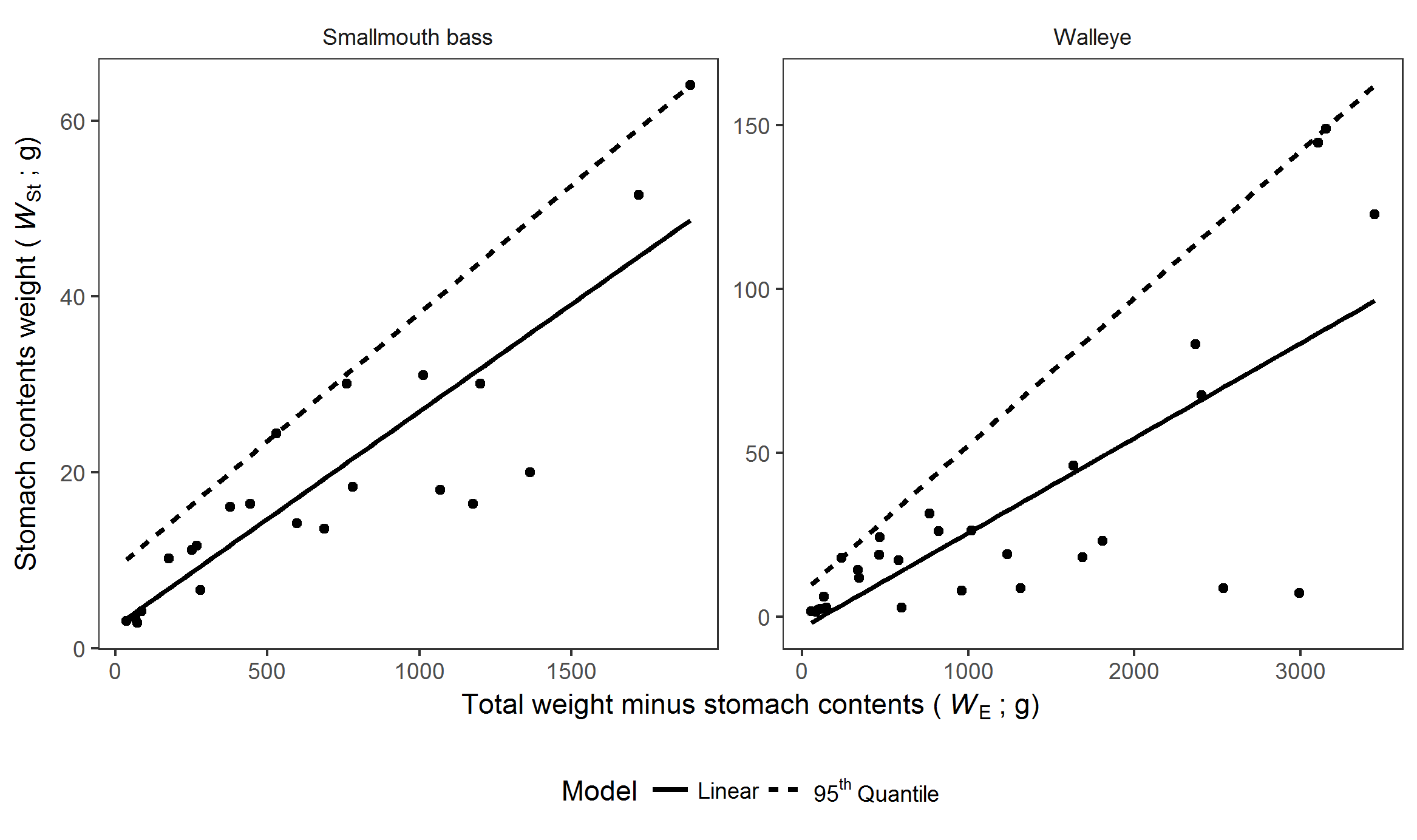


Figure 1.

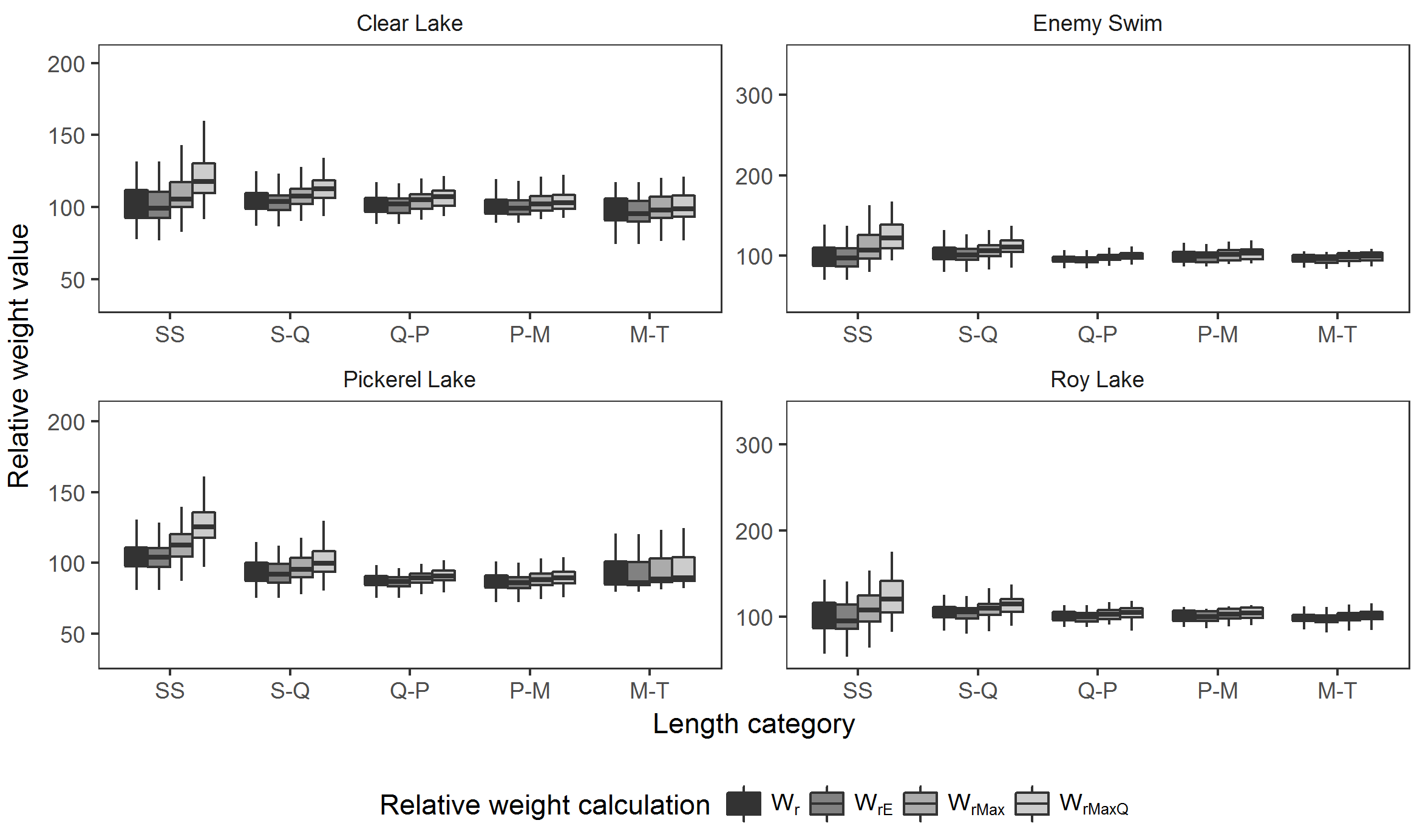


Figure 2.

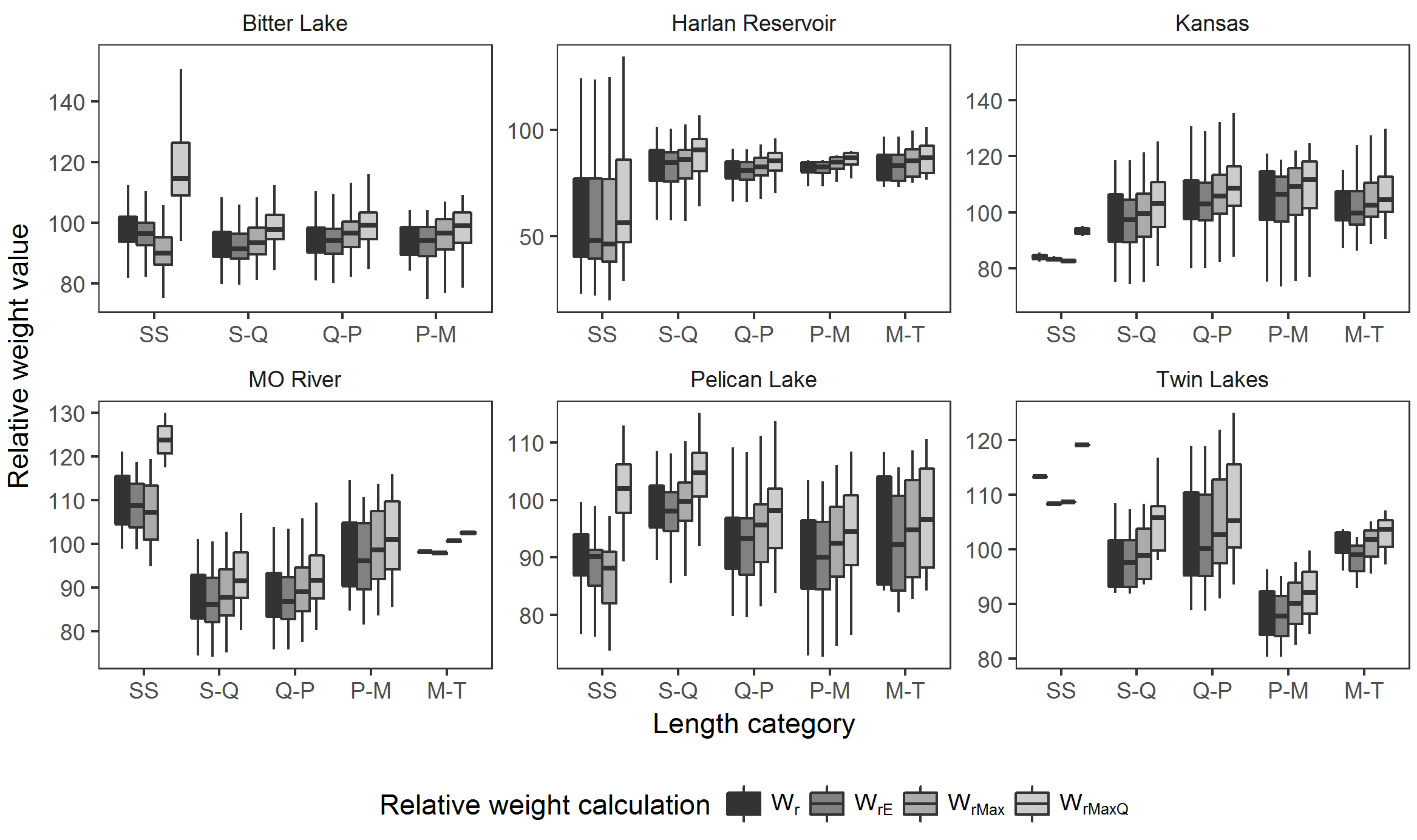


Figure 3.