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 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. 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 SS, 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.

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. We used quantile regression at the 99th quantile to model *W*St because the ordinary least squares “best fit” line was lower than the actual values in many cases, thus returning estimated maximum stomach contents values that were less than the observed values. Quantile regression can estimate the functional relationships between variables for any portions of a distribution (Koenker and Basset 1978; Cade and Noon 2003). We used the rq() function in the “quantreg” package (Koenker 2017) in R 3.3.3 (R Development Core Team 2017) to model the 99th quantile of *W*St as a function of *W*E. To evaluate goodness of fit, we used R1 for quantile regressions (Koenker and Machado 1999).We estimated *W*StMax of each individual with the quantile regression lines for both species. We then calculated *Wr*Max by adding the estimated maximum stomach contents weight (g) to the total empty weight of each individual (*W*E) and calculating *Wr* from the species’ *Ws* equation.

We tested for normality of our *Wr*E, *Wr*, and *WrMax* 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, and *Wr*Max by length category and population with Wilcoxon two-sample tests (Pope and Kruse 2007). To evaluate potential biological significance of differences among *Wr*, *Wr*E, and *Wr*Max values within a length category, we calculated the percent difference between calculated values of relative weight using the equation

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where *z* = the experimental value (i.e., *Wr*E, *Wr, Wr*Max) and *z*1 = the observed value (*Wr, Wr, WrMax*), depending on the comparison made. Alpha for all statistical tests was set equal to 0.05. All statistical analyses were conducted using R version 3.3.3 (R Development Core Team 2017).

<A>Results

We collected total length, total weight, and stomach-contents weight data from 1,133 smallmouth bass individuals from four impoundments in eastern South Dakota (Clear, *n* = 294; Enemy Swim, *n* = 252; Pickerel, *n* = 296; Roy, *n* = 289). For walleye, we collected length, total weight, and stomach-contents weight data from 953 individuals from six populations including impoundments in eastern South Dakota (Bitter, *n* = 346; Pelican, *n* = 62; Twin, *n* = 23), Nebraska (Harlan Reservoir, *n* = 140), Kansas (lake unknown, *n* = 283), and the Missouri River upstream of Ft. Peck Reservoir in Montana (*n* = 99). Details of collection method and time of year of collection are unknown. We removed species × lake × length category groups that had n < 3 individuals. This led to removal of 10 walleye: 1 >T from Harlan Reservoir, 2 SS from Kansas, 2 SS from MO River, 2 M-T from MO River, 1 SS from Twin, and 2 P-M from Twin.

Quantile regression of *W*St as a function of *W*E at the 99th quantile provided good fits for smallmouth bass (n = 22; R1 = 0.78; Figure 1) and walleye (n = 29; R1 = 0.74; Figure 1). Ordinary least squares linear regression of *W*St as a function of *W*E provided 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).

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 SS, 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 the length categories for select populations (Table 1). The percent differences represent decreases in relative weight from *Wr*Max to *Wr*E of 3 *Wr* units (M-T category for Enemy Swim; Figure 1, panel A) to a maximum decrease of 25 *Wr* units (SS for Roy; Figure 1, panel A). Significant differences between *Wr* and *Wr*Max existed in every length category except the M-T category (Table 1). Percent differences in relative weight ranged from -2.3% for the M-T category for pickerel (Table 1) translating to a decrease from *Wr*Max to *Wr* by 2 *Wr* units (Figure 1, panel A) to -18.7% for the SS category for Roy (Table 1), a difference of 23 *Wr* units (Figure 1, panel A).

For walleye, Wilcoxon two-sample comparison tests indicated that there were statistically significant differences between *Wr*E and *Wr*Max in every length category except the M-T length category (Table 1). The smallest percent difference between *Wr*E and *Wr*Max was -4.68% (P-M category for Harlan Reservoir; Table 1) representing an increase in relative weight from *Wr*E to *Wr*Max of 4 *Wr* units (Figure 1, panel B). The largest percent difference between *Wr*E and *Wr*Max was -11.7% (SS category for Pelican; Table 1), representing an increase relative weight from *Wr*E to *Wr*Max of 12 *Wr* units (Figure 1, panel B). Significant difference between *Wr* and *Wr*Max existed in every length category except the M-T category (Table 1). The smallest percent difference between *Wr* and *Wr*Max was -3.31% (S-Q category for Kansas; Table 1) representing an increase in relative weight from *Wr* to *Wr*Max of 3 *Wr* units (Figure 1, panel B) while the largest percent difference was -15.6% (SS category for Bitter; Table 1) representing an increase in relative weight from *Wr* to *Wr*Max of 18 *Wr* units (Figure 1, panel B).

<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*, for some length categories, the increase is significant. For example, estimates of *Wr*MAX were significantly larger than estimates of *Wr*E in smallmouth bass in the SS length category, by as many as 20 *Wr* units, suggesting that at maximum stomach capacity the stomach contents of fishes can have significant 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 slope coefficients, *b*, for smallmouth (*b* = 0.0381) and walleye (*b* = 0.0467) 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 for the differences in slope coefficients 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. 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 -20.9% difference in the substock length category of smallmouth bass in Roy lake which translates to a change in *Wr* of 25 units. 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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<A>Supplements

A repository that includes the R code used in this manuscript is available at <https://github.com/stevenranney/fishStomachContents>.

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 smallmouth bass (*Micropterus dolomieu*) and walleye (*Sander vitreous*) individuals (*Wr*), individuals minus stomach contents (*Wr*E), and individuals at estimated maximum stomach capacity (*Wr*MAX) by population and five-cell length category. Asterisks (\*) indicate comparisons that were significantly different.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Length Category | Population | *n* | *Wr*E *×* *Wr* | % difference | *Wr*E *×* *Wr*Max | % difference | *Wr* *×* *Wr*Max | % difference |
| Smallmouth bass | SS | Clear | 53 | 0.596 | -1.07 | 5.07e-09\* | -15.7 | 2.24e-08\* | -14.8 |
| Enemy Swim | 83 | 0.46 | -2.41 | 5.27e-14\* | -20.1 | 7.51e-13\* | -18.1 |
| Pickerel | 61 | 0.556 | -0.799 | 6.28e-13\* | -17.1 | 4.59e-12\* | -16.4 |
| Roy | 77 | 0.566 | -2.61 | 4.36e-10\* | -20.9 | 2.9e-09\* | -18.7 |
| S-Q | Clear | 101 | 0.359 | -1.33 | 2.89e-10\* | -7.76 | 1.38e-08\* | -6.52 |
| Enemy Swim | 106 | 0.372 | -2.13 | 2.3e-09\* | -9.38 | 1.18e-07\* | -7.4 |
| Pickerel | 95 | 0.521 | -1.43 | 1.36e-08\* | -7.8 | 2.99e-07\* | -6.45 |
| Roy | 108 | 0.369 | -0.649 | 8.07e-10\* | -7.8 | 3.21e-08\* | -7.2 |
| Q-P | Clear | 61 | 0.467 | -1.54 | 0.000223\* | -4.68 | 0.00167\* | -3.19 |
| Enemy Swim | 30 | 0.398 | -1.17 | 0.00116\* | -4.66 | 0.0055\* | -3.53 |
| Pickerel | 69 | 0.334 | -0.496 | 1.03e-05\* | -4.62 | 2e-04\* | -4.14 |
| Roy | 44 | 0.341 | -1.67 | 0.00111\* | -5 | 0.0119\* | -3.39 |
| P-M | Clear | 40 | 0.569 | -0.592 | 0.0317\* | -3.61 | 0.0914 | -3.03 |
| Enemy Swim | 29 | 0.677 | -0.221 | 0.0872 | -3.63 | 0.132 | -3.42 |
| Pickerel | 64 | 0.337 | -1.2 | 0.00162\* | -3.97 | 0.0197\* | -2.8 |
| Roy | 17 | 0.658 | -0.755 | 0.131 | -3.55 | 0.218 | -2.82 |
| M-T | Clear | 39 | 0.576 | -0.815 | 0.142 | -3.44 | 0.223 | -2.65 |
| Enemy Swim | 4 | 0.686 | -0.848 | 0.686 | -3.41 | 0.686 | -2.58 |
| Pickerel | 7 | 0.62 | -1.31 | 0.535 | -3.58 | 0.535 | -2.3 |
| Roy | 43 | 0.399 | -0.979 | 0.0216\* | -3.42 | 0.0999 | -2.47 |
| Walleye | SS | Bitter | 68 | 0.243 | -0.539 | 1.31e-20\* | -16 | 9.15e-20\* | -15.6 |
| Harlan Reservoir | 5 | 0.69 | -2.83 | 0.69 | -14.9 | 0.69 | -12.4 |
| Pelican | 8 | 0.645 | -0.318 | 0.00699\* | -11.7 | 0.0104\* | -11.4 |
| S-Q | Bitter | 81 | 0.544 | -0.522 | 1.86e-09\* | -6.54 | 2.4e-08\* | -6.05 |
| Harlan Reservoir | 50 | 0.537 | -1.12 | 0.00218\* | -6.87 | 0.00803\* | -5.81 |
| Kansas | 44 | 0.57 | -2.4 | 0.0122\* | -5.64 | 0.0392\* | -3.31 |
| MO River | 36 | 0.52 | -0.235 | 0.00151\* | -6.01 | 0.00624\* | -5.79 |
| Pelican | 14 | 0.352 | -1.77 | 0.00915\* | -6.31 | 0.0308\* | -4.62 |
| Twin | 9 | 0.73 | -0.688 | 0.0625 | -7.69 | 0.0939 | -7.06 |
| Q-P | Bitter | 186 | 0.459 | -0.563 | 2.02e-11\* | -5.11 | 9.41e-10\* | -4.57 |
| Harlan Reservoir | 61 | 0.542 | -0.472 | 0.000178\* | -5.4 | 0.00101\* | -4.95 |
| Kansas | 187 | 0.609 | -0.624 | 1.02e-06\* | -5.18 | 1.28e-05\* | -4.58 |
| MO River | 52 | 0.628 | -1.11 | 0.000785\* | -5.2 | 0.00276\* | -4.13 |
| Pelican | 28 | 0.655 | -0.949 | 0.0135\* | -5 | 0.0375\* | -4.09 |
| Twin | 8 | 0.721 | -0.401 | 0.382 | -4.91 | 0.382 | -4.53 |
| P-M | Bitter | 11 | 0.748 | -0.258 | 0.217 | -4.79 | 0.243 | -4.54 |
| Harlan Reservoir | 14 | 0.748 | -0.0245 | 0.0212\* | -4.68 | 0.0212\* | -4.66 |
| Kansas | 32 | 0.634 | -2.03 | 0.0845 | -4.6 | 0.17 | -2.62 |
| MO River | 7 | 0.71 | -0.121 | 0.456 | -4.77 | 0.535 | -4.66 |
| Pelican | 8 | 0.721 | -0.36 | 0.382 | -4.71 | 0.442 | -4.37 |
| M-T | Harlan Reservoir | 9 | 0.73 | -0.0645 | 0.34 | -4.48 | 0.34 | -4.42 |
| Kansas | 18 | 0.58 | -1.8 | 0.111 | -4.5 | 0.252 | -2.75 |
| Pelican | 4 | 0.686 | -2.1 | 0.686 | -4.51 | 0.686 | -2.47 |
| Twin | 3 | 0.4 | -3.37 | 0.4 | -4.51 | 0.507 | -1.18 |

<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. The linear regression (solid line) does not truly estimate the maximum stomach contents for each species. Note different scales on both axes.

Figure 2. Box plot of relative weight with (*Wr*) and without stomach contents (*Wr*E) and at estimated maximum stomach capacity from quantile regression at the 99th quantile (*Wr*Max) by length category (Gabelhouse 1984) and population for smallmouth bass *Micropterus dolomieu* (Panel A) and walleye *Sander vitreus* (Panel B). 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.

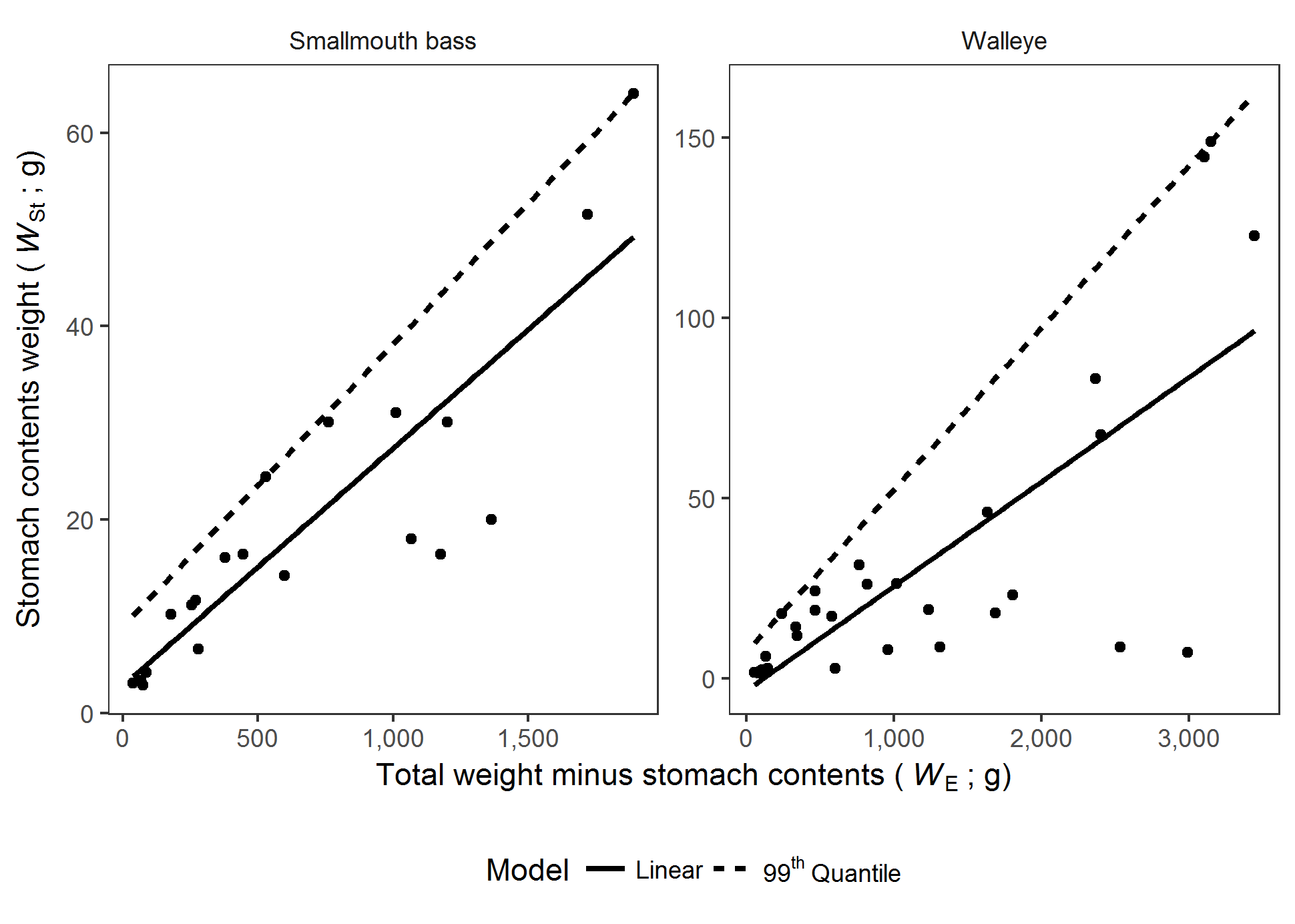


Figure 1.

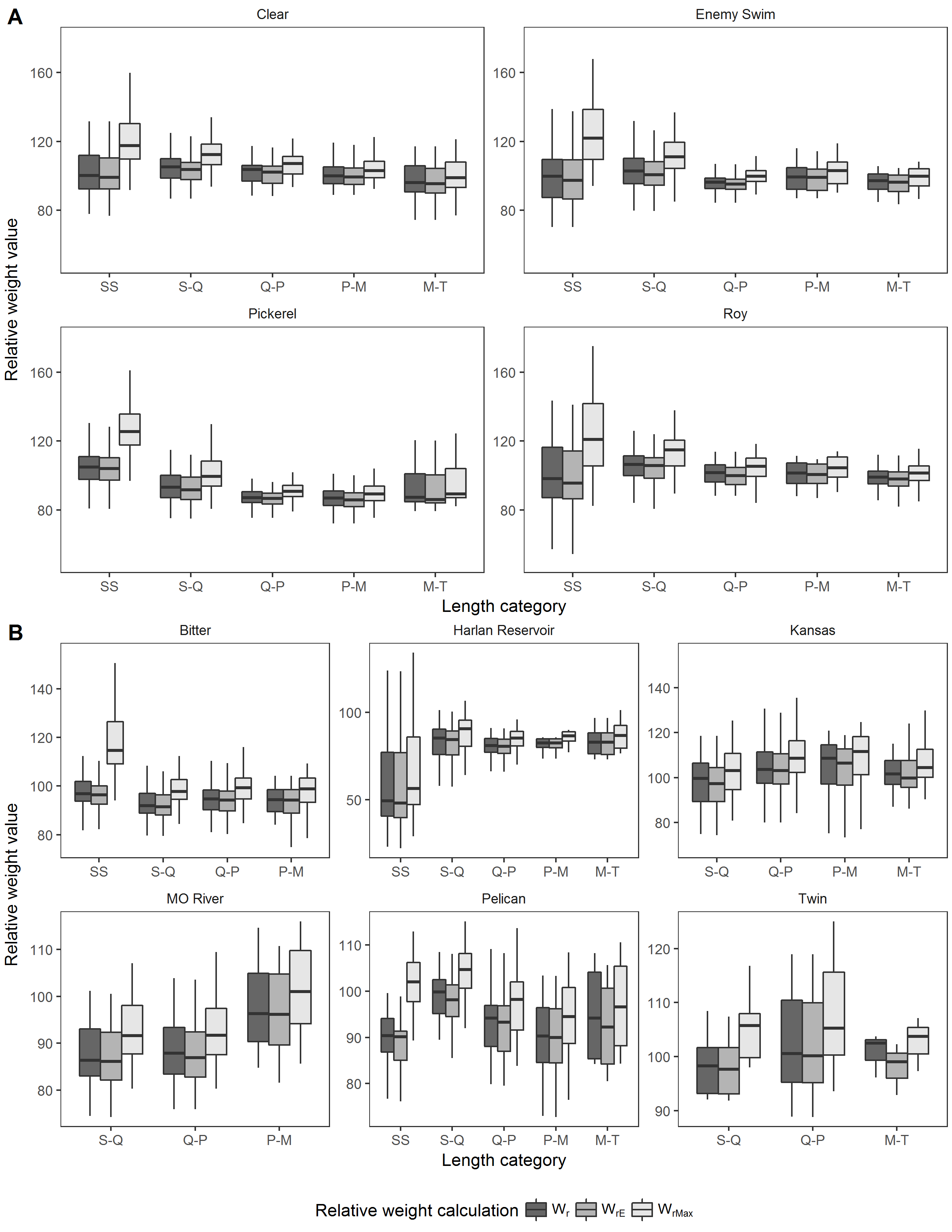


Figure 2.