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An improved procedure to assess fish condition on the basis of length-weight relationships

Hartmut Richter; Christian Lückstädt; Ulfert L. Focken; Klaus Becker

Institute for Animal Production in the Tropics and Subtropics, University of Hohenheim, Stuttgart, Germany

Abstract

In a recent article, a new factor has been proposed to assess condition in fish (Jones et al. 1999). It is based not only on body mass and length, but also on body height. The new factor, B (= $M/(L^2 \times H)$; M, L and H = body mass, length and height, respectively), was tested against the traditional factor of Fulton, ($K = M/L^3$) using data sets for two salmonid species, and it was found to be a better pred'ictor of body mass from body dimensions. B assumes that body thickness is better correlated with length than height. To test this, we compared K and B, as well as K' (= M/L^b; b derived from regression of Log[M] against Log[L]) and B' (= $M/(L \times H^2)$), using data on milkfish, *Chanos chanos*. The factor B' consistently gave the best results, and in larger fish K' was found to be a better predictor of body mass than B. Regression analysis of body mass and height on length showed that body thickness varies isometrically with height but allometrically with length, explaining why B' is better than B.

Kurzfassung

In einem kürzlich erschienenen Artikel wurde ein neuer Faktor zur Beschreibung der Fischkondition vorgeschlagen (Jones et al. 1999), der zusätzlich zur Körpermasse und Körperlänge auch die Körperhöhe berücksichtigt. Dieser Faktor, B (= $M/(L^2 \times H)$; M, L und H = Körpermasse, -länge und -höhe) wurde mit der traditionellen Konditionsfunktion (Fulton, $K = M/L^3$) anhand zweier Datensätze von Salmoniden verglichen, wobei er eine bessere Vorhersage der Körpermasse aus den Körperdimensionen liefert. B nimmt an, dass Körperdicke mit der Körperlänge besser korreliert, als mit der Höhe. Um dies zu überprüfen, wurden hier sowohl K und B, als auch K' (= M/L^b; b hergeleitet aus der Regression von Log[M] gegen Log[L]) und B' (= $M/(L \times H^2)$) mit Daten von Milchfischen, *Chanos chanos*, verglichen. B ergab gleichmäßig bessere Ergebnisse als die anderen Faktoren und K' ergab bessere Vorhersagen der Körpermasse bei größeren Fischen als B. Regressionsanalysen von Körpermasse und Höhe gegen Länge zeigten, dass Körperdicke isometrisch mit der Höhe variiert, aber allometrisch mit der Länge, und dies erklärt die bessere Anwendbarkeit von B' verglichen mit B.

Introduction

In the field of fisheries science, much literature has been devoted to the study of fish condition (*e.g.* Wilson and Pitcher 1983; de Silva 1985; Kum agai *et al*. 1985; Bagarinao and Thayaparan 1986; Getachew 1987; Mundahl and Wissing 1987) and the suitability of mathematical equations for its description (*e.g.* Ricker 1975; Bagenal and Tesch 1978;

Bolger and Connolly 1989). The basic assumption underlying the use of condition factors is that fish in better "condition" (nutritional and health status) are more full-bodied and therefore heavier at a given length. Fish condition has therefore been traditionally estimated by the equation proposed by Fulton (1911):

$$K = 100 \times M/L^3 \qquad \text{(Eq. 1)}$$

where K = condition factor, M = body mass, L = body length.

This equation assumes isometric growth, i.e. that the relative proportions of body length, height and thickness do not change in fish of similar condition as these increase in weight. It has, however, been shown that fish often grow allometrically, i.e. that these proportions are not constant, with the rate of allometry changing between different growth "stanzas" (*e.g.* in brown trout, *Salmo trutta* L., as demonstrated by Bagenal and Tesch 1978). One of the best ways to determine allometric growth in a fish species is to assess the condition of a single population over a considerable range of body lengths at the same time of year. A gradual rise in condition with increasing length usually indicates allometry, as found by Weatherley (1959) for tench, *Tinca tinca* (L.). This phenomenon is inconvenient in the assessment of fish condition, since it increases the scatter around the mean condition factor K of a population. As a result, in comparisons between two populations from different habitats or samples from different times of the year, no statistically significant differences might be found when in fact these would become apparent if the allometry factor were eliminated. Worse, two such samples might be assessed as being statistically different with respect to fish condition, whereas a closer analysis would reveal that these discrepancies are merely due to differences in mean fish length between the samples.

To reduce or eliminate the effects of allometry from the estimation of fish condition, the condition factor, K', has been proposed (*e.g.* Bagenal and Tesch 1978):

$$K = 100 \times M/L^b \qquad \text{(Eq. 2)}$$

where b is a constant determined from the length-weight relationship:

$$M = a \times L^b \qquad \text{(Eq. 3)}$$

One of the problems with the condition factor K' is that it is very difficult to obtain a reliable value for b, particularly if the data set used to estimate b is small or does not span a wide enough range of body lengths. Furthermore, as pointed out above, the value of b is not constant for any species, but varies between stanzas, so that the results gained from a particular data set cannot be transferred to or compared with another data set, even if it is on the same species.

To overcome or minimise these problems, Jones *et al.* (1999) proposed a new condition factor based not only on the length and weight of the fish, but also on the height. The reasoning behind this factor was that the mass of a body is related to its density and its dimensions in three planes, while on the other hand, body height is more easily and reliably measured than girth or body thickness. The proposed condition factor therefore made more allowance for body height and thickness when these are allometrically related to length, but at the same time required little additional effort to be accurately determined. The new factor, termed *B*, is computed by the following equation:

$$B = M/(H \times L^2) \qquad \text{(Eq. 4)}$$

where M = Body Mass, H = Body Height, L = Body Length.

Using data on Atlantic salmon, *Salmo salar* L., and chinook salmon, *Oncorhynchus tshawytscha* (Walbaum), Jones *et al.* (1999) demonstrated that the variability between the actual mass and the mass back-calculated from the length, height and average *B* was lower than that between actual mass and the value back-calculated from length and average *K*. This was also demonstrated by the fact that the relationship between body mass and B/B_{avg} gave less scatter and was more constant over a wide range of body mass than the equivalent K/K_{avg}, particularly in the case of chinook salmon, which was said to "become deep and full bodied from its early torpedo shape", suggesting allometric growth in this species. A comparison between *K* and *B* for a variety of other fish species showed that the values of *B* were more similar between different species (lower coefficient of variation) than the corresponding values of *K*.

The condition factor *B* proposed by Jones *et al.* (1999) is based on the assumption that the mass *M* of a body can be calculated from its density · and dimensions L_1, L_2 and L_3 as follows:

$$M = \rho \times L^{a}{}_1 \times L^{b}{}_2 \times L^{c}{}_3 \qquad \text{(Eq. 5)}$$

where *a*, *b*, and *c* are constants. Their aim was to find the most accurate relationship between $L^{b}{}_2$, mass and body dimensions, so that the condition factor of the fish would be affected only by the proportionality constant ?. Since the shape of a fish is probably best described as an ellipsoid, the above equation approximates to:

$$M = 4/3\ \pi \times \rho \times L \times H \times T \qquad \text{(Eq. 6)}$$

or, after removal of the constants:

$$\rho \propto M(L \times H \times T) \qquad \text{(Eq. 7)}$$

where M = mass, ρ = density, L = length, H = height, T = thickness, $\propto$ denotes "proportional to"

Jones *et al.* (1999) argued that the thickness of a fish is the most labour-intensive of the three dimensions to determine, is difficult to measure without a high degree of error and, unlike length and height (which can be estimated from underwater photographs), must be determined by handling the fish. Therefore, they decided to replace the factor *T* in the above equation with *L*, and arrived at Eq. 4. This assumes a linear relationship between length and thickness, even when the fish are growing allometrically, so that in the classical length-weight relationship (Eq. 2) any significant deviation in the parameter b from the "ideal" value of 3.0 may be attributed entirely to a change in relative height.

It is difficult to imagine that the above assumption should hold true. In species which become more eel-like as the fish ages, i.e. where relative length increases, this would imply that the fish becomes wider relative to body height. We therefore propose that the mass-dimension relationship based on length and height which reduces the effect of allometric growth to a minimum should be as follows:

$$B' = M/(H \times L^2) \qquad \text{(Eq. 8)}$$

Material and Methods

To test the above condition factor B' and compare it to the preceding factors K, K' and B, we investigated the mass-dimension relationship in a data set on milkfish, *Chanos chanos* Forsskål. The data were obtained from various sources in Luzon and Panay, Philippines, and had been collected from five sampling sites on sixteen distinct sampling occasions between June 1995 and August 1998. The dimensions used for our analysis were total length, height at the anterior edge of the dorsal fin (both to the nearest mm) and total weight (to the nearest 0.1 g). The data set was made up of a total of 828 fish, ranging from 93 to 377 mm total length and 6.3 to 528.5 g total weight (Figure 1). A preliminary analysis of Log[length] to Log[weight] suggested that this species has' allometric growth (b in Eq. 3 = 3.131; SE_b = 0.025; df = 826; r^2 = 0.949; $p < 0.001$ for deviation of b from 3.0) so that this data set is eminently suited to test whether B' gives a better description of the mass-dimension relationship than B.

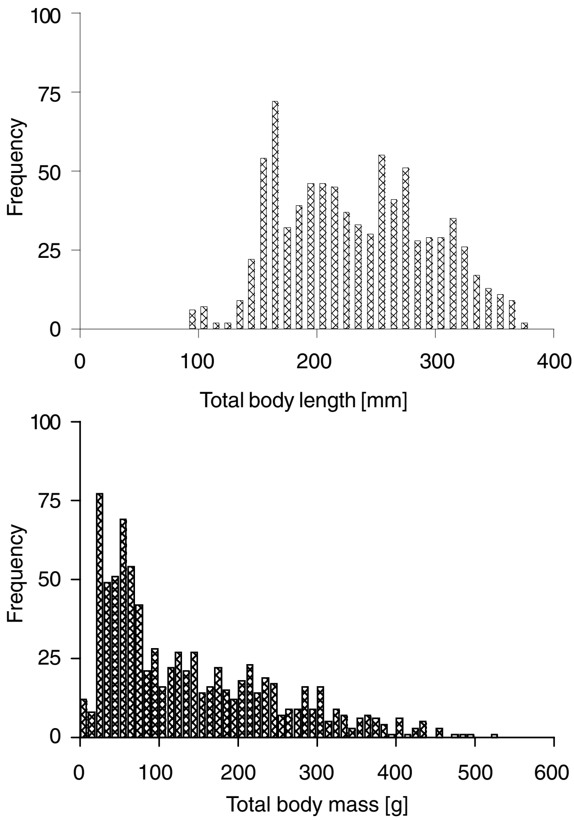

Figure 1: Length-frequency and mass-frequency distributions of the combined milkfish data set analysed here.

The condition factors K, K', B and B' were calculated individually for each fish by Eqs. 1, 2, 4 and 8. A multiplier of 100 was used in the case of B and B' for the sake of standardisation, and a sample average was determined for each condition factor. These averages were then used to back-calculate the body mass of each individual fish according to the following equations:

$$M_{\mathrm{calc}[K]} = K_{\mathrm{avg}} \times L^3 \qquad \text{(Eq. 9)}$$

$$M_{\mathrm{calc}[K]} = K'_{\mathrm{avg}} \times L^{3.131} \qquad \text{(Eq. 10)}$$

$$M_{\mathrm{calc}[B]} = B_{\mathrm{avg}} \times L^2 \times H \qquad \text{(Eq. 11)}$$

$$M_{\mathrm{calc}[B']} = B'_{\mathrm{avg}} \times L \times H^2 \qquad \text{(Eq. 12)}$$

These back-calculated masses were regressed against the actual body masses in line with the analysis performed by Jones *et al.* (1999; their Figures 1 and 2) with the y-intercept forced through the origin (linear regression of the form $M_{\mathrm{calc}} = i + d \times M$ for each condition factor with the intercept i fixed at zero). In our study, the predictive ability of the various models was not only tested by comparing the scatter around the regression line (highest coefficient of determination, r^2) but also by assessing how close the regression slope d came to the ideal value of 1.0 (t-test, Sokal and Rohlf 1995). We also plotted body mass against K/K_{avg}, K'/K'_{avg}, B/B_{avg} and B'/B'_{avg}, respectively, according to Jones *et al.* (1999; their Figures 3 and 4) and calculated linear regression lines of the form:

$$F/F_{\mathrm{avg}} = f + g \times M \qquad \text{(Eq. 13)}$$

(F and F_{avg} represent the condition factor and the mean condition factor under consideration, f = y-intercept, g = slope of the regression line)

In each case, we also used a t-test to assess the departure of the regression slope g from 0.0 (dependence of condition factor on body mass, i.e. reduced ability of the condition factor to allow for allometry) and the intercept f from 1.0.

Results

As found by Jones *et al.* (1999), the factor B gave a closer fit in the regression of back-calculated on recorded weight than K or K' (coefficient of determination, Table 1; see also Figure 2); however, the proposed factor B' gave an even better fit. More importantly, the deviation of the regression line, d, from a value of 1.0 was least significant when B' was applied (Table 1); moreover, the traditional factor K' performed better in this respect than the one proposed by Jones *et al.* (1999). The analysis of body mass against (condition factor)/(average condition factor) for the various factors (Table 2, Figure 3) showed that all of them deviated significantly from a slope of zero, but the level of significance was lowest in the case of B'. In no case did the y-intercept deviate significantly from 1.0.

Table 1: Results of the regression analysis between the actual body mass and the body mass back-calculated from the condition factors *K*, *K'*, *B* and *B'*. The y-intercept was forced through the origin in each case. *: 0.01 < p < 0.05 **: 0.001 < p < 0.01 ***: p < 0.001

Regression statistic	*K*	*K'*	*B*	*B'*
Coefficient of determination, r^2	0.959	0.962	0.984	0.987
Regression slope, *d*	0.951	0.989	0.966	0.995
SE_d	4.00×10^{-3}	4.11×10^{-3}	2.57×10^{-3}	2.43×10^{-3}
Degrees of freedom	827	827	827	827
p for departure of *d* from 1.0	***	**	***	*

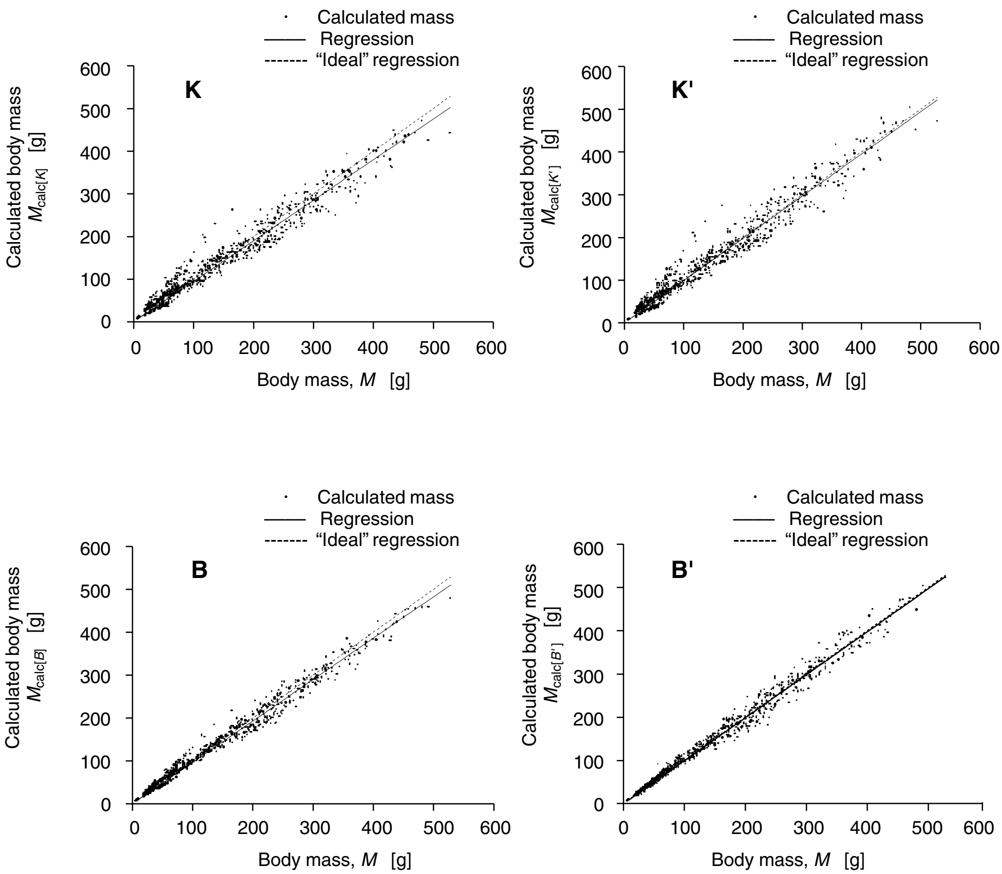

Figure 2: Plots of observed against back-calculated body mass, and of the resulting regression (intercept forced through zero) for the condition factors *K, K', B* and *B'*. "Ideal" regression (intercept = 0.0, slope = 1.0) included for comparison.

Table 2: Results of the regression analysis between the ratio of condition factor to average condition factor, and body mass, for the condition factors *K*, *K'*, *B* and *B'*. *: 0.01 < p < 0.05, **: 0.001 < p < 0.01, ***: p < 0.001, n.s.: not significant

Regression statistic	*K*	*K'*	*B*	*B'*
Degrees of freedom	826	826	826	826
Regression slope, *g*	5.35×10^{-4}	2.30×10^{-4}	3.25×10^{-4}	0.65×10^{-4}
SE_g	5.99×10^{-5}	6.31×10^{-5}	3.62×10^{-5}	2.64×10^{-5}
p for departure of *g* from 0.0	***	***	***	*
y-intercept, *f*	0.926	0.968	0.955	0.991
SE_f	0.187	0.197	0.113	0.082
p for departure of *f* from 1.0	n.s.	n.s.	n.s.	n.s.

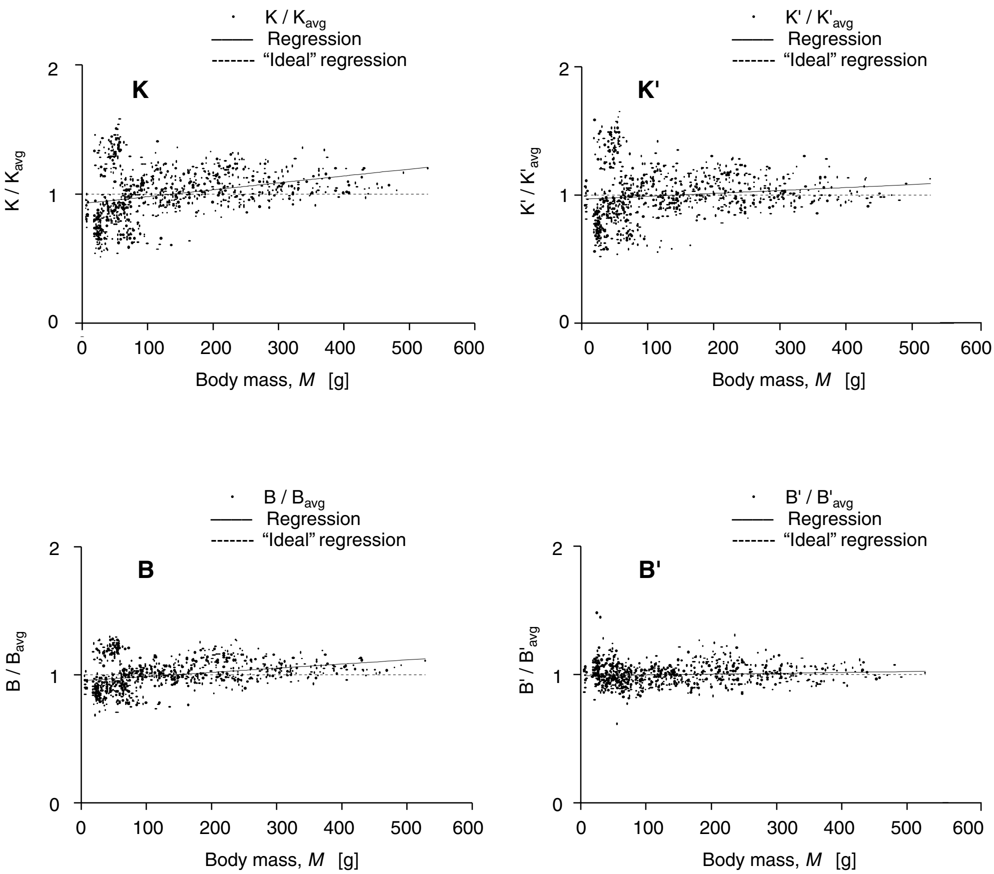

Figure 3: Plots of observed body mass against the ratio of condition factor to average condition factor, and of the resulting regression for the condition factors K, K', B and B'. "Ideal" regression (intercept = 1.0, slope = 0.0) included for comparison.

Discussion

The regression of observed against back-calculated body masses (Table 1, Figure 2) shows that, although the overall predictive powers of the factor *B* were better than those of the factors *K* and *K'*, the factor *K'* performed better at the upper extreme of the range, i.e. in the case of large fish. The proposed factor *B'*, on the other hand, produced better results than the other three factors throughout the range of body weights analysed. These findings are corroborated by the regression of F/F_{avg} on body mass, where factor *B'* yielded the least scatter and lowest slope.

To find possible causes for the better performance of *B'* compared to the other three factors (as well as that of *K'* compared to *B* in at least some respects), we must look at the relative changes between the three body dimensions *L*, *H* and *T*. Jones *et al.* (1999) investigated the relationship between length and height and stated that "the power law equation ... gave consistently higher r^2s over other models." They did not, however, give any detailed analysis results other than in their relevant figure (plot of length vs. height) which included the coefficients of determination for the power model only and was not referenced in the text. We tested the relationship between these two dimensions by a linear model (linear regression; $y = ax$, intercept forced through the origin) and by the power model (nonlinear regression; $y = ax^h$). The power model also gave the better fit in the case of our milkfish data (linear; $r^2 = 0.915$; power: $r^2 = 0.918$) and the parameter *h* in this model was estimated to be 1.065 ($SE_h = 0.0118$, df = 826, $p < 0.001$ for departure of *h* from 1.0).

This has very interesting implications for the relationship between body mass and the three dimensions determining body volume, as well as the equation best suited to describe body condition. The above regression demonstrated that:

$$H \cdot L^{1.065} \qquad \text{(Eq. 14)}$$

Assuming that body density is independent of body size and varies only with condition, and that the average condition of our milkfish did not differ between size classes, the parameter ? can be dropped from Eq. 6, which can then be rewritten as:

$$M \cdot L \times H \times T \qquad \text{(Eq. 15)}$$

Substituting the parameter *H* with its equivalent in terms of *L* from Eq. 14, this gives:

$$M \cdot L \times L^{1.065} \times T \qquad \text{(Eq. 16)}$$

Since the parameter *b* in the length-weight relationship $M = a \times L^b$ was found to be 3.131 for our combined milkfish data, the following relationship between body length and thickness can be derived from a combination of Eqs. 3 and 16:

$$L^{3.313} \cdot M \text{ or } L^{3.313} \cdot L \times L^{1.065} \times T \qquad \text{(Eq. 17)}$$

giving

$$T \cdot L^{3.313}/L^{2.065} \text{ or } T \cdot L^{1.066}, \qquad \text{(Eq. 18)}$$

which implies a nearly isometric relationship between body height *H* and thickness *T*.

In view of the above, it is hardly surprising that the condition factor B' is a better predictor of body mass from body length and height than the other factors, at least in the case of milkfish.

One final point to be discussed is the variation of the factor B with what is generally regarded as condition. As Jones *et al.* (1999) pointed out, "the study of condition assumes that heavier fish of a given length are in better condition". On the other hand, it was their stated intention to devise a model in which "the proportionality constant [density, ·· in Eq. 4] would be the only regression parameter to be determined". We would like to point out that, as a fish's condition increases, body water is replaced mainly by lipid and, to a lesser extent, protein while ash content remains relatively constant (Focken and Becker 1993, Kühlmann 1998). Thus, a condition factor based only on variation in density would actually *decrease* as the fish's condition improves. Furthermore, whether the fluctuations in body density are large enough to be captured by a condition factor is open to debate. If the relationship of body density to lipid content determined by Siri (1956, cited in Durnin and Womersley 1974) is applied to relatively fatty fish such as common carp, *Cyprinus carpio* L., over the entire range of body fat content (2 to 39% of dry matter, Focken and Becker 1993), the body density would be expected to change by less than 10 % (1.01 to 1.09 $g \cdot m^{-3}$).

In summary, we prefer the use of the condition factor B' over B since it is based on the same parameters, is just as simple to calculate and gives a better description of the relationship between body mass and dimensions needed to reduce the effects of allometry on the estimation of fish condition. Even in those cases where body height is available, the traditional factor K' can be a better predictor of body mass than B for the larger fish in the population being analysed, although it is not as good as B'. The traditional factor K' seems to perform quite adequately when data on body height are not available.

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Authors' address: Dr. Hartmut Richter; Christian Lückstädt; Ulfert L. Focken; Klaus Becker, Institut für Tierproduktion in den Tropen und Subtropen, Fachgebiet für Tierernährung und Aquakultur, Universität Hohenheim, Fruwirthstraße 12, 70599 Stuttgart, Germany, Tel: +49-711-459-3158; Fax.: +49-711-459-3702; E-mail: inst480@uni-hohenheim.de

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