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Mathematical models to predict growth, fillet traits, and composition of wild traíra, *Hoplias malabaricus*

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ABSTRACT - This study aimed to determine the length-weight relationship and mathematical models to predict dressed and fillet weight and yield and fillet composition of wild traíra, *Hoplias malabaricus* (Bloch, 1794). A total of 80 marketable-sized fish from 292.28 to 2879.57 g and 32.06 to 61.19 cm were used. The length:weight ratio was estimated using the equation: $W = a \times L^b$, in which W is body weight (g) and L is length (cm). The models of dressed and fillet weight and yield and body were elaborated using first-order ($\hat{y}_i = \beta 0 + \beta 1x_i$) or second-order ($\hat{y}_i = \beta 0 + \beta 1x_i + \beta 1x_i^2$) linear regression analyses. The value of slope b in the length:weight ratio was 3.3732 and intercept was 0.0029. The prediction equations obtained for dressed weight, fillet weight, dressed yield, fillet yield, fillet gross energy, moisture, crude protein, crude lipid, and ash were, respectively: $\hat{y} = 0.3244 + 0.9373W$, $\hat{y} = 0.7651 + 0.4181W$, $\hat{y} = 939.8015 + 0.0019W$, $\hat{y} = 420.55170 + 0.0064W$, $\hat{y} = 997.9600 + 0.0630W$, $\hat{y} = 810.6500 - 0.0085W$, $\hat{y} = 184.080 - 0.0111W$, $\hat{y} = 3.1131 + 0.0049W$, and $\hat{y} = 10.6110 + 0.0009W$, in which W is the body weight of fish (g). We demonstrated the possibility of elaborating realistic expressions to describe degutted weight, fillet weight, and fillet composition. However, lower mathematical adjustment was observed to estimate realistic prediction of dressed and fillet yield.

Keywords: aquaculture, carcass, fish, growth curve, meat quality

Introduction

Hoplias malabaricus (Bloch, 1794) is a neotropical freshwater fish widely distributed in Latin America (Bertollo et al., 2000) from Colombia to Argentina (Balboni et al., 2011). This fish species inhabits lentic and lotic environments (Silva et al., 2013), is appreciated as sporting fish (Balboni et al., 2011), and fillet of wild fish is known to be rich in protein and polyunsaturated fatty acids (Torres et al., 2012).

Growth is characterized by change in size and tissue composition, and is one the most important parameter in aquaculture. The body composition of fish has been received attention in studies on nutrition (Dumas et al., 2010), genetics improvement (Gjedrem, 2000; Tobin et al., 2006), human health (Hunter and Roberts, 2000), and particularly because of increasing interest in fish quality and safety products (Mozaffarian and Rimm, 2006) to ensure the nutritional quality of fish (Azam et al., 2004). Carcass traits of fish has also been used to estimate and introduce selection program (Quinton et al., 2005; Navarro et al., 2009). Body composition and carcass traits are markedly influenced by fish species and size and considered as priority variable in fish processing industry (Neira et al., 2004).

Although several studies have evaluated the biology of growth (Balboni et al., 2011) (Bialetzki et al., 2008), genetics (Cioffi et al., 2009), reproduction (Marques et al., 2001; Querol et al., 2003; Chaves et al., 2011), and feeding habits (Carvalho et al., 2003), only a single study has evaluated the proximate composition and fillet yield of *H. malabaricus* (Santos et al., 2001), and this is the first mention of using mathematical modeling to estimate growth, fillet composition, and yield for this fish species.

Building a mathematical model of fish growth offers a robust and practical tool to estimate weight at time between sampling intervals and may be very helpful for the accurate estimation of the standing biomass and feeding allowance during fish culture. Mathematical modelling has been intensively used to elaborate equations to describe or simulate body composition of fish, and linear regression has been proposed to predict body composition of farmed and wild fish (Dumas et al., 2010).

Skin-on fillet of traíra is preferred for cutting bones during processing and preserving fillet integrity before frying. Despite the great social and economic importance of *H. malabaricus* to the South America communities, the usefulness data of length:weight ratio, fillet yield, and composition is poorly documented. Thus, this work was carried out to elaborate mathematical models of growth, dressing and fillet weight, and yield and fillet composition of wild *H. malabaricus* using linear regression.

Material and Methods

A total of 80 fish from 292.28 to 2879.57 g and 32.06 to 61.19 cm, of combined sex, were obtained already slaughtered from fishermen on the Paraná river (Panorama, SP, Brazil; 21°21'23"S 51°51'35"W) and transported on ice in sealed polystyrene boxes. Combined sexes were preferred to mimic practical conditions of fishing and marketing fish because there are no reliable morphological differences to identify sex in *H. malabaricus*. Individually, total length and body weight were determined using ictiometer (0.1 cm) and precision balance (0.01 g), respectively.

Fish were manually gutted and filleted without including the nape and belly flap, and both fillets were weighed together (Navarro et al., 2009), which derived traits of dressed yield (100 × gutted body weight/body weight) and fillet yield (100 × fillets weight/body weight) that were recorded. Skin-on fillets were obtained and stored in plastic bags at −20 °C until laboratorial analysis to determine proximate analysis. Fish processing was performed by the same operator.

Fish fillets were minced, and the proximate composition analyses of each fish samples were performed in duplicate following the AOAC (2010) procedures. Water content was determined by placing the fish in a pre-weighed aluminum foil tray for drying in an electric oven at 55 °C until constant weight and oven drying at 105 °C for 24 h; crude protein (nitrogen × 6.25) was determined by Kjeldahl method, after acid hydrolysis; lipid was extracted by petroleum ether in a Soxhlet apparatus followed by determination of lipid gravimetrically; and ash was determined by combustion at 550 °C, in a muffle furnace overnight, until constant weight.

Each fish was considered as experimental replicate. Data on total length (L) in cm, and body weight (W) in g, were recorded for each fish. The parameters a (intercept) and b (slope) of the length:weight ratio were estimated using the equation: $W = a \times L^b$ (Ricker, 1973). Parameters a and b were estimated by the least-square method using log-transformed data according to the expression: $log\ W = log\ a + b\ log\ L$, in which a is the intercept of the regression curve and b is the regression coefficients. The average value for b was tested to verify if it was significantly different from 3 using t test at the α = 0.05 significance level.

Prediction equations of fillet composition of *H. malabaricus* were elaborated using first-order ($\hat{y}_i = ß0 + ß1x_i$) or second-order ($\hat{y}_i = ß0 + ß1x_i + ß1x_i^2$) linear regression analysis. All statistical procedures were performed using SPSS statistical package (Statistical Package for the Social Sciences, version 14.0).

Results

The length:weight ratio was established through the equation $W = 0.0029 \times L^{3.3732}$ ($R^2 = 0.9614$) (Figure 1). The average value of *b* was significantly different from 3 ($P<0.05$) according to the t test.

The relationship between dressed and fillet weight to body weight was best fit using first-order linear regression analysis, expressed as: dressed weight $\hat{y} = 0.3244 + 0.9373W$ ($R^2 = 0.9992$) and fillet weight $\hat{y} = 0.7651 + 0.4181W$ ($R^2 = 0.9599$). However, lower mathematical adjustment between dressed yield and fillet yield to body weight was observed, described according to the expressions: dressed yield $\hat{y} = 939.8015 + 0.0019W$ ($R^2 = 0.0035$) and fillet yield $\hat{y} = 420.5517 + 0.0064W$ ($R^2 = 0.0001$), respectively (Table 1).

The relationship between fillet gross energy, moisture, crude protein, crude lipid, and ash to body weight was best expressed using first-order linear regression analysis (Table 2), according to the expressions: gross energy, $\hat{y} = 997.9600 + 0.0630W$ ($R^2 = 0.8539$); moisture, $\hat{y} = 810.6500 - 0.0085W$ ($R^2 = 0.7566$); crude protein, $\hat{y} = 184.0800 - 0.0111W$ ($R^2 = 0.6746$); crude lipid, $\hat{y} = 3.1131 + 0.0049W$ ($R^2 = 0.8542$); and ash, $\hat{y} = 10.6110 + 0.0009W$ ($R^2 = 0.7847$).

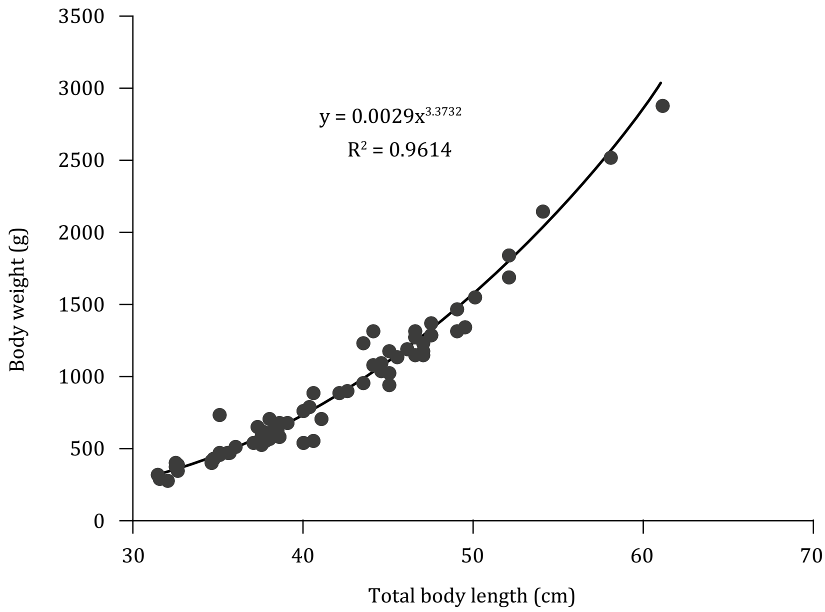

Figure 1 - Length to weight relationship of market-sized wild traíra, *Hoplias lacerdae*.

Table 1 - Statistical details showing number of fish studied (*n*), intercept (*ß0*), slope (*ß1*), and coefficient of determination (R^2) between fillet traits and body weight of market-sized wild *Hoplias malabaricus*

Item	Dressed weight (g)	Fillet weight (g)	Dressed yield (g/kg)	Fillet yield (g/kg)
Body weight				
Range	276.33-2678.64	114.63-1253.55	925.96-945.38	358.93-465.11
Mean	813.81	369.62	938.63	425.23
Statistical details				
n	80	80	80	80
ß0	0.3244	0.7651	939.8015	420.5517
ß1	0.9373	0.4181	0.0019	0.0064
R^2	0.9992	0.9599	0.0035	0.0001

The relationship between fillet humidity and fat was also best fit using first-order linear regression analysis according to the expression: $\hat{y}$ = 408.861 – 0.4998x (R^2 = 0.8309) (Figure 2). Except for crude protein, all other linear regressions were highly significant, and the coefficient of determination ranged from 0.8161 to 0.8539 (P<0.05).

Discussion

In the present study, the b value (3.3732) was significantly higher than 3 and the "cube law" could not be applied for this fish species. If growth model of fish follows the "cube law", Fulton's condition factor (k) or isometric factor ($k = W/L^b$) is validated, the length to weight exponent b value is equal to 3 (Gulland, 1983), and body form remains a constant proportion to length (Weatherley and Gill, 1987). However, Fulton's condition factor is only applied to compare fish of the same size; however, allometric condition factor, which occurs when b is different from *3*, is observed when fish of different stages is used (Braga, 1986). Parameter b, unlike parameter a, may vary seasonally and the length:weight ratio is affected (Cherif et al., 2008). To date, in this study, only market-sized fish were used; however, length

Table 2 - Statistical details showing number of fish studied (n), intercept (*ß*0), slope (*ß1*), and p-coefficient of determination (R^2) between fillet composition and body weight of market-sized wild *Hoplias malabaricus*

Item	Gross energy (kcal/kg)	Moisture (g/kg)	Crude protein (g/kg)	Crude lipid (g/kg)	Ash (g/kg)
Body composition					
Range	982.34-1091.34	780-809.10	160.00-188.00	4.10-19.10	10.50-12.30
Mean	1046.75	803.27	174.48	7.41	11.40
Statistic details					
n	80	80	80	80	80
*ß*0	997.9600	810.6500	184.0800	3.1131	10.6110
*ß*1	0.0630	−0.0085	−0.0111	0.0049	0.0009
R^2	0.8539	0.7566	0.6746	0.8542	0.7847

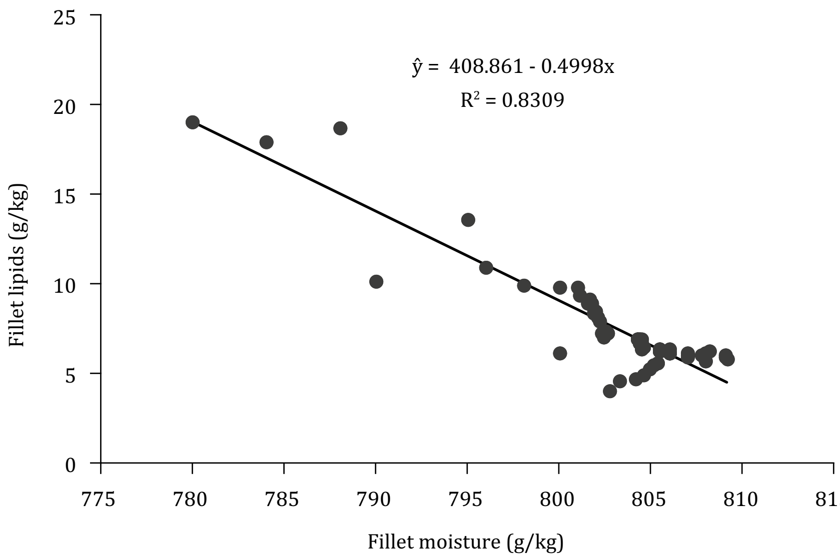

Figure 2 - Relationship between content of moisture and lipids in the fillet of market-sized wild traíra, *Hoplias lacerdae.*

was quite variable, from 32.06 to 61.19 cm, because fish at different stages were used, and allometric growth was obtained.

In this study, fish were not classified considering sex to mimic practical conditions, because there are no reliable visually morphological differences to identify sex of *H. malabaricus* during fishing and marketing. To date, higher mathematical adjustment was obtained to describe length:weight ratio of fish in this study; besides, combined sexes were used. This relationship allows estimating the body weight from length and also extrapolates gutted weight and fillet weight of fish during marketing.

In the present study, the relationship between body weight and fillet weight was high, while the relationship between body weight and fillet yield was low. Similar results were previously observed in Nile tilapia (*Oreochromis niloticus*; Rutten et al., 2004), rainbow trout (*Oncorhynchus mykiss*; Rasmussen and Ostenfeld, 2000), catfish (*Pangasianodon hypophthalmus*; Sang et al., 2009), and European sea bass (*Dicentrarchus labrax*; Vandeputte et al., 2017).

The mean value of dressed (938.63 g/kg) and fillet (425.23 g/kg) yields of wild *H. malabaricus* observed in this study approximated the 928.1 g/kg and 419.9 g/kg (skin-on fillet), respectively, observed in piava, *Leporinus obtusidens* by Geraldo et al. (2015); similarly, it approximated the 923.5 g/kg of dressed yield obtained in rainbow trout (Souza et al., 2015) and 914.4 g/kg in surubin, *Pseudoplatystoma* spp (Fantini et al., 2014). However, higher values of fillet yield (skin-on) were observed in European sea bass (457.0 g/kg), gilthead sea bream (*Sparus aurata*; 477.3 g/kg), and rainbow trout (Testi et al., 2006).

In the present study, the high variation observed in fillet yield (358.93 to 465.11 g/kg) is in agreement to previously described in the same fish species (348.2 to 538.5 g/kg) by Santos et al. (2001). Fillet yield varies among fish species (Rasmussen and Ostenfeld, 2000; Testi et al., 2006) and is markedly affected by nutrition (Lanari et al., 1999; Geraldo et al., 2015) and processing method (Margeirsson et al., 2007).

Linear regression analysis has been extensively used for predicting body component because of the very high relationships found between body weight and proximate composition of fish. In general, lower variations of crude protein and ash are observed, while humidity and crude lipid are quite variable (Breck, 2014). As fish grows in size, it deposits relatively more fat than other tissues, as previously reported for other fish species (Geraldo et al., 2015).

In the present study, lower mean value of body crude lipids (7.41±0.59 g/kg) was observed in the fillets of fish, in agreement with the 8.4 g/kg previously described for this same fish species (Santos et al., 2001), and higher than 5.6 to 6.4 g/kg found in pirarucu, *Arapaima gigas* (Fogaça et al., 2011). However, higher values of crude lipids ranging from 39 to 61 g/kg in fillets of sea bass (Lanari et al., 1999), 79.6 to 90.4 g/kg in rainbow trout (Souza et al., 2015), and 85 to 218 g/kg in Atlantic salmon, *Salmo salar* (Mørkøre et al., 2001) were described.

Body composition of fish is affected by many factors such as fish species, environmental variables, dietary factors, and body size (Breck, 2014). Determining body component in relation to fish size is strongly associated to meat quality and is considered an important attribute used by consumers. In addition, proximate composition is also used to select appropriate species and genetic improvement programs (Neira et al., 2004; Quinton et al., 2005; Tobin et al., 2006; Navarro et al., 2009) to improve meat quality for human consumption.

The content of moisture in whole body is a good indicator of the relative content of lipids and energy, and low percentage of moisture is associated to high content of lipids and energy (Dempson et al., 2004). In this study, positive linear relationship between body weight and lipid contents in the fillet was observed; however, moisture and crude protein content of fillet linearly decreased with the increase of body weight. Similarly, increased lipid content with increasing size of fish was described in rainbow trout (Souza et al., 2015), matrinxã (*Brycon cephalus;* Macedo-Viegas et al., 2000), and African catfish (*Clarias gariepinus*; Salisu and Faturoti, 2016).

Determining fillet traits and composition are important to address requirements of specific market according to sensory perception of consumers and enables the fish industry and fish farmers to adapt to the demands of consumers (Tobin et al., 2006).

The technical difficulty, high cost, and time associated to continuing chemical analysis emphasizes the importance of developing mathematical models to predict fillet traits and composition of fish with a high accuracy.

Conclusions

Fillet yield and composition of *H. malabaricus* varies according to body weight and dressed weight, fillet weight, and fillet composition and can be estimated by first-order linear regression analysis. No reliable equations were found to estimate dressed yield and fillet yield of market-sized *H. malabaricus* using linear regression analysis.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Investigation: W.M. Furuya. Methodology: M. Michelato, T.P. Cruz, A.V. Urbich, J.W.A. Ribeiro and D.C. Batista. Project administration: V.R.B. Furuya. Supervision: V.R.B. Furuya and A.L. Salaro. Validation: W.M. Furuya. Writing-original draft: M. Michelato and W.M. Furuya. Writing-review & editing: W.M. Furuya.

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