Aquaculture and Fisheries 4 (2019) 89–97

Contents lists available at ScienceDirect

Aquaculture and Fisheries

journal homepage: http://www.keaipublishing.com/en/journals/aquaculture-and-fisheries

The potential of *Hoplias malabaricus* (Characiformes: Erythrinidae), a Neotropical carnivore, for aquaculture

Marcos Daniel Renó Faria[a], Aderbal Cavalcante-Neto[a], Ivan Bezerra Allaman[b], Aline Dal'Olio Gomes[c], Renata Guimarães Moreira[c], Eric M. Hallerman[d], Alexandre Wagner Silva Hilsdorf[a,*]

[a] Unit of Biotechnology, University of Mogi das Cruzes, Mogi das Cruzes, SP, 08780-970, Brazil
[b] Department of Exact Sciences and Technology, State University of Santa Cruz, Ilhéus, BA, 45662-900, Brazil
[c] Department of Physiology, Bioscience Institute, University of São Paulo, São Paulo, SP, 05508-020, Brazil
[d] Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University, Blacksburg, VA 23061-0321, USA

ARTICLE INFO

Keywords:
Farming
Growth models
Native species
Trahira
Fatty acids

ABSTRACT

We describe key production-related traits of trahira (*Hoplias malabaricus*), an aquaculture candidate species, in a semi-intensive fish farming system. We quantified growth from hatch through grow-out at two stocking densities and evaluated fillet protein, lipids and fatty-acid content. We made 2430 observations of growth and morphometrics on 270 juvenile fish allocated to four fish ponds, two at 5 fish/m^2 (90 animals) and two at 10 fish/m^2 (180 animals) through 11 months. The fish reached an average length of 27.5 cm (± 0.38) and 27.0 cm (± 0.24), and weight of 263.0 g (± 10.54) and 246.7 g (± 6.89), respectively, at the low and high densities. There was no significant difference in weight ($P > 0.05$) between the densities for any of the parameters assessed, and hence the same growth curve applied to both densities ($A = 292.9$; $B = 28.1$; and $K = 0.65$). Standard length, however, differed significantly ($P < 0.05$) between densities, with $K = 0.35$ at the low and $K = 0.29$ at the high density. At both stocking densities, total lipids increased throughout the trial, while protein content decreased. Oleic acid (C18:0) increased throughout the experimental period, while docosahexaenoic acid and the n3/n6 profile decreased, with no differences among stocking densities. *Hoplias malabaricus* may prove a viable aquaculture species in Neotropical regions, where development of native species may contribute to sustainable aquaculture production.

1. Introduction

Aquaculture development has driven many alien species introductions worldwide (Naylor, Williams, & Strong, 2001; Pérez, Alfonsi, Nirchio, Muñoz, & Gómez, 2003). Environmental risks posed by fish introductions may threaten native fish diversity; hence, evaluation of native aquaculture candidate species is strategic for development of sustainable fish farming (Ross & Beveridge, 1995). The Neotropical region is rich in native fish genetic resources potentially useful for aquaculture (Hilsdorf & Hallerman, 2017). Among those resources, species of the genus *Hoplias* (trahiras) comprise eight valid species (Oyakawa & Mattox, 2009) which occur throughout drainages from Costa Rica to Argentina (Froese & Pauly, 2017). The different trahiras are economically important for local artisanal fisheries in many Neotropical countries (Oliveira & Nogueira, 2000; Ramsundar, 2005). However, trahiras have not been farmed even at small scale in Neotropical countries. For instance, the aquaculture production of all trahiras in Brazil in 2016 was just 806,365 kg (IBGE, 2016, p. 44).

Hoplias malabaricus, also known as wolf fish, tiger fish, or trahira (Image S1), is a candidate species for aquaculture production. It is a carnivorous fish that preferentially inhabits lotic environments, also occurring in lentic waters such as lakes and reservoirs (Azevedo & Gomes, 1943). *H. malabaricus* is well adapted to hypoxic waters, can maintain constant oxygen uptake down to a PiO_2 of 20 mmHg (Rantin, Glass, Kalinin, Verzola, & Fernandes, 1993), and can reproduce in these hypoxic waters (Gomes, Honji, Tolussi, Ribeiro, & Moreira, 2015). Constraints to full development of aquaculture production of *H. malabaricus* include feeding costs, presence of intramuscular bones, and the continuing availability of market-sized fish from capture fisheries. However, new processing techniques, yielding boneless trahira fillets, high fillet yield – around 44%, and high nutritional quality of the meat (Santos, Melo, Lopes, & Malgarim, 2001) have attracted consumers to

* Corresponding author. Universidade de Mogi das Cruzes, Núcleo Integrado de Biotecnologia, P.O. Box 411, Mogi das Cruzes, SP, 08780-911, Brazil.
E-mail address: wagner@umc.br (A.W.S. Hilsdorf).

https://doi.org/10.1016/j.aaf.2019.01.002
Received 27 July 2018; Received in revised form 15 January 2019; Accepted 16 January 2019
Available online 28 January 2019

trahira as a delicacy fish. Despite the relatively high costs of producing carnivorous fish, high meat quality and attractive prices in local markets have made trahira a good choice for commercial fish farming. However, technical aquaculture limitations, such as commercial availability of feed-trained fingerlings (Bondad-Reantaso, 2007), cannibalism during the fingerling stage (Luz, Salaro, Souto, & Zaniboni-Filho, 2000), lack of nutritional studies (Vieira & Lopes, 2006), and lack of assessment of growth rate in farming systems hinder achievement of large-scale aquaculture production of trahira.

Characterization of the fish growth curve supports identification and adoption of management practices that optimize production, providing insight into the nutritional needs of each growth phase (Tholon & Queiroz, 2009). These curves can be used to determine the optimal age for slaughter (Luo et al., 2015; Mello et al., 2015). Growth models used to characterize the growth of fishes (Enberg, Dunlop, & Jørgensen, 2008, pp. 1564–1572) include the von Bertalanffy (1938), logistic (Richards, 1959), and Gompertz (1825) models.

Development of attractive aquaculture products also depends on their nutritional value. Consumption of fish and fish products is highly recommended by health authorities, not only for their protein content, but also as an important source of essential fatty acids (FAs) (Garaffo et al., 2011), mainly omega 3 (*n*3) polyunsaturated fatty acids (PUFAs). To develop an aquaculture candidate species, it is useful to combine profitable growth rate with high nutritional content, such as high levels of PUFAs (Ogata, Emata, Garibay. & Furuita, 2004).

Assessment of trahira production under culture conditions (Luz et al., 2000; Luz, Salaro, Souto, Reis, & Sakabe, 2001; Nogueira et al., 2005; Salaro, Luz, Nogueira, Sakabe, & Lambertucci, 2003; Salaro, Luz, Sakabe, Kasai, & Lambertucci, 2008) have mostly focused on aspects of producing the species *Hoplias lacerdae*. To gain insight into the potential of *H. malabaricus* for aquaculture in the Neotropics, we: (i) determined the best growth model for *H. malabaricus* through one year of semi-intensive production; (ii) quantified the growth rate of *H. malabaricus* from fry through grow-out under contrasting production densities; and (iii) assessed fillet quality in terms of total protein, lipid levels and fatty acid profile.

2. Material and methods

2.1. Fish and rearing conditions

A total of 270 *H. malabaricus* juveniles were obtained from the Brumado Fish Hatchery, Ltd. in the State of São Paulo, which had produced them from wild broodstock. To assure proper taxonomic identification, the broodstock was assessed morphologically based on diagnostic characters set out for the species by Oyakawa and Mattox (2009).

The growth trial was carried out at the Ponte Nova Fish Farm located in Salesópolis County, State of São Paulo, Brazil (23°31′85″ S, 45°50′77″ W, 798 m elevation). The region has a subtropical climate with mean annual temperature of 19 °C. Juveniles were stocked in four concrete ponds of 12.6 m^3 (4.5 m × 2.0 m × 1.4 m) in a completely randomized design. To assess the rate of growth models under contrasting stocking densities, fish were stocked at 5 fish/m^2 (90 juveniles) and 10 fish/m^2 (180 juveniles). Fish were fed exclusively using an extruded commercial diet (NutriPeixe TC 40, Purina, Brazil), and the feeding regime was based on that commercially proposed for carnivorous fishes (Tables S1 and S2). The growth trial lasted 11 months from September to August. Every 40 days through the experiment, all individuals were anesthetized with 0.01% benzocaine previously diluted in ethanol. Individuals were weighed using a balance with a 1-g precision and standard length was measured with the aid of an analog caliper.

Each day, we assessed the quality of continuously flowing inlet water by measuring the temperature (°C) and oxygen (mg/L) using a Model 55-12 FT meter (YSI, Yellow Springs, Ohio, USA), total ammonia level using ammonia test strips (Tetra®, Blacksburg, VA, USA), and pH using colorimetric test strips (Macherey-Nagel®, Bethlehem, PA, USA).

2.2. Grow-out performance and growth model data analysis

To determine the most appropriate nonlinear model for characterization of growth of trahira at each stocking density, we tested: the Gompertz model, in which $y = A\ \exp(-Be^{-Kx})$; the logistic model, in which $y = A(1 + Be^{-Kx})^{-1}$; and the von Bertalanffy model, in which $y = A(1–Be^{-Kx})^3$, where y represents the trait (weight or standard length); e is the base of natural logarithms; and x is the age in days. Generally, the fixed effects A, B, and K represent the average values of the population parameters. These model parameters have the following biological interpretations: A is the superior asymptotic response trait, B is a constant without biological interpretation, and K is the ratio between the relative growth rate and the adult animal response traits (weight and standard length). The higher the value of K, the more precocious is the animal.

The choice of the best nonlinear model for each trait (weight and standard length) and each density (5 fish/m^2 and 10 fish/m^2) was based on the Akaike Information Criterion (*AIC*) (Akaike, 1974; Sakamoto, Ishiguro, & Kitagawa, 1986), as suggested by Katsanevakis (2006), and the Bayes Information Criterion (*BIC*) (Schwarz, 1978). Using this approach, the smaller the criterion value, the better-fitting the model.

After the choice of the best-fitting nonlinear model for each trait, we used a mixed-model approach to obtain accurate estimates of function parameters of animal growth (Cao & Wang, 2011; Pinheiro & Bates, 1995; Schinckel & Craig, 2002; Sofaer, Chapman, Sillett, & Ghalambor, 2013). Then the model parameters (A, B, and K) were maintained as fixed or included as random in the most appropriate nonlinear model using the Likelihood-Ratio Test (LRT) as a criterion, and then estimated and compared among the density. A random effect was considered to have an express influence when its inclusion in the model caused significant increases in ln. To determine the most adequate model, the likelihood-ratio test (LRT) was applied in reduced sequence models (Kimura, 1980; Rao, 1973, pp. 417–420).

The value obtained for the statistical LRT then was compared to the chi-square table (χ^2_{tab}) with the appropriate degrees of freedom: if $LR > \chi^2_{tab}$, the effect was considered to have a significant influence. The level of significance used was 5%. LRT was also applied for equality of the parameters A, B and K between the densities studied (Regazzi, 2003) to assess whether a single curve would be adequate to describe the growth (weight- or length-at-age) of trahiras grown at different densities. The growth-model testing described above was performed using the packages, Stats version 3.4.1, nlme version 3.1–131, and car version 2.1–5 of R.3.4.1 (R Core Team, 2017).

For the traits we studied, *AGR* is the weight or length gain observed over a unit of time. As the age is updated, *AGR* represents the average growth rate of animals in the population. We calculated the absolute growth rate (AGR) at age from the first derivative of the adjusted growth model.

Growth parameters based on morphometric measures were calculated to assess growth performance and models, including: condition factor (K) = total weight/total length^3 × 100; feed efficiency (*FE*) = biomass increment × 100/food consumed; specific growth rate (SGR) = 100 × [(ln (W_f) − ln (W_i))/T], where ln (W_f) and ln (W_i) are the natural logarithms of the weight at the beginning (W_i) and end (W_f) of the experiment, and T is the time interval in days; and survival (S) = final number of fish × 100/initial number of fish. The coefficient of variation for weight (*CV*, %) within tanks was used to assess size variation and was calculated as: weight standard deviation/mean weight × 100. The coefficient of variation was used because body weight often shows a higher coefficient of variation in fish than in terrestrial livestock (Gjedrem, 1998). The length-weight relationship was estimated by logarithmic transformation of equation $W = a \times Lb$, where W = body weight (g); L = standard body length (cm); a = the intercept; and b = the regression slope.

The growth performance metrics are expressed as mean ± standard error. A one-way analysis of variance (ANOVA) was used to test the significance ($P < 0.05$) of any difference in growth at the two stocking densities. All data analyses were performed using SIGMA Stat for Windows Version 2.0 (Jandel Corporation®).

2.3. Lipids and protein content profile

Ten fish from each experimental group (5 fish/tank) were collected at one month of age (initial sample), after 90 days (five months of age - intermediate sample), and at the end of the experiment (nine months of age - final sample) to analyze body composition. These animals were sacrificed by cervical dislocation after sedation (with benzocaine at 100 mg/L) with Institutional Animal Care and Use Ethics Committee approval (#2018/01). A sample of white epaxial muscle was collected from the anteriodorsal region and frozen at −80 °C until analysis.

Total proteins were extracted from muscle tissue by precipitation and solubilization according to Milligan and Girard (1993). Tissue protein content was analyzed by the colorimetric method of Lowry, Rosebrough, Farr, and Randall (1951), using bovine serum albumin to develop the standard curve (Sigma Diagnostics, St. Louis, MO, USA), and expressed as mg/g of dry mass. Total lipids were extracted from muscle and diet with chloroform: methanol: water (2:1:0.5) according to Folch, Less, and Stanley (1957), modified by Parrish (1999) for aquatic organisms. The total lipid content of tissues was quantified by the enzyme-colorimetric method described by Frings, Fendly, Dunn, and Quenn (1972) using cod liver oil (Sigma Diagnostics, Inc., Livonia, MI) for the standard curve and expressed as mg/g of mass.

Methylation of the lipid extracts was performed with acetyl chloride (5% CH_3COCl in methanol) (Christie & Han, 2010, p. 448), and fatty acid (FA) composition was determined as methyl esters using a gas chromatograph (GC) (Model 3900, Varian Analytical Instruments, Walnut Creek, CA, USA) coupled to flame ionization detection (FID). FAs were identified by comparing retention time, using a known standard of methyl esters (FAME) (Supelco, 37 components; Sigma–Aldrich; Larodan Malmö, Sweden, Mixture Me93, and Qualmix PUFA Menhaden Oil). The FAMEs were analyzed on a capillary column, CP Wax 52 CB, with 0.25 µm thickness, 0.25 mm inside diameter, and 30 m length. Hydrogen was used as the carrier gas at a linear velocity of 22 cm/s. The temperature program was 170°C for 1 min followed by a 2.5°C/min ramp up to 240°C, and a final hold time of 5 min. Injector and flame ionization detector (FID) temperatures were 250 and 260°C, respectively.

The percentage of FA was used to calculate the indices of atherogenicity (AI) and thrombogenicity (TI), as proposed by Ulbritch and Southgate (1991):

$$AI = [(4 \times C14{:}0) + C16{:}0 + C18) / (\Sigma\ MUFA + \Sigma\ n6\ PUFA + \Sigma\ n3\ PUFA)];$$

$$TI = [(C14{:}0 + C16{:}0 + C18{:}0) / (0.5 \times \Sigma\ MUFA) + (0.5 \times \Sigma\ n6\ PUFA) + (3 \times \Sigma\ n3\ PUFA) + (n3 / n6)]$$

Values were expressed as mean ± standard error. The comparison of growth parameters and body composition between stocking densities during the experiment were performed using one-way analysis of variance (ANOVA). For all the analyses, differences were considered to be significant when $P \leq 0.05$. These analyses were performed using the statistical software BioStat 2009 (AnalystSoft, Inc., Walnut, CA, USA).

3. Results

3.1. Test environment

The average water temperature during the spring/summer season (September to March) was 24.3 °C (± 2.2) and during the autumn/winter (March to September) was 19.6 °C (± 2.6). The lowest temperature measured was 16.1 °C and the highest 28 °C. Dissolved oxygen ranged from 5 to 9 mg/L, the ammonium ion concentration ranged from 0.10 to 0.20 mg/L, and the pH ranged from 6.7 to 7.2. These water quality parameters were within the range for routine fish farming operations in the region.

Table 1
Akaike (*AIC**) and Bayesian (*BIC**) information criteria[a] for different growth models applied to the weight and standard length (SL) traits in relation to age for trahira, *Hoplias malabricus*.

	5 fish m^{-2}			
	Weight		SL	
Model	*AIC*	*BIC*	*AIC*	*BIC*
Logistic	**7261.32**	**7312.26**	**2979.00**	**3029.94**
Gompertz	7287.53	7338.47	2985.4	3036.34
Von Bertalanffy	7307.54	7358.48	2988.48	3039.41
	10 fish m^{-2}			
Logistic	**13290.19**	**13348.13**	**5242.54**	**5300.48**
Gompertz	13368.91	13426.85	5260.92	5318.86
Von Bertalanffy	13410.95	13468.90	5267.59	5325.53

[a] Bold values indicate the best-supported model for each criterion.

3.2. Growth model assessment

According to the *AIC* and *BIC* criteria (Table 1), for both weight and standard length at both stocking densities, the logistic model best fit the data for size-at-age of the animals. The likelihood ratio test for the weight trait indicated that the A and B parameters at both densities must be included as random parameters in the logistic model ($P < 0.05$), while K must be included as a fixed parameter ($P > 0.05$). The same outcomes were observed for the trait standard length (Table 1).

Comparing the growth curves for both densities, the parameter-equality tests applied to the logistic model for weight showed that the hypotheses $A_1 = A_2$, $B_1 = B_2$ and $K_1 = K_2$ were not rejected (Table 1); hence, a single model can be used to describe weight-at-age for *H. malabaricus* (Fig. 1). Thus, the equation describing weight-at-age was estimated ($A = 292.90$; $B = 28.14$; and $K = 0.65$). Regarding the parameters A and B, the equality hypothesis was not rejected, indicating that trahira has the same ultimate size (A) and the same constant of integration (B) at both stocking densities. Maximum increment

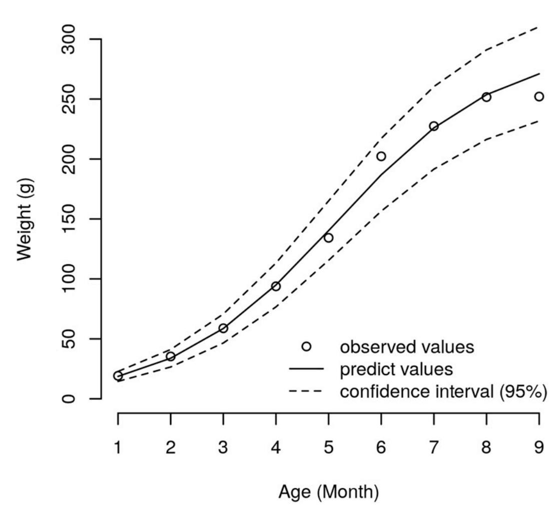

Fig. 1. Growth of weight based on the values observed and predicted by the logistic model, with the 95% confidence interval.

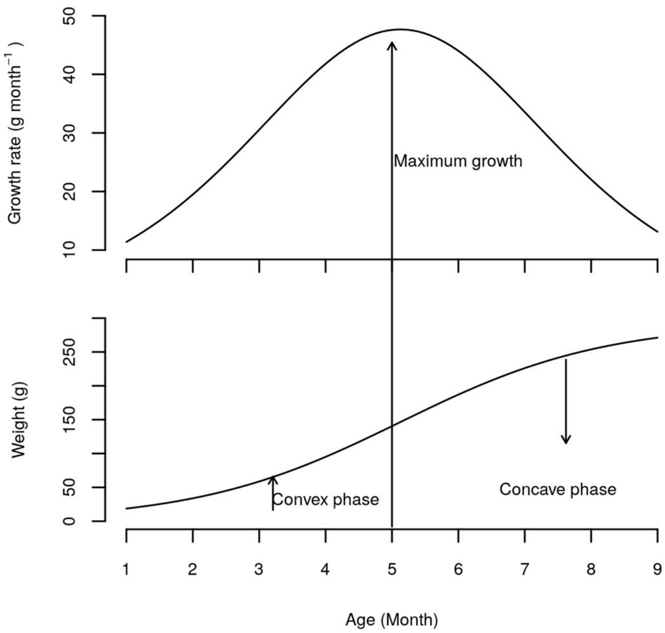

Fig. 2. Absolute growth rate and logistic curve adjusted to both stocking densities.

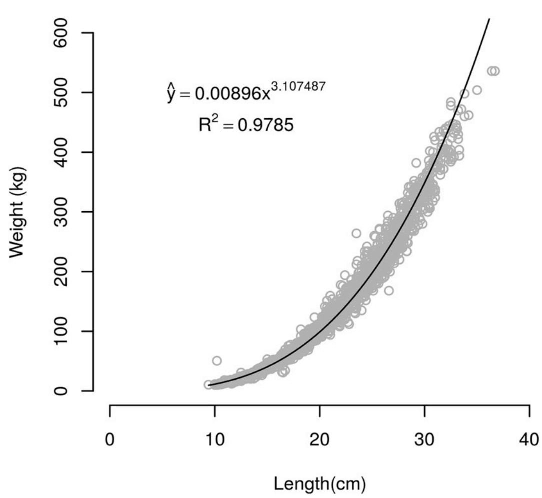

Fig. 3. Length-weight relationship for *H. malabaricus* under intensive farming management.

for weight-at-age, i.e., the highest absolute growth rate, occurred before the fifth month of age for the lower density (5 fish/m^2) and the sixth month of age for the higher density (10 fish m^{-2}) (Fig. 2). The length-weight relationship, $W = 0.00896 \times b^{3.1074}$, $R^2 = 0.9785$ (Fig. 1), showed a mean *b* value of 3.07, which differs slightly from the standard value of 3.0. Thus, *H. malabaricus* under semi-intensive farming conditions presents positive allometric growth, i.e., individuals increase in relative body thickness, becoming heavier at a given length as the fish grows (Tesch, 1968). The *b* value for trahira is between 2.5 and 3.5, as is found for most fish species (Froese, 2006). Equality tests for the parameters within the Huxley model regarding the length-weight relationship at both stocking densities did not differ significantly ($P > 0.05$) (see Fig. 3).

3.3. Grow-out performance

Table 2 summarizes the growth performance of *H. malabaricus* under the two density conditions. Initial total length, final total length and body weight, as well as the majority of the growth parameters, were statistically equal at both stocking densities. Conversely, feed conversion rate and survival rate showed statistically significant differences between stocking densities by the end of the experiment. The coefficients of variation for growth traits were high and within the range found in fish and shellfish (CV = 17%–29%, Gjedrem, 1998).

Table 2
Growth rate parameters from *H. malabaricus* juveniles reared at two stocking densities (5 fish/m^2 and 10 fish/m^2) under on-farm grow-out conditions*.

Growth parameters	Stocking densities	
	5 fish/m^2	10 fish/m^2
Initial total length (cm)	12.0 ± 0.06[a]	12.2 ± 0.04[a]
Final total length (cm)	27.5 ± 0.38[a]	27.0 ± 0.24[a]
Initial body weight (g)	18.6 ± 0.26[a]	19.4 ± 0.18[a]
Final body weight (g)	263.0 ± 10.54[a]	246.7 ± 6.89[a]
Relative growth (%)	43.03 ± 12.51[a]	39.58 ± 9.85[a]
Specific growth rate (% /day)	0.36 ± 0.08[a]	0.35 ± 0.07[a]
Food conversion rate (%)	3.90:1[a]	3.34:1[b]
Condition factor (*K*)	1.23 ± 0.03[a]	1.23 ± 0.30[a]
Feed efficiency (%)	34.24 ± 8.22[a]	37.05 ± 6.53[a]
Coefficient of variation (%)	24.8 ± 1.29[a]	23.67 ± 0.82[a]
Survival rate (%)	69[a]	76[b]

*Data are shown as mean ± standard error. Means in a row followed by the same superscript are not significantly different ($P \leq 0.05$).

3.4. Protein and lipid body profile of H. malabaricus

The total protein level of the fillet decreased between the initial sample and subsequent samples ($P < 0.001$, Table 3), but there were no differences between the treatments ($P > 0.05$). Conversely, the lipid concentration of fillets increased in animals at both densities by the end of the experiment ($P < 0.001$), and were not significantly different between the treatments.

The fillet FA profile of animals from both densities showed an increase in saturated fatty acids (SFA) at the end of the experiment ($P = 0.002$ and $P < 0.001$, respectively, Table 3), mainly due to C18:0. n3 PUFAs decreased through the experiment in both treatments, with docosahexaenoic acid (DHA) most responsible for this decrease. The decrease in n3 PUFAs was associated with a decrease in the n3/n6 ratio at the end of the experiment at both stocking densities. No significant differences were found in AI and TI among stocking densities.

4. Discussion

Our results showed that stocking densities had little influence on growth rate, protein and lipid content, or fatty acid profile of fillets of *H. malabaricus*.

4.1. Growth model and grow-out performance

Successful cultivation of an aquaculture candidate species depends on genetic make-up and physiological plasticity so that the species can adjust to culture conditions and show a viable growth rate for commercialization (Avault, 1993). Hence, modeling fish growth is a first step for assessing an aquaculture candidate species because it supports predictions of how well the fish will grow under various production systems.

High-productivity fish farming systems monitor physical and chemical water quality because it directly affects physiological processes of fish. The physical and chemical water quality parameters did not change in a way that would affect growth or fillet composition, except for water temperature. Total ammonia concentration and pH remained constant and within fish-farming standards throughout the experiment. pH values remained between 6 and 8. The saturation level of DO was

Table 3
Total protein, lipid (% wet weight) and fatty acid profiles (% of total lipids) of *H. malabaricus* juvenile fillets produced at two stocking densities (5 fish/m^2 and 10 fish/m^2).

	Initial	Intermediate		Final	
		5 fish/m^2	10 fish/m^2	5 fish/m^2	10 fish/m^2
Total proteins	32.6 ± 1.41^a	24.0 ± 1.34^b	22.4 ± 1.12^b	23.9 ± 0.75^b	21.9 ± 1.05^b
Total lipids	1.4 ± 0.11^a	1.6 ± 0.32^a	1.4 ± 0.32^a	8.7 ± 1.21^b	6.5 ± 0.37^b
Fatty acids					
C17:0	0.4 ± 0.15	0.5 ± 0.11	0.6 ± 0.26	0.8 ± 0.66	0.6 ± 0.39
C17:1cis	0.4 ± 0.09	0.3 ± 0.11	0.3 ± 0.08	0.2 ± 0.04	0.2 ± 0.09
C18:0anteiso	0.1 ± 0.00	0.2 ± 0.12	0.2 ± 0.04	0.3 ± 0.16	0.3 ± 0.16
C19:0	0.1 ± 0.03	0.4 ± 0.24	0.2 ± 0.03	0.1 ± 0.03	0.1 ± 0.02
C23:0	Nd	0.1 ± 0.06	0.4 ± 0.34	1.4 ± 0.39	Nd
ΣOFA - BFA	0.6 ± 0.44	1.4 ± 0.73	1.2 ± 0.67	1.7 ± 1.42	1.1 ± 0.43
C14:0	1.5 ± 0.42	1.6 ± 0.41	1.9 ± 0.36	1.8 ± 0.29	1.7 ± 0.28
C16:0	19.3 ± 0.74	20.0 ± 0.73	20.7 ± 0.86	20.9 ± 1.84	21.2 ± 1.23
C18:0	7.9 ± 1.02^a	8.8 ± 1.14^{ab}	8.1 ± 1.17^{bc}	8.8 ± 1.08^c	9.2 ± 1.52^c
C20:0	0.3 ± 0.12	0.3 ± 0.06	0.3 ± 0.10	0.3 ± 0.03	0.3 ± 0.05
ΣSFA	29.1 ± 1.19^a	30.7 ± 0.52^{ab}	31.2 ± 1.41^{bc}	31.9 ± 1.63^c	32.6 ± 1.22^c
C16:1n7	4.1 ± 0.76	4.1 ± 0.93	4.6 ± 0.78	3.7 ± 0.97	3.5 ± 0.88
C18:1n7	2.4 ± 0.35	2.6 ± 0.26	2.5 ± 0.17	2.2 ± 0.16	2.2 ± 0.13
C18:1n9	25.5 ± 3.05	26.3 ± 4.87	28.8 ± 4.65	28.0 ± 6.20	27.3 ± 6.15
C20:1n9	0.7 ± 0.29	0.3 ± 0.28	0.4 ± 0.35	0.6 ± 0.63	0.2 ± 0.25
C20:1n11	0.6 ± 0.38	0.8 ± 0.05	0.8 ± 0.03	0.7 ± 0.06	0.9 ± 0.31
ΣMUFA	32.9 ± 3.88	33.9 ± 5.76	37.0 ± 5.21	35.2 ± 6.75	34.0 ± 6.91
C18:3n3	0.6 ± 0.22	0.6 ± 0.16	0.7 ± 0.17	0.8 ± 0.11	0.7 ± 0.18
C18:4n3	0.2 ± 0.07	0.4 ± 0.12	0.3 ± 0.13	0.3 ± 0.08	0.2 ± 0.06
C20:5n3	1.2 ± 0.11	1.3 ± 0.27	1.2 ± 0.18	0.8 ± 0.23	0.8 ± 0.15
C22:5n3	1.2 ± 0.20	1.4 ± 0.25	1.1 ± 0.18	1.0 ± 0.33	1.1 ± 0.36
C22:6n3	12.9 ± 3.45^a	11.0 ± 4.05^{ab}	8.2 ± 2.23^{bc}	6.6 ± 2.66^c	8.0 ± 3.94^c
Σ n3 PUFA	16.1 ± 3.54^a	15.0 ± 4.34^{ab}	11.8 ± 2.46^{bc}	9.5 ± 3.03^c	10.9 ± 4.24^c
C18:2n6cis	10.7 ± 1.91	10.0 ± 0.99	10.5 ± 1.58	12.0 ± 0.97	12.5 ± 0.76
C18:3n6	0.4 ± 0.09	0.4 ± 0.18	0.5 ± 0.05	0.8 ± 0.20	0.8 ± 0.14
C20:2n6	1.1 ± 0.45	1.0 ± 0.44	1.3 ± 1.34	1.5 ± 1.44	0.9 ± 0.32
C20:3n6	3.7 ± 0.82	2.9 ± 0.70	2.5 ± 0.58	2.5 ± 0.89	2.7 ± 0.70
C20:4n6	3.1 ± 0.88^a	2.9 ± 0.98^{ab}	2.3 ± 0.82^{bc}	2.5 ± 1.18^{ab}	2.9 ± 1.31^{ab}
C22:2n6	0.7 ± 0.36	0.3 ± 0.14	0.3 ± 0.15	1.9 ± 1.41	0.2 ± 0.04
C22:4n6	1.6 ± 0.48	1.2 ± 0.49	0.9 ± 0.39	0.9 ± 0.43	1.1 ± 0.63
C22:5n6	0.4 ± 0.34	0.5 ± 0.55	0.7 ± 0.10	1.2 ± 1.08	0.3 ± 0.33
Σ n6 PUFA	21.3 ± 1.27^a	19.0 ± 1.59^{ab}	18.8 ± 2.62^{bc}	21.6 ± 4.10^a	21.4 ± 2.32^a
Σ total PUFA	37.4 ± 3.72^a	34.0 ± 5.54^{ab}	30.5 ± 4.67^b	31.2 ± 6.80^b	32.3 ± 6.32^b
n3/n6	0.8 ± 0.17^a	0.8 ± 0.19^a	0.6 ± 0.10^a	0.4 ± 0.09^b	0.5 ± 0.15^b
AI	0.5 ± 0.02	0.5 ± 0.02	0.5 ± 0.04	0.6 ± 0.04	0.6 ± 0.03
TI	0.4 ± 0.05	0.4 ± 0.06	0.5 ± 0.04	0.6 ± 0.09	0.5 ± 0.09

*Data are shown as mean ± standard error. Means in a row followed by the same superscript are not significantly different ($P \leq 0.05$).
ΣOFA: odd fatty acids, ΣSFA: saturated fatty acids; ΣMUFA: monounsaturated fatty acids; ΣPUFA: polyunsaturated fatty acids; Σn6: omega 6; Σn3: omega 3; AI: atherogenic index; TI: thrombogenic index. *Data are shown as mean ± standard error. Means in a row followed by the same superscript are not significantly different ($P < 0.05$). Nd – not detected.

about 9.0 mg/L at 20 °C, and about 7.8 mg/L at 27 °C. Even at higher temperatures, observed DO concentrations throughout the experiment were appropriate for production of trahira. Variations in temperature above or below the optimum of a species can change its growth rate (El-Sayed, El-Ghobashi, & Al-Amoudi, 1996; Person-Le, Mahe, Le Bayon, & Le Delliou, 2004; Ribeiro, Moreira, Cantelmo, & Esposito, 2014; Tolussi, Hilsdorf, Caneppele, & Moreira, 2010). The temperature ranged between 16 and 28 °C depending on the season. Water temperature was below the range for warm water farmed fishes (26.06–31.97 °C, Boyd & Tucker, 1998, p. 700), which negatively influenced growth performance at both stocking densities.

Three nonlinear mathematical models relate fish growth to age; these models have three parameters, which at least theoretically have biological importance (Freitas, 2005; Enberg et al., 2008, pp. 1564–1572). Various authors have suggested the use of nonlinear mixed models using both fixed and random effects to increase their predictive accuracy (Schinckel & Craig, 2002; Cao & Wang, 2011). Using *BIC* and *AIC* tests (Table 1), we found that the logistic model best captured growth in weight- and length-at-age of *H. malabaricus*. The best-fitting adjusted model varies among species. For instance, in Nile tilapia *Oreochromis niloticus*, the logistic model best describes the morphometric growth under culture conditions (Ansah & Frimpong, 2015). In the Neotropical aquaculture species tambaqui *Colossoma macropomum*, Mello et al. (2015) concluded that the Gompertz nonlinear regression model was most appropriate. Growth models for Neotropical carnivorous species have been assessed only for wild populations, with the von Bertalanffy model best describing growth of spotted surubim *Pseudoplatystoma corruscans* (Mateus & Petrere, 2004), duckbill catfish *Sorubim* cf. *lima* (Penha, Mateus, & Barbieri, 2004), *H. malabaricus* (Tordecilla-Petro, Sánchez-Banda, & Olaya-Nieto, 2005), and dorado *Salminus brasiliensis* (Zuliani et al., 2016). The divergence in the best-supported growth model is a result of the specific growth pattern of the species under study (Sarmento et al., 2006), and also the sample size and frequency (temporal resolution) of growth measurements; that is, when the inflexion point of the curve ranges from 0 to 1, the best adjustment will be obtained with the models of Brody and Gompertz. However, when it oscillates between 1 and 2, it will be obtained with the Gompertz or logistic models (Richards, 1959).

Assessment of growth models for cultured *H. malabaricus* using the LRT showed that the mixed-model approach provided a better fit to the data than traditional modeling with only fixed effects. Cao and Wang (2011) suggested the use of mixed-effects model increases the accuracy of predictions about growth. Craig and Schinckel (2001) developed mixed nonlinear models for porcine growth and showed more accurate estimates for parameters of functions for animal growth than traditional, fixed-effects models.

The typical lifetime growth curve of fish has a sigmoid shape, i.e., growth during early life is slow and is followed by a period of acceleration, and then growth reaches its maximum around puberty, when deceleration occurs (Berg & Butterfield, 1976, p. 240). Fig. 2 shows this pattern for weight growth in trahira, in which absolute growth and the logistic curve were adjusted for the two stocking densities. At the lower stocking density (5 fish/m^2), the convex phase of the growth curve started earlier than at the higher stocking density (10 fish/m^2). However, the growth rate in the fish at a higher stocking density increased until the sixth month of grow-out. Some authors have observed the same effect in other species, for example, Piaia and Baldisserotto (2000) for *Rhamdia quelen* and Salaro et al. (2003) for *Hoplias lacerdae*, reported that in captivity at high-density the fish tended to gather for feeding, decreasing territorial behavior and cannibalism. In our study of *Hoplias malabaricus*, the survival rate was 69% at a density of 5 fish/m^2 and 76% at 10 fish/m^2.

Growth models for farmed fishes may be affected by environmental factors, particularly oxygen availability and temperature, as well as culture-dependent factors such as stocking density and feeding. To assess the growth curve for a candidate fish for aquaculture, such as *H. malabaricus*, it is important to understand and manage culture variables in order to improve growth rate, and to determine the optimal cost-benefit weight for harvest size (Kapetsky & Nath, 1997, p. 128; Gomiero et al., 2009). Grow-out performance of *H. malabaricus* during the one year-production cycle had similar outcomes for the two stocking densities, as can be seen in Table 2. This outcome has also been observed with the congeneric trahira species *Hoplias lacerdae* through 120 days of growth (Salaro et al., 2003). The coefficients of variation for growth of *H. malabaricus* were higher than for other farmed carnivorous species, such as *Clarias gariepinus* (ranging between 0.38% and 6.5%, (Hengsawat, Ward & Jaruratjamorn, 1997), and similar to other Neotropical species of the genus *Pseudoplastytoma* (CV ranging between 18 and 45%, Miranda & Ribeiro, 1997; Turra et al., 2009). The mean weight after 11 months of grow-out did not differ significantly between the two densities, 263.0 g and 246.7 g for 5 and 10 fish/m^2, respectively. Although the specific growth rate of *H. malabaricus* was half that of *Pseudoplatystoma* catfish (sorobim) (Scorvo-Filho, Romagosa, Ayroza, & Frascá-Scorvo, 2008), an important Neotropical carnivorous farmed fish, we note that the juveniles we used originated from wild broodstock which had not undergone genetic improvement. The high coefficient of variation at the last weight measurement may reflect the full range of phenotypic variation for the trait. After the eleventh month of rearing, including the winter months, fish weighing more than 450 g were found among the trial fish. The market demand for an individual portion (plate size) and the growth rate achieved in this study indicate the commercially interesting weight for trahira is between 500 and 600 g. Observation of fish with higher growth rates under semi-intensive culture management suggests that *H. malabaricus* may have potential for improved growth by selective breeding. Domestication and selective breeding to improve feed conversion rate would address a factor critical for adoption of *H. malabaricus* for commercial aquaculture.

The extent of genetic variation found within and among populations provides the basis for a genetic improvement program, i.e., phenotypic variation and underlying heritability for growth rate are functions of relevant genetic variation (Gjedrem & Baranski, 2009). The establishment of a selective breeding program using genetically diverse populations has the potential to improve growth rate to market size for succeeding generations of *H. malabaricus*.

4.2. Nutritional aspects of farmed H. malabaricus

Regarding the body composition, total protein concentrations in fillets decreased through the experiment at both stocking densities; however, the values still remained higher than those for other species analyzed, such as Murray cod *Macarllochella peelii peelii* (Palmeri, Turchini, De Silva, 2007), gilthead sea bream *Sparus aurata* (Senso, Suarez, Ruiz-Cara, & Garcia-Gallego, 2007), Tiete tetra *Brycon insignis* (Tolussi et al., 2010), goldfish *Carassius auratus* (Dal Bosco, Mugnai, Mourvaki E., & Castellini, 2012), and Nile tilapia (Ribeiro et al., 2014; Vieira, Hilsdorf, & Moreira, 2012). The decrease in fillet protein may be due to utilization of protein as an energy source for growth, suggesting that use of a higher protein diet (> 40%) may be appropriate for grow-out of *H. malabaricus*.

Lipid content is also an important aspect of fillet quality (Quinton, McMillan, & Glebe, 2005). Fillets can be classified as "lean" when the lipid content is below 2.5% and as "semi-skimmed" between 2.5% and 10% (Bennion, 1980, p. 598; Jacquot, 1961). In the present study, high concentrations of lipids in the muscle of *H. malabaricus* juveniles were such that the fillet would be classified as high-quality, in the semi-skimmed range. The fillet fatty-acid profile showed few changes over time, but we noted an interesting content of SFAs and PUFAs. The major FAs in *H. malabaricus* juvenile fillets were: C16:0, C18:0, C18:1n9, C18:2n6 (linoleic acid, LA), ARA (C20:4n6), and DHA. FAs of aquatic origin are characterized by the predominance of PUFAs, especially EPA (C20:5n3) and DHA (Arts, Brett, & Kainz, 2009, p. 380), as seen in our results.

Despite the increase of SFA observed in the fillets of fish at harvest at both stocking densities, values remained lower than those found by Kasai et al. (2011) in *H. lacerdae* fingerlings. On the other hand, total PUFA presented a significant decrease between the initial and later samplings at both densities due to decreasing n3 PUFA content, specifically DHA. The percentages of total, n3 PUFAs/DHA, nonetheless is high and similar to those of *H. malabaricus* fillets from fish captured from the wild (Gutierrez & Silva, 1993; Petenuci et al., 2016; Torres, Zambiazi, Chiattone, Fonseca, & Costa, 2012). The DHA content in *H. malabaricus*, when its freshwater origin is considered, is higher than many other economically important freshwater fishes, including Nile tilapia (Vieira et al., 2012), common carp *Cyprinus carpio* (Živić et al., 2014), sábalo *Prochilodus lineatus* (Luzia, Sampaio, Castellucci, & Torres, 2003), pintado *Pseudoplatystoma corruscans* (Martino, Cyrino, Portz, & Trugo, 2002), peacock bass *Cichla* sp. (Inhamuns, Franco, & Batista, 2009), and spotted pim *Pimelodus maculatus,* threespot leporinus *Leporinus friderici,* and dorado *Salminus brasiliensis* (Andrade, Rubira, Matsushita, & Souza, 1995).

H. malabaricus juveniles had a high percentage of C18:2n6 (almost 90% of total PUFAs), suggesting that they tend to accumulate n3 PUFAs, mainly DHA, in the fillet, even at high stocking densities and with a relatively low percentage of this FA in the diet. This FA is mainly found in soybean, corn, and sunflower (Matsushita et al., 2006, pp. 125–131), suggesting the inclusion of a higher proportion of these ingredients in the commercial diet, together with the low animal protein content, results in a low percentage of EPA and DHA, the main FAs of fishmeal. Hence, the high percentage of C18:2n6 in the muscle tissue reflects that of the diet. This FA is considered essential to freshwater fishes and humans because it acts as the main precursor of arachidonic acid (ARA) (C20:4n6), also found in a reasonable percentage in the fillet of *H. malabaricus*. ARA is the precursor of many physiologically active compounds, such as prostaglandins, thromboxanes, and leukotrienes. In fishes, production of these hormones can influence growth, vitellogenesis, immune response, and physiological response to environmental stress (Bell, Tocher, MacDonald, & Sargent, 1995). Greater fish consumption is associated with increased n3 PUFA intake and with an increase in the n3/n6 ratio, which plays a critical role in improved cognition and cardiovascular health in humans (Liu et al., 2017; Marik & Varon, 2009).

In the present study, despite a decrease in the n3/n6 ratio at the end of the experiment, the values remained between 0.4 and 0.8. The optimal ratio of n3/n6 is not known for most organisms and is hypothesized to be species-specific (Sargent, 1995). *AI* and *TI* showed very low values in comparison to those observed in other animals, such as Atlantic bluefin tuna *Thunnus thynnus* (*AI* = 0.7) (Garaffo et al., 2011) and terrestrial livestock animals such as rabbit (0.7 and 0.99; Dal Bosco, Castellini, Bianchi, & Mugnai, 2004) and poultry (0.49 and 0.88; Castellini, Bosco, Mugnai, & Pedrazzoli, 2006). Among PUFAs, the main fatty acids with anti-atherogenic action (inhibiting platelet aggregation and decreasing plasma cholesterol concentration) are C18:2n6, C18:3n3, EPA and DHA, which are also known to have anti-thrombogenic effects (preventing the formation of clots in blood vessels). On the other hand, SFAs such as C14:0 and C16:0 are known as health risk factors (Lajous et al., 2013; Ulbritch & Southgate, 1991).

5. Conclusions

The search for new native aquaculture species as an alternative to introduced ones has been on the agenda of ministries of agriculture in multiple Neotropical countries (Garcia-Trejo, Hurtado-Gonzalez, Soto-Zarazua, & Gutierrez-Yurrita, 2014; Ross & Beveridge, 1995). The trahira *Hoplias malabaricus* is distributed through many Neotropical countries. In Brazil, it has been captured in reservoirs and supplied to markets and after intramuscular bone removal, it is prepared for consumption using many different recipes. The results of this study indicated logistic as the best model to explain growth in weight- and length-at-age in trahira under aquaculture operations. And that density did not induce modified fillet protein or lipid deposition, including fatty acids. Trahira fillet composition showed high fatty-acid contents for n3 and n6 PUFAs, such as DHA, LA and ARA compared to other tropical aquaculture species. Therefore, market demand, adaptation to farming conditions, low requirement for dissolved oxygen, ready consumption of processed feed, considerable growth potential, along with high nutritional quality and superior meat flavor, indicate that *H. malabaricus* is a suitable candidate for development of profitable aquaculture operations in Central and South American countries.

Acknowledgments

We gratefully acknowledge the support of Department of Water and Electric Energy staff for their help during the development of this work. Also, we thank the Foundation for Supporting Teaching and Research for funding this work, Funding for Eric Hallerman's participation in this work was provided in part by the Virginia Agricultural Experiment Station and the Hatch Program of the National Institute of Food and Agriculture, U.S. Department of Agriculture. Emmanuel Frimpong provided useful comments on the draft manuscript. This work was developed as part of the full requirements for the Master of Science thesis of M.D.R. Faria in Biotechnology at the University of Mogi das Cruzes (UMC). A.W.S.H. and R.G.M. are recipient of CNPq productivity scholarship.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aaf.2019.01.002.

References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control, 19*, 716–723.

Andrade, A. D., Rubira, A. F., Matsushita, M., & Souza, N. E. (1995). n3 fatty acids in freshwater fish from south Brazil. *Journal of the American Oil Chemists Society, 72*, 1207–1210. https://doi.org/10.1007/BF02540990.

Ansah, Y. B., & Frimpong, E. A. (2015). Using model-based inference to select a predictive growth curve for farmed tilapia. *North American Journal of Aquaculture, 77*, 281–288. https://doi.org/10.1080/15222055.2015.1020080.

Arts, M. T., Brett, M. T., & Kainz, M. J. (2009). *Lipids in Aquatic Ecosystems.* New York: Springer.

Avault, J. W. (1993). Ten requirements for culturing a 'new' species: a checklist. *Aquaculture Magazine, 19*, 73–78.

Azevedo, P., & Gomes, A. L. (1943). Contribuições ao estudo da traíra *Hoplias malabaricus* (Bloch, 1974). *Boletim de Industria Animal, 5*, 15–64.

Bell, J. G., Tocher, D. R., MacDonald, F. M., & Sargent, J. R. (1995). Effects of dietary borage oil enriched in y-linolenic acid, 18:3 (n-6)] or marine fish oil [enriched in eicosapentaenoic acid, 20:5 (n-3)] on growth, mortalities, liver histopathology and lipid composition of juvenile turbot (*Scophthalmus maximus*). *Fish Physiology and Biochemistry, 14*, 373–383. https://doi.org/10.1007/BF00003375.

Bennion, M. (1980). *The Science of Food.* New York: Harper & Row Pubs.

Berg, R. T., & Butterfield, R. M. (1976). *New Concepts of Cattle Growth.* Sydney: Sydney University Press.

Bondad-Reantaso, M. G. (Ed.). (2007). *Assessment of freshwater fish seed resources for sustainable aquaculture. FAO Fisheries Technical Paper No. 501* (pp. 628). Rome: Food and Agriculture Organization of the United Nations.

Boyd, C. E., & Tucker, C. S. (1998). *Pond aquaculture water quality management.* Massachusetts: Kluwer Academic Publishers.

Cao, Q. V., & Wang, J. (2011). Calibrating fixed- and mixed-effects taper equations. *Forest Ecology and Management, 262*, 671–673. https://doi.org/10.1016/j.foreco.2011.04.039.

Castellini, C., Bosco, A. D., Mugnai, C., & Pedrazzoli, M. (2006). Comparison of two chicken genotypes organically reared: oxidative stability and other qualitative traits of the meat. *Italian Journal of Animal Science, 5*, 29–42. https://doi.org/10.4081/ijas.2006.29.

Christie, W. W., & Han, X. (2010). *Lipids Analysis - Isolation, Separation, Identification and Lipidomic Analysis.* Bridgewater, UK: The Oily Press ISBN: 9780955251245.

Craig, B. A., & Schinckel, A. P. (2001). Nonlinear mixed effects model for swine growth. *Animal Science, 17*, 256–260. https://doi.org/10.15232/S1080-7446(15)31637-5.

Dal Bosco, A., Castellini, C., Bianchi, L., & Mugnai, C. (2004). Effect of dietary linoleic acid and vitamin E on fatty acid composition, storage stability and sensory traits of rabbit meat. *Meat Science, 66*, 407–413. https://doi.org/10.1016/S0309-1740(03)00127-X.

Dal Bosco, A., Mugnai, C., Mourvaki, E., & Castellini, C. (2012). Seasonal changes in the fillet fatty acid profile and nutritional characteristics of wild Trasimeno Lake goldfish (*Carassius auratus L.*). *Food Chemistry, 132*, 830–834. https://doi.org/10.1016/j.foodchem.2011.11.043.

El-Sayed, A. F. M., El-Ghobashi, Y. A., & Al-Amoudi, M. (1996). Effects of pond depth and water temperature on the growth, mortality and body composition of Nile tilapia, *Oreochromis niloticus* (L.). *Aquaculture Research, 27*, 681–687. https://doi.org/10.1046/j.1365-2109.1996.00776.x.

Enberg, K., Dunlop, E. S., & Jørgensen, C. (2008). Fish growth. In S. E. Jørgensen, & B. D. Fath (Eds.). *Encyclopedia of Ecology*Oxford, UK: Elsevier ISBN-13: 978-0444520333.

Folch, J., Less, M., & Stanley, G. H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry, 226*, 497–503.

Freitas, A. R. (2005). Curvas de crescimento na produção animal. *Revista Brasileira de Zootecnia, 34*, 786–795. https://doi.org/10.1590/S1516-35982005000300010.

Frings, C. S., Fendly, T. W., Dunn, R. T., & Quenn, C. A. (1972). Improved determination of total lipids by the sulpho-phospho-vanilin reaction. *Clinical Chemistry, 18*, 673–674.

Froese, R. (2006). Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. *Journal of Applied Ichthyology, 22*, 241–253. https://doi.org/10.1111/j.1439-0426.2006.00805.x.

Froese, R., & Pauly, D. (Eds.). (2017). *FishBase. World Wide Web electronic publication. version (02/2017)*. Available at: www.fishbase.org.

Garaffo, M. A., Vassallo-Agius, R., Nengas, Y., Lembo, E., Rando, R., Maisano, R., et al. (2011). Fatty acids profile, atherogenic (IA) and trombogenic (IT) health lipid indices, of raw roe of blue fin tuna (*Thunnus thynnus* L.) and their salted product "bottarga". *Food and Nutrition Sciences, 2*, 736–743. https://doi.org/10.4236/fns.2011.27101.

Garcia-Trejo, F., Hurtado-Gonzalez, S., Soto-Zarazua, G., & Gutierrez-Yurrita, J. (2014). Development of freshwater native species with aquacultural potential. In M. P. Hernandez-Vergara, & C. I. Perez-Rostro (Eds.). *Sustainable Aquaculture Techniques* (pp. 67–86). Rijeka, Croatia: Tech Publishers. https://doi.org/10.5772/57089 ISBN 978-953-51-1224-2.

Gjedrem, T. (1998). Developments in fish breeding and genetics. *Acta Agriculturae Scandinavica, Section A - Animal Science, 28*, 19–26. http://aims.fao.org/serials/c_4444ea4f.

Gjedrem, T., & Baranski, M. (2009). *Selective Breeding in Aquaculture: An Introduction.* Dordrecht: Springer221. https://doi.org/10.1007/978-90-481-2773-3.

Gomes, A. O., Honji, R. M., Tolussi, C. E., Ribeiro, C. S., & Moreira, R. G. (2015). The role of ovarian steroids in reproductive plasticity in *Hoplias malabaricus* (Teleostei: Characiformes: Erythrinidae) in tropical reservoirs with different degrees of pollution. *General and Comparative Endocrinology, 222*, 1–10. https://doi.org/10.1016/j.ygcen.2014.10.008.

Gomiero, J. S. G., Freitas, R. T. F., Santos, V. B., Silva, F. F., Rodrigues, P. B., & Logato, P. V. R. (2009). Curvas de crescimento morfométrico de piracanjuba (*Brycon orbignyanus*). *Ciencia E Agrotecnologia, 33*, 882–889. https://doi.org/10.1590/S1413-70542009000300031.

Gompertz, B. (1825). On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. *Philosophical Transactions of the Royal Society of London, 115*, 513–583.

Gutierrez, L. E., & Silva, R. C. M. (1993). Fatty acid composition of commercially important fish from Brazil. *Scientia Agricola, 3*, 478–483. https://doi.org/10.1590/S0103-90161993000300023.

Hengsawat, K., Ward, F. J., & Jaruratjamorn, P. (1997). The effect of stocking density on yield, growth and mortality of African catfish (*Clarias gariepinus* Burchell 1822) cultured in cages. *Aquaculture, 152*, 67–476. https://doi.org/10.1016/S0044-

8486(97)00008-2.
Hilsdorf, A. W. S., & Hallerman, E. (2017). *Genetic Resources of Neotropical Fishes.* Cham, Switzerland: Springerhttps://doi.org/10.1007/978-3-319-55838-7 ISBN: 978-3-319-55836-3.
IBGE (2016). *Produção da pecuária municipal.* Brasília: Instituto Brasileiro de Geografia e Estatística, Ministério do Planejamento, Orçamento e Gestão.
Inhamuns, A. J., Franco, M. R. B., & Batista, W. S. (2009). Seasonal variations in total fatty acid composition of muscles and eye sockets of tucunaré (*Cichla* sp.) from the Brazilian Amazon area. *Food Chemistry, 117*, 272–275. https://doi.org/10.1016/j.foodchem.2009.03.113.
Jacquot, R. (1961). Organic constituents of fish and foods. In G. Borgsrom (Vol. Ed.), *Fish and Food: Vol. 1*, (pp. 144–192). New York, USA: Academic Press.
Kapetsky, J. M., & Nath, S. S. (1997). *A strategic assessment of the potential for freshwater fish farming in Latin America. COPESCAL Technical Paper No. 10.* Rome: Food and Agriculture Organization of the United Nations.
Kasai, R. Y. D., Salaro, A. L., Zuanon, J. A. S., Sabarense, C. M., Tavares, M. M., & Campelo, D. A. V. (2011). Feed training of giant trahira fingerlings fed diets containing different levels of vitamin C. *Revista Brasileira de Zootecnia, 40*, 463–468. https://doi.org/10.1590/S1516-35982011000300001.
Katsanevakis, S. (2006). Modelling fish growth: model selection multi-model inference and model selection uncertainty. *Fisheries Research, 81*, 229–235. https://doi.org/10.1016/j.fishres.2006.07.002.
Kimura, D. K. (1980). Likelihood methods for the von Bertalanffy growth curve. *Fishery Bulletin, 77*, 765–776.
Lajous, M., Willett, W. C., Robins, J., Young, J. G., Rimm, E., Mozaffarian, D., et al. (2013). Changes in fish consumption in midlife and the risk of coronary heart disease in men and women. *American Journal of Epidemiology, 178*, 382–391. https://doi.org/10.1093/aje/kws478.
Liu, J., Cui, Y., Li, L., Wu, L., Hanlon, A., Pinto-Martin, J., et al. (2017). The mediating role of sleep in the fish consumption - cognitive functioning relationship: a cohort study. *Scientific Reports, 7*, 17961. https://doi.org/10.1038/s41598-017-17520-w.
Lowry, O. H., Rosebrough, N. J., Farr, A. L., & Randall, R. J. (1951). Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry, 193*, 265–275.
Luo, J., Lei, H., Shen, L., Yang, R., Pu, Q., Zhu, K., et al. (2015). Estimation of growth curves and suitable slaughter weight of the Liangshan pig. *Asian-Australasian Journal of Animal Sciences, 28*, 1252–1258. https://doi.org/10.5713/ajas.15.0010.
Luzia, L. A., Sampaio, G. R., Castellucci, C. M. N., & Torres, E. A. F. S. (2003). The influence of season on the lipid profiles of five commercially important species of Brazilian fish. *Food Chemistry, 83*, 93–97. https://doi.org/10.1016/S0308-8146(03)00054-2.
Luz, R. K., Salaro, A. L., Souto, E. S., Reis, A., & Sakabe, R. (2001). Desenvolvimento de alevinos de trairão alimentados com dietas artificiais em tanques de cultivo. *Revista Brasileira de Zootecnia, 30*, 1159–1163. https://doi.org/10.1590/S1516-35982001000500004.
Luz, R. K., Salaro, A. L., Souto, E. F., & Zaniboni-Filho, E. (2000). Avaliação de canibalismo e comportamento territorial de alevinos de trairão (*Hoplias lacerdae*). *Acta Scientiarum, 22*, 465–469. https://doi.org/10.4025/actascibiolsci.v22i0.2929.
Marik, P. E., & Varon, J. (2009). Omega-3 dietary supplements and the risk of cardiovascular events: a systematic review. *Clinical Cardiology, 32*, 365–372. https://doi.org/10.1002/clc.20604.
Martino, R. C., Cyrino, J. E. P., Portz, L., & Trugo, L. C. (2002). Performance and fatty acid composition of surubim (*Pseudoplatystoma coruscans*) fed diets with animal and plant lipids. *Aquaculture, 209*, 233–246. https://doi.org/10.1016/S0044-8486(01)00847-X.
Mateus, L. A. F., & Petrere, M., Jr. (2004). Age, growth and yield per recruit analysis of the pintado *Pseudoplatystoma corruscans* (Agassiz, 1829) in the Cuiabá River basin, Pantanal Mato Grossense, Brazil. *Brazilian Journal of Biology, 64*, 257–264. https://doi.org/10.1590/S1519-69842004000200011.
Matsushita, M., Justi, K. C., Padre, R. G., Milinsk, M. C., Ayashi, C., Gomes, S. T. M., et al. (2006). Influence of diets enriched with different vegetable oils on the performance and fatty acid profile of Nile tilapia (Oreochromis niloticus) fingerlings. *Acta Scientiarum Technology, 28*http://www.redalyc.org/html/3032/303226516013/.
Mello, F., Oliveira, C. A. L., Ribeiro, R. P., Resende, E. K., Povh, J. A., Fornari, D. C., et al. (2015). Growth curve by Gompertz nonlinear regression model in females and males in tambaqui (*Colossoma macropomum*). *Anais da Academia Brasileira de Ciência, 87*, 2309–2315. https://doi.org/10.1590/0001-3765201520140315.
Milligan, C. L., & Girard, S. S. (1993). Lactate metabolism in rainbow trout. *Journal of Experimental Biology, 180*, 175–193.
Miranda, M. O. T., & Ribeiro, L. P. (1997). Características zootécnicas do surubim *Pseudoplatystoma corruscans*. In M. O. T. Miranda (Ed.). *Surubim* (pp. 43–56). Brazil: Belo Horizonte (IBAMA).
Naylor, R. L., Williams, S. L., & Strong, D. R. (2001). Aquaculture - a gateway for exotic species. *Science, 294*, 1655–1656. https://doi.org/10.1126/science.1064875.
Nogueira, G. C. C. B., Salaro, A. L., Luz, R. K., Zuanon, J. A. S., Lambertucci, D. M., Salerno, R. A., et al. (2005). Desempenho produtivo de juvenis de trairão (Hoplias lacerdae) alimentados com rações comerciais. *Revista Ceres, 52*, 491–497. http://www.ceres.ufv.br/ojs/index.php/ceres/article/view/3065.
Ogata, H. Y., Emata, A. C., Garibay, E. S., & Furuita, H. (2004). Fatty acid composition of five candidate aquaculture species in Central Philippines. *Aquaculture, 236*, 361–375. https://doi.org/10.1016/j.aquaculture.2003.10.015.
Oliveira, R. D., & Nogueira, F. M. de B. (2000). Characterization of the fishes and of subsistence fishing in the Pantanal of Mato Grosso, Brazil. *Revista Brasileria de Biologia, 60*, 435–445. https://doi.org/10.1590/S0034-71082000000300008.
Oyakawa, O. T., & Mattox, M. T. G. (2009). Revision of the Neotropical trahiras of the *Hoplias lacerdae* species-group (Ostariophysi: Characiformes: Erythrinidae) with descriptions of two new species. *Neotropical Ichthyology, 7*, 117–140. https://doi.org/10.1590/S1679-62252009000200001.
Palmeri, G., Turchini, G. M., & De Silva, S. S. (2007). Lipid characterisation and distribution in the fillet of the farmed Australian native fish, Murray cod (*Maccullochella peelii peelii*). *Food Chemistry, 102* 796-238.
Parrish, C. C. (1999). Determination of total lipid, lipid classes and fatty acids in aquatic samples. In M. T. Arts, & B. C. Wainman (Eds.). *Lipids in Freshwater Ecosystems* (pp. 4–12). New York: Springer-Verlag.
Penha, J. M. F., Mateus, L. A. F., & Barbieri, G. (2004). Age and growth of the duckbill catfish (*Sorubim* cf. *lima*) in the Pantanal. *Brazilian Journal of Biology, 64*, 125–134. https://doi.org/10.1590/S1519-69842004000100014.
Pérez, J. E., Alfonsi, C., Nirchio, M., Muñoz, C., & Gómez, J. A. (2003). The introduction of exotic species in aquaculture: a solution or part of the problem? *Interciencias, 28*, 234–238.
Person-Le, J. R., Mahe, K., Le Bayon, N., & Le Delliou, H. (2004). Effects of temperature on growth and metabolism in a Mediterranean population of European sea bass. *Dicentrarchus labrax. Aquaculture, 237*, 269–280. https://doi.org/10.1016/j.aquaculture.2004.04.021.
Petenuci, M. E., Rocha, I. N. A., de Sousa, S. C., Schneider, V. V. A., Costa, L. A. M. A., & Visentainer, J. V. (2016). Seasonal variations in lipid content, fatty acid composition and nutritional profiles of five freshwater fish from the Amazon Basin. *Journal of the American Oil Chemists Society, 93*, 1373–1381. https://doi.org/10.1007/s11746-016-2884-8.
Piaia, R., & Baldisserotto, B. (2000). *Densidade de estocagem e crescimento de alevinos de Jundiá Rhamdia quelen (Quoy & Gaimard, 1824)*, *Vol. 30*Santa Maria: Ciência Ruralhttps://doi.org/10.1590/S0103-84782000000300024.
Pinheiro, J. C., & Bates, D. M. (1995). Approximations to the log-likelihood function in the nonlinear mixed-effects model. *Journal of Computational & Graphical Statistics, 4*, 12–35.
Quinton, C. D., McMillan, I., & Glebe, do B. D. (2005). Development of an Atlantic salmon (*Salmo salar*) genetic improvement program: genetic parameters of harvest body weigth and carcass quality traits estimated with animal models. *Aquaculture, 247*, 211–217. https://doi.org/10.1016/j.aquaculture.2005.02.030.
R Core Team (2017). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.
Ramsundar, H. (2005). The distribution and abundance of wetland ichthyofauna, and exploitation of the fisheries in the Godineau Swamp, Trinidad – Case study. *Revista de Biologia Tropical, 53*, 11–23.
Rantin, F. T., Glass, M. L., Kalinin, A. L., Verzola, R. M. M., & Fernandes, M. N. (1993). Cardio-respiratory responses in two ecologically distinct erythrinids (*Hoplias malabaricus* and *Hoplias lacerdae*) exposed to graded environmental hypoxia. *Environmental Biology of Fishes, 36*, 93–97.
Rao, C. R. (1973). *Linear Statistical Inference and its Applications* (2nd ed.). New York: John Wiley & Sons.
Regazzi, A. J. (2003). Teste para verificar a igualdade de parâmetros e a identidade de modelos de regressão não-linear. *Revista Ceres, 50*, 9–26. http://www.ceres.ufv.br/ojs/index.php/ceres/article/view/2854.
Ribeiro, C. S., Moreira, R. G., Cantelmo, O. A., & Esposito, E. (2014). The use of *Kluyveromyces marxianus* in the diet of red Stirling tilapia (*Oreochromis niloticus*) exposed to natural climatic variation: effects on growth performance, fatty acids and protein deposition. *Aquaculture Research, 45*, 812–827. https://doi.org/10.1111/are.12023.
Richards, F. J. (1959). A flexible growth function for empirical use. *Journal of Experimental Botany, 10*, 290–300. https://doi.org/10.1093/jxb/10.2.290.
Ross, L., & Beveridge, M. C. M. (1995). Is a better strategy necessary for development of native species for aquaculture? A Mexican case study. *Aquaculture Research, 26*, 539–547. https://doi.org/10.1111/j.1365-2109.1995.tb00944.x.
Sakamoto, Y., Ishiguro, M., & Kitagawa, G. (1986). *Akaike Information Criterion Statistics.* Dordrecht: Reidel.
Salaro, A. L., Luz, R. K., Nogueira, G. C. C. B., Reis, A., Sakabe, R., & Lambertucci, D. M. (2003). Diferentes densidades de estocagem na produção de alevinos de trairão (*Hoplias* cf. *lacerdae*). *Revista Brasileira de Zootecnia, 32*, 1033–1036. https://doi.org/10.1590/S1516-35982003000500001.
Salaro, A. L., Luz, R. K., Sakabe, R., Kasai, R. Y. D., & Lambertucci, D. M. (2008). Níveis de arraçoamento para juvenis de trairão (*Hoplias lacerdae*). *Revista Brasileira de Zootecnia, 37*, 967–970. https://doi.org/10.1590/S1516-35982008000600002.
Santos, A. B., Melo, J. F. B., Lopes, P. R. S., & Malgarim, M. B. (2001). Composição química e rendimento do filé da traíra (*Hoplias malabaricus*). *Revista da Faculdade de Zootecnia, Veterinária e Agronomia, 7/8*, 33–39. http://revistaseletronicas.pucrs.br/ojs/index.php/fzva/article/view/2134/0.
Sargent, J. R. (1995). Origins and functions of lipids in fish eggs: nutritional implications. In N. R. Bromage, & R. R. Roberts (Eds.). *Broodstock Management and Egg and Larval Quality* (pp. 353–372). Oxford: Blackwell Science.
Sarmento, J. L. R. S., Regazzi, A. J., Sousa, W. H., Torres, R. A., Breda, F. C., & Menezes, G. R. O. (2006). Estudo da curva de crescimento de ovinos Santa Inês. *Revista Brasileira de Zootecnia, 35*, 435–442. https://doi.org/10.1590/S1516-35982006000200014.
Schinckel, A. P., & Craig, B. A. (2002). Evaluation of alternative nonlinear mixed effects models of swine growth. *The Professional Animal Scientist, 18*, 219–226. https://doi.org/10.15232/S1080-7446(15)31525-4.
Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics, 6*, 461–464.
Scorvo-Filho, J. D., Romagosa, E., Ayroza, L. M. S., & Frascá-Scorvo, C. M. D. (2008). Desempenho produtivo do pintado, *Psedoplatystoma corruscans* (Spix e Agassiz, 1829), submetidos a diferentes densidades de estocagem em dois sistemas de criação: intensivo e semi-intensivo. *Boletim do Instituto de Pesca, 34*, 181–188.
Senso, L., Suarez, M. D., Ruiz-Cara, T., & Garcia-Gallego, M. (2007). On the possible effects of harvesting season and chilled storage on the fatty acid profile of the fillet of farmed gilthead sea bream (*Sparus aurata*). *Food Chemistry, 101*, 298–307. https://

doi.org/10.1016/j.foodchem.2006.01.036.
Sofaer, H. R., Chapman, P. L., Sillett, T. S., & Ghalambor, C. K. (2013). Advantages of nonlinear mixed models for fitting avian growth curves. *Journal of Avian Biology, 44*, 469–478. https://doi.org/10.1111/j.1600-048X.2013.05719.x.
Tesch, F. W. (1968). Age and growth. In W. E. Ricker (Ed.). *Methods for Assessment of Fish Production in Fresh Waters* (pp. 93–123). Oxford, UK: Blackwell Scientific Publications.
Tholon, P., & Queiroz, S. A. (2009). Modelos matemáticos utilizados para descrever curvas de crescimento em aves aplicadas ao melhoramento genético animal. *Ciência Rural, 39*, 2261–2269. http://www.redalyc.org/html/331/33118928015/.
Tolussi, C. E., Hilsdorf, A. W. S., Caneppele, D., & Moreira, R. G. (2010). The effects of stocking density in physiological parameters and growth of the endangered teleost species piabanha, *Brycon insignis* (Steindachner, 1877). *Aquaculture, 310*, 221–228. https://doi.org/10.1016/j.aquaculture.2010.10.007.
Tordecilla-Petro, G., Sánchez-Banda, S., & Olaya-Nieto, C. (2005). Crecimiento y mortalidad del moncholo (*Hoplias malabaricus*) en la Ciénaga Grande de Lorica, Colombia. *MVZ-Córdoba, 10*, 623–632. http://www.scielo.org.co/scielo.php?pid=S0122-02682005000200004&script=sci_arttext&tlng=en.
Torres, L. M., Zambiazi, R. C., Chiattone, P. V., Fonseca, T. P., & Costa, C. S. (2012). Composição em ácidos graxos de traíra (*Hoplias malabaricus*) e pintadinho (sem classificação) provenientes da região sul do Rio Grande do Sul e Índia Morta no Uruguai. *Semina: Ciências Agrárias, Londrina, 33*, 1047–1058. https://doi.org/10.5433/1679-0359.2012v33n3p1047.
Turra, E. M., Queiroz, B. M., Teixeira, E. A., Faria, P. M. C., Crepaldi, D. V., & Ribeiro, L. P. (2009). Densidade de estocagem do surubim Pseudoplatystoma spp., cultivado em tanque-rede. *Revista Brasileira de Saúde e Produção Animal, 10*, 177–187. http://revistas.ufba.br/index.php/rbspa/article/viewArticle/1049.
Ulbritch, T. L. V., & Southgate, D. A. T. (1991). Coronary heart disease: Seven dietary factors. *The Lancet, 338*, 985–992. https://doi.org/10.1016/0140-6736(91)91846-/m.
Vieira, V. A. R. O., Hilsdorf, A. W. S., & Moreira, R. G. (2012). The fatty acid profiles and energetic substrates of two Nile tilapia (*Oreochromis niloticus,* Linnaeus) strains, Red-Stirling and Chitralada, and their hybrid. *Aquaculture Research, 43*, 565–576. https://doi.org/10.1111/j.1365-2109.2011.02862.x.
Vieira, V. L., & Lopes, P. R. S. (2006). Aspectos da biologia, reprodução e manejo da traíra (*Hoplias malabaricus*). In B. Baldisserotto, & L. C. Gomes (Eds.). *Espécies nativas para piscicultura no Brasil* (pp. 287-302). Santa Maria: Editora UFSM ISBN. 978-85-7993-271-7.
Von Bertalanffy, L. (1938). A quantitative theory of organic growth (inquiries on growth laws. II). *Human Biology, 10*, 181–213.
Živić, I., Živić, M., Bjelanović, K., Spasić, M., Rašković, B., Stanković, M., et al. (2014). *Fatty acid profile in muscles of carp (Cyprinus carpio L.) raised in a semi-intensive production system fed with grains, pelleted and extruded feed. 66*, Belgrade: Archives of Biological Sciences877–887. https://doi.org/10.2298/ABS1402877Ž.
Zuliani, M. S., Ambrosio, A. M., Francisco, T. M., Balbi, T. J., Okada, E. K., & Gomes, L. C. (2016). Age and growth parameters of the dourado *Salminus brasiliensis* (Cuvier, 1816) from the river Cuiabá, Mato Grosso State, Brazil. *Acta Scientiarum. Biological Sciences, 38*, 59–65. https://doi.org/10.4025/actascibiolsci.v38i1.27868.