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Allometric relationship and growth models of juveniles of *Cichlasoma festae* (Perciforme: Cichlidae), a freshwater species native in Ecuador

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Abstract: Ecuador is considered the fishing capital of the Southeastern tropical Pacific with more than 900 native species. *Cichlasoma festae* represents an economic important freshwater species of much local use. Thus, in this study, our goal was to characterize this fish species during juvenile stages, as the first step for its conservation and valuation, and also for the preparation of proposals for sustainable rural development and formulation of plans for environmentally responsible fisheries management. The study lasted 25 weeks and was undertaken in the ictiohidrographic area of Province of Los Rios, which accounts for 35 % of native fish species in Ecuador. Weekly, the individual biometric parameters total length (L), body width (BW) and body depth (BD) of 90 juveniles of *C. festae* were measured. Growth was determined using non-linear biological regression models. The average standard length varied between 6.30 cm and 12.25 cm and the average weight varied between 4.99 and 35.71 g. The length-weight relationship was best fit by the equation $lnW = -3.92 + 2.96\ ln(L)$, and the species presented negative allometric growth. Finally, the best fit for the growth of *C. festae* was the Von Bertalanffy's model where $L_\infty = 19.758$ cm, $k = 0.028$ cm week^{-1} and $t_0 = -14.463$ week^{-1}. We concluded that to support sustainable and reliable fisheries production studies, the growth record from length may be obtained with standard methods as those evaluated in this study, or may be obtained with new safer tools such as photogrammetry. Rev. Biol. Trop. 65 (3): 1185-1193. Epub 2017 September 01.

Key words: *Cichlasoma festae*, growth models, allometry, conservation, native species.

Ecuador is considered a biodiversity reservoir especially for the native's freshwater fish species in the Southeastern Tropical Pacific (Álvarez-Mieles et al., 2013). Nine hundred and fifty-one Ecuadorian native species are recognized and grouped in 22 orders, 72 families, 17 subfamilies and 393 genders which represent the 7.8 % of freshwater species of the world, and a 21 % of the species in South America (Barriga, 2012).

In Ecuador, fisheries contribute with 7 % of the total supply of animal protein, estimated at 391 700 t catches made by capture fisheries in 2011 (Sirén, 2011). These catches are made by artisanal fishers in areas such as rivers, lakes, ponds, lagoons, gorges and dams. Ecuador harbors the largest artisanal and small-scale fisheries with responsible practices and environmentally friendly fishing activities that promote conservation of aquatic resources and ecosystems (Rodriguez et al., 2014). This way, Agbayani, Baticados, Quinitio and Tormon-West (2013) indicated that small-scale aquaculture may contribute with food security in the poorest rural areas, and may promote social cohesion and local endogenous development, and at the same time, may enhance livelihoods and biodiversity conservation. The plan is that the conservation of native fisheries resources can be integrated as an essential part of biodiversity maintenance, and joint efforts between authorities, scientists, and local fishers can work together for the sustainability and management of these aquatic zoogenetic resources.

Currently, the native cichlids in Ecuador have come to risk (García, Tume, & Juárez, 2012), mainly due to the replacement of native species by foreign species such as tilapia, because these have highly invaded most areas, and the high catches of native local resources (Canonico, Arthington, McCrary, & Thieme, 2005).

In order to produce and preserve the native species, the administration state created the Cachari Experimental Station, located in Babahoyo in the province of Los Ríos, where a conservation programme for native species is currently being developed by the Subsecretaría de Acuacultura of Ministerio de Agricultura, Ganadería, Acuacultura y Pesca (MAGAP). According to MAGAP, the cultivation of *Cichlasoma festae* is becoming more and more popular due to its good growth rate, fecundity, ease of manipulation, ability to grow under suboptimal environmental conditions, disease resistance and good consumer acceptance. The first step in developing a conservation plan of a native resource, is the characterization of the species, knowledge of the allometric relationships and estimating its growth models (Delgadillo-Calvillo et al., 2012).

Currently, very few studies have characterized the growth of *C. festae* in Ecuador. In fishes, the stock assessment uses biological parameters that influence growth such as the weight and length (Karachle & Stergiou, 2012; Wells, Kohin, Teo, Snodgrass, & Uosaki, 2013; Siddique, Arshad, & Amin, 2015). According to Santos, Gaspar, Vasconcelos and Monteiro (2002), length-weight relationship presents several applications, i.e. fish biology, physiology, ecology and fisheries assessment and management. For fisheries population assessment, management and conservation of native species in Ecuador, a mathematical expression of the mean individual body growth was required, relating the size of the species to its age (Katsanevakis & Maravelias, 2008). Nowadays, different growth models are applied: Von Bertalanffy growth pattern is the most widespread in studies (Von Bertalanffy, 1938), although Gompertz pattern (Gompertz, 1825) and Richard's growth model (Ricker, 1975) are frequently also applied. On the other side, since cichlid farming practices in Ecuador is a relatively recent activity, there are no specific and formal growth studies for local species. Thus, the aim of this research was to provide an initial characterization of the *Cichlasoma festae* growth during its juvenile stage under semi-controlled conditions, in order to enhance the conservation of this genetic resource, and to promote a sustainable and reliable fishery production.

MATERIALS AND METHODS

Study area and culture conditions: The study was carried out in the Breeding and Conservation Center for Native Species of the Cachari Experimental Station (1º47'59" S - 79º28'54" W) of the Sub-Secretary of fish farming, from the MAGAP on Babahoyo, province of Los Rios (Ecuador). The climate of this area is tropical with an average temperature of 25 ºC, an annual rainfall of 2 400 mm and a relative humidity of 82 %. A total of 720 juveniles of *C. festae* of three weeks old were cultured, in net cages fixed in a pond bypass of the Babahoyo River, between September 2014 and February 2015. Since male and female could not be differentiated morphologically, sexing of the sampled fish was not carried out. The net cages were fixed in a surface of 1 m^2 and submerged 1 m, and were filled at a density of 20 fish per m^2, for a total of 18 net cages fixed. A random sample of five fingerlings per cage was taken every week, and each fish was weighed and measured individually. The following biometric parameters were obtained: total length (L), body width (BW) and body depth (BD) (with an ichthy-meter) and body weight (W) (on a top loading digital balance to an accuracy of 0.1 g) (Santos et al*.,* 2002). The juveniles of *C. festae* were fed with an extruded concentrate composed by 35 % protein, which was initially administered *ad libitum*, and then adjusted to 3 % of live weight, according to the nutritional recommendations of MAGAP. The study was carried out according to the Ecuadorian national recommendations for the management of fish, taking into consideration the regulations of animal welfare.

Growth model estimations: Firstly, the normality of the distribution of body weight and total length was verified using a Kolmogorov-Smirnov test. The variability of the individual weights and length was expressed as the coefficient of variation. Growth was modelled using non-linear regression analysis. The estimation of growth parameters was performed from weight after Gómez-Ponce, Granados-Flores, Padilla, López-Hernández, and Núñez-Nogueira (2011) and length following Milatou and Megalofonou (2014). We decided to build a model of growth from the length due to less variability of data. Different growth models were fitted to explain the growth of *C. festae* according to Barreto, Lessa, Hazin, and Santana (2011): the von Bertalanffy's growth model (VBGM, von Bertalanffy, 1938); the Gompertz's growth model (Gompertz, 1825); and the Richard's growth model (Ricker, 1975). The models were detailed as follows:

$$\text{VBGM: } L_{(t)} = L_\infty (1 - e^{-k(t-t_0)});$$

$$\text{Gompertz: } L_{(t)} = L_\infty e^{[-ae(-kt)]};$$

$$\text{Richard: } L_{(t)} = \frac{L_\infty}{[1 + e^{(-kt+b)}]^m};$$

where $L_{(t)}$ = length at age t; L_∞ = maximal asymptotic length; k = growth coefficient; t_0 = theoretical age at which fish has zero length; and b = regression parameters and m = constant.

The different growth models were fitted with iterations by means of the Levenberg-Marquardt method for nonlinear least squares. The selection of the best model took place by using the coefficient of determination (R^2), the mean squared error (MSE) and Akaike Criterion (AIC) (Akaike, 1974). AIC is a measure of the quality of a selected statistical model that best fits the data using the maximum likelihood technique, according to the methodology proposed by Katsanevakis and Maravelias (2008). Bias-corrected form (AIC_C) of *AIC* was used for model selection as follows:

$$AIC_C = AIC + \frac{2\,k\,(k+1)}{n-k-1},$$

where

$$AIC = n\,(log\,(2\pi \frac{RSS}{n}) + 1) + 2\,k;$$

RSS is the residual sum of squares, *n* the number of observations and *k* is the number of estimable parameters. The model with the smallest AIC_C value ($AIC_{C,\ min}$) was selected as the best among the models tested. The AIC differences ($\Delta_i = AIC_{C,i} - AIC_{C,\ min}$) were computed over all models. Finally, models with differences $\Delta_i > 10$ have essentially no support and might be omitted from further consideration; models with differences $\Delta_i < 2$ have substantial support, while there is considerably less support for model with $4 < \Delta_i < 7$ (Burnham & Anderson, 2002).

Fulton condition factor (*K*): Fulton Condition factor (K), which is defined as the well-being of the fish, was calculated using the following equation $K = 100\ W/L^3$, where W is total weight, and L is the total length in cm (Froese, 2006). K is a useful tool for monitoring of feeding intensity, age and growth rates (González et al., 2016).

Length-weight relationship: Length-weight (L-W) relationship of *C. festae* was evaluated using the allometric regression analysis (González et al., 2016; Dantas, de Araújo, Fernandes de Oliveira, Silva, & Costa, 2016). The estimation of L-W relationship was made by the adjustment of an exponential curve to the data expressed in its logarithmic form (Santos et al., 2002). L-W relationship was expressed as $W = a\ L^b$, the logarithmic transformation of which fives the linear equation log *W* = log *a* + *b* log *L,* where, *W* is the total weight in grams, *L* is the total length in centimetres, *a* is constant for the initial growth index and *b* is the growth coefficient. Constant *a* and *b* represent the point at which the regression line intercepts the *y* axis and the slope of the regression line, respectively. The L-W relationship shows an isometric growth when $b = 3$. Finally, in order to confirm the values of the constant *b* (slope of L-W relationship model) they were compared with Student's t-test (H_0: b=3) to detect any significant differences on the L-W relationship.

The level of significance in all cases was considered at $P \leq 0.05$. All statistical analyses were done using SPSS v.15.

RESULTS

Growth models estimations: A total of 720 juveniles of *C. festae* were cultivated during 25 weeks. At the beginning of the study, the average weight and length were 4.99 g (Standard Deviation, SD = 0.13) and 6.3 cm (SD = 0.14), respectively, and the average daily growth was 0.199 $g.day^{-1}$. At the end of the experiment the average weight and length were 35.71 g (SD = 16.38) and 12.25 cm (SD = 2.32). Both individual distributions of weight (Kolmogórov-Smirnov = 0.11; P = 0.20) and length (Kolmogórov-Smirnov = 0.12, P = 0.145) were adjusted to a normal distribution; but a variability lower than 3 % was found for both weight and length data. From the fourth week of the experiment, the weight coefficient of variation (CV) increased significantly ($P < 0.01$); these differences remained during the subsequent weeks ($P < 0.01$) (data no presented). The fish final weight showed a variation of 36 % for the sample as a whole, while lower CV for length was observed in a range between 10 to 20 % (data no presented) with a mean value 15.7 %.

The growth parameters estimated for juveniles of *C. festae*: See table 1. Von Bertalanffy's model presented the greater value L_∞ (19.758 cm). Likewise, VBGM showed the higher growth constant of all the studied models ($0.028.week^{-1}$). Finally, only VBGM model described t_0 value, which indicates the theoretical age at which fish has zero length (-14.463 weeks). These parameters were used to construct the growth curve of *C. festae* (Fig. 1).

The coefficient of determination (R^2), the mean square error (MSE) and Akaike Criterion (*AIC*, AIC_C and the differences Δ_i) were calculated for each data set in each estimated model, (Table 2). The coefficient of determination is widely used by statisticians as a goodness of fit indicator; which had the upper value for VBGM. Likewise Von Bertalanffy's model presented the lower SEM. Finally, the lowest AIC values were estimated using VBGM model which was considered the best model describing the growth of *C. festae* Those were followed by Richard's model, which reached a very similar AIC value ($\Delta_i < 2$) and the Gompertz's model ranked fourth with $\Delta_i > 2$.

Fulton condition factor (*K*): The mean value of the condition factor *K* was 1.76 (SD =0.26) for the original data (from a range of 0.65 to 3). The coefficient of variation was not high (14.90 %).

TABLE 1
Growth models and parameters estimated for *Cichlasoma festae*

Model	L_∞	SD	CI (-/+)	*k*	SD	CI (-/+)	t_0	SD	CI (-/+)
VBGM	19.758	2.32	15.21/24.3	0.028	0.06	0.014/0.039	-14.463	1.726	-17.28/-10.51
Gompertz ^{2}	16.51	0.998	14.55/18.47	0.008	0.001	0.006/0.009	-	-	-
Richard^3	16.50	4.49	7.67/25.32	0.008	0.009	-0.009/0.024	-	-	-

VBGM: von Bertalanffy's growth model; L_∞ = maximal asymptotic length (cm); SD: Standard deviation; CI: Confidence interval; *k* = growth constant ($week^{-1}$); t_0 = theorical age at which fish length is zero (weeks), ^{2} a= 1.059; ^{3} b= -4.846; m= 135.136.

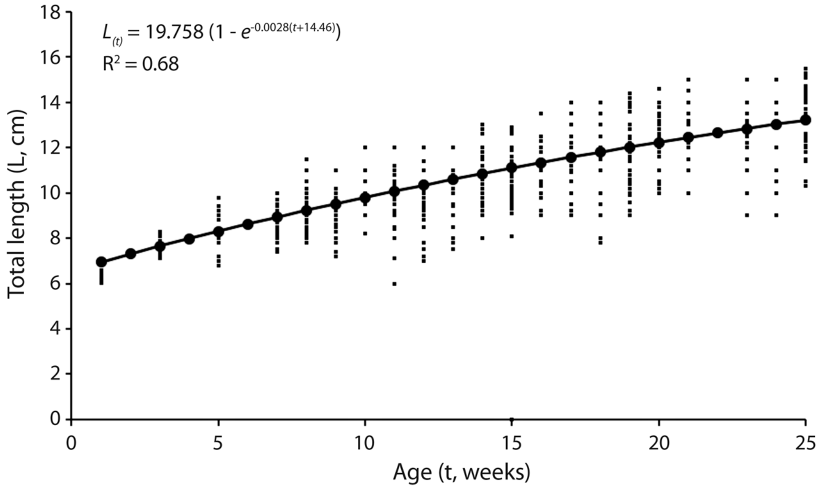

Fig. 1. Estimated Von Bertalanffy's growth curve and observed values for *Cichlasoma festae*.

TABLE 2
Ranking of the four models based on R^2, MSE and Akaike information criterion values

Model	R^2	MSE	AIC	AIC_C	Δ_i
VBGM	0.6839	1273.9	1824.86	1824.88	0
Gompertz	0.6837	1274.6	1827.10	1827.14	2.26
Richard	0.6837	1274.6	1825.10	1825.12	0.24

VBGM: von Bertalanffy's growth model; R^2: coefficient of determination; MSE: the mean square error; AIC: Akaike Criterion AIC_C: Bias-corrected form of *AIC*; Δ_i: AIC differences ($\Delta_i = AIC_{C,i} - AIC_{C,min}$).

Length-weight relationship: L-W relationship was estimated by the function: $W = 0.0198\ L^{2.96}$ ($lnW = -3.92 + 2.96\ ln(L)$) with a coefficient of determination (R^2) of 94.7 %; and allometric coefficient (*b*) lower than 3. The parameter *b* had a mean value of 2.96 (SD = 0.019), subsequently, the significance was verified considering the value of 3 by the use of a t-test (*t*-test = 25.7; $P \leq 0.05$), therefore, an allometric growth during juvenile stage of *C. festae* was obtained (Fig. 2).

DISCUSSION

The average daily growth of juveniles of *C. festae* was lower than those reported for *Tilapia nilotica* (0.49 day^{-1}) (Gómez-Ponce et al., 2011). At the beginning of the study, variability lower than 3 % was found in both weight and length, similar to *Dicentrarchus labrax* results of Saillant et al. (2003). The low correlation between weight-length with the width (lower than 0.6), could be referred to a juvenile stage data of *Cichlasoma*, but not to the final stage, where length and weight increased faster than width (Rodríguez et al., 2014).

The Von Bertalanffy's growth model was fitted to mean length and growth parameters $L_{(t)} = 19.758\ (1 - e^{-0.0028(t+14.46)})$ with an R^2 of 0.68. Studies on *Tilapia* growth in Mexico obtained 56.83 for L_∞ and 0.13 for *k* (Palacios, 1995). Likewise, Gómez-Ponce et al. (2011) obtained higher values of L_∞ and *k* (L_∞ = 28.11 cm; k = 0.33 $week^{-1}$) for Tilapia. However, no *C. festae* data were available.

The condition factor *K* is a useful index to monitor feeding intensity, age, and growth rates

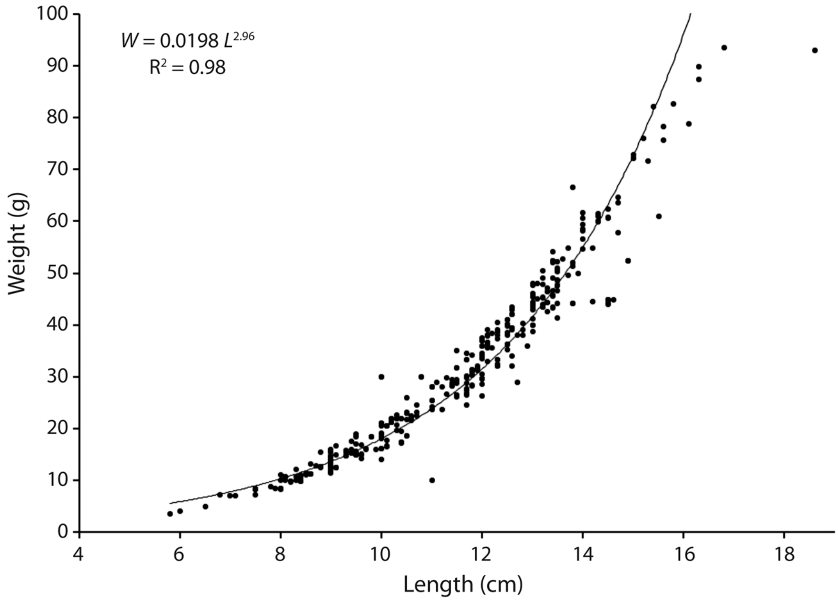

Fig. 2. Length-weight relationship of *Cichlasoma festae.*

in fish (Oni, Olayemi, & Adegboye, 1983). It is strongly influenced by both biotic and abiotic environmental conditions and can be used as an index to assess the status of the aquatic ecosystem in which fish live. The condition factor values of *C. festae* from the current study (1.76) were lower than those registered by Chukwuemeka, Tsadu, Ayanwale, Erhabor, and Falusi (2014) in *Tilapia aurea*, *Tilapia galileae* and *Auchenoglanius occidentalis* and lower than those reported by Anene (2005) in four cichlid fishes (4.9). However, Fagbuaro, Oso, Olurotimi and Akinyemi (2015) recorded significantly lower values (0.68) in *Clarias gariepinus* fish. The condition factor *K* obtained in this study implies that the fish may not have feed to the required level.

The length-weight relationship allowed a closer view of the type of growth of this native species. Santos et al., (2002) defined that the isometric type of growth is when the length and weight increase in the same proportion. According to Delgadillo-Calvillo et al. (2012), in aquaculture, the weight is directly proportional to the cube of its length (b=3); this shows an isometric growth, therefore, if $b < 3$ the growth is negative allometric, while for value over 3, the allometric is positive. The estimated parameter allometric (b) from the weight-length relationship had the value of 2.96 and the intercept of 0.0198. The results showed that the rate of weight gain is less than the rate of length increase. The L-W relationship showed a growth of negative allometric type, the value of the coefficient was b= 2.96. García et al., (2012) indicated an isometric growth between length and weight for *Oreochromis niloticus* in Peru. Similar results were published by Kullander (2003) for *Cichlidae,* where the estimation of b was found between 2.93 and 3.33, and the intercept a was found between 0.00576 and 0.0602. In a similar study by Gómez-Ponce et al. (2011) for *Oreochromis niloticus* in Mexico, allometric coefficients ranged between 2.5 and 3.5 were shown, giving credence to the results of this study.

Barreto et al. (2011) have studied the fish growth by making captures during different growth stages; they have classified the fishes and later have adjusted the recorded measures to a biologic function of Von Bertalanffy. In this study, a direct method was selected according

Dampin, Tarnchalanukit, Chunkao, and Maleewong (2012) which studied the growth model of *Oreochromis niloticus* in net cages fixed with semi-controlled conditions. Although of various failures in breeding, the productive cycle is beginning to be discovered, and the breeding can be reproduced in semi-controlled conditions for future experimental models, and to be used in aquaculture conservation.

In order to improve the conservation of native species, future studies must be developed by small scale fishers generating synergies with researchers. Since stakeholder participation is importantly directed to environmental decision-making processes, they may support the conservation of these local genetics resources. The benefits of different sectors participation on the water quality governance include not only improved interaction and dialogue, but also mutual exchange of knowledge, transparency in the process, and impulse trust among participants.

Future efforts should include genetic and reproductive characterization, in order to promote an integral conservation plan of this resource in Ecuadorian rivers. The obtained non-linear models such L-W relationship as a growth model, constituted suitable indicators of this fish growth; they are easy to obtain, avoid the direct fish handling and diminish risk factors associated with stress and pathology. Moreover, the growth record from length might be associated to photogrammetry, similar to Perea, García, Acero, Valerio and Gómez (2008) in snails; this indicates a great useful for developing of sustainable and reliable fishery production.

RESUMEN

Relación alométrica y modelos de crecimiento de juveniles de *Cichlasoma festae* (Perciforme: Cichlidae), una especie nativa de agua dulce en Ecuador. Ecuador se considera la capital pesquera del Pacífico tropical suroriental con más de 900 especies nativas. *Cichlasoma festae* representa una importante especie de agua dulce de gran uso local. Por lo tanto, en este estudio, nuestro objetivo fue caracterizar esta especie durante la etapa juvenil, como primer paso para su conservación y valoración, así como para la preparación de propuestas para el desarrollo rural sostenible y la formulación de planes para una gestión pesquera ambientalmente responsable. El estudio duró 25 semanas y se llevó a cabo la zona ictiohidrográfica de la Provincia de Los Ríos, que representa el 35 % de las especies nativas en Ecuador. Semanalmente, se midieron los parámetros biométricos individuales longitud total (L), ancho corporal (BW) y profundidad corporal (BD) de 90 juveniles de *C. festae*. El crecimiento se determinó utilizando modelos de regresión biológicos no lineales. La longitud media estándar varió entre 6.30 y 12.25 cm y el peso promedio varió entre 4.99 y 35.71 g. La relación longitud-peso se ajustó a la ecuación $lnW = -3.92 + 2.96\ ln(L)$, y la especie presentó crecimiento alométrico negativo. Finalmente, el mejor ajuste para el crecimiento de *C. festae* fue el modelo de Von Bertalanffy donde $L_\infty = 19.758$ cm, $k = 0.028$ cm week^{-1} y $t_0 = -14.463$ week^{-1}. Concluimos que el registro de crecimiento de la longitud podría estar asociado a la fotogrametría como una herramienta para el desarrollo de una producción pesquera sostenible y segura.

Palabras clave: *Cichlasoma festae,* modelos de crecimiento, alometría, conservación, especies nativas.

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