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Application of multifactorial discriminant analysis in the morphostructural differentiation of wild and cultured populations of Vieja Azul (*Andinoacara rivulatus*)

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Abstract: To better determine the ecological variation (body shape and structure) of the Vieja Azul (*Andinoacara rivulatus*; syn.: *Aequidens rivulatus*) in northwest Ecuador (Los Ríos Province), 300 specimens of both sexes (150 male and 150 female) were collected from 3 different locations, one from a wild production system and two from fish farm populations in the Quevedo River. Twelve meristic, 26 traditional morphometric, and 32 truss measurements, among 25 anatomical landmarks, were determined. The body weight (BW), total length (TL), eye diameter (ED), dorsal fin ray length (DFRL), and body perimeter 3 (P3) showed significant differences ($P < 0.05$) between production systems, and sex had significant influence on preanal length (Pre-AL), P3, and body width 2 (LC2). Females showed higher mean values than males in all measurements, except for BW. The Fulton factor differed for both factors considered. The canonical discriminant analysis revealed a percentage of correct assignment of 64.42% for the dataset, 85% and 60.9% for cultured and wild females, and 62.1% and 56.3% for wild and cultured males, respectively, as well as morphometric variation between groups. Results could be attributed to environmental conditions (habitat, temperature, and food). The Mahalanobis test showed greater distances among females than among males. In conclusion, this study provides valuable morphological information on the shape and structure of *Andinoacara rivulatus* that can be used to characterize and quantify the changes that occur as a consequence of adaptation to a different habitat. The authors hope that the information obtained from the present study will be helpful for fisheries, biologists, and taxonomists.

Key words: *Andinoacara rivulatus*, condition factor, discriminate analysis, length–weight relationship, morphometric characteristics, population

1. Introduction

Ecuador is considered to be an important biodiversity reserve for native freshwater fish species in the southeastern tropical Pacific (FAO, 2019), where 951 Ecuadorian native species are recognized (Barriga, 2012). Most neotropical cichlids occupy lentic habitats within lakes, rivers, and streams of slow current. *Andinoacara rivulatus* (syn.: *Aequidens rivulatus*) originates from the Pacific side of South America in the coastal waters from the Tumbes River in Peru to the Esmeraldas River in Ecuador.

Currently, the native cichlids in Ecuador are threatened (García et al., 2012), mainly due to the replacement of native species with foreign ones. Besides, overexploitation of rivers and degradation of natural habitats have caused a decline in the production of wild fishery resources (Ajah et al., 2006; Barange et al., 2018). Therefore, better knowledge of native resources has become necessary to preserve these native species and produce food in an efficient and sustainable way. Consequently, fish farms have been established to raise and produce fish to be sold in local markets in the last few years. The family Cichlidae is one of the most appreciated species in Ecuador for the quality of its meat.

The phenotypic plasticity of fish, assessed by morphological and meristic measurements (Elliot et al., 1995), is greater than in the rest of vertebrates, and this variation can be partly attributed to the influence of environmental parameters (Wimberger, 1992). Although comparisons of the morphology between cultured and wild fishes of several species have already been carried out by several authors (Solomon et al., 2015; Gonzalez et al., 2016), to our knowledge, the evaluation on the effect of environmental factors on the differentiation of *Andinoacara rivulatus* in the rivers of the Ecuador is limited. Therefore, the aim of the present study is to investigate the morphometric and meristic variations between wild and cultured populations of *Andinoacara rivulatus* in both sexes in order to illustrate intraspecific variations.

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2. Materials and methods

2.1. Ethical note

The study was carried out according to the Ecuadorian national recommendations for fish management, with consideration for the rules on animal welfare.

2.2. Study area and data sampling

This study was carried out in Los Ríos Province (Ecuador). The climate of the area is tropical with an average temperature of 25 °C, annual rainfall of 2400 mm, and relative humidity of 82%. Wild fish were caught from 3 separate locations within their natural geographic distributions in the Quevedo River (Los Ríos Province, Ecuador). Cultured fish were collected from 2 fish farms

A total of 300 *Andinoacara rivulatus* individuals (150 wild and 150 cultured, of both sexes) were obtained at random from weekly catches made following the procedure described by Konings (1989) in 2017. All individuals were healthy adult fish. In the river, diurnal catches were made by native fishermen following the procedures described by Frost and Kipling (1980), Chávez-Lomelí et al. (1988), and Konings (1989). On the farms, fish were caught using standard fishing equipment. Farmed fish were fed 3 times per day, adjusting the consumption to 1.5% biomass. The diet composition was 32% crude protein, 7% fat, 5% crude fiber, 9% ash, and 12% moisture. The wild fish ate natural food based on phytoplankton and zooplankton. Males and females were differentiated by their morphological characters.

Immediately after being caught, the specimens were kept in glass flow-through aquaria with continuous air filled with 200 L of dechlorinated tap water, transported alive, and placed into 2 masonry tanks (with a capacity of 500 L) (dissolved oxygen = 6.20 ± 0.0 mg/L, temperature = 20.5 ± 0.2 °C and pH = 5.6 ± 0.1). All fish rested for 48 h before the experiment, with a fasting time of 24 h before slaughter. On the day of the experiment, the water in the tank was reduced by half, and the fish were quickly caught with a net and transferred to a plastic box (100 L) and kept indoors. For stunning, the fish were placed at the same time in a mixture of 40 L of ice and 40 L of water (0.8 °C) until the apparent stunning was over (20 min). After confirmation of death, the fish were identified and weighed, and then morphometric measurements and meristic counts were performed.

2.3. Body measurements

Measurements, except width and perimeter, were taken on the left side of each fish by the same person; most of the morphometric characters were measured following the conventional method described by Diodatti et al. (2008). The specimens were measured using a measuring board, making use of tape and digital calipers graduated in millimeters (with an accuracy of 0.01 mm), and then weighed with an electronic balance up to the nearest 0.1 g. Meristic characters were examined according to Froese and Pauly (http://www.fishbase.org). A total of 38 body measurements were registered, including 26 morphometric variables and 12 meristic counts (Table 1). Additionally, 32 truss network measurements (Strauss and Bookstein, 1982) were determined based on 25 landmarks of the left lateral plane (Figure 1).

2.4. Fulton factor

The Fulton factor (K) was calculated with the following equation: $K = (100 \times BW)/SL^3$, where BW is the body weight (g) and SL is the standard length (cm).

2.5. Length–weight relationship

Length–weight relationships were calculated using allometric regression analysis (9). Length–weights were determined by logarithmic transformation of the following linear regression equation: $\log BW = a + (b \times \log SL)$, where BW is the body weight (g), SL is the standard length (cm), a is the intercept, and b is the slope of the regression curve (Ruiz-Campos et al., 2010).

2.6. Statistical analyses

All statistical analyses were performed using SAS University Edition 3.5 (SAS Institute, Cary, NC, USA) and Statistica 12.0 for Windows (StatSoft, Tulsa, OK, USA). Each collection site was considered a priori as a discrete group. To evaluate whether the data had equal variances, a Bartlett test was done prior to further analyses.

The morphometric and meristic data were analyzed separately. The raw data of the meristic characters were used in analysis. However, all morphometric characters were standardized according to Elliott et al. (1995). The efficiency of the size-adjustment transformations was assessed by testing the significance of the correlation between a transformed variable and standard length.

Size-adjusted morphometric data and meristic characters were compared by univariate analysis of variance (ANOVA procedure) and the Kruskal–Wallis test (NPAR1WAY procedure), respectively, using the production system (cultured or wild) and sex (male or female) as the fixed effect. In addition, the DISCRIM procedure was used to perform a canonical discriminant analysis of size-adjusted geometric morphometric data, using the production system (cultured or wild) and sex (male or female) as the grouping variable. The probabilities to enter and remain in the model were both set at $P < 0.05$. The spatial distribution of fish was represented by canonical scatterplot, thus permitting the visualization of relationships among the group of individuals (Turan, 1999). The representation of the Mahalanobis distances by cluster and the percentage of correct assignment were also considered.

Table 1. Definitions of morphometric measurements and meristic counts of *Andinoacara rivulatus* used in this study.

Character	Description	Acronyms
Weight	Total weight including gut and gonads	BW
Total length	Tip of the upper jaw to the caudal end of the caudal fin	TL
Standard length	Tip of the upper jaw to the tail base	SL
Head length	From the front of the upper lip to the posterior end of the opercula membrane	HL
Eye diameter	The greatest bony diameter of the orbit	ED
Preorbital length	Front of the upper lip to cranial eye edge	Pre-OL
Predorsal length	Front of the upper lip to the origin of the dorsal fin	Pre-DL
Prepectoral length	Front of the upper lip to the origin of the pectoral fin	Pre-PcL
Prepelvic length	Front of the upper lip to the origin of the pelvic fin	Pre-PvL
Preanal length	Front of the upper lip to the origin of the anal fin	Pre-AL
Dorsal fin length	From base of first dorsal spine to base of last dorsal ray	DFL
Dorsal fin ray length	From base to tip of the fifth dorsal ray	DFRL
Pectoral fin length	From base to tip of the pectoral fin	PcFL
Pelvic fin length	From base to tip of the pelvic fin	PvFL
Anal fin length	From base of first anal spine to base of last anal ray	AFL
Anal fin ray length	From base to tip of the last anal ray	AFRL
Upper jaw length	Straight line measurement between the snout tip and posterior edge of maxilla	UJL
Body depth 1	Body depth at the level of the first ray of the dorsal fin	AC1
Body depth 2	Body depth at the level of the first ray of the anal fin	AC2
Body depth 3	Body depth at the level of the first radius of the caudal fin	AC3
Body perimeter 1	Body perimeter at the level of the first ray of the dorsal fin	P1
Body perimeter 2	Body perimeter at the level of the first radius of the anal fin	P2
Body perimeter 3	Body perimeter at the level of the last ray of the dorsal fin	P3
Body width 1	Straight line measurement from side to side at the level of the base of first dorsal spine	LC1
Body width 2	Straight line measurement from side to side at the level of the base of first anal spine	LC2
Body width 3	Straight line measurement from side to side at the level of the base of last dorsal ray	LC3
Dorsal fin rays	Number of thorns in the dorsal fin	DFR
Radius dorsal fin	Number of cartilage found in the space between thorns from the dorsal fin	RDF
Pectoral fin rays	Number of thorns in the pectoral fin	PcFR
Radius pectoral fin	Number of cartilage found in the space between thorns in the pectoral fin	RPcF
Pelvic fin rays	Number of thorns in the pelvic fin	PvFR
Radius pelvic fin	Number of cartilage found in the space between thorns in the pelvic fin	RPvF
Anal fin rays	Number of thorns in the anal fin	AFR
Radius anal fin	Number of cartilage found in the space between thorns in the anal fin	RAF
Caudal fin rays	Number of thorns in the caudal fin	CFR
Radius caudal fin	Number of cartilage found in the space between thorns in the caudal fin	RCF
Scales	Number of scales in the lateral line scale	SC
Gills	Number of gills	G

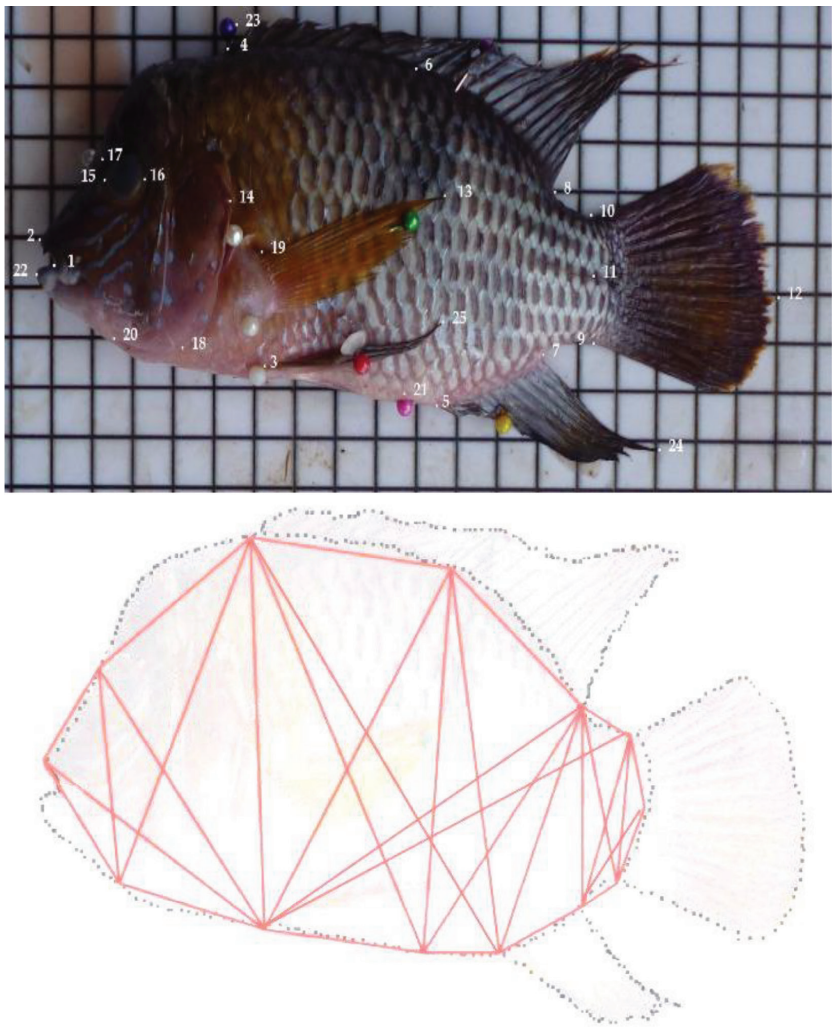

Figure 1. (a) Location of 25 anatomic landmark points designed on the left-side view of *Andinoacara rivulatus*; (b) 32 truss characters making up a truss network. 1- Commissure of the mouth; 2- most cranial point of the upper premaxilla; 3- origin of pelvic fin; 4- origin of dorsal fin; 5- origin of anal fin; 6- most cranial point of the base of the tenth spine of the dorsal fin; 7- ending of anal fin; 8- ending of dorsal fin; 9- ventral origin of caudal fin; 10- dorsal origin of caudal fin; 11- most cranial point of caudal peduncle; 12- most caudal point of caudal peduncle; 13- ending of pectoral fin; 14- end of operculum; 15- cranial edge of the eye; 16- caudal edge of the eye; 17- preoccipital (most posterior aspect of neurocranium); 18- below operculum; 19- origin of pectoral fin; 20- lower end of the head; 21- anal opening; 22- most cranial point of the lower premaxilla; 23- ending of 1st dorsal fin ray; 24- ending of the last anal fin ray; 25- ending of the pelvic fin radius.

3. Results

3.1. Morphometric and meristic characters

The habitat (rivers or fish farms) had a significant influence ($P < 0.05$) on BW, K, TL, ED, DFRL, and P3 (Table 2), whereas sex only influenced Pre-Al, P3, and LC2. In general, mean values were higher in females.

The eye, with an average diameter of 1.1 cm, was located approximately 2 cm from the tip of the upper jaw. The origin of the pectoral fin was slightly anterior to the dorsal and pelvic fins, located at the same distance from the tip of the upper jaw, with no significant differences ($P > 0.05$) between groups. The most caudal position was occupied by the anal fin, whose length was approximately 34.96% of the dorsal fin. The length of the pectoral and pelvic fin rays was similar ($P > 0.05$) among them but longer ($P < 0.05$) than the anal fin. None of these measurements or their relationship with standard length differed significantly ($P > 0.05$) between production systems or sexes.

The coefficient of variation (CV) of the different measures ranged from 4.85 (P2) to 41.71 (DFRL) (Table 2). The measures with lower coefficient of variation were TL, SL, Pre-DL, Pre-PcL, Pre-PvL, DFL, LC1, P2, and P1, which did not exceed 10%, whereas those that presented greater variation were factor K, DFRL, UJL, AC1, and

Table 2. Descriptive statistics of body measurements (original data) of *Andinoacara rivulatus* from both hatchery and wild populations.

Character[1]	Wild				Cultured				P-value		
	Males (N = 75)		Females (N = 75)		Males (N = 75)		Females (N = 75)				
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	System	Sex	System × sex
BW	162.61	22.66	158.58	16.77	156.06	14.64	151.13	14.29	0.029	0.162	0.888
K	5.98	24.53	5.13	24.73	5.12	32.32	5.16	23.28	0.011	0.014	0.006
TL	18.33	7.98	18.31	7.66	18.74	10.63	19.07	8.44	0.013	0.331	0.994
SL	14.20	7.75	14.54	9.45	14.40	10.39	14.74	9.89	0.122	0.312	0.346
HL	4.84	6.27	4.91	8.25	4.90	10.75	4.88	11.24	0.882	0.761	0.626
ED	1.13	17.52	1.15	12.03	1.07	14.06	1.01	14.87	0.002	0.519	0.203
Pre-OL	2.12	12.66	2.13	17.39	2.19	18.18	2.01	9.61	0.692	0.190	0.163
Pre-DL	6.26	6.85	6.48	8.67	6.26	10.16	6.28	9.19	0.355	0.295	0.365
Pre-PcL	5.55	7.5	5.64	7.58	5.68	9.06	5.77	7.39	0.157	0.333	0.991
Pre-PvL	6.12	9.68	6.28	10.94	6.24	9.99	6.49	8.44	0.169	0.097	0.717
Pre-AL	9.98	12.15	10.72	10.27	10.22	9.82	10.87	9.10	0.371	0.002	0.848
DFL	8.60	9.76	8.74	9.45	8.80	9.91	9.09	8.72	0.099	0.192	0.660
DFRL	0.85	32.02	0.91	41.71	1.08	41.29	1.27	33.6	0.000	0.096	0.378
PcFRL	4.63	10.41	4.58	9.67	4.57	17.55	4.8	11.33	0.525	0.477	0.258
PvFRL	4.69	12.5	4.55	12.07	4.55	14.47	4.74	13.21	0.832	0.818	0.187
AFL	3.02	9.93	3.07	7.42	3.12	12.09	3.1	11.13	0.317	0.819	0.544
AFRL	3.51	20.72	3.27	16.73	3.56	18.7	3.46	17.84	0.372	0.200	0.576
UJL	0.62	16.02	0.64	21.53	0.64	20.04	0.64	26.15	0.585	0.740	0.764
AC1	7.56	22.23	8.34	19.09	7.66	20.05	7.64	20.69	0.353	0.231	0.209
AC2	6.81	25.39	7.68	23.23	6.86	21.64	7.05	23.28	0.380	0.114	0.301
AC3	2.53	19.28	2.77	19.07	2.58	16.86	2.66	16.43	0.730	0.094	0.392
P1	16.18	6.92	16.57	7.38	16.24	5.91	16.15	5.38	0.406	0.488	0.256
P2	14.91	8.06	15.41	8.47	14.88	7.26	14.8	4.85	0.154	0.341	0.189
P3	6.00	7.92	6.3	8.32	5.86	6.95	6.00	7.78	0.022	0.020	0.395
LC1	2.59	8.15	2.64	9.05	2.59	9.59	2.62	10.1	0.835	0.461	0.769
LC2	1.83	10.02	1.84	13.96	1.76	10.95	1.93	13.58	0.883	0.049	0.091
LC3	0.89	14.94	0.9	19.18	0.90	23.61	0.98	15.39	0.188	0.234	0.264

[1]See Table 1; K = Fulton condition factor.

AC2 (>20%). The CV of the morphometric characters was not significantly ($P > 0.05$) different between production systems or sexes.

The body measurements related to standard length were compared on the basis of statistic r (correlation coefficient) and b (allometric coefficient) (Table 3). The highest correlated body measurements were TL (r = 0.92), DFL (r = 0.82), Pre-AL (r = 0.80), Pre-PvL (r = 0.76), and Pre-DL (r = 0.73); the least correlated were LC3 (r = 0.29), P2 (r = 0.28), AFRL (r = 0.26), LC1 and LC2 (r = 0.18), DFRL (r = 0.15), and ED (r = 0.06). For the other morphometric variables, the correlation coefficient ranged from 0.3 to 0.65. Factor K presented a negative correlation coefficient (b = –0.79). For the standard length, P1, P2, P3, LC1, LC2, and ED showed allometric coefficients under 0.25, while AC1 and AC2 were over 1.1. AC3 and Pre-AL showed isometric growth (b = 1). The remaining morphometric characters had a coefficient b between 0.4 and 0.8 (Huxley, 1932).

Between populations, the BW/SL ratio was significantly higher ($P < 0.05$) in the wild population (11.12 vs. 10.47), while the cultured population showed higher values of Pre-

PvL/SL (0.44 vs. 0.43), DFL/SL (0.62 vs. 0.60), and DFRL/SL (0.08 vs. 0.06) ratios. Regarding sex, no significant ($P > 0.05$) differences were detected, although the higher mean values of the aforementioned ratios were obtained for wild females in BW/SL (11.14); cultured females in TL/SL, P1/SL, and P2/SL (1.30, 1.12, and 1.03, respectively); and wild males in Pre-AL/SL (0.73) (Table 4).

Among the 26 transformed morphometric measurements (Table 5), 6 characters (BW, P3, Pre-PvFL, DFL, DFRL, and ED) were found significantly different ($P < 0.05$) for production systems and 7 for sex (TL, ED, Pre-PvL, Pre-AL, DFL, P3, and LC2). BW (159.49 g vs. 149.91 g) and P3 (6.13 cm vs. 5.92 cm) were significantly higher ($P < 0.05$) in wild specimens, while Pre-PvL (6.34 cm vs. 6.19 cm), DFL (8.92 cm vs. 8.66 cm), DFRL (1.15 cm vs. 0.88 cm), and ED (1.13 cm vs. 1.05 cm) were significantly higher ($P < 0.05$) in cultured ones. TL (18.71 cm vs. 18.28 cm), P3 (6.16 cm vs. 5.93 cm), LC2 (1.88 cm vs. 1.79 cm), Pre-PVL (6.38 cm vs. 6.18 cm), Pre-AL (10.79 cm vs. 10.11 cm), DFL (8.91 cm vs. 8.71 cm), and ED (1.14 cm vs. 1.05 cm) were significantly higher ($P < 0.05$) in female specimens.

The values of meristic characters are shown in Table 6. The mean values of DFR, RDF, PvFR, RPvF, AFR, RAF, CFR, RCF, and scale on lateral line and gills (Table 4) were not different between groups ($P > 0.05$), whereas PcFR and RPcF were higher ($P < 0.05$) in wild fish. The CV was very low (<8%), except for PcFR, RPcF, and gills (>8%) in wild females and PvFR and RPvF in cultured females. The most frequent classes of DFR, RDF, PcFR, RPcF, CFR, RCF, AFR, and RAF were 23–24 (41.3%), 24–25 (31.7%), 11–12 (25.0%), 12–13 (47.1%), 15–16 (37.5%), 16–17 (18.3%), 10–11 (56.7%), and 11–12 (25.9%), respectively. Pelvic fin rays and radius of pelvic fin ranged from 4 to 8, with most of them showing values in the range of 5–6 (91.3%). The ranges of the dorsal (21–28 vs. 21–26), pectoral (11–17 vs. 11–14), and caudal fin (13–18 vs. 14–18) characters were higher in wild than in cultured fish. Conversely, the range for pelvic fin characters was higher in cultured (5–8) than in wild (5–7) fish, while it was similar for anal fin characters and gills.

After standardizing measures according to Elliot et al. (1995), standard length only showed significant correlations with body weight, total length, and factor K (Tables 7 and 8). There was no significant correlation ($P > 0.05$) between standardized truss measurements and standard length. Several significant ($P < 0.05$) positive correlations were found between the morphometric characters of the 4 populations (males and females of wild and cultured system). Most correlation coefficients were between 0.4 and 0.7. The results reveal that the size effect was almost entirely eliminated in the populations during analysis as there were no significant correlations between TL and SL, with most of the remaining parameters measured with the analyzed characters. The discriminant analysis selected 15 morphometric variables (Pre-AL, DFRL, ED, DFL, P3, LC3, BW, TL, AFRL, PvFRL, PrE-PcL, AC3, LC2, P1, and Pre-DL) as predictors, although only 6 presented a significant P-value ($P < 0.05$) (Pre-AL, DFRL, ED, P3, BW, and TL) (Table 9). In the original classification matrices, the mean percentage of correct assignment (data not presented) was 64.42% for the whole dataset, 85% for cultured females, 60.9% for wild females, 62.1% for wild males, and 56.3% for cultured males. This is demonstrated through spatial distribution of the fish by a canonical score represented in 2D graphics (Figure 2). The representation

Table 3. Correlation, regression, and allometric coefficients between standard length and body measurements (original data) of *Andinoacara rivulatus* from both hatchery and wild populations.

Character[1]	Correlation coefficient	Regression coefficient	Allometric coefficient
BW	0.51	0.26	0.92
K	–0.79	0.63	–2.08
TL	0.92	0.84	0.83
HL	0.64	0.40	0.62
ED	0.06	–0.01	0.13
Pre-OL	0.30	0.08	0.52
Pre-DL	0.73	0.52	0.68
Pre-PcL	0.66	0.43	0.56
Pre-PvL	0.76	0.58	0.79
Pre-AL	0.80	0.64	0.92
DFL	0.82	0.66	0.84
DFRL	0.15	0.00	0.39
PcFRL	0.62	0.38	0.88
PvFRL	0.50	0.24	0.70
AFL	0.60	0.36	0.67
AFRL	0.26	0.06	0.53
UJL	0.38	0.14	0.82
AC1	0.53	0.28	1.17
AC2	0.52	0.27	1.32
AC3	0.50	0.24	0.94
P1	0.31	0.09	0.21
P2	0.28	0.07	0.22
P3	0.34	0.11	0.29
LC1	0.18	0.02	0.17
LC2	0.18	0.02	0.22
LC3	0.29	0.08	0.57

[1]See Table 1.

Table 4. Descriptive statistics of ratio between body measurements and standard length (original data) of *Andinoacara rivulatus* from both hatchery and wild populations.

Character[1]	Wild (N = 150)		Cultured (N = 150)		Wild				Cultured				P-value		
					Males (N = 75)		Females (N = 75)		Males (N =7 5)		Females (N = 75)				
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	System	Sex	System × sex
BW/SL	11.12	15.01	10.47	13.16	11.10	16.69	11.14	12.97	10.68	14.26	10.14	10.48	0.034	0.520	0.346
TL/SL	1.27	3.49	1.29	4.02	1.29	3.16	1.26	3.58	1.29	4.14	1.30	3.88	0.069	0.270	0.055
HL/SL	0.34	7.30	0.34	8.36	0.35	6.74	0.33	7.57	0.35	7.45	0.34	9.66	0.743	0.032	0.713
ED/SL	0.08	16.42	0.07	17.91	0.08	17.24	0.08	15.48	0.08	17.34	0.07	17.93	0.022	0.140	0.436
Pre-OL/SL	0.15	14.87	0.15	16.61	0.15	13.55	0.14	16.33	0.15	18.51	0.14	8.21	0.995	0.010	0.375
Pre-DL/SL	0.44	7.92	0.44	5.76	0.45	8.38	0.44	7.28	0.44	6.30	0.43	4.52	0.301	0.138	0.974
Pre-PcL/SL	0.39	7.83	0.40	6.50	0.40	7.06	0.38	8.49	0.40	6.66	0.40	6.38	0.096	0.105	0.335
Pre-PvL/SL	0.43	7.71	0.44	5.11	0.44	7.09	0.43	8.37	0.44	5.39	0.45	4.62	0.041	0.580	0.101
Pre-AL/SL	0.72	8.26	0.73	4.43	0.71	9.68	0.73	6.18	0.72	4.85	0.75	2.53	0.148	0.050	0.447
DFL/SL	0.60	6.52	0.62	4.76	0.61	6.35	0.59	6.30	0.62	4.91	0.63	4.58	0.006	0.193	0.051
DFRL/SL	0.06	36.11	0.08	39.19	0.06	31.57	0.06	41.65	0.08	44.01	0.09	31.53	0.001	0.420	0.401
PvFRL/SL	0.32	11.63	0.32	10.98	0.33	9.14	0.31	13.49	0.32	10.51	0.33	11.86	0.990	0.198	0.035
PcFRL/SL	0.32	9.29	0.33	11.32	0.33	6.77	0.31	11.24	0.32	13.03	0.33	8.10	0.662	0.405	0.037
AFL/SL	0.21	7.84	0.22	9.60	0.22	8.86	0.21	5.81	0.22	10.62	0.21	7.25	0.149	0.039	0.997
AFRL/SL	0.24	20.69	0.25	16.82	0.25	19.74	0.22	20.45	0.25	15.72	0.24	18.66	0.395	0.027	0.362
UJL/SL	0.04	18.93	0.04	19.31	0.04	15.26	0.04	23.21	0.05	19.18	0.04	19.84	0.574	0.437	0.889
AC1/SL	0.55	19.15	0.53	15.45	0.54	21.10	0.56	16.75	0.54	15.90	0.52	14.87	0.343	0.787	0.299
AC2/SL	0.50	22.71	0.48	17.13	0.49	24.19	0.52	20.90	0.48	17.51	0.48	16.95	0.346	0.410	0.404
AC3/SL	0.18	18.01	0.18	12.80	0.18	18.77	0.19	17.28	0.18	13.67	0.18	11.62	0.770	0.538	0.611
P1/SL	1.15	9.28	1.14	9.76	1.16	9.95	1.13	8.19	1.15	10.22	1.12	8.80	0.838	0.100	0.993
P2/SL	1.06	9.46	1.05	10.99	1.07	9.59	1.05	9.38	1.06	11.72	1.03	9.57	0.542	0.227	0.798
P3/SL	0.43	9.35	0.42	10.33	0.43	9.63	0.43	9.20	0.42	10.14	0.42	10.90	0.118	0.961	0.909
LC1/SL	0.18	10.88	0.18	12.90	0.19	9.99	0.18	11.95	0.18	12.15	0.18	14.32	0.956	0.316	0.706
LC2/SL	0.13	13.50	0.13	14.05	0.13	12.74	0.13	14.30	0.13	13.25	0.13	14.65	0.902	0.816	0.046
LC3/SL	0.06	17.30	0.07	18.99	0.06	17.75	0.06	16.44	0.06	19.00	0.07	18.55	0.280	0.876	0.070

[1]See Table 1.

Table 5. Descriptive statistics of body measurements (adjusted data) of *Andinoacara rivulatus* from both hatchery and wild populations.

Character[1]	Wild (N = 150)		Cultured (N = 150)		Wild				Cultured				P-value		
					Males (N = 75)		Females (N = 75)		Males (N = 75)		Females (N = 75)				
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	System	Sex	System × sex
Adj_BW	149.91	13.01	159.49	15.32	155.21	16.83	164.89	13.00	151.45	14.35	147.45	10.53	0.018	0.519	0.122
Adj_TL	18.49	3.92	18.28	3.33	18.02	3.08	18.60	2.83	18.27	3.87	18.83	3.31	0.052	0.000	0.970
Adj_HL	4.90	7.91	4.88	5.72	4.84	5.19	4.92	6.33	4.90	7.19	4.89	9.15	0.834	0.682	0.505
Adj_ED	1.13	12.76	1.05	17.49	1.01	14.51	1.10	19.54	1.10	12.70	1.19	11.72	0.009	0.007	0.974
Adj_Pre-OL	2.12	15.55	2.13	14.02	2.12	12.44	2.13	16.08	2.19	17.82	2.01	7.46	0.697	0.168	0.138
Adj_Pre-DL	6.27	5.36	6.36	6.56	6.27	6.35	6.49	6.42	6.27	5.99	6.28	4.30	0.169	0.122	0.168
Adj_Pre-PcL	5.72	5.42	5.59	6.26	5.55	6.11	5.64	6.46	5.68	5.74	5.77	4.87	0.050	0.186	0.994
Adj_Pre-PvL	6.34	5.07	6.19	7.52	6.12	7.00	6.28	8.01	6.25	5.17	6.50	3.97	0.029	0.009	0.581
Adj_Pre-AL	10.48	4.83	10.31	8.84	9.99	9.68	10.72	6.07	10.23	4.55	10.87	2.37	0.136	0.000	0.727
Adj_DFL	8.92	4.72	8.66	6.18	8.60	6.36	8.75	5.95	8.81	4.66	9.10	4.19	0.003	0.021	0.457
Adj_DFRL	1.15	37.72	0.88	36.90	0.85	31.65	0.91	42.34	1.08	41.28	1.27	31.44	0.000	0.099	0.380
Adj_PcFRL	4.66	11.45	4.61	7.86	4.63	6.76	4.59	9.20	4.57	13.09	4.80	7.98	0.411	0.317	0.132
Adj_PvFRL	4.63	10.97	4.63	10.34	4.68	9.06	4.56	11.85	4.55	10.49	4.74	11.47	0.771	0.748	0.105
Adj_AFL	3.12	9.01	3.05	6.98	3.02	8.50	3.08	4.49	3.13	10.05	3.10	7.21	0.198	0.784	0.413
Adj_AFRL	3.52	16.29	3.41	18.69	3.51	19.68	3.27	16.66	3.56	15.72	3.46	17.49	0.327	0.169	0.533
Adj_UJL	0.64	18.49	0.63	18.24	0.62	15.09	0.64	21.67	0.64	18.88	0.64	18.31	0.616	0.796	0.638
Adj_AC1	7.64	14.85	7.91	19.71	7.56	21.29	8.34	16.84	7.66	15.71	7.61	13.72	0.237	0.175	0.126
Adj_AC2	6.91	16.19	7.19	23.34	6.81	24.31	7.67	21.06	6.86	17.27	6.99	14.71	0.259	0.078	0.201
Adj_AC3	2.61	12.80	2.64	18.45	2.53	18.70	2.77	17.33	2.58	13.74	2.65	11.36	0.671	0.060	0.314
Adj_P1	16.22	5.35	16.36	6.64	16.18	6.92	16.58	6.17	16.25	5.71	16.16	4.84	0.382	0.431	0.211
Adj_P2	14.86	6.32	15.14	7.77	14.91	7.82	15.43	7.46	14.89	7.22	14.81	4.66	0.129	0.306	0.163
Adj_P3	5.92	6.96	6.13	7.90	6.00	7.76	6.30	7.35	5.87	6.51	6.00	7.56	0.015	0.014	0.348
Adj_LC1	2.60	9.53	2.61	8.38	2.59	7.99	2.64	8.90	2.60	9.30	2.61	10.10	0.824	0.467	0.740
Adj_LC2	1.83	12.54	1.84	11.50	1.83	10.01	1.84	13.35	1.76	10.74	1.93	13.23	0.860	0.042	0.086
Adj_LC3	0.93	17.69	0.89	15.38	0.89	14.68	0.90	16.55	0.90	18.62	0.98	15.36	0.134	0.159	0.200

[1]See Table 1.

Table 6. Descriptive statistics of the meristic characters (original data) of *Andinoacara rivulatus* from both hatchery and wild populations.

	Wild				Cultured						
	Males (N = 75)		Females (N = 75)		Males (N = 75)		Females (N = 75)		K–W		
Character[1]	Mean	CV	Mean	CV	Mean	CV	Mean	CV	System	Sex	System × sex
DFR	24.10	5.58	24.43	4.24	24.38	3.42	23.60	4.84	0.454	0.451	0.048
RDF	23.10	5.82	23.43	4.42	23.38	3.56	22.60	5.06	0.454	0.451	0.048
PcFR	13.07	6.44	13.43	8.93	12.69	7.06	12.50	6.09	0.002	0.641	0.008
RPcF	12.07	6.98	12.43	9.65	11.69	7.66	11.50	6.62	0.002	0.641	0.008
PvFR	6.00	4.45	6.00	0.00	5.94	4.14	5.90	10.86	0.090	0.520	0.256
RPvF	5.00	5.35	5.00	0.00	4.94	4.98	4.90	13.08	0.090	0.520	0.256
AFR	11.21	6.90	10.96	7.00	11.16	5.63	11.05	5.47	0.939	0.243	0.688
RAF	10.21	7.58	9.96	7.71	10.16	6.18	10.05	6.02	0.939	0.243	0.688
CFR	16.03	4.56	15.78	5.72	15.97	4.63	16.05	5.88	0.718	0.722	0.840
RCF	15.03	4.86	14.78	6.10	14.97	4.94	15.05	6.28	0.718	0.722	0.840
SC	18.90	6.38	19.26	6.50	19.38	6.52	19.10	4.77	0.484	0.902	0.374
G	3.90	7.95	3.83	10.13	3.91	7.58	3.95	5.66	0.341	0.771	0.611

[1]See Table 1.

by cluster of Mahalanobis distances also shows that wild males are more distant while wild and cultured females are the nearest ones (Figure 3).

3.2. Fulton condition factor

K mean values (5.50 ± 1.30 and 5.25 ± 0.08 for the original and adjusted dataset) were significantly ($P > 0.05$) different between populations. The coefficient of variation was higher in the first case (24.15% and 14.55%, respectively).

3.3. Length–weight relationship

The parameter b ranged from 0.778 to 1.048, with a mean value of 0.922 ± 0.153 ($R^2 = 0.263$), and with a slightly higher average value in the cultured fish (0.980 ± 0.186 ($R^2 = 0.357$) vs. 0.834 ± 0.245 ($R^2 = 0.186$)).

4. Discussion

4.1. Morphometric and meristic characters

Different authors have used morphological and meristic features to identify adaptation processes in wild and cultured populations of the same species (Solomon et al., 2015). On the basis of the classification of Negi and Nautiyal (2002), *Andinoacara rivulatus* presents 11 genetically controlled morphological characters, 6 intermediate characters, and 10 environmentally controlled characters. A total of 24 characters have been studied in percentages of standard fish length, from which 10 characters were genetically controlled, 6 characters were intermediate, and 8 characters were environmentally controlled. All meristic characters were genetically controlled. The results of the present work indicate that *Andinoacara rivulatus* could be classified into the category of fish showing a wide distribution because only 40.7% of their morphometric characters show narrow range differences and are genetically controlled, and the environmentally controlled characters accounted for 33%.

Kanwal and Pathani (2011), after studying the relative growth of different measures, concluded that total length, standard length, and predorsal and postdorsal lengths are the fast growing parts of the fish. The part with the lowest relative growth was the caudal fin. Those results do not agree with the ones found in the present study.

The specimens of the present study were longer, had a similar head length and head width, and had a lower eye length than those studied by Wijkmark et al. (2012). According to Vreven et al. (1998), the confinement of domesticated fish would result in a higher K value. Contrary to this, in our work, the value of K is similar in both populations. These results also differ from those obtained by González et al. (2016).

The morphometric characters allow to describe the specimens in the present study as follows: moderately deep; laterally compressed; head relatively short; snout somewhat produced; mouth terminal; jaws isognathus; maxilla extending posteriorly to vertical halfway between nostril and from anterior margin of orbit; predorsal contour straight ascending; steeper than prepelvic contour; slightly curved posterior to orbit or close to dorsal-fin base; orbit in middle of length of head in upper half of depth of head. These descriptions are similar to those of Wijkmark et al. (2012).

Table 7. Significant (P < 0.05) Pearson correlation coefficients between standard length and adjusted morphometric characters of *Andinoacara rivulatus* from wild populations of both sexes (males upper diagonal/females above diagonal).

Males/females	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
SL																										
Adj_BW		1.00		0.89	0.82	0.78	0.75	0.71	0.42	0.39															0.39	
Adj_K	1.00			0.89	0.82	0.78	0.75	0.71	0.42	0.39															0.39	
Adj_TL														0.52	0.43										0.55	0.43
Adj_AC1	0.75	0.75			0.98	0.96	0.79	0.76	0.40	0.38							0.41									
Adj_AC2	0.68	0.68		0.98		0.98	0.77	0.75									0.41									
Adj_AC3	0.65	0.65		0.93	0.95		0.69	0.67									0.44									
Adj_P1	0.67	0.67		0.52	0.48			0.92	0.46	0.62																
Adj_P2	0.78	0.78		0.47	0.43		0.73		0.41	0.56																
Adj_P3				0.48	0.43	0.48																				
Adj_LC1			0.49					0.47			0.45	0.37				0.37										
Adj_LC2										0.45		0.71		0.41		0.46										
Adj_LC3										0.50																
Adj_UJL																										
Adj_Pre-PvL															0.47	0.41	0.58			0.52						
Adj_Pre-DL													0.53				0.63			0.39						
Adj_Pre-AL																	0.37									
Adj_HL																				0.50						
Adj_ED																										
Adj_Pre-OL																										
Adj_Pre-PcL														0.68			0.65		0.65				–0.41			
Adj_PvFRL							0.46					–0.52														
Adj_DFL			0.42						0.42						–0.61	0.45										
Adj_DFRL																										
Adj_AFL			0.51					0.47									0.45									
Adj_AFRL						–0.44																				0.48
Adj_PcFRL																		–0.46						0.49		

[1]For characters see Table 1; K = Fulton condition factor.

Table 8. Significant (P < 0.05) Pearson correlation coefficients between standard length and adjusted morphometric characters of *Andinoacara rivulatus* from cultured populations of both sexes (males upper diagonal/females above diagonal).

Males/females	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
SL																										
Adj_BW		1.00		0.90	0.81	0.64	0.70	0.64	0.44	0.57	0.39	0.45									0.42			0.39		
Adj_K	1.00			0.90	0.81	0.64	0.70	0.64	0.44	0.57	0.39	0.45									0.42			0.39		
Adj_TL														0.60	0.49	0.50	0.50			0.41					0.38	0.63
Adj_AC1	0.86	0.86			0.96	0.86	0.75	0.59	0.45	0.51																
Adj_AC2	0.74	0.74		0.96		0.93	0.70	0.52	0.45	0.49		0.36														
Adj_AC3	0.48	0.48		0.77	0.78		0.54		0.36	0.35																
Adj_P1								0.75		0.48														0.36		
Adj_P2	0.45	0.45					0.74		0.39	0.43	0.47													0.47		
Adj_P3							0.57	0.52													0.38					
Adj_LC1								0.47			0.70	0.49														
Adj_LC2							0.58	0.85											0.43							
Adj_LC3							0.61	0.75	0.49	0.46	0.74															
Adj_UJL																							−0.39			
Adj_Pre-PvL			0.62													0.47	0.62			0.39						
Adj_Pre-DL			0.52				−0.45							0.49			0.42									
Adj_Pre-AL														0.60						0.45	0.40					
Adj_HL														0.52					0.40	0.48						
Adj_ED																										
Adj_Pre-OL															0.45		0.47									
Adj_Pre-PcL			0.51											0.79	0.57		0.47									
Adj_PvFRL														0.60	0.53					0.68		0.49		0.38	0.38	
Adj_DFL			0.79											0.50	0.50											
Adj_DFRL								−0.45			−0.57															
Adj_AFL			0.63																		0.53	0.51				
Adj_AFRL			0.47											0.48			0.59									0.39
Adj_PcFRL			0.47									−0.45						−0.55				0.66				

[1]For characters, see Table 1; K = Fulton condition factor.

Table 9. Discriminant functions for truss measurements of *Andinoacara rivulatus* for both cultured and wild populations of both sexes.

Character[1]	Wilks' lambda	Partial lambda	F-remove –3,86	P-level	Toler.	1-Toler. (R-Sqr.)
Adj_Pre-AL	0.291	0.910	2.838	0.043	0.774	0.226
Adj_DFRL	0.291	0.911	2.800	0.045	0.913	0.087
Adj_ED	0.300	0.885	3.742	0.014	0.843	0.157
Adj_DFL	0.285	0.930	2.174	0.097	0.614	0.386
Adj_P3	0.293	0.904	3.055	0.033	0.677	0.323
Adj_LC3	0.289	0.917	2.592	0.058	0.665	0.335
Adj_BW	0.309	0.858	4.751	0.004	0.293	0.707
Adj_TL	0.307	0.862	4.597	0.005	0.538	0.462
Adj_AFRL	0.283	0.937	1.912	0.134	0.699	0.301
Adj_PvFRL	0.288	0.920	2.507	0.064	0.671	0.329
Adj_Pre-PcL	0.284	0.934	2.029	0.116	0.609	0.391
Adj_AC3	0.281	0.942	1.775	0.158	0.409	0.591
Adj_LC2	0.285	0.929	2.175	0.097	0.569	0.431
Adj_P1	0.277	0.957	1.273	0.289	0.455	0.545
Adj_Pre-DL	0.276	0.961	1.172	0.325	0.754	0.246

[1]See Table 1.

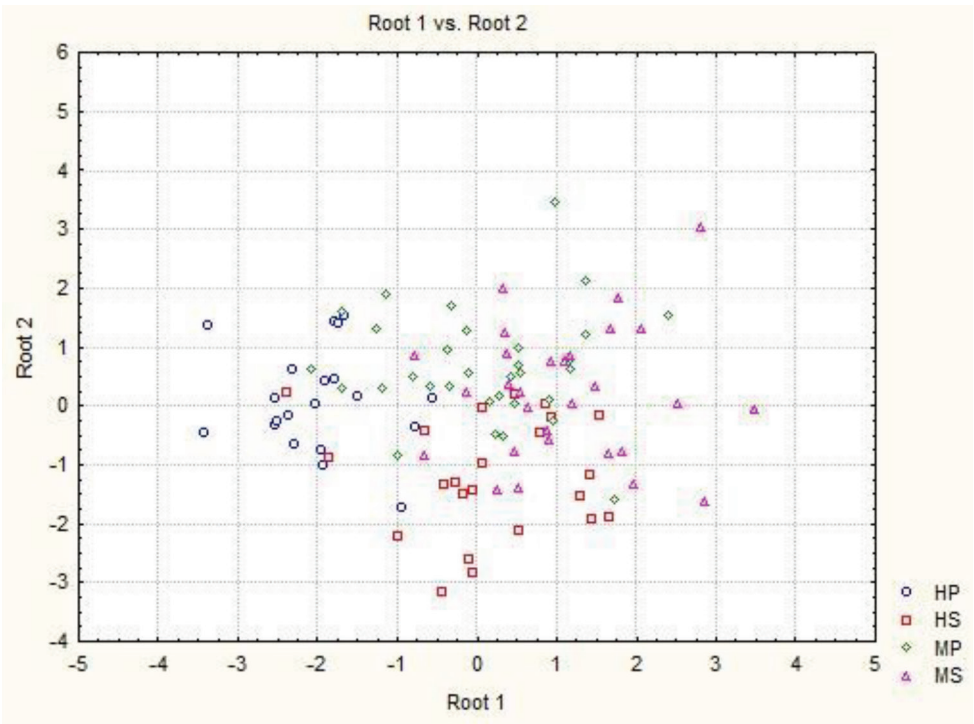

Figure 2. Plot of the individual observation discriminant scores obtained with the canonical discriminant function. HP: Cultured females; HS: wild females; MP: cultures males; MS: wild males.

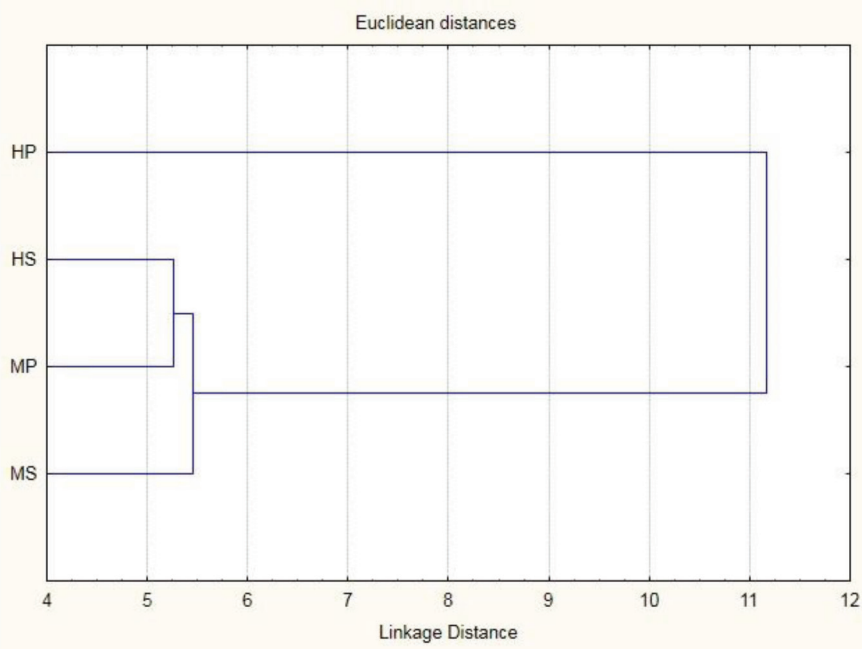

Figure 3. Cluster from Mahalanobis distances for cultured and wild populations of both sexes. HP: Cultured females; HS: wild females; MP: cultures males; MS: wild males.

Different body parts of *Andinoacara rivulatus* showed positive and significant correlations, except for factor K, which was negatively correlated with most of the morphometric characters studied. When morphometric characters were related to standard length, the most and least correlated variables were similar to those obtained by Kanwal and Pathani (2011), although in the current study the values of the correlation coefficients were lower. These differences among studies could be due to the fact that Kanwal and Pathani (2011) related the morphological variables to the total length, while in the present study those variables were linearly related to the standard length. Moreover, the low and nonsignificant correlations in some of the variables suggest that they do not increase proportionally.

In the current study, only 2 morphometric parameters (DFRL and P3) differ between populations. In contrast, several authors (Solomon et al., 2015; González et al., 2016) found significant differences between natural and domesticated fish populations. Besides, a few of the registered meristic characters (PcFR and RPcF) showed significant differences between populations, similar to the findings of Solomon et al. (2015). The causes of differences between populations are often quite difficult to explain, but it is well known that morphometric characters can show a high degree of plasticity in response to environmental conditions such as temperature, turbidity, food availability, and water depth and flow (Wimberger, 1992).

Truss measurements are a powerful tool for the analysis of shape and can effectively be used to distinguish between hatchery and wild stocks, as well as remove the need to find the types and optimal number of characters for stock separation and provide information about the entire fish form (Turan et al., 2004).

Canonical discriminant analysis demonstrated a strong influence of origin in the morphometric variables measured in the present work. The differences between populations for truss measurements reveal a deeper body in its anterior part, a longer trunk and a deeper peduncle in the wild specimens, and a greater distance between the origins of the dorsal and anal fins in cultured fishes. These differences might be due to an acclimation to repel the agitated water of rivers (Wimberger, 1992). The higher number of cases from the wild population misclassified into the cultured group might be caused by a higher morphological variability in the former due to the adaptation to the changeability of the natural environment compared to that in the fish farms, mainly the presence of predators and feed availability (Narváez et al., 2005). The fact that only 7 morphometric variables were needed to separate the 2 groups indicates that Fisher's linear discriminant analysis could be useful to identify the origin of stocks on a commercial basis (González et al., 2016).

4.2. Fulton condition factor

The K value is used as an index to assess the status of the aquatic ecosystem. The specimens of *Andinoacara rivulatus*

from the current study showed a K value (5.51) slightly higher than that recorded by Anene (2005) in 4 cichlid fish (4.9) and by González et al. (2016) in *Cichlasoma festae* in habitats similar to those of the present study, which indicates a greater capacity for food consumption in the species of the current study.

Significant correlation coefficients do not exist between K and TL and between K and SL. These results are not consistent with those obtained by Anene (2005), who registered a significant and progressive decrease between 120 and 150 mm, and González et al. (2016) in *Cichlasoma festae* (r = 0.523). Sasi and Berber (2012) recorded increases in K until the age of 5 years (from 1.6 to 2.5) and decreases afterwards.

The absence of statistical differences between populations, in disagreement with the results obtained by González et al. (2016), indicates that the quantitative and/or qualitative level of feed should be increased in the farms in order to improve growth.

4.3. Length–weight relationship

The length–weight relationship parameter (b) did not remain within the expected range (2 to 4) (Koutrakis and Tsikliras, 2003) and was lower than that reported by González et al. (2016) in *Cichlasoma festae*. Part of these differences could be attributed to the fact that the animals were adults in the present study, so the absolute and relative growth rates were low and allometric. The length–weight relationship is isometric when juvenile and adult specimens are taken together (Mir et al., 2015). Again, since the coefficient b was higher in the cultured than in the wild fish, and it might be possible that nutritional deficiencies did not allow the normal growth of the fish. In fish farms, environmental and nutritional conditions should be better than in a natural environment. Despite this, optimum levels of growth in these populations were not reached, which has to be taken into account to achieve more efficient production.

Our results showed that habitat (river or farm) presented a low impact on the morphometric measurements and meristic counts of *Andinoacara rivulatus*. Both groups were accurately separated by linear discriminant functions that included 7 truss morphometric measures.

In summary, this study provides valuable morphological information on the shape and structure of *Andinoacara rivulatus* that can be used to characterize and visualize the changes that occur as a consequence of adaptation to a different habitat. The authors believe that the information obtained from the present study will be helpful for fisheries, biologists, and taxonomists.

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