Length-weight relationships native fish of Southern Altiplano: Lauca National Park, Chile

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ABSTRACT

Two genera of fish, Orestias (Cyprinodontidae) and Trichomycterus (Trichomicteridae), inhabit in the Lauca National Park, UNESCO Biosphere Reserve, located at the Andes highlands in northern Chile. The present study analyzed the length-weight relationship for four native species of Orestias (O. parinacotensis, O. laucaensis, O. chungarenensis and O. piacotensis) and two native species of Trichomycterus (T. chungarenensis and T. laucaensis), obtained at seven different localities. Our results showed that the growth coefficient values “b” for Orestias ranged from 2.89 (O. parinacotensis) through 4.04 (O. piacotensis) and Trichomycterus between 2.53 (T. laucaensis in Parinacota wetland) through 3.14 (T. laucaensis in Caquena River). All length-weight relationships were significant (p < 0.01), with r² higher than 0.82. O. laucaensis, O. piacotensis and T. chungarenensis showed positive allometric growth (b > 3). However, two species O. parinacotensis and T. laucaensis showed negative allometric growth (b < 3). Only O. chungarenensis showed isometric growth with b = 3. Intense anthropic activity, exotic fish introduction, and climate change present important risks for a unique endemic fish community of the high Andes.

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Introduction

The Andean arid highland plain, known as Altiplano is characterized by having freshwater systems with extreme climatic conditions and located 3500 m over sea level (Ochsenius 1986; Montgomery et al. 2003; Risacher et al. 2003a; Vila et al. 2007). The present climate is dry and cold, the temperature may reach 0°C as an annual average (Romero et al. 2013) and solar radiation may exceed 300 Wm⁻² (Rundel and Palma 2000; Risarcher et al. 2003b; Placzek et al. 2006; Sáez et al. 2007; Rondanelli et al. 2015). The rainfalls occur only during summer, phenomenon called “Invierno Altiplánico” (Altiplanic Winter), and they reach less than 100 mm/year, intensifying during the cyclic climatic event called “El Niño” (Aceituno 1996). These environmental characteristics, added to historical volcanic
activity have originated endemic flora and fauna highly adapted to these conditions (Vila et al. 2013; Victoriano et al. 2015; Valladares et al. 2018).

Lauca National Park, UNESCO Biosphere Reserve is a unique area with altiplanic and pre-altiplanic lakes, rivers and wetlands at northern Chile (Rundel and Palma 2000) and it has been historically inhabited by native Cyprinodontidae fish of four Orestias species: Orestias parinacotensis Arratia (1982); O. laucaensis, Arratia (1982), O. chungarenensis Vila and Pinto (1986), O. piacotensis Vila et al. (2006) and three Trichomycteridae catfish: Trichomycterus rivulatus Valenciennes, 1846, T. chungaraensis, Arratia (1983) and T. laucaensis, Arratia (1983).

Only Orestias has colonized the lakes where they inhabit mainly the littoral macrophytes providing food, shelter, and reproduction activities (Vila et al. 2006; 2010). Orestias chungarenensis and O. piacotensis are found only at Chungará Lake and Piacota Lake, respectively. O. laucaensis inhabits Cotacotani Lake and Lauca River and O. parinacotensis inhabits Parina Cotana wetland (Arratia 1982; Vila et al. 2010). Meanwhile, the Trichomycterus catfish inhabit mainly the running waters of Lauca River and springs, which feed the wetlands. Thus, Trichomycterus chungaraensis has been found only at Mal Paso spring, a tributary of Chungará Lake. Trichomycterus laucaensis inhabits the Lauca River, while T. rivulatus shows a wide distribution in the area wetlands.

Unfortunately, studies of climate change have estimated a decrease in annual rainfall around 10.5 mm and an increase of 1.9 °C in temperatures, producing this way a change in the timing of the cold and warm periods for the coming years (Conaf 2018), which added to the demand of water for human consumption place at risk the integrity and stability of the systems (Dorador et al. 2003; Vila et al. 2007). On the other hand, the introduction and naturalization of an exotic species Oncorhynchus mykiss (Vila et al. 2006; Rojas et al. 2019) has also been reported, negatively affecting the survival of native species (Vila et al. 2006).

Biometric studies of Freshwater fishes of the Altiplano in relation to their size are lacking. In this context, the aim of this research proposes to estimate the length-weight relationship of the native Orestias and Trichomycterus populations inhabiting the different freshwater systems of Lauca National Park. This information will deepen our understanding and improve the conservation of these unique species living in a UNESCO Biosphere Reserve, National Park.

**Materials and methods**

Using electrofishing (SAMUS —725) equipment, fish were collected at Lauca National Park (18°14′S; 69°21′W, Figures 1 and 2). A total of 116 Orestias specimens and 116 Trichomycterus were obtained at seven different localities, were sampled during February and March 2016 and 2017 (Table 1). Immediately after collecting fish were anesthetized with MS 222 and measured, and they were returned after recovering. The species included in this study were Orestias parinacotensis (from Parina Cotana wetland), O. laucaensis (from Lauca River, Caquena River and Cotacotani lake), O. chungarenensis (from Chungará Lake), O. piacotensis (from Piacota lake), Trichomycterus laucaensis (from Lauca River, Caquena River and Parina Cotana wetland) and T. chungaraensis (from Mal Paso spring). Fish total length from mouth border to caudal fin (TL cm) were measured with a Vernier 0.1 cm precision caliper. The weight was obtained with a digital balance with 0.01 gr precision (Ohaus Scout® SPX1202).
Length-weight relationship

The relationship between total length and body weight (LWR) was estimated by the following formula: \( W = a T^b \) (Le Cren 1951; Froese 2006). Data were changed to a
logarithmic equation as \( \log(W) = a + b \log(TL) \), to calculate the parameters \( a \) and \( b \), \( “a” \) was considered constant and \( “b” \) the slope of this relationship (Gould 1966). We used the Analysis of variance ANOVA to evaluate the statistical significance of the regression model \((P < 0.05)\) and the coefficient of determination \((r^2)\) as a measure of the prediction quality of linear regression.

When the \( b \) parameter = 3, fish show isometric growth. When \( b < 3 \), there is a negative allometric growth. If \( b > 3 \), there is a positive allometric growth. Through the student \( t \)-test (two tail), isometric growth is assigned when \( b \) is not statistically different of \( 3 \) \((p > 0.05)\) and while a statistically difference of \( b \) from \( 3 \) indicates an allometric growth either positive or negative \((P < 0.05)\). All statistical analyses were done by R 3.6.1 software (R development core team 2019).

### Results

The studied specimens showed a total length between 2 and 10 cm, with weights that varied between 0.1 and 10.9 g (Table 1). Among Orestias populations, \( O. \) piacotensis showed a lower weight and length with \( 0.82 \pm 0.55 \) gr and \( 4.18 \pm 0.69 \) cm, respectively. Trichomycterus populations with a lower average weight were \( T. \) laucaensis at Caquena river with \( 1.43 \pm 0.69 \) g. Trichomycterus chungaraensis showed the lower average length with \( 4.84 \pm 1.49 \) cm (Table 1).

Linear regressions were significant for the ten analyzed populations of Orestias and Trichomycterus \((p < 0.01)\), with \( r^2 \) higher than 0.82 (Table 2). The \( b \) LWR values for Orestias laucaensis (Lauca River, Cotacotani Lake and Caquena River populations) and \( O. \) piacotensis showed a positive allometric growth \( b > 3.0 \) \((t\)-test, \( P < 0.001)\), while \( O. \) parinacotensis showed a negative allometric growth with \( b < 3.0 \) \((t\)-test, \( P < 0.01)\). The catfish populations of Trichomycterus laucensis from Lauca River, Caquena River and Parinacota wetland showed a negative allometric growth with \( b < 3.0 \) \((t\)-test, \( P < 0.001)\), while \( T. \) chungaraensis showed positive allometric growth with \( b > 3.0 \) \((t\)-test, \( P < 0.01)\). Only Orestias chungaraensis showed an isometric growth with \( b = 3 \) \((t\)-test, \( P > 0.05)\) (Table 2).

### Discussion

The altiplanic fish have adapted to extreme freshwater systems conditions including altitude over 3500 over sea level, high salinity, solar radiation, daily, and seasonally extreme temperatures. (Vila et al. 2007; Márquez-García et al. 2009; Rondanelli et al. 2015). These

| Species               | Locality            | Latitude/Longitude | N’Ind. | Habitat | Body weight (gr) | Total length (cm) |
|-----------------------|---------------------|--------------------|--------|---------|----------------|-------------------|
| O. laucaensis         | Lauca               | 18° 05’S/69° 15’W  | 15     | River   | 0.1 7.01 1.7 ± 1.39 | 2 7.5 4.68 ± 1.11 |
| O. laucaensis         | Cotacotani          | 18°11’S/69° 13’W   | 22     | Lake    | 0.6 3.7 1.72 ± 0.83 | 4.5 7.2 5.7 ± 0.79 |
| O. laucaensis         | Caquena             | 18° 03’S/69° 12’W  | 13     | River   | 0.5 7.6 3.52 ± 2.22 | 3.6 8 5.88 ± 1.31 |
| O. piacotensis        | Placota             | 18° 11’S/69° 15’W  | 32     | Lake    | 0.2 2.4 0.82 ± 0.55 | 3.29 5.96 4.18 ± 0.69 |
| O. parinacotensis     | Parinacota          | 18° 10’S/69° 20’W  | 14     | Wetland | 0.5 3.9 1.75 ± 1.04 | 3.7 6.8 5.01 ± 1.00 |
| O. chungaraensis      | Chungará            | 18° 15’S/69° 07’W  | 20     | Lake    | 0.6 10.9 4.85 ± 3.43 | 4.5 9.8 7.25 ± 1.72 |
| T. laucaensis         | Lauca               | 18° 05’S/69° 15’W  | 33     | River   | 0.9 5.7 2.52 ± 1.28 | 4.9 8.2 6.17 ± 0.99 |
| T. laucaensis         | Parinacota          | 18° 10’S/69° 20’W  | 16     | Wetland | 0.9 2.8 1.55 ± 0.48 | 4.8 7 5.59 ± 0.50 |
| T. chungaraensis      | Mal Paso            | 18°15’S/69° 10’W   | 53     | Spring  | 0.2 9.5 1.48 ± 1.79 | 3.05 10 4.84 ± 1.49 |
| T. laucaensis         | Caquena             | 18° 2’S/69° 12’W   | 14     | River   | 0.6 2.5 1.43 ± 0.69 | 3.8 6.5 5.11 ± 0.92 |
conditions added to the lack of connectivity among the systems have modeled a unique and endemic fish fauna of the diverse native killifish and catfish of the area.

Overall, 50% of the length-weight relationships of the analyzed species and populations showed positive allometric growth $b > 3.0$ values showing a higher proportional gain of weight than length, this has been documented for species which gain weight at early age (Froese 2006). This was the case of $O$. laucaensis, $O$. piacotensis, and $T$. chungaraensis. Instead, the populations $O$. parinacotensis and $T$. laucaensis (Lauca river, Caquena river, and Parinacota wetland) species showed $b < 3$ values which show negative allometric growth. It is possible that specimens of higher size are thinner and less robust (Jobling 2002).

Only the species $O$. chungarensis showed a $b = 3$ value, in which individuals’ incremental weight is proportional to their incremental length (Froese 2006). It is important to consider that Chungará Lake, where this species lives, has the higher volume and surface of water, as well as the presence of littoral macrophytes of Lauca National Park allowing this species higher resources and refuge (Vila et al. 2006; 2011; Guerrero et al. 2015).

Although Lauca National Park freshwater systems have been protected by the Chilean legislation since 1965 and later during 1983 declared by UNESCO Biosphere Reserve (Rundel and Palma 2000), there is a permanent and indiscriminate water use by agriculture and mining. In addition to climatic change has caused a significant decrease in precipitation for this area producing negative hydric balances (Dorador et al. 2003; Vila et al. 2007).

On the other hand, the exotic rainbow trout $O$. mykiss from fish hatchery activities in the area, are affecting negatively the abundance and distribution of native species by food competition and direct depredation (Rojas et al. 2019). In view of the high degree of endemism of native taxa, these data allowed us to obtain information about the length-weight relationships of the Lauca National Park fish for future fish studies and conservation actions this unique ancestral fish community of the Altiplano.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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| Species          | Locality     | a   | b  | b (95% CI) | t-test | $r^2$ | Growth behavior  |
|------------------|--------------|-----|----|------------|--------|-------|-----------------|
| $O$. laucaensis  | Lauca        | −1.96 | 3.14 | 2.98–3.29 | <0.001 | 0.97  | Positive allometric |
| $O$. laucaensis  | Cotacotani   | −2.48 | 3.54 | 3.27–3.82 | <0.001 | 0.97  | Positive allometric |
| $O$. laucaensis  | Caquena      | −2.05 | 3.31 | 2.95–3.646| 0.001  | 0.98  | Positive allometric |
| $O$. piacotensis | Piaucota     | −2.67 | 4.04 | 3.37–4.71 | <0.001 | 0.83  | Positive allometric |
| $O$. parinacotensis | Parinacota  | −1.82 | 2.89 | 2.36–3.43 | <0.001 | 0.92  | Negative allometric |
| $O$. chungarensis | Chungará     | −2.43 | 3.51 | 3.24–3.79 | 0.691  | 0.83  | Isometric       |
| $T$. laucaensis  | Laucia       | −1.99 | 2.98 | 2.59–3.37 | <0.001 | 0.88  | Negative allometric |
| $T$. laucaensis  | Parinacota   | −1.71 | 2.53 | 1.98–3.08 | <0.001 | 0.82  | Negative allometric |
| $T$. chungaraensis | Mal Paso     | −2.12 | 3.14 | 2.99–3.28 | <0.001 | 0.97  | Positive allometric |
| $T$. laucaensis  | Caquena      | −1.72 | 2.62 | 2.27–2.97 | <0.001 | 0.96  | Negative allometric |
invasive fish species at freshwater systems. Presently, he is a PhD candidate and teaches at the Faculty of Sciences, Universidad de Chile, Santiago University and University of Educational Sciences.

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References

Aceituno P. 1996. Elementos del clima en el Altiplano Sudamericano. Revista Geofísica IPGH. 44:37–55.
Arratia G. 1982. Peces del Altiplano de Chile. In: Veloso A, Bustos E, editors, El hombre y los ecosistemas de montaña MAB-6. El ambiente natural y las poblaciones humanas de Los Andes del Norte Grande de Chile, Volumen I. La vegetación y los vertebrados inferiores de los pisos altitudinales entre Arica y El Lago Chungará. Montevideo, Uruguay: ROSTLAC, UNESCO; p. 93–133.
Arratia, G. 1983. Trichomycterus chungaraensis n. sp. and Trichomycterus laucaensis n. sp. (Pisces, Siluriformes, Trichomycteridae) from the high Andean range. Stud Neotrop Fauna Environ. 18(2): 65–87.
Conaf. 2018. Documento Testimonial y de Análisis de los Efectos del Cambio Climático en el Sistema Nacional de Áreas Silvestres Protegidas del Estado. Santiago. Chile; p. 76.
Dorador C, Pardo R, Vila I. 2003. Variaciones temporales de parámetros físicos, químicos y biológicos de un lago de altura: el caso del lago Chungará. Rev Chil Hist Nat. 76(1):15–22.
Froese R. 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. J Appl Ichthyol. 22(4):241–253.
Gould SJ. 1966. Allometry and size in ontogeny and phylogeny. Biol Rev Camb Philos Soc. 41(4): 587–638.
Guerrero CJ, Poulin ELIE, Méndez MA, Vila IRMA. 2015. Caracterización trófica de Orestias (Teleostei: Cyprinodontidae) en el Parque Nacional Lauca. Gayana (Concepc.). 79(1):18–25.
Jobling M. 2002. Environmental factors and rates of development and growth. In: Hart PJB, Reynolds JD, Editors. Handbook of fish biology and fisheries, Vol: 1 Fish biology, Blackwell Science Ltd.; p. 97–122. https://www.nhbs.com/handbook-of-fish-biology-and-fisheries-volume-1-book
Le Cren ED. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the Perch (Perca fluviatilis). J Ani Ecol. 20(2):201–219.
Márquez-García M, Vila I, Hinojosa LF, Méndez MA, Carvajal JL, Sabando MC. 2009. Distribution and seasonal fluctuations in the aquatic biodiversity of the southern Altiplano. Limnolog Ecol Manage Inland Waters. 39(4):314–318.
Montgomery E, Rosko M, Castro S, Keller B, Bevacqua P. 2003. Interbasin underflow between closed Altiplano Basins in Chile. Ground Water. 41(4):523–531.
Ochsenius C. 1986. La glaciaciòn Puna durante el Wisconsin, deglaciaciòn y máximo lacustre en la transiciòn Wisconsin-Holoceno y refugios de megafauna postglaciales en la puna y desierto de Atacama. Rev Geografìa Norte Grande. 13:29–58.
Placzek C, Quade J, Patchett PJ. 2006. Geochronology and stratigraphy of late Pleistocene lake cycles on the southern Bolivian Altiplano: implications for causes of tropical climate change. Geol Soc Am Bull. 118(5-6):515–532.
Risacher F, Alonso H, Salazar C. 2003a. Hydrochemistry of two adjacent acid saline lakes in the Andes of northern Chile. Chem Geol . 187(1-2):39–57.
Risacher F, Alonso H, Salazar C. 2003b. The origin of brines and salts in Chilean salars: a hydrochemical view. Earth Sci Rev . 63(3-4):249–293.
Rojas P, Vila I, Habit E, Castro SA. 2019. Homogenization of the freshwater fish fauna of the biogeographic regions of Chile. Global Ecol Conserv. 19:e00658.
Rondanelli R, Molina A, Falvey M. 2015. The Atacama surface solar maximum. Bull. 625 Amer.Meteor. Soc. 96(3):405–418.
Romero H, Smith P, Mendonça M, Méndez M. 2013. Macro y mesoclimas del altiplano andino y desierto de Atacama: desafíos y estrategias de adaptación social ante su variabilidad. Rev Geogr Norte Gd. 55(55):19–41.

Rundel PW, Palma B. 2000. Preservar los ecosistemas únicos de puna del altiplano andino: una descripción descriptiva del Parque Nacional Lauca, Chile. Mt Res Dev. 20(3):262–271.2.0.CO;2

Sáez A, Valero-Garcés BL, Moreno A, Bao R, Pueyo JJ, González-Sampérez P, Giralt S, Taberner C, Herrera C, Gibert RO. 2007. Lacustrine sedimentation in active volcanic settings: the Late Quaternary depositional evolution of Lake Chungará (northern Chile). Sedimentology. 54(5):1191–1218.

Valladares MA, Méndez MA, Collado GA. 2018. Influenced but not determined by historical events: genetic, demographic and morphological differentiation in Heleobia ascotanensis from the Chilean Altiplano. PeerJ. 6:e5802.

Victoriano P, Muñoz-Mendoza C, Sáez P, Salinas H, Muñoz-Ramirez C, Sallaberry M, Fliba P, Méndez MA. 2015. Evolution and conservation on top of the world: phylogeography of the marbled water frog (Telmatobius marmoratus species complex; Anura, Telmatobiidae) in protected areas of Chile. J Hered. 106 Suppl 1:546–559.

Vila I, Pinto M. 1986. A new species of killifish (Pisces, Cyprinodontidae) from the Chilean Altiplano. Rev Hydrobiol Tropicale. 19:233–239.

Vila I, Pardo R, Dyer B, Habit E. 2006. Peces límnicos: diversidad, origen y estado de conservación. In: Vila I, Veloso A, Schlatter R, Ramírez, C, editors, Macrófitas y vertebrados de los sistemas límnicos de Chile. Santiago, Chile: Editorial Universitaria; p. 73–102.

Vila I, Pardo R, Scott S. 2007. Freshwater fishes of the Altiplano. Aquat Ecosyst Health Manag. 10(2):201–211.

Vila I, Scott S, Lam N, Iturra P, Mendez MA. 2010. Karyological and morphological analysis of divergence among species of the killifish genus Orestias (Teleostei: Cyprinodontidae) from the southern Altiplano. Origin and Phylogenetic Interrelationships of Teleosts, 471–480.

Vila I, Scott S, Mendez MA, Valenzuela F, Iturra P, Poulin E. 2011. Orestias gloriae, a new species of Cyprinodontid fish from saltpan spring of the southern high Andes (Teleostei: Cyprinodontidae). Ichthyol Explorat Freshwaters. 22:345–353.

Vila I, Morales P, Scott S, Poulin E, Véliz D, Harrod C, Méndez MA. 2013. Phylogenetic and phylogeographic analysis of the genus Orestias (Teleostei: Cyprinodontidae) in the southern Chilean Altiplano: the relevance of ancient and recent divergence processes in speciation. J Fish Biol. 82(3):927–943.