Journal of Freshwater Ecology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tjfe20

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

Pablo Rojas, Rodrigo Pardo & Irma Vila

To cite this article: Pablo Rojas, Rodrigo Pardo & Irma Vila (2021) Length-weight relationships native fish of Southern Altiplano: Lauca National Park, Chile, Journal of Freshwater Ecology, 36:1, 285-291, DOI: 10.1080/02705060.2021.1971782

To link to this article: https://doi.org/10.1080/02705060.2021.1971782

Published online: 07 Sep 2021.

JOURNAL OF FRESHWATER ECOLOGY
2021, VOL. 36, NO. 1, 285–291
https://doi.org/10.1080/02705060.2021.1971782

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

Pablo Rojas[a], Rodrigo Pardo[b] and Irma Vila[a]

[a]Departamento de Ciencias Ecológicas, Universidad de Chile, Santiago, Chile; [b]Aqua Expert, Centro de Estudios Ambientales, Providencia, Chile

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. chungarensis and O. piacotensis*) and two native species of Tricomycterius (*T. chungaraensis* 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 r^2 higher than 0.82. *O. laucaensis*, *O. piacotensis* and *T. chungaraensis* showed positive allometric growth ($b > 3$). However, two species *O. parinacotensis* and *T. laucaensis* showed negative allometric growth ($b < 3$). Only *O. chungarensis* 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.

ARTICLE HISTORY
Received 28 April 2021
Accepted 17 August 2021

KEYWORDS
Andean high plateau; freshwater fish; total length; weight relationships

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° 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

CONTACTO Irma Vila limnolog@uchile.cl Departamento de Ciencias Ecológicas, Universidad de Chile, Santiago, Chile.

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. chungarensis* Vila and Pinto (1986), *O. piacotensis* Vila et al. (2006) and three Trichomicteridae 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 chungarensis* 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 Parinacota 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 Parinacota wetland), *O. laucaensis* (from Lauca River, Caquena River and Cotacotani lake), *O. chungarensis* (from Chungará Lake), *O. piacotensis* (from Piacota lake), *Trichomycterus laucaensis* (from Lauca River, Caquena River and Parinacota wetland) and *T. chungaraensis* (frorm 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).

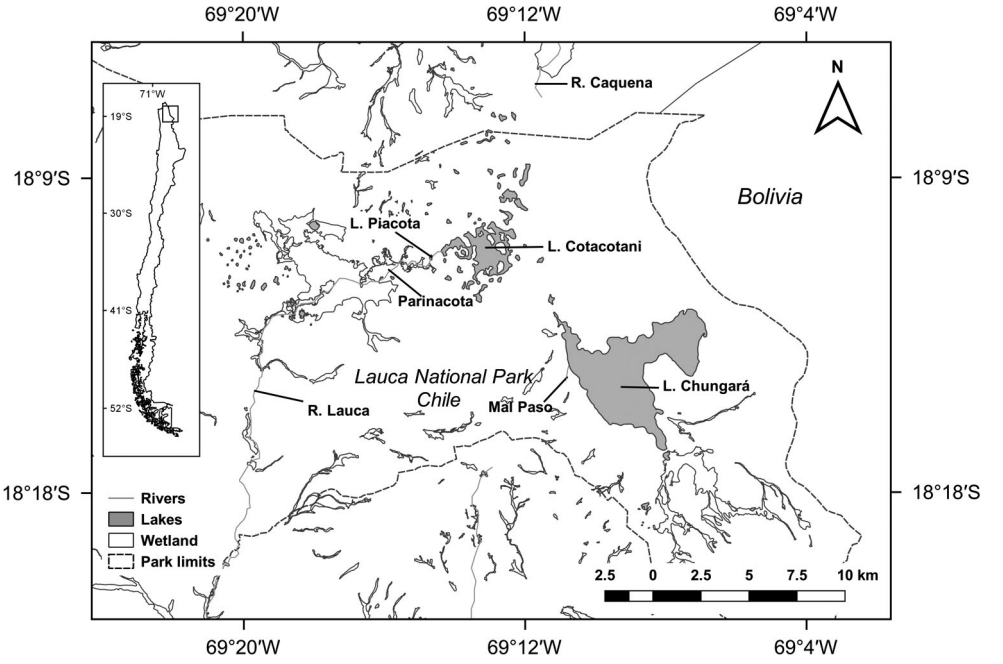

Figure 1. Freshwater systems location and geographic distribution of *Orestias* and *Trichomycterus* in Lauca National Park (Chile). *O. piacotensis* in Piacota, *O. laucaensis* and *T. laucaensis* in Lauca River, *O. laucaensis* in Cotacotani Lake, *O. parinacotensis* in the Parinacota Wetland, *O. piacotensis* in Piacota Lake, *O. laucaensis* and *T. laucaensis* in Caquena River, *O. chungarensis* in Chungará Lake, *T. chungaraensis* in Mal Paso spring.

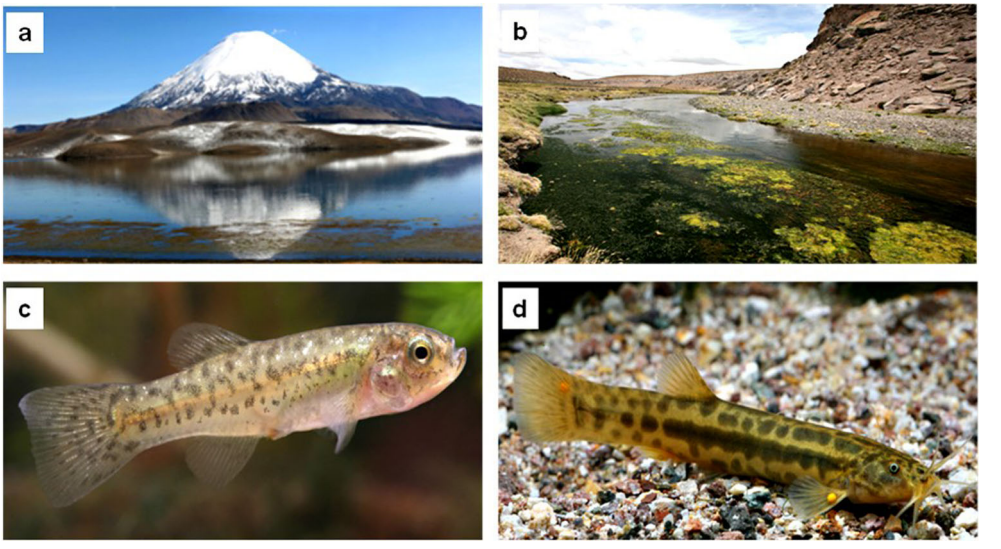

Figure 2. Main freshwater systems and reference species of the Lauca National Park. (a) Chungará Lake, (b) Lauca River, (c) *Orestias chungarensis*, (d) *Trichomycterus laucaensis*. The photos were photographed by Dr. Manuel Contreras.

Length-weight relationship

The relationship between total length and body weight (LWR) was estimated by the following formula: $W = a\ TL^b$ (Le Cren 1951; Froese 2006). Data were changed to a

Table 1. Localities and habitats of the species of *Orestias* and *Trichomycterus* collected. Weight, body length and mean body weight and body length.

Species	Locality	Latitude/ Longitude	N°Ind.	Habitat	Body weight (gr)			Total length (cm)		
					Min	Max	Mean ± SD	Min	Max	Mean ± SD
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	Piacota	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. chungarensis	Chungará	18° 15′/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′4S/69°12′W	14	River	0.6	2.5	1.43 ± 0.69	3.8	6.5	5.11 ± 0.92

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 ± 0.55 gr and 4.18 ± 0.69 cm, respectively. *Trichomycterus* populations with a lower average weight were *T. laucaensis* at Caquena river with 1.43 ± 0.69 g. *Trichomycterus chungaraensis* showed the lower average length with 4.84 ± 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 chungarensis* 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

Table 2. Length–weight relationship estimations of six fish species, Lauca National Park, based on the equation log (W) = log a + b log(L); a = intercept of regression line; b = slope of regression line; b (95% CI) confidence interval of b parameter; r^2: coefficient of determination; the student *t*-test significance conducted to verify if b is significantly different from the consensus b = 3.

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	Piacota	−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 allonetric
O. chungarensis	Chungará	−2.43	3.51	3.24–3.79	0.691	0.98	Isometric
T. laucaensis	Lauca	−1.99	2.98	2.59–3.37	<0.001	0.88	Negative allonetric
T. laucaensis	Parinacota	−1.71	2.53	1.98–3.08	<0.001	0.82	Negative allonetric
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

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 competence 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).

Notes on contributors

Pablo Rojas, Biology Teacher, Magister of Ecology and Evolutive Biology, Universidad de Chile. Limnology and fish community are his scientific working areas. He has also explored the effects of

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.

Rodrigo Pardo, PHD Biology and Evolutive Sciences Universidad de Chile. Presently, he is working in Limnology and fish ecology. His research has been centered on the ecology characteristics of limnic fishes. He has also studied zooplankton and benthos in relation with trophic nets. Presently, he teaches at the University of Chile and directs a Center of Aquatic Ecology: AquaExpert.

Irma Vila, Biology and Chemistry Teacher Universidad de Chile, MSc, Ohio St. University, USA. Limnology Professor of Ecological Sciences Department, Universidad de Chile. Her main contributions have been related to altiplanic freshwater systems limnology and fish ecology from where she has described three new species.

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 glaciación Puna durante el Wisconsin, deglaciación y máximo lacustre en la transición Wisconsin-Holoceno y refugios de megafauna postglaciales en la puna y desierto de Atacama. Rev Geografía 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 adyacent 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-Sampériz 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, Munoz-Ramirez C, Sallaberry M, Fibla 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. Re '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.