ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/346060689

Invasion of salmonids in the Puna and Southern Chilean Altiplano: patterns and threats to the biodiversity

Article *in* BioInvasions Records · January 2020

DOI: 10.3391/bir.2020.9.4.19

CITATIONS
0

READS
101

4 authors, including:

Gabriel Lobos
University of Chile
49 PUBLICATIONS **773** CITATIONS
SEE PROFILE

Franco Cruz-Jofré
University of Chile
12 PUBLICATIONS **20** CITATIONS
SEE PROFILE

Pablo Fibla
University of Chile
17 PUBLICATIONS **75** CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Evolution of the Altiplano's species (Andean Plateau) View project

All content following this page was uploaded by Gabriel Lobos on 21 November 2020.

The user has requested enhancement of the downloaded file.

BioInvasions Records (2020) Volume 9, Issue 4: 853–864

Research Article

Invasion of salmonids in the Puna and Southern Chilean Altiplano: patterns and threats to the biodiversity

Gabriel Lobos[1,*], Paola Saez[2,3], Roberto Villablanca[4], Miguel Prado[5], Franco Cruz-Jofré[2,6], Pablo Fibla[2] and Marco A. Méndez[2,3,7]

[1]*Centro de Gestión Ambiental y Biodiversidad, Facultad de Ciencias Veterinarias y Pecuarias, Universidad de Chile. Avenida Santa Rosa #11735, La Pintana, Santiago, Chile*

[2]*Laboratorio de Genética y Evolución, Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile. Las Palmeras #3425, Santiago, Chile*

[3]*Center of Applied Ecology and Sustainability (CAPES)*

[4]*SEREMI del Medio Ambiente, Región de Antofagasta. Avenida José Miguel Carrera #1701, Antofagasta, Chile*

[5]*Servicio Agrícola y Ganadero. Ercilla #405, Los Ángeles, Chile*

[6]*Escuela de Medicina Veterinaria, Facultad de Recursos Naturales y Medicina Veterinaria, Universidad Santo Tomás. Los Limonares #190, Viña del Mar, Chile*

[7]*Instituto de Ecología y Biodiversidad (IEB), Facultad de Ciencias, Universidad de Chile. Santiago, Chile*

Author e-mails: *galobos@ug.uchile.cl (GL), paolasaezg@gmail.com (PS), rvillablanca.2@mma.gob.cl (RV), miguel.prado@sag.gob.cl (MP), f.cruzjofre@gmail.com (FC), pfibla@gmail.com (PF), mmendez@uchile.cl (MM)*

**Corresponding author*

Citation: Lobos G, Saez P, Villablanca R, Prado M, Cruz-Jofré F, Fibla P, Méndez MA (2020) Invasion of salmonids in the Puna and Southern Chilean Altiplano: patterns and threats to the biodiversity. *BioInvasions Records* 9(4): 853–864, https://doi.org/10.3391/bir.2020.9.4.19

Received: 19 March 2020

Accepted: 12 June 2020

Published: 18 September 2020

Handling editor: Jean Ricardo Simões Vitule

Thematic editor: Karolina Bącela-Spychalska

Copyright: © Lobos et al.

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International - CC BY 4.0).

OPEN ACCESS

Abstract

There is scarce documentation of the presence of trout in the Puna and southern Altiplano in Chile, in spite of the risk that they represent for these ecosystems of high environmental value, which have endemic and highly threatened fish and amphibians. We report that *Oncorhynchus mykiss* has expanded its range to the entire Chilean Altiplano and that *Salmo trutta* occurs only in the extreme south of the Chilean Puna. The existence of trout culture stations is related to the presence of feral trout, which cohabit with threatened native fish and amphibians. The control of trout expansion, by protecting areas of high value for native fish and banning any future aquaculture projects in this area, are priority to avoid the invasion this species to new localities in these ecosystems. The presence of salmonids in the countries that border Chile make this a regional threat for the highlands of southern South America.

Key words: *Oncorhynchus mykiss*, *Salmo trutta*, highland environments, invasive species, Chilean aquaculture

Introduction

Invasive alien species have a preponderant role in the loss of biodiversity in freshwater systems (Kolar and Lodge 2000; Crawford and Muir 2008; De Silva et al. 2009; Martín-Torrijos et al. 2016). Invasive fish are relevant agents in the global decline of freshwater aquatic fauna, particularly for amphibian populations which can be driven to extinction (Cambray 2003; Casal 2006; Helfman 2007). Invasive fish also affect native fish by predation (Soto et al. 2001, 2006; Quiroga et al. 2017), affect the functioning of stream

communities (Flecker and Townsend 1994; Townsend 1996; Potgieter 2014) and socio-economic conflicts (Ellender et al. 2014; Lima Junior et al. 2018; Weyl et al. 2018).

Salmonids were introduced in South America from the Northern Hemisphere, which has been poorly documented (Crawford and Muir 2008). Two species have been naturalized widely in continental waters, rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) and brown trout *Salmo trutta fario* Linnaeus, 1758. The natural distribution of *O. mykiss* ranges from the Bering Sea (Alaska) to Baja California (Crawford and Muir 2008). This species was introduced in Argentina from the USA in 1904 (Pascual et al. 2002). In Chile, this species was introduced in 1905 with individuals from Germany; they were first brought to Argentina, and later transported to the central area of Chile (Welcomme 1988; Iriarte et al. 2005). There have been numerous later introductions in both Chile and Argentina to reinforce the establishment of populations (Riva Rossi et al. 2004). Welcomme (1988) indicated that the species was introduced from England to Brazil (1913), from the USA to Colombia and Ecuador (1920) and to Lake Titicaca in Peru in 1927. Between 1930 and 1960 it was introduced from the USA to Venezuela, Uruguay, Guyana and Paraguay (MacCrimmon 1971; Lever 1996). The native distribution of *S. trutta* includes Eurasia and North Africa. It has been introduced in all continents including Antarctica (MacCrimmon and Marshall 1968; Weyl et al. 2018). MacCrimmon (1971) and Lever (1996) indicate that it was introduced in Argentina from England (1904), to Chile from Germany (1905) and to Peru from an unknown source in 1928. The motives for all these introductions were aquaculture and recreational fishing (i.e., sport fishing) (Crawford and Muir 2008).

Rainbow trout have formed self-sustaining populations in the Argentinean Patagonia, where they are dominant and where it cohabits with *Salmo trutta* (Pascual et al. 2001, 2002; Riva Rossi et al. 2004). *Oncorhynchus mykiss* has been naturalized in Chile from the Loa River (Antofagasta Region) to Tierra del Fuego (Magallanes Region), a range of 3556 km in latitude. *Salmo trutta* is present from the Aconcagua River (Valparaíso Region) to Tierra del Fuego (Arratia 1978; Soto et al. 2001; Iriarte et al. 2005), 2344 km latitudinally. Soto et al. (2006) indicated that 95% of the total fish biomass in 13 rivers of southern Chile (39–52°S latitude) is *S. trutta* and *O. mykiss*.

The extreme north of Chile is part of the Atacama Desert, which is the southernmost part of the coastal desert of Peru and Chile, which extends from 5° to 27° S latitude (Arroyo et al. 1988). At altitudes above 2500 m above sea level (masl) the landscape is dominated by mountain and shrubs in what is known as the Puna. At the altitudes of above 3700 masl it changes to the Altiplano Plateau, which extends from 15° to 24° S (Gregory-Wodzicki 2000). There are few aquatic ecosystems in these desert environments; however they are inhabited by diverse and endemic fish and amphibians. These include the fish genera *Orestias* and *Trichomycterus*, which have a high

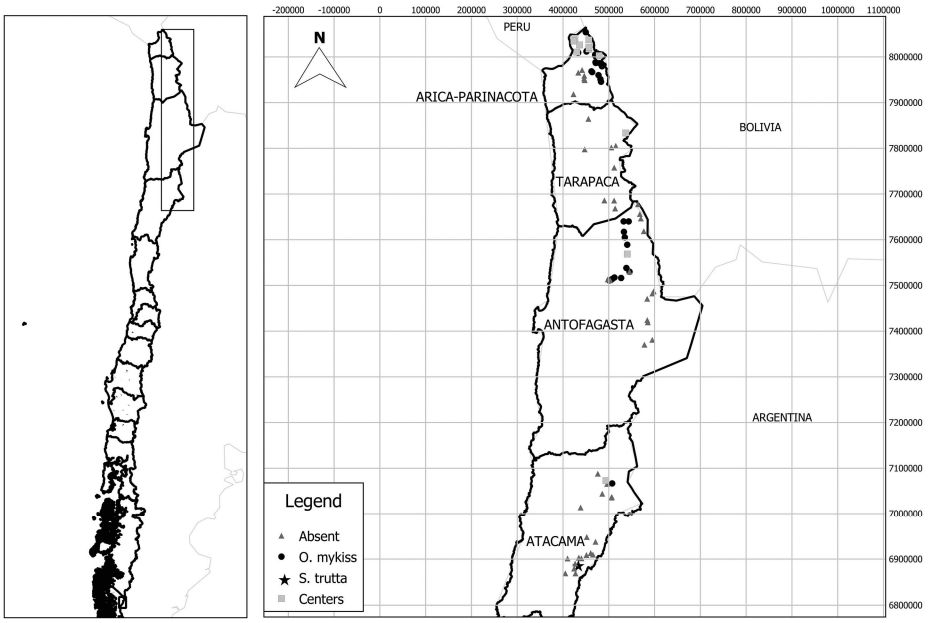

Figure 1. Distribution of salmonids *Oncorhynchus mykiss* and *Salmo trutta* in the highlands of northern Chile with identification of the reproduction centers. The box over the map in the left panel shows the study area within the country.

degree of diversification and endemicity (Vila et al. 2006, 2011, 2013), and the amphibian genus *Telmatobius* with at least nine species described from this area of Chile (Lavilla 2005; Veloso 2006; Méndez and Correa 2008; Correa et al. 2011).

In recent years we have observed the presence and expansion of salmonids in these environments, which represent a serious threat to endemic fish and amphibians. Thus, the objectives of this study are to report presence of alien salmonids formally, update their distribution, explore the patterns that underlie their invasion and establish the potential consequences that this invasion may have on the biological diversity of the highlands of northern Chile.

Materials and methods

Study area

The study was performed in the highlands of northern Chile, in the Puna and Altiplano ecosystems, which include between the Arica-Parinacota Region and the northern extreme of the Atacama Region (17.7° to 28° S) (Figure 1). We considered all the records obtained above 2000 masl, in order to evaluate the presence of salmonids in a wider scale. We sampled in 80 localities in years between 2008 and 2019 (Supplementary material Table S1).

Fish and amphibian field surveys

At each of the sampling stations we performed transects of 100 m length and 4–10 m wide (encompassed an area of 400–1000 m^2) along the homogeneous riparian zone, where amphibians were collected manually and with dip nets.

Table 1. Sources of salmonids introduction in the highlands of northern Chile.

Localities	Administrative region	Coordinates		SUBPESCA permissions*	Objectives
		Longitude	Latitude		
Caquena	Arica-Parinacota	−69.20	−18.06	1126/1997	Aquaculture
Colpitas	Arica-Parinacota	−69.41	−17.93	1127/1997	Aquaculture
Ancolacane	Arica-Parinacota	−69.60	−17.85	1125/1997	Aquaculture
Cosapilla	Arica-Parinacota	−69.41	−17.75	1129/97	Aquaculture
Guacoyo	Arica-Parinacota	−69.41	−17.90	1128/1997	Aquaculture
Chislluma	Arica-Parinacota	−69.42	−17.43	1995, Prado com. Pers.	Aquaculture
Tacora	Arica-Parinacota	−69.43	−17.46	1995, Prado com. Pers.	Aquaculture
Alcerreca	Arica-Parinacota	−69.39	−17.59	1995, Prado com. Pers.	Aquaculture
Villablanca	Tarapaca	−68.65	−19.59	Unknown	Aquaculture
Conchi Dam	Antofagasta	−68.61	−21.99	Unknown	Sport fishing
La Ola Dam	Atacama	−69.06	−26.46	Unknown	Sport fishing

* Subsecretaria de Pesca, Economy Department, Government of Chile

For fish in these stations we also used a SAMUS 725 MD electrofishing device; between 1 (small stream) to 4 samples by site (major stream, rivers). In a few cases we report personal observations (see Table S1).

Official records of programs of introduction of salmonids

The administrative authority in Chile that approves the development of aquaculture programs and recreational fishing is the National Fishing Service, SERNAPESCA. We consulted it about the information available in the study regions (Table 1).

Results

Salmonid species records

The Chilean Puna and Altiplano have been widely invaded by *Oncorrynchus mykiss* (streams, rivers, lakes) (Table S1), with a gap in the Tarapacá Region (Figure 2). *Salmo trutta* has only been recorded in the Atacama Region, in a transition zone to Mediterranean environments. In the Arica-Parinacota Region (Figure 3) *O. mykiss* was present in 16 of 23 sampled sites (69.56%); in the Antofagasta Region (Figure 4) in 13 of 27 (48.15%), and in the Atacama Region in 2 of the 23 sites sampled (8.69%), while *S. trutta* was found in one site (Figure 5).

Distribution

In northern Chile, *O. mykiss* extends for a range of 1002 km in latitude, from 2192 masl elevation in the Las Cascadas del Río Loa (Site S35) to 4560 masl in Misitune (S2) and Lake Chungará (S12) (Table S1). The most northern record we found of *S. trutta* was in Ramadillas (S59), Atacama Region, at 2100 masl. There are a large number of salmonid cultivation centers in the Arica-Parinacota Region, due to the public policy of developing small fish cultures associated with local human communities (Table 1). There is only one reproductive center in the Tarapacá Region, in Villablanca; this did not have the administrative permission from SERNAPESCA, and is currently abandoned (SERNAPESCA, Tarapacá

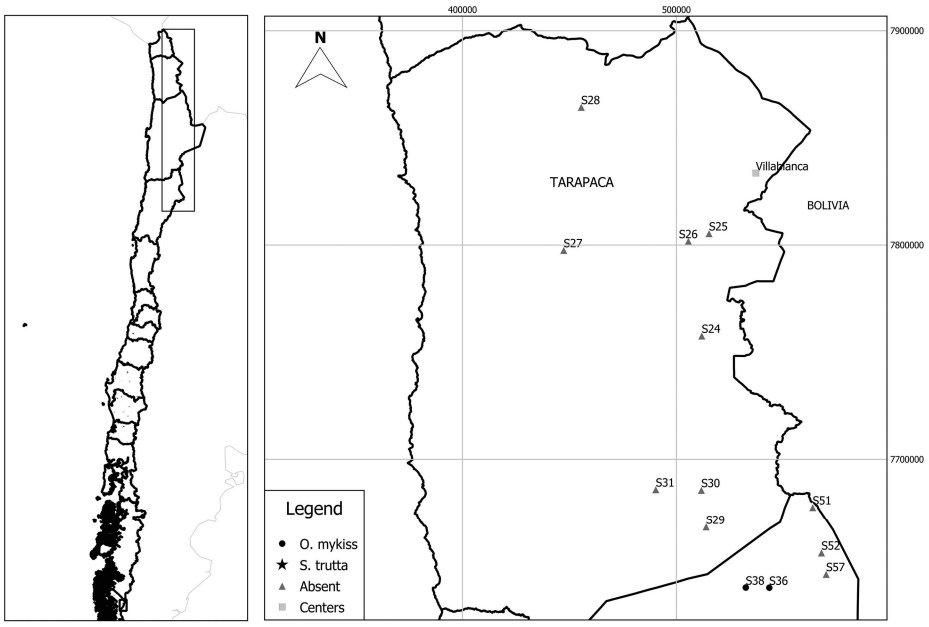

Figure 2. Distribution of salmonids *Oncorhynchus mykiss* and *Salmo trutta* in Tarapacá administrative region and reproduction centers. The box over the map in the left panel shows the study area within the country.

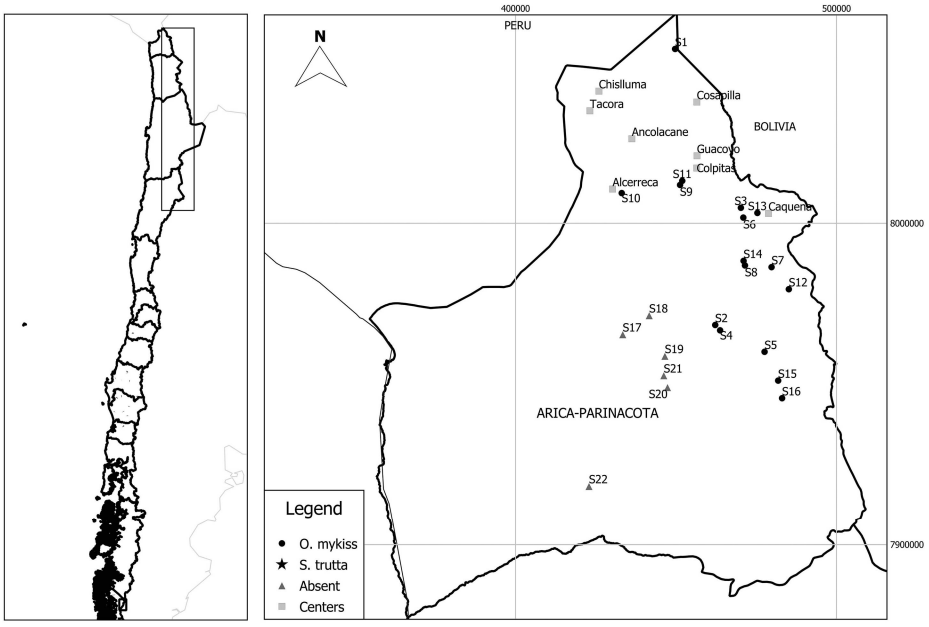

Figure 3. Distribution of salmonids *Oncorhynchus mykiss* and *Salmo trutta* in Arica-Parinacota administrative region and reproduction centers. The box over the map in the left panel shows the study area within the country.

Region, *pers. comm.*). Our records for the Antofagasta and Atacama regions indicate that salmonids were liberated for recreational activities such as sport fishing. There is close correspondence between the presence of salmonid cultivation centers and the presence of feral populations (Figures 2 to 5).

Threats to biodiversity

Of the 16 sites with rainbow trout in the Arica-Parinacota Region, 14 (87.50%) were shared with native fish, 10 (62.50%) with amphibians and 8

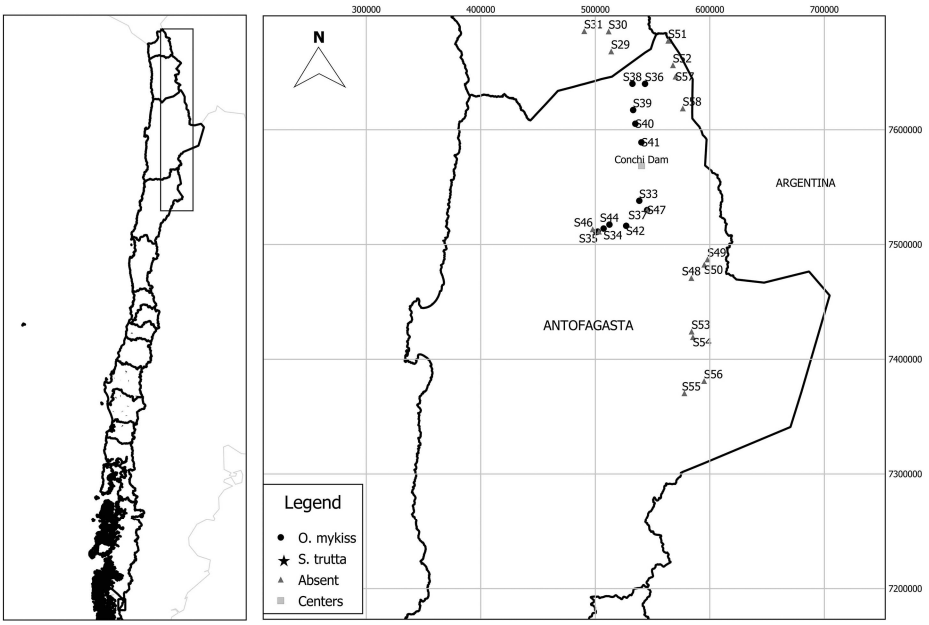

Figure 4. Distribution of salmonids *Oncorhynchus mykiss* and *Salmo trutta* in Antofagasta administrative region and reproduction centers. The box over the map in the left panel shows the study area within the country.

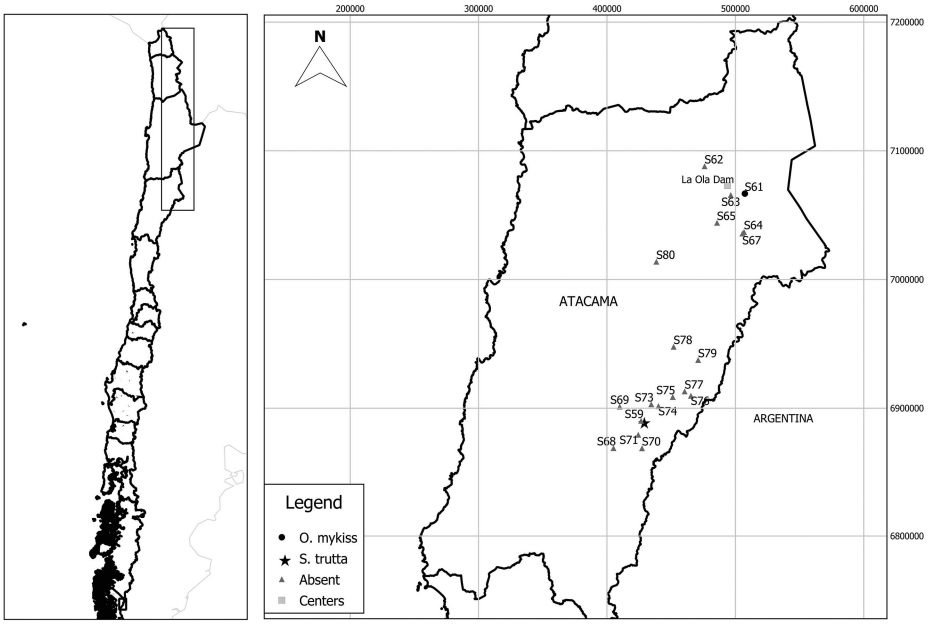

Figure 5. Distribution of salmonids *Oncorhynchus mykiss* and *Salmo trutta* in Atacama region and reproduction centers. The box over the map in the left panel shows the study area within the country.

(50.00%) with both groups (Table S1). Two of the native fish species are classed as Vulnerable (IUCN 2020) (*Orestias chungarensis* Vila & Pinto, 1987 called karachi or Andean killifish, *Trichomycterus chungarensis* Arratia, 1983 called suches or Chungará catfish) and three as Near Threatened (*Orestias laucaensis* Arratia, 1982 with a common name corvinilla or Andean killifish, *Trichomycterus rivulatus* Valenciennes, 1846 called suches or Puna catfish, *T. laucaensis* Arratia, 1983 called suches or Lauca catfish). Among the amphibians marbled water frog *Telmatobius marmoratus*

(Dumeril & Bibron, 1841) is considered Vulnerable, *Pleurodema marmoratum* (Dumeril & Bibron, 1840) (marbled four-eyed frog) and *Rhinella spinulosa* (Wiegmann, 1834) (warty toad) as Least Concern (IUCN 2020).

We report the presence of rainbow trout in 13 sites in the Antofagasta Region. In one site it was present along with the native fish *Basilichthys* cf. *semotilus* (Cope, 1874) called pejerrey or silverside; a Least Concern species for IUCN but with Extinction Threat under national law (Species Classification Regulations of the Ministry of the Environment). In one site the trout was found together with the amphibian *R. spinulosa*, a species listed as Least Concern. There are no records of native fishes and anurans in the highlands of the Atacama Region, except for one population of Chile four-eyed frog *Pleurodema thaul* (Lesson, 1826) (Correa et al. 2009).

Discussion

Highland environments in southern South America have high relevance in terms of biodiversity. For example, in the Lake Titicaca watershed (Bolivia, Chile and Peru), 93% of the fish species (38 species) are endemic (Reis et al. 2016). At least 7 species of the genera *Orestias* and *Pseudorestias* have been described in Chile; at least 6 of them are endemic with restricted distribution (Parenti 1984; Vila et al. 2007, 2013; Arratia et al. 2017). The high elevation environments are the habitat for anurans of the genus *Telmatobius*. Species of this genus live in wetlands, bogs, lakes, rivers and wetlands associated with salt flats between 5° and 27° S latitude. Up to now, 63 species of *Telmatobius* are recognized (Frost 2020), nine of which inhabit Chile (Lobos et al. 2013); these are completely aquatic and highly endemic (Veloso 2006; Méndez and Correa 2008; Correa et al. 2011).

Lake Titicaca (Peru and Bolivia) has received special attention as the introduction of the salmonids *Oncorhynchus mykiss, Salvelinus namaycush* (Walbaum, 1792) (great lake trout), *Salvelinus fontinalis* (Mitchill, 1814) (brook trout) and *Salmo trutta* has placed several native populations of *Orestias* in serious danger (Vila et al. 2007). Aguilera et al. (2006) examined 32 highland lakes in the Eastern Andes of Bolivia; rainbow trout were found in half of them. These authors reported no negative effect of the trout on zooplankton density, suggesting a moderate to low top-down effect of the trout; to the lack of running water and littoral zones in most of the lakes and high ultraviolet radiation make it difficult for trout to spawn. Barros and Gonzo (2004) indicated that rainbow trout were introduced in the Puna of Argentina in the 1960s; they analyzed two populations in the Los Patos and Aguas Calientes rivers in the Puna, finding that the fish length and weight were lower than those found in rivers of Argentina at higher latitudes. This was complemented by Fernández (2009), who indicated the presence of trout in the Cerro Gordo River (elevation 4070 m) and the Aguas Calientes River (4063 m) in the Puna of the Catamarca and Salta Provinces.

The presence of trout in the highlands of northern Chile is not well documented. In a review of the fishes of the Altiplano, Vila et al. (2007) indicated that trout had expanded to the Chilean Altiplano, and Vargas et al. (2015) indicated their presence generally in the Chilean part of the Titicaca ecoregion. In one of the few more precise reports, Pardo and Vila (2008) documented the presence of *O. mykiss* in Lake Chungará. Our study found that *O. mykiss* dominates in the southern Chilean Altiplano, especially in the Arica-Parinacota Region; where since 1995 there has been a strong impulse for the development of small fish cultivation by the Chilean State. In one of these areas, Colpitas (Table 1), we found that a mudslide completely destroyed the installation, which was then abandoned; we collected an adult and two juveniles of *O. mykiss* in a stream of this site. We found expansion of *O. mykiss* in the south of this region, especially in the Ancuta locality (S5), where we captured more than 1000 alevins. The development of small cultivation centers is a risk factor in the expansion of trout near these centers; in other parts of our study area the lower development of aquiculture has helped to contain and restrict this invasion. The Altiplano of the Tarapacá Region is so far free of trout, although a clandestine attempt at cultivation may have facilitated the invasion process. The motives for introduction in the Antofagasta and Atacama Regions have been more oriented to recreational uses; introduction of rainbow trout in artificial dam reservoirs has been to stimulate sport fishing. However, this kind of initiative has had negative effects; for example, the introduction of trout in the Conchi S32 reservoir has led to their spread in the upper and middle parts of the Loa River, where they may affect the highly threatened *Basilichthys* cf *semotilus*, which is probably a new species (Dyer 2000).

Salmo trutta is so far restricted only to the Puna of the Atacama Region, not yet expanding more in the north of the country. Its presence in Ramadillas (S59) probably came from the Lautaro reservoir, 41 km downstream from S59 in the Copiapó River watershed; trout have been introduced in this reservoir (elevation 800 masl), where we captured *S. trutta* but not *O. mykiss*.

There are few studies in South America that explore the effect of invasive fish. One study documented the decrease of three species of *Telmatobius* frogs (water frog) in Tucumán Province (Argentina) due to the introduction of *O. mykiss* (Barrionuevo and Ponssa 2008); *Telmatobius laticeps* Laurent, 1977 and *T. ceiorum* Laurent, 1970 were absent from the surveyed streams between 2000 and 4200 masl, while small numbers of *T. pisanoi* Laurent, 1977 were found at the edge of its historical distribution. A negative association between the presence of *O. mykiss* and the endangered *Telmatobius macrostomus* (Peters, 1873) (lake Junin frog) was documented in the Reserva Nacional de Junín in Perú (4080 to 4546 masl elevation); probably due to the impact on the tadpoles (Watson et al. 2017). Another study evaluated the predatory impact of *O. mykiss* on Andean amphibians

in Ecuador, demonstrating the voracity of the fish on the tested anurans (Martín-Torrijos et al. 2016). Quiroga et al. (2017), reported the predation of *O. mykiss* on the endangered naked characin *Gymnocharacinus bergii* Steindachner, 1903 in a valley of Argentine Patagonia. In this way, in an occasional find, we found an individual of *Orestias laucaensis* in the stomach of an adult trout in Misitune (S2).

The Arica-Parinacota Region currently has the highest propagation of *O. mykiss*; however, the Puna localities (sites S17–S23), which have threatened amphibian species (Table S1) have not yet been invaded, thus the protection of this sector from the advance of this invasion (monitoring/inspection, prohibition of salmonid introduction) is urgent. The lower presence in other regions is related to the low number of cultivation centers, thus future cultivation projects should be to ban, considering the risk they represent for biodiversity. This is particularly true in the Antofagasta Region, where several small streams and springs harbor local endemic amphibian species and are still free from invasion (sites S48–S52). The Tarapacá Region is apparently still free of trout, which must be maintained considering the important presence of threatened fish and amphibians in its surface water courses. The low aquiculture activity in the continental waters of the Atacama Region has favored the scarce propagation of trout, although it is important to continue the monitoring of the brown trout, since this is the northern limit of its distribution in the country.

One of the main threats is our lack of knowledge with respect to the risk that the introduction of trout represents in areas of high environmental value. The Web page of SERNAPESCA indicates with respect to trout "Their presence sustains recreational fishing, of world quality in the southern part of the country. A number of measures have been established for their administration: temporary closure, minimum sizes and extraction quotas related to recreational fishing, which must be monitored to assure their conservation." (http://www.sernapesca.cl/recurso/salmonideos; accessed 6 March 2020).

In this context, an example is Southern Africa, where management actions are complicated, because non-native fishes are important components in regional economies and food security (Ellender et al. 2014). Regrettably, in Chile trout are one of the few freshwater species of Chile with conservation plans. In a mistaken perception, Chilean environmental legislation considers periods of closures, minimum size captures and populations' reinforcement in some basins. It is a priority to define high value areas for native fish, where aquaculture cannot proceed; as well as to control invasive species in those areas.

In addition, environmental education of key stakeholders including local people, anglers and legislators is needed. In the same line campaigns of public awareness (e.g. interviews with expert on biological invasions, citizen science) with respect to the value of our biological patrimony are essential to the protection of the aquatic resources.

Finally, the Convention on Biological Diversity proposed the Aichi biodiversity targets to improve conservation policies and to balance economic development, social welfare, and the maintenance of biodiversity and ecosystem services (Lima Junior et al. 2018).

In this scenario, Chile as a signatory country of the CBD endorses the Aichi targets and therefore should be compliant with this framework specially with target 9; that stablishes that by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

Acknowledgements

This study was partially financed by the Ministry of the Environment of Chile as part of the Project for Recovery, Conservation and Management of Chilean Amphibians, and by the Environmental Protection Fund 2-G-022-2015 del MMA. We especially thank Charif Tala, Vinko Malinarich, Patricio Rivas and Sandra Díaz for their support in the development of this topic in the country. We also thank Prof. Olaf L.F. Weyl and anonymous reviewers for their constructive commentary, which improved the manuscript.

Funding Declaration

This project received financial support from Ministry of the Environment of Chile (project number: 2-G-022-2015, to GL), and ANID PIA/BASAL FB0002 and ANID-FONDECYT 1200419 (to MAM, PS). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Ethics and Permits

This project was realized with number permit 4495 Chilean Agricultural and Livestock Service and permits for capture of fishes numbers 1947 and 3199 (National Fishing Service).

References

Aguilera X, Declerck S, De Meester L, Maldonado M, Ollevier F (2006) Tropical high Andes lakes: a limnological survey and assessment of exotic rainbow trout (*Oncorhynchus mykiss*). *Limnologica* 36: 258–268, https://doi.org/10.1016/j.limno.2006.08.001

Arratia G (1978) Comentarios sobre la introducción de los peces exóticos en aguas continentales de Chile. *Ciencias Forestales, Chile* 2: 21–30

Arratia G, Vila I, Lam N, Guerrero CJ, Quezada-Romegialli C (2017) Morphological and taxonomic descriptions of a new genus and species of killifishes (Teleostei: Cyprinodontiformes) from the high Andes of northern Chile. *PLoS ONE* 12: e0181989, https://doi.org/10.1371/journal.pone.0181989

Arroyo MTK, Squeo F, Armesto JJ, Villagrán C (1988) Effects of aridity on plant diversity on the northern Chilean Andes: Results of a natural experiment. *Annals of the Missouri Botanical Garden* 75: 55–78, https://doi.org/10.2307/2399466

Barrionuevo JS, Ponssa LM (2008) decline of three species of the genus *Telmatobius* (Anura: Leptodactylidae) from Tucumán province, Argentina. *Herpetologica* 64: 47–62, https://doi.org/10.1655/06-057.1

Barros S, Gonzo G (2004) Poblaciones naturalizadas de truchas arco iris (*Oncorhynchus mykiss*) en la Puna de Argentina: bases ecológicas para su manejo. In: University of Kent-Canterburry, Universidad Nacional de la Amazonía Peruana (eds), VI Congreso Internacional sobre Manejo de Fauna Silvestre en la Amazonía y Latinoamérica, Iquitos, Perú. Wildlife Conservation Society, pp 116–126

Cambray JA (2003) Impact on indigenous species biodiversity caused by the globalization of alien recreational freshwater fisheries. *Hidrobiologia* 500: 217–230, https://doi.org/10.1023/A:1024648719995

Casal C (2006) Global documentation of fish introductions: the growing crisis and recommendations for action. *Biological Invasions* 8: 3–11, https://doi.org/10.1007/s10530-006-1833-0

Correa C, Riveros E, Lobos G, Velazquez N (2009) Amphibia, Anura, Leiuperidae, *Pleurodema thaul* (Lesson, 1827): Altitudinal distribution extension and new records from its northern range. *Check List* 5: 1–5, https://doi.org/10.15560/6.1.010

Correa C, Cisternas J, Correa-Solís M (2011) Lista comentada de las especies de anfibios de Chile (Amphibia: Anura). *Boletín de Biodiversidad de Chile* 6: 1–21

Crawford S, Muir A (2008) Global introductions of salmon and trout in the genus *Oncorhynchus*: 1870-2007. *Reviews in Fish Biology and Fisheries* 18: 313–344, https://doi.org/10.1007/s11160-007-9079-1

De Silva SS, Nguyen TT, Turchini GM, Amarasinghe US, Abery NW (2009) Alien species in aquaculture and biodiversity: a paradox in food production. *AMBIO: Journal of the Human Environment* 38: 24–28, https://doi.org/10.1579/0044-7447-38.1.24

Dyer B (2000) Systematic review and biogeography of the freshwater fishes of Chile. *Estudios Oceanológicos* 19: 77–98

Ellender BR, Woodford DJ, Weyl OLF, Cowx IG (2014) Managing conflicts arising from fisheries enhancements based on non-native fishes in southern Africa. *Journal of Fish Biology* 85: 1890–1906, https://doi.org/10.1111/jfb.12512

Fernández L (2009) Búsqueda de peces autóctonos. In: González R, Lobos F (eds), Los Vertebrados del Salar del Hombre Muerto, Minera del Altiplano S.A. Salta, Argentina, pp 25–33

Flecker AS, Townsend CR (1994) Community-wide consequences of trout introduction in New Zealand stream. *Ecological Applications* 4: 798–807, https://doi.org/10.2307/1942009

Frost DR (2020) Amphibian species of the world: an online reference. Version 6.0. http://research.amnh.org/herpetology/amphibia/index.html (accessed 22 May 2020)

Gregory-Wodzicki K (2000) Uplift of the Central and Northern Andes: A review. *GSA Bulletin* 112: 1091–1105, https://doi.org/10.1130/0016-7606(2000)112<1091:UHOTCA>2.0.CO;2

Helfman GS (2007) Fish conservation: a guide to understanding and restoring global aquatic biodiversity and fishery resources. Island Press, 600 pp

Iriarte JA, Lobos GA, Jaksic FM (2005) Invasive vertebrate species in Chile and their control and monitoring by governmental agencies. *Revista Chilena de Historia Natural* 78: 143–154, https://doi.org/10.4067/S0716-078X2005000100010

IUCN (2020) The IUCN Red List of Threatened Species. Version 2020-1. http://www.iucnredlist.org (accessed 22 May 2020)

Kolar CS, Lodge DM (2000) Freshwater nonindigenous species: interactions with other global changes. 1st ed. Washington DC, Island Press, 384 pp

Lavilla E (2005) Lista sistemática y bibliografía comentada sobre el género *Telmatobius*. In: Asociación Herpetológica Española (ed), Estudios sobre las ranas andinas de los géneros *Telmatobius* y *Batrachophrynus* (Anura: Leptodactylidae). Monografías de Herpetología, Valencia, pp 283–349

Lever C (1996) Naturalized fishes of the world. Academic Press, California, 408 pp

Lima Junior DP, Magalhães ALB, Pelicice FM, Vitule JRS, Azevedo-Santos VM, Orsi ML, Simberloff D, Agostinho AA (2018) Aquaculture expansion in Brazilian freshwaters against the Aichi Biodiversity Targets. *Ambio* 47: 427–440, https://doi.org/10.1007/s13280-017-1001-z

Lobos G, Vidal M, Correa C, Labra A, Díaz-Páez H, Charrier A, Rabanal F, Díaz S, Tala C (2013) Anfibios de Chile, un desafío para la conservación. Ministerio de Medio Ambiente, Fundación Facultad de Ciencias Veterinarias y Pecuarias de la Universidad de Chile y Red Chilena de Herpetología, Santiago, 104 pp

MacCrimmon HR (1971) World distribution of rainbow trout (*Salmo gairdneri*). *Journal of the Fisheries Research Board of Canada* 28: 663–704, https://doi.org/10.1139/f71-098

MacCrimmon HR, Marshall TL (1968) World distribution of brown trout *Salmo trutta*. *Journal of the Fisheries Research Board of Canada* 25: 2527–2548, https://doi.org/10.1139/f68-225

Martín-Torrijos L, Sandoval-Sierra JV, Muñoz J, Diéguez-Uribeondo J, Bosch J, Guayasamin JM (2016) Rainbow trout (*Oncorhynchus mykiss*) threaten Andean amphibians. *Neotropical Biodiversity* 2: 26–36, https://doi.org/10.1080/23766808.2016.1151133

Méndez M, Correa C (2008) Diversidad de especies: Anfibios. In: Comisión Nacional del Medio Ambiente (ed), Biodiversidad de Chile, Patrimonio y Desafíos. Ocho Libros Editores, Santiago de Chile, pp 284–289

Pardo R, Vila I (2008) Threatened fishes of world: *Trichomycterus chungaraensis* Arratia 1983 (Trichomycteridae). *Environmental Biology of Fishes* 81: 369–370, https://doi.org/10.1007/s10641-007-9212-y

Parenti LR (1984) A taxonomic revision of the Andean killifish genus *Orestias* (Cyprinodontiformes, Cyprinodontidae). *Bulletin of the American Museum of Natural History* 178: 110–214

Pascual MA, Bentzen P, Riva Rossi C, Mackey G, Kinnison M, Walker R (2001) First documented case of anadromy in a population of introduced rainbow trout in Patagonia, Argentina. *Transactions of the American Fisheries Society* 130: 53–67, https://doi.org/10.1577/1548-8659(2001)130<0053:FDCOAI>2.0.CO;2

Pascual MA, Macchi P, Urbanski J, Marcos F, Riva Rossi C, Novara M, Dell'Arciprete P (2002) Evaluating potential effects of exotic freshwater fish from incomplete species presence-absence data. *Biological Invasions* 4: 101–113, https://doi.org/10.1023/A:1020513525528

Potgieter MJ (2014) The impact of introduced trout on ecosystem structure and functioning in streams of the Drakensberg, South Africa. BSc (hons) research report, University of Pretoria, South Africa, 32 pp

Quiroga S, Kacoliris F, Garcia I, Povedano H, Velasco M, Zalba S (2017) Invasive rainbow trout *Oncorhynchus mykiss* preying on the endangered naked characin *Gymnocharacinus bergii* at its thermal limits. *Journal of Fish Biology* 91: 1745–1749, https://doi.org/10.1111/jfb.13478

Reis ER, Albert JS, Di Dario F, Mincarone MM, Petri P, Rocha LA (2016) Fish biodiversity and conservation in South America. *Journal of Fish Biology* 89: 12–47, https://doi.org/10.1111/jfb.13016

Riva Rossi CM, Lessa EP, Pascual MA (2004) The origin of introduced rainbow trout (*Oncorhynchus mykiss*) in the Santa Cruz River, Patagonia, Argentina, as inferred from mitochondrial DNA. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 1095–1101, https://doi.org/10.1139/f04-056

Soto D, Jara F, Moreno CA (2001) Escaped salmon in the inner seas, southern Chile: facing ecological and social conflicts. *Ecological Applications* 11: 1750–1762, https://doi.org/10.2307/3061093

Soto D, Arismendi I, González J, Sanzana J, Jara F, Jara C, Guzman E, Lara A (2006) Southern Chile, trout and salmon country: invasion patterns and threats for native species. *Revista Chilena de Historia Natural* 79: 97–117, https://doi.org/10.4067/S0716-078X2006000100009

Townsend CR (1996) Invasion biology and ecological impacts of brown trout *Salmo trutta* in New Zealand. *Biological Conservation* 78: 12–22, https://doi.org/10.1016/0006-3207(96)00014-6

Vargas P, Arismendi I, Gomez-Uchida D (2015) Evaluation taxonomic homogenization of freshwater fish assemblages in Chile. *Revista Chilena de Historia Natural* 88: 16, https://doi.org/10.1186/s40693-015-0046-2

Veloso A (2006) Batracios de las cuencas hidrográficas de Chile: origen, diversidad y estado de conservación. In: Vila I, Veloso A, Schlatter R, Ramírez C (eds), Macrófitas y Vertebrados de los Sistemas Límnicos de Chile. Editorial Universitaria, Santiago de Chile, pp 103–140

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 (eds), Macrófitas y Vertebrados de los Sistemas Límnicos de Chile. Editorial Universitaria, Santiago de Chile, pp 73–102

Vila I, Pardo R, Scott S (2007) Freshwater fishes of the Altiplano. *Aquatic Ecosystem Health & Management* 10: 201–211, https://doi.org/10.1080/14634980701351395

Vila I, Scott S, Méndez M, 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). *Ichthyological Exploration of 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. *Journal of Fish Biology* 82: 927–943, https://doi.org/10.1111/jfb.12031

Watson AS, Fitzgerald AL, Baldeón OJD, Elías RK (2017) Habitat characterization, occupancy and detection probability of the Endangered and endemic Junín giant frog *Telmatobius macrostomus*. *Endangered Species Research* 32: 429–436, https://doi.org/10.3354/esr00821

Welcomme RL (1988) International introductions of inland aquatic species. FAO, Rome, Fish Tech Pap 294, 328 pp

Weyl OLF, Ellender BR, Ivey P, Jackson MC, Tweddle D, Wasserman RJ, Woodford DJ, Zengeya TA (2018) Africa: brown trout introductions, establishment, current status, impacts and conflicts. In: Lobón-Cerviá J, Sánz N (eds), Brown trout: biology, ecology and managements. Wiley-Blackwell, pp 623–639, https://doi.org/10.1002/9781119268352.ch24

Supplementary material

The following supplementary material is available for this article:

Table S1. Sites of samples for *Oncorhynchus mykiss* and *Salmo trutta*. Presence of native fish and anurans in each site is indicated.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2020/Supplements/BIR_Lobos_etal_SupplementaryMaterial.xlsx

View publication stats