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New distribution records, habitat description and comments on the natural history of the poorly known frog *Atelognathus solitarius* (Anura, Batrachylidae) from northwestern Patagonia, Río Negro Province, Argentina

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Abstract. *Atelognathus solitarius* is probably the least-known species of its genus. The species was described in 1970 based on a single specimen from the Las Bayas Creek, Río Negro Province, Argentina; later publications that reported new specimens did not provide new localities. Here, we present an update of its distribution, describe the habitats it occupies, detail features of its natural history, and discuss conservation aspects. For this purpose, all available records were compiled from herpetological collections, literature, and new data obtained during field trips to the type locality and surroundings. We confirmed the presence of the species near its type locality and extended the known distribution about 30 km WSW and 30 km NW. Furthermore, we discovered that in addition to using small streams, *A. solitarius* uses lagoons in volcanic tablelands. Future studies on the biological and ecological aspects of the species are essential to update the current conservation category of 'Insufficiently Known' for Argentinean categorization or 'Data Deficient' for IUCN.

Key words: distribution, habitat, Patagonia, conservation, amphibians.

Introduction

The genus *Atelognathus* Lynch 1978 is composed of five species of frogs that are distributed in Patagonia of Argentina and Chile (Basso 1998, Barrasso & Basso 2019). For *Atelognathus patagonicus*, *A. nitoi*, *A. reverberii*, and *A. praebasalticus* studies have shown aspects of their ecology, morphology, taxonomy, conservation efforts, and geographical distribution (e.g. Cei 1969, 1972, Cuello et al. 2006a,b, 2008, 2009, 2014, 2017, Basso & Úbeda 1997, Basso 1998, Úbeda et al. 1999, Díaz-Páez et al. 2011, Martinazzo et al. 2011a,b, Barrasso & Basso 2019). *Atelognathus solitarius* is the least-known species of the genus, with four publications limited to its description (Cei 1970) and serology (Cei 1972), morphology (Lynch 1978), and a catalog of herpetological collection (Literas et al. 2018); no sites besides the type locality were provided. The description of *A. solitarius* was based on a single male [IBA-UNC 2045] collected from Las Bayas Creek, 48 km south of Pilcaniyeu, near the village of Las Bayas, Río Negro Province, Argentina (Cei 1970). No information was provided by Cei about its ecology or morphological variation. Due to its restricted known distribution range (type locality), and the lack of published ecological information for more than 40 years, it has been listed as "Insufficiently Known" (Vaira et al. 2012, Secretaría de Ambiente Humano y Desarrollo Sustentable 2013) in Argentina and "Data Deficient" (IUCN 2019) by the Global IUCN Red List.

Here, we present new records of *A. solitarius* that confirm its continued presence near the type locality and update the known distribution range through compiling all known sources. We also report a new habitat, aspects of growth and sexual maturation, a record of predation, and discuss its conservation status.

Material and Methods

We compiled locality data of *A. solitarius* from several sources. We reviewed the herpetological collections of the Instituto de Biología Animal de la Universidad Nacional de Cuyo (IBA-UNC), deposited in the Facultad de Ciencias Agrarias, UNCuyo (Mendoza, Argentina) and of the Instituto de Diversidad y Evolución Austral (IDEAus-CONICET; acronym CNP.A), Puerto Madryn (Chubut, Argentina). We used data obtained from a technical report made under the Inventory Plan of National Parks Lanín and Nahuel Huapi (Christie 1984). We reviewed the online catalog of the Museum of Vertebrate Zoology at Berkeley (MVZ; http://mvz.berkeley.edu/Herp_Collection.html; accessed in December 2019), California, USA. Additionally, from 1982 to 2017, we made thirteen visits to the type locality and surrounding areas (radius of 30 km) in search of new records.

All locality data were mapped using hand-held GPS and/or high-resolution aerial maps, at approximately 10 m of precision. The names of the lagoons and different sites follow those from Topographic Sheet N° 4172-30 "Las Bayas" of Instituto Geográfico Nacional de la República Argentina (IGN) and from Geological Sheet 4172-IV, San Carlos de Bariloche (Giacosa & Heredia 2002). A Minimum Convex Polygon (the smallest polygon around all localities in which no internal angle exceeds 180 degrees) was drawn in Google Earth Pro™ (v 7.3), approximating the area of the species range.

Collection and treatment of animals followed standard practices relevant at the time of collection (1980–1990), and coincided with the practices suggested by Heyer (1994) and the new standards guidelines of the American Society of Ichthyologists and Herpetologists (Beaupre et al. 2004). We measured and weighed 49 over-anesthetized individuals 1–3 days post-capture from Laguna de los Médanos (34 collected in 1982, 15 collected in 1986; see Table 1). Snout to vent length (SVL) was measured along the venter to the nearest millimeter using a flexible plastic ruler, and the weight was taken using a Pesola™ spring scale (10 g capacity, 0.1 g subdivisions). We assessed the reproductive condition for specimens by examining the ova and oviducts of females and the length of testes of males. The reproductive condition of adults was recorded

Table 1. Localities and coordinates of occurrences of *A. solitarius*. L – Locality number; Latitude/Longitude, in datum WGS 84; N – number of collected individuals; vouchers with * in the MVZ collection are cataloged as *Atelognathus* sp.

L	Locality description	Latitude Longitude	Elev. (m)	N	Date	Voucher numbers	Source	Brief comment
1	Bank of Las Bayas Creek, 48 km south of Pilcaniyeu	-41.4608 -70.6557	978	1	January 6, 1969	IBA-UNC 2045	Cei (1970)	Holotype, Fig. 2A-B; coordinates approximated by us
				2	January 10, 1970	IBA-UNC 2129-1 IBA-UNC 2129-2	Literas et al. (2018)	
				1	April 8, 1970	IBA-UNC 2131	IBA-UNC	
2	Laguna de los Médanos (Fig. 2D-E)	-41.5201 -70.7270	1170	50	April 2, 1982	MVZ 188227-188270 MVZ 188934 MVZ 188959 MVZ 200492 MVZ 274614-274616*	Christie (1984)	In Christie (1984) as "Laguna de los Juncos"
				18	November 23, 1986	MVZ 232546-232563	This study	
				6	January 10, 1998	CNP.A 33 CNP.A 376 CNP.A 3405-3408	This study	
3	Arroyo Chenqueniyén, 10 km E and 3 km S of Cerro Pico Quemado	-41.5272 -70.9759	1150	1	February 25, 1982	MVZ 188226	Christie (1984)	
4	Provincial Road (RP) N° 80	-41.3631 -71.0114	1175	2	February 25, 1982	RDS 10721, 10722	This study	RDS field-number.
				6	February 25, 2008	RDS 18824-18829	This study	In Christie (1984) as "Provincial Road N° 318, 3 km N. Las Bayas Creek, 1175 m…"
				1	January 15, 2009	RDS 199985	This study	
				2	February 10–11, 2010	RDS 19988, 19989	This study	
5	On Escorial de Chenqueniyén, 4.5 km W Alto del Escorial	-41.5067 -70.7364	1186	1	November 23, 1986	MVZ 274609	This study	Specimen not associated with any lagoon
6	less than 500 m north of the Laguna de los Médanos margin	-41.5003 -70.7391	1164	1	March 16, 2017	CNP.A 4316	This study	Small lagoon related to Laguna de los Médanos

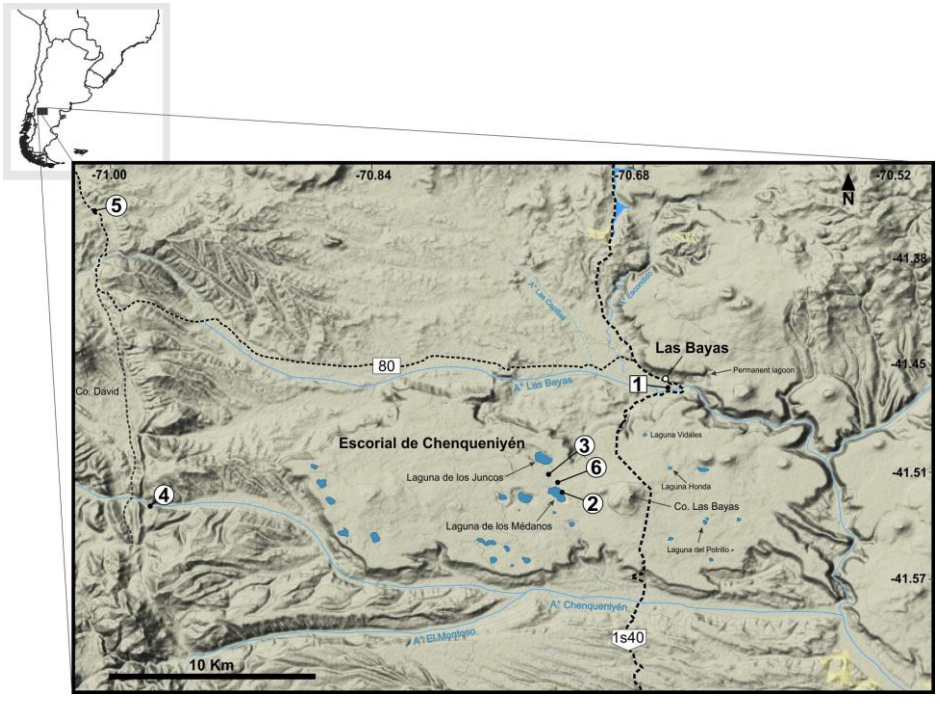

Figure 1. Map of localities of *Atelognathus solitarius*.
1) type locality,
2) Laguna de los Médanos,
3) Arroyo Chenqueniyén,
4) Provincial Road N° 80,
5) Escorial de Chenqueniyén,
6) north of the Laguna de los Médanos.
Locality numbers correspond to those in Table 1.

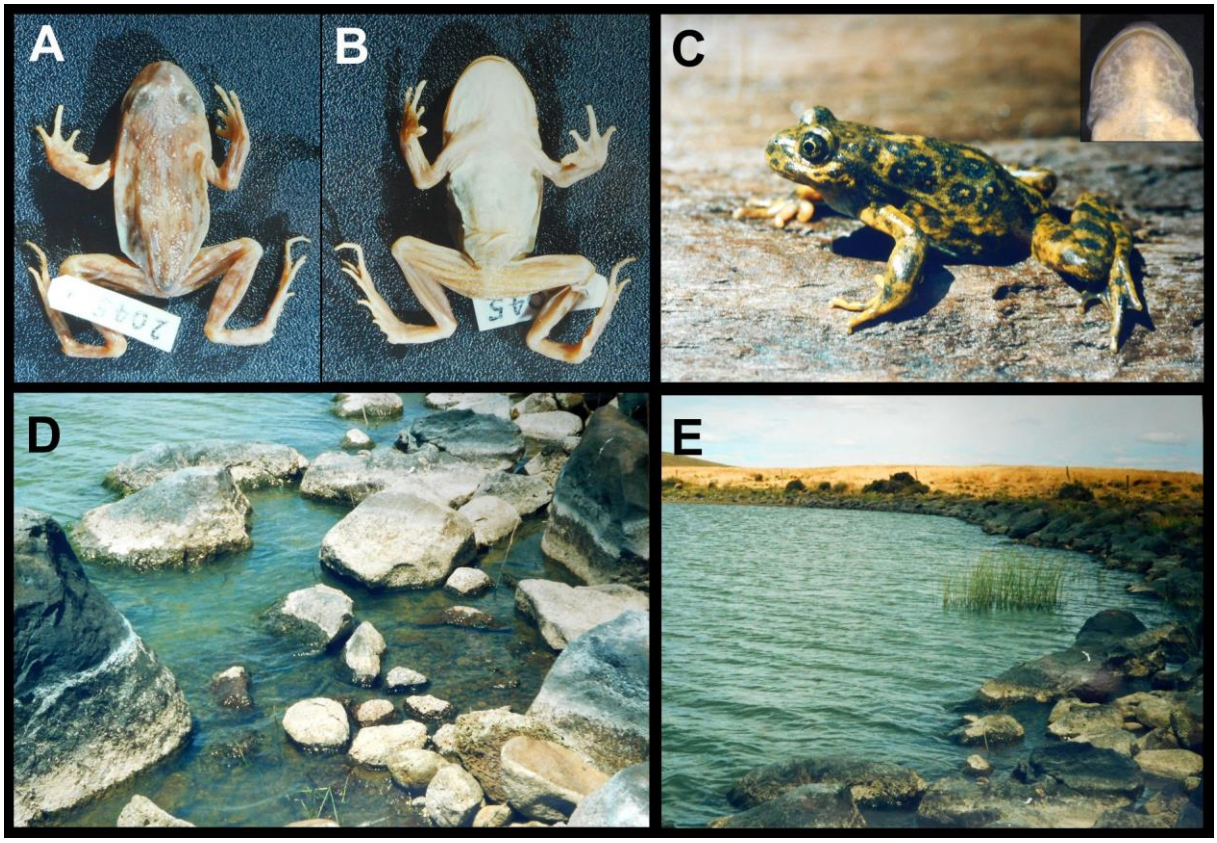

Figure 2. A) and B) dorsal and ventral views of the holotype of *Atelognathus solitarius* (IBA-UNC 2045), C) an adult found in Laguna de los Médanos, *in situ,* and a close-up of its gular region, as preserved specimen (CNP.A 3407), D) details of the rocky coast of Laguna de los Médanos, and E) general view of the coast of Laguna de los Médanos.

for 34 specimens from Laguna de los Médanos: 13 females and 14 males collected in 1982, and 3 males and 4 females collected in 1986. The maximum SVL that we observed was obtained from three metamorphs collected in Laguna de los Medanos (1986) and held in captivity for two and three years; we did not evaluate their reproductive condition.

Results

Localities

We compiled a list of six occurrence locations for *A. solitarius*, based on published, unpublished personal field observations and collection data. One author (RDS) worked on the technical report edited by Christie (1984); this allows us to provide report's vouchers and clarify some localities (summarized in Table 1 and Fig. 1). We provide additional images of the holotype, as well as another individual and the habitat used by this species in the Laguna de los Médanos (Fig. 2).

We correct the first record in the technical report by Christie (1984, p. 16): "Laguna de los Juncos" should correspond to Laguna de los Médanos, based on an analysis of Topographic Sheet N° 4172-30 "Las Bayas" (edited after 1986) by the collector RDS; this was corrected in the MVZ catalog in November 2019. The locality "Provincial Road N° 318 […]" in Christie (1984, p. 16; #4 in Table 1) no longer exists on new maps, but in old editions of Automóvil Club Argentino maps, the Provincial Road N° 80 was mentioned as Provincial Road N° 318; and thus here we use the name "RP N° 80". We provide further previously unpublished information about this location (also annotated as 8.6 km N, 1.3 km E Cerro David) from three field visits (Table 1). On February 25, 2008, in addition to the specimens reported in Table 1, about a dozen specimens of recently metamorphosed frogs were found under rocks near a pool.

On February 10, 2011, a visit to Las Bayas Creek, a permanent lagoon, and several dry lagoons on a volcanic tableland located northeast of Las Bayas revealed only some *Pleurodema bufoninum* (Anura, Leptodactylidae). Other trips to the area failed to reveal *A. solitarius*: at Laguna de los Juncos (Fig. 1; March 2, 2016, completely dry; October 25, 2016, with water; December 12, 2016, dry) and to the permanent lagoon near Las Bayas (Fig. 1; December 12, 2016).

The Minimum Convex Polygon around type locality at Las Bayas (#1), Laguna de los Médanos (#2), Chenqueniyén Creek (#3) and intermittent stream on RP N° 80 (#4) has an area of 300 km^2. This measure is approximate because it does not consider discontinuities in the distribution range (Rapoport 1982, Burgman & Fox 2003, Joppa et al. 2016).

Microhabitats

During an April 1982 visit to Laguna de los Médanos by RDS and Miguel I. Christie, clusters of up to seven frogs were found under a single stone near the water's edge, under rocks on the slope of the sinkhole, and along the flatland adjacent to the lagoon. No frogs were found under mats of dried aquatic vegetation on the beach, and no larvae

or frogs were seen swimming in the shallow water. After a rainstorm, during a one-hour walk on the flats, three adult *Atelognathus* were found active in the open, including the MVZ: Herp: 274609 specimen. In November 1986, Laguna de los Médanos had less water than in 1982, and the water's edge was now further away from the rock wall bordering the lagoon (RDS, pers. data). Again no frogs or larvae were seen in the aquatic vegetation in the shallow water. Frogs were under rocks near the water's edge, with as many as 10 clustered together under the same rock. Many of these frogs had recently metamorphosed, as they still had remnants of their larval tails. No active frogs were found during the nearly three hours of walking across the (now) dry flatlands of the Escorial.

At the RP N° 80 locality, recently metamorphosed *P. bufoninum* and *A. solitarius* were found together in the rock rubble near the creek pools in February 2008 (#4, Table 1).

Post-metamorphic growth and sexual maturity

We provide the first information about the length and weight for this species. The measured individuals from the Laguna de los Médanos (April 1982, austral autumn; N = 34) had an average SVL of 32.5 mm (range 28–38) and weight of 2.8 g (range 1.9–4.0). Apparently, the smaller animals of this sample had metamorphosed some time earlier, as there are no notes about axillary scars or resorbed tails. The measured individuals from Laguna de los Médanos (November 1986, austral late spring; N = 15) contained the largest animals, with an average length of 36.4 mm (29–41) and weight of 3.6 g (1.9–5.2). Some smaller specimens (up to 37 mm SVL) still had tail buds. The sizes of the smallest animals in these two samples suggest that the size at metamorphosis is between 28 and 29 mm SVL.

The three largest wild-caught individuals (2 females, 1 male) were 41 mm SVL (Laguna de los Médanos, 1986), but individuals maintained in captivity post-metamorphosis for two to three years grew larger (43–45 mm SVL) than any of the wild-caught specimens. The size at metamorphosis (28 mm) was around 68% of the adult length (41 mm), indicating that much of the maximum size is achieved during the aquatic (larval) stage of the life cycle, and only about 30 percent in the terrestrial environment.

These records suggest that metamorphosis begins earlier in the austral spring, as some November 1986 animals still had tail buds. But four others in that collection had adult gonads, with pigmented ova or large (8 × 1 mm) testes within a black tunica. Most of this late spring collection contained recently metamorphosed animals along with a few individuals that had overwintered and were in their second growing season.

No animals have yet been captured during reproduction, so we do not yet know the size at breeding maturity in nature. However, we have limited information from the dissections of the 1982 and 1986 Laguna de los Médanos specimens. Three females (36, 37, and 38 mm SVL) from the 1982 (austral autumn) sample had pigmented ova and convoluted oviducts, perhaps indicating that they had bred during the previous summer or spring. Ten males from this samples ranged from 30–33 mm SVL, and their testes were from 2–4 mm in length. Their testes were unpigmented, in contrast from those described for the holotype (30.5 mm SVL, testes of 1–2 mm but mature and pigmented; Cei 1970). Three of four females from the 1986 (austral late spring) sample showed evidence of reproduction (pigmented ova and convoluted oviducts; 40, 41, and 41 mm SVL). The fourth female (35 mm SVL) had unpigmented ova and her oviducts were not convoluted. One male (41 mm SVL) had testes that were 8 mm in length within a black tunica. Based on the 34 individuals examined, where we found 6 females and 1 male with signs of reproductive maturity, reproductive maturity in females can happen at 36 mm SVL and in males at 41 mm, although further data are needed (Fig. 3).

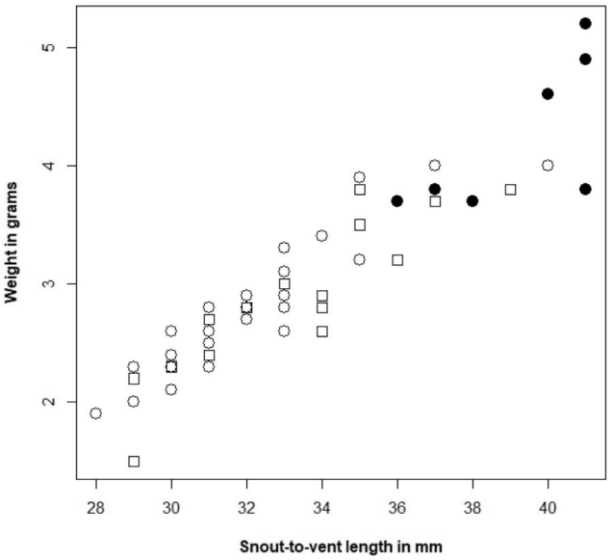

Figure 3. Relationship between the body length (SVL) and weight of 49 *Atelognathus solitarius* collected at the Laguna de los Médanos (1982 and 1986). □ – individuals whose gonads were not examined; ○ – individuals with immature gonads; ● – individuals whose gonads indicated reproductive maturity.

Morphological and coloration variations

Based on the seven adult individuals collected in 1998 we corroborated the color pattern in life described by Cei (1970), but we also observed variability among individuals. The dorsal pattern may have spots with a central wart that may be pigmented with a reddish color or have the same color as background (Fig. 2C). The ventral side can be whitish with tiny, almost invisible spots on the throat as in the holotype (Cei 1970), or may have patches of dark spots on each side of the gular region, also observed in preserved specimens (Fig. 2C). The gular region pattern can be seen on the underside of the thighs and on the ventrolateral areas of the body. The rhomboid pupil mentioned as a distinctive character (Cei 1970) may be difficult to differentiate between rhomboidal and circular in some individuals.

Vocalization

During the visit to Laguna de los Médanos in November 1986, two animals gave loud, high-pitched vocalizations upon capture. The calls lasted 3–5 seconds, and were reminiscent of the calls of the terrestrial morphotype of *A. patagonicus* from Laguna Blanca National Park in Neuquén (RDS, pers. obs.) or specimens of *A. reverberii* (Cei 1969).

Depredation

A Shrike-tyrant (*Agriornis montanus*, Family Tyrannidae) captured and swallowed an *A. solitarius* in a crevice in the basaltic cliff bordering the water at Laguna de Los Médanos, April 1982 (see more details in eBird list No. S56474734; https://ebird.org/checklist/S56474734).

Discussion

Although we compiled six locations of occurrence and contribute information on its biology, further studies on *A. solitarius* must be done.

For example, further searches should be made in the RN N° 80 stream system and along Arroyo Chenqueniyén to better understand the range of the species outside of the basaltic tableland with the endorheic lagoons. Likely the largest subpopulations occur around the lagoons on the Escorial Chenqueniyén. Although we have only searched for frogs in Laguna de los Médanos and Laguna de los Juncos, 15–20 additional potential breeding lagoons are identifiable from satellite images. When Laguna de los Médanos and Laguna de los Juncos have water, they are extremely rich in potential food (RDS, pers. obs.). The abundance of aquatic birds, including swans, ducks, and flamingos also indicates that these waters are very rich in algae, aquatic plants such as *Myriophyllum quitense*, and micro-invertebrates. There are no fish, and the only two frog species found around the lagoons are *A. solitarius* and *P. bufoninum*, so it seems reasonable that the larvae may development successfully throughout the lagoons.

Accumulated rainfall per year for Las Bayas shows alternation of dry and wet periods from 1987 to 2018 (Fig. 4). Interannual rainfall fluctuations due to multi-year cycles such as the El Niño Southern Oscillation Phenomenon determine the existence of years of total or partial drying-up of the lagoons, which can cause fluctuations in the abundance of larval populations and, consequently, affect the recruitment at the end of metamorphosis. This could explain the observed temporal differences in the abundance of individuals found. Unfortunately, there are no rainfall data for 1982 and 1986 when many specimens were collected, but we presume the high water levels then likely resulted from high annual precipitation.

Cei (1970) described the habitat of the species as rocky ravines of Las Bayas Creek (800–900 m a.s.l.), while he noted that other species, such as *A. reverberii* and *A. praebasalticus*, inhabit lagoons. The present data also support their occurrence near small streams in the open steppe habitat to the south and north of the Escorial. Additionally, our work shows that they live in endorheic lagoons on the basaltic Escorial Chenqueniyén tableland (high densities around Laguna de los Médanos). Lagoons are the optimal habitat for other species of the genus (Úbeda et al. 1999, Cuello et al. 2017). It is reasonable to assume that the endorheic lagoons on these basaltic tablelands would be the most suitable places for reproductive and larval development, because the areas of these lagoons are probably much larger than the pools in the small streams on the steppe and they are very rich in phytoplankton and microorganisms. All described *Atelognathus* larvae (Cei 1969, Lavilla 1988, Basso & Úbeda 1997, Úbeda & Basso 2003, Meriggio et al. 2004) correspond to the benthic ecomorphological guild within exotrophic larvae of lentic systems according to the classification of Altig & Johnston (1989), and most species inhabit vegetated lagoons in the semi-desert environments of Patagonia. These microhabitats provide food and refuge against predators (aquatic birds) for the tadpoles as well as for the final stages of metamorphosis and metamorphs, similar to what was found for *A. patagonicus* (Cuello et al. 2006a, 2008, 2009, 2017). Because larvae of *A. solitarius* have not been found, larval morphology and other aspects of the aquatic part of the life cycle remain unknown.

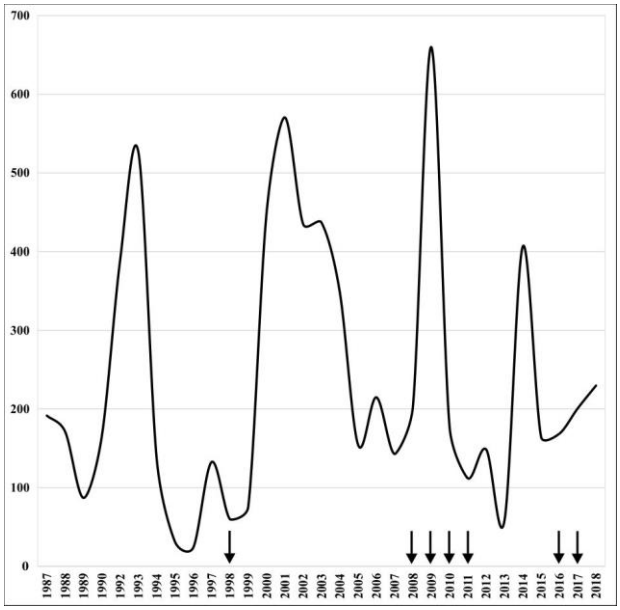

Figure 4. Accumulated precipitation per year from the Las Bayas weather station, 1987–2018 (obtained from the Hydrological Database of the Argentine Republic http://bdhi.hidricosargentina.gob.ar/, May 2019). Arrows indicate the years in which we conducted field searches for *Atelognathus solitarius*.

The analysis of the size and reproductive conditions of the samples of frogs from Laguna de los Médanos lead us to suggest that this is a species that achieves around 78% of its reproductive length while still living as tadpoles in the water. The animals metamorphosed at about 28 mm SVL, thus only 8 mm of growth length is needed to reach reproductive maturity. For *A. reverberii*, tadpoles in captivity may take a little more than a year to metamorphose, with froglets being smaller (14 mm, Cei 1969) than the wild *A. solitarius* metamorphs (28–29 mm) found in this study.

For two other cogeneric Patagonian species, *A. nitoi* (occurring in forest lagoons) and *A. patagonicus* (lagoons on arid basaltic tablelands), phenotypic plasticity in the duration of larval development has been described, adjusting to the different hydroperiods of the lagoons (Úbeda et al. 1999, Cuello et al. 2014), with two larval developmental strategies: seasonal tadpoles that metamorphose during the same season, and overwintering tadpoles that undergo metamorphosis in the following spring. The metamorphs of *A. nitoi* range between 17 and 23 mm (Úbeda et al. 1999), while mean sizes of metamorphs of *A. patagonicus* of seasonal versus overwintering tadpoles in a permanent pond were 22.26 and 23.06 mm, respectively,

without significant statistical differences (Cuello et al. 2014). New studies are necessary to resolve if the sizes of the metamorphs found in *A. solitarius* (28–29 mm) are related to a larval development strategy or are a characteristic of the species. We do not yet know anything about the length of the larval part of the life history of *A. solitarius*. If the animals metamorphose in the spring with about 78% of the reproductive length, then it is possible that they can grow to maturity within that same summer–autumn, and be ready to reproduce at the next reproductive season. How long they can live as adults is unknown, but in captivity one animal survived for nearly three years after capture as a newly metamorphosed froglet.

Future studies on biological and ecological aspects of *A. solitarius* are essential to establish a conservation category for the species (see Giraudo et al. 2012). The known distribution range is not included in any protected area and is subject to extensive sheep farming, the same threats previously detected by Basso et al. (2012); no conservation actions are in progress. With this contribution, we hope to provide a starting point for future studies that provide new information for this poorly known species.

Note. While our article was in press has been published Rebuilding the cytogenetics of Atelognathus (Anura: Batrachylidae): half a century of confusion (Baldo et al. 2020).

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