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Información sobre la distribución geográfica de la lagartija de arena *Liolaemus cuyumhue*

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A new species of *Liolaemus* from Añelo sand dunes, northern Patagonia, Neuquén, Argentina, and molecular phylogenetic relationships of the *Liolaemus wiegmannii* species group (Squamata, Iguania, Liolaemini)

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Abstract

The *wiegmannii* group of *Liolaemus* includes *L. arambarensis*, *L. azarai*, *L. lutzae*, *L. occipitalis*, *L. multimaculatus*, *L. rabinoi*, *L. riojanus*, *L. salinicola*, *L. scapularis*, *L. wiegmannii*, and the species described here. We used sequences of the mitochondrial cyt–b, 12S, and ND4, and the nuclear C–mos gene regions to infer the phylogeny of the majority of the species of the *wiegmannii* group. We describe a new species that is closely related to *L. multimaculatus* and *L. riojanus*, but can be distinguished by a different dorsal coloration, absence of suprascapular spots, and smaller size. *Liolaemus cuyumhue* **sp. nov.** lives in marked geographic isolation with respect to other closely-related species of the *wiegmannii* group.

Key words: Argentina; Iguania; Liolaemini; *Liolaemus cuyumhue* **sp. nov.**; Neuquén province, Phylogeny, *wiegmannii* group; Northern Patagonia

Resumen

El grupo *wiegmannii* de *Liolaemus* incluye *L. arambarensis*, *L. azarai*, *L. lutzae*, *L. occipitalis*, *L. multimaculatus*, *L. rabinoi*, *L. riojanus*, *L. salinicola*, *L. scapularis*, *L. wiegmannii*, y la especie descripta aquí. Utilizamos secuencias de los genes mitocondriales cit–b, 12S, y ND4, y del gen nuclear C–mos para inferir la filogenia de la mayoría de las especies del grupo *wiegmannii* con la excepción de *L. arambarensis* y *L. rabinoi*. Describimos una nueva especie que está estrechamente relacionada a *L. multimaculatus* y *L. riojanus*, pero puede ser distinguida por una coloración dorsal diferente, la ausencia de manchas supraescapulares y su pequeño tamaño. *Liolaemus cuyumhue* **sp. nov.** vive en marcado aislamiento geográfico con respecto a otras especies cercanamente relacionadas del grupo *wiegmannii*.

Palabras clave: Argentina; Iguania; Liolaemini; *Liolaemus cuyumhue* **sp. nov.**; Provincia de Neuquén, Filogenia, grupo *wiegmannii*; Patagonia norte

Introduction

Liolaemus is the largest lizard genus of southern South America with more than 220 species described. Several species groups have been recently described based on molecular or morphological characters (e.g. Schulte *et al*., 2000; Morando 2004; Lobo 2001, 2005; Avila *et al*. 2006; Abdala 2007), and among these the *wiegmannii* group has been recognized as monophyletic based on morphological, behavioral, and molecular studies (Etheridge 1995, 2000; Halloy *et al*. 1998; Schulte *et al*. 2000, Avila *et al*. 2006). Etheridge (1995,

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2000) morphologically characterized the group by the presence of two or more rows of lorilabial scales rather than one, which are smaller than the supralabial scales; flat or concave rather than convex infralabials; mental scale narrower anteriorly than posteriorly; and six scales in contact with mental. This group includes 10 species, *Liolaemus arambarensis* Verrastro *et al*., *L. azarai* Avila, *L. lutzae* Mertens, *L. multimaculatus* Duméril and Bibrón, *L. occipitalis* Boulenger, *L. rabinoi* Cei, *L. riojanus* Cei, *L. salinicola* Laurent, *L. scapularis* Laurent, and *L. wiegmannii* Duméril and Bibrón (Etheridge 1995, 2000; Verrastro *et al*. 2003; Avila 2003). The first four species are restricted to coastal sand dune environments, such as the beaches and coastal dunes along the Atlantic shores of Brazil, Uruguay, and Argentina; while the latter species (except *L. wiegmannii*) live inland, on isolated sand flats and dune systems of western Argentina (Etheridge 2000). All species are strictly arenicolous with the exception of *L. wiegmannii*, which is considered to be the least specialized species and not a sand obligate (Etheridge 2000; Halloy *et al*. 1998; Laurent 1983, 1984). However, the large geographic distribution and preliminary molecular studies suggest that *L. wiegmannii* might be a complex of several species (Avila 2003, Morando 2004, Avila *et al*. 2006). Recent exploration of a poorly known sand dune system in eastern Neuquén province allowed us to collect a small sample of a new member of this group that seems to be morphologically closely related to *Liolaemus multimaculatus* and *L. riojanus*. Here we describe this lizard as a new species of the *Liolaemus wiegmannii* group, and we present a molecular phylogeny of this group.

Materials and methods

Sixteen specimens of the new species were examined, and we also examined sample series of other species of the *wiegmannii* group (Appendix I) from the herpetological collections of Fundación Miguel Lillo (FML), Argentina; Instituto y Museo de Ciencias Naturales, Universidad Nacional de San Juan (IMCN-UNSJ), Argentina; Bean Life Science Museum, Brigham Young University (BYU), USA; Museo de La Plata, Universidad Nacional de La Plata (MLP.S), Argentina; Museo Argentino de Ciencias Naturales Bernardino Rivadavia (MACN), Argentina; and the collection CENPAT–CONICET, Centro Nacional Patagónico, Puerto Madryn (LJAMM), Argentina. Specimens under the acronym CENAI (Centro Nacional de Investigaciones Iológicas), are now housed in MACN. Specimens were collected by hand, sacrificed by a pericardial injection of sodium pentothal Abbot®, fixed in 10–20% formalin and later transferred to 70% ethanol. Measurements were taken with a dial caliper to the nearest 0.1 mm, and scale counts were made with the aid of a stereoscopic microscope from specimens fixed as described above. Scale terminology follows Smith (1946), and recent treatments of related species by Etheridge (2000) and Etheridge and Christie (2003). Nomenclature for neck folds follows Frost (1992). Coloration in life was observed from the holotype and paratypes at the time of capture. Sex was determined by dissection or by the thickness of the base of the tail and presence and number of precloacal pores. Where numbers of paired scales are provided they are given as Left-Right. Molecular procedures: Protocols for DNA extraction, mtDNA primer descriptions, PCR, and sequencing procedures follow Morando *et al*. (2003, 2004) for the cytochrome–b (cyt-b, 810 bp), ND4 (708 bp), and 12S (821 bp) regions. For the nuclear gene C–mos, procedures follow Avila *et al.* (2004**,** 2006). This 484 bp PCR product was sequenced in the same way as the mtDNA genes. See Appendix II for specimens used for molecular analyses. Alignment: Sequences were edited and aligned using the program Sequencher 3.1.1 (™Gene Codes Corporation Inc. 1995), and the protein coding regions cyt–b and ND4 were translated into amino acids for confirmation of alignment. Missing data were present in a few sequences, and these were coded as “?”. Phylogenetic Analyses: Separate Bayesian analyses (based on GTR + I + Γ model of evolution) (Gu *et al*. 1995; Yang 1994), determined using ModelTest v3.7 (Posada and Crandall 1998), were performed for each gene partition using MrBayes 3.1.2 (Huelsenbeck and Ronquist 2001) to detect potential areas of incongruence (Wiens 1998). *A priori* the specific parameter values were uniform and were estimated as part of the analysis. From a random starting tree, we performed two independent runs (between 3.0 x 10^6 and 5.0 x

10^6 generations) and sampled the Markov chains at intervals of 1,000 generations. We determined when stationarity was reached (in order to discard the "burn-in" samples) by plotting the log-likelihood scores of sample points against generation time; when the values reached a stable equilibrium, stationarity was assumed. The equilibrium samples (the trees retained after burn-in of 10,000 generations) were used to generate a 50% majority rule consensus tree. The percentage of samples that recover any particular clade on this tree represents that clade's posterior probability (PP); these are the *P*-values, and we consider $P \geq 0.95$ as evidence of significant support for a clade (Huelsenbeck and Ronquist 2001). The combined data set of 2,823 bp was used for phylogenetic analyses using MrBayes 3.1.2 (Huelsenbeck and Ronquist 2001), with parameters estimated independently for each partition. We ran the combined matrix for 5×10^6 generations and sampled every 1,000 generations. We used PAUP* (version 4.0b4b; Swofford 2001) to run 10,000 pseudoreplicates for maximum parsimony (MP) bootstrap (Felsenstein 1985), with strong support being inferred if $BS \geq 70$ (Hillis and Bull, 1993; with caveats).Voucher specimens of the new species are deposited in the herpetological collection of the Fundación Miguel Lillo, Tucumán (FML), Museo de La Plata (MLP.S) and Museo Argentino de Ciencias Naturales (MACN). Lizards tissues marked as MTR, LG and MZUSP are deposited in Museum of Zoology at the University of São Paulo. As *L. rabinoi* is presumably extinct and we were unable to analyze the type series, data were obtained from Cei (1974, 1986), Cei *et al*. (1975) and Etheridge (2000); data for *L. arambarensis* were obtained from Verrastro *et al*. (2003); data for *L. riojanus* were taken from Cei (1979), Etheridge (2000), and Laspiur *et al*. (2006)

Results

Liolaemus cuyumhue sp. nov.

Figure 1.

Type material. *Holotype*: MACN 38981 (Fig. 1), an adult male from sand dunes near Ruta Provincial 7, 28.7 km NW Añelo, Añelo Basin, Añelo Department, Neuquén Province, Argentina (38° 11' S, 69° 01' W, 259 m), collected 2 February 2003 by L. J. Avila, M. Morando, C. H. F. Perez, and K. Dittmar.

Paratypes (Fig. 2): FML 17592, LJAMM 4520–1 (males), from sand dunes, southern edge of Ruta Provincial 7, (38° 13' S, 68° 57' W, 260 m), Añelo Department, Neuquén Province; 15 November 2003; collected by D. R. Perez, J. Perez, M. Perez, and M. Perez Carrió; FML 17594, MACN 38982–3, MLP.S 2587, 2591 (males), FML 17593, LJAMM 3692, MACN 38984, MLP.S 2586, 2588/9–90 (females) from sand dunes near Ruta Provincial 7, (38° 13' S, 68° 57' W, 258 m), Añelo Department, Neuquén Province; 10 February 2006; collected by D. R. Perez, C. de la Vega and D. Zuñiga.

Diagnosis. *Liolaemus cuyumhue* is a member of the *wiegmannii* group of *Liolaemus* lizards, characterized by the presence of two or more rows of lorilabials scales rather than one between subocular and supralabilals, smaller in size than in other *Liolaemus*; flat or concave rather than convex infralabials, mental scale narrower anteriorly than posteriorly; and with the exception of *L. cuyanus* and *L. mapuche*, six scales in contact with the mental (Etheridge, 1995, 2000; Abdala, 2002). *Liolaemus cuyumhue* is distinguished from *L. riojanus* because its background coloration is yellow-cream to a light red-brick tonality rather than orange-brick or light ochre; dorsal spots are larger than in *L. riojanus*, and usually have few blue iridescent scales distributed on the dorsolateral areas of the body, rather than mostly grouped into small clumps of 2–4 scales on the sides of the body. *L. cuyumhue* never have suprascapular spots and series of dorsolateral yellow spots as is observed in some populations of *L. riojanus*. Another difference from *L. riojanus*, females of *L. cuyumhue* always lack precloacal pores. *L. cuyumhue* males are smaller than *L. multimaculatus* males (61.7 mm vs 72 mm SVL), with smaller dorsal scales, and fewer scales around midbody (62–71 vs 68–92). *L. cuyumhue* lack the dark brown/black scapular spots always present in *L. multimaculatus*. *L. cuyumhue* have smaller circular brown spots, speckles of smaller white dots, and a low density of blue iridescent scales distributed on the dorsolateral areas of the body instead of rhomboidal to circular gray, tan, or brown spots, speckles of white scales, and blue iridescent scales scattered irregularly on a gray or brown background, observed in *L. multimaculatus*. *L. cuyumhue* never have the general coloration of grey and blue scales observed in *L. rabinoi*, and never have iridescent blue scales clumped into small patches of 3–11 scales each on the sides of the body. *Liolaemus cuyumhue* lack the sexual dichromatism observed in *L. wiegmannii*, have smooth or slightly keeled dorsal head scales instead of rugose and protruded, dorsal narines instead of lateral, more supralabial (8–11 vs 4–6) and infralabial scales (7–10 vs 5–7), and smaller body scales (midbody scale counts 64–71 vs 38–60, dorsal body scale counts 78–90 vs 42–62). *L. wiegmannii* females sometimes have precloacal pores (0–6) but these are completely absent in *L. cuyumhue* females. Dorsal scales in *L. cuyumhue* are smooth to slightly keeled and juxtaposed to slightly imbricated instead of strongly keeled and imbricated as in *L. wiegmannii*. *L. cuyumhue* males lack dorsolateral and lateral dark spots, paravertebral lines, numerous and larger blue scales in lateral areas, and bright yellow or orange scales, all characteristics of *L. wiegmannii*. *L. cuyumhue* always lack pre and postscapular spots or paravertebral lines observed in *L. azarai*, body size is larger (maximum SVL in males 61.7 vs 54.3 mm; in females 59.9 vs 48.7 mm), and have smaller body scales (midbody scale counts 64–71 vs 32–42, dorsal body scales 78–90 vs 42–60). *L. cuyumhue* males have higher number of precloacal pores (7–9 vs 5–6) but in females these always are absent (2–3 in *L. azarai* females). *L. cuyumhue* is slightly larger than *L. arambarensis* (maximum SVL 60 vs 56 mm in males, 54.3 vs 48.7 mm in females), have smaller dorsal scales, with more scales around midbody (64–71 vs 60–66), and along the trunk (78–90 vs 57–64). *L. cuyumhue* lack a mid-dorsal white line and two dorsolateral stripes, with two series of paravertebral brown marks resembling triangles bordered by a white bar, as observed in *L. arambarensis*. *L. cuyumhue* is considerably smaller than *L. lutzae* (males 61.7 mm vs 84.0 mm, females 59.9 mm vs 69.0 mm), dorsal coloration lacks the conspicuous wide vertebral band bordered with dark paravertebral spots, and wide gray dorsolateral stripes observed in *L. lutzae*. *L. cuyumhue* is smaller (males 61.7 mm vs 70.0 mm, females 59.9 mm vs 60.0 mm), lacks strongly keeled and imbricate dorsal scales, lacks a dark longitudinal bar above the forelimb insertion, and lacks the ventral sexual dimorphism observed in *L. occipitalis*. *L. cuyumhue* is smaller than *L. salinicola* and *L. scapularis* (61.7 vs 76 vs 77 mm in males, 59.9 vs 68 vs 65 mm in females) and lacks stripes and gray throat observed in *L. salinicola* and the scapular mark characteristic of *L. scapularis*.

Description of the holotype. Adult male. SVL 51.2 mm, total length 111.2 mm. Axilla groin distance 23.4 mm. Head width 10.8 mm, head length 12.9 mm, head height 6.6 mm, snout length 4.8 mm, horizontal diameter of orbit 2.5 mm, internarinal distance 3.3 mm; eye-nostril distance 1.9. Arm length 15.1 mm, tibial length 11.5 mm, foot length 15 mm (all from the right side). Dorsal head scales smooth, flat to slightly concave, a few pitted with scale organs. Eighteen dorsal head scales (from a line drawn horizontally between anterior margin of external auditory meatus to anterior margin of rostral). Rostral pentagonal, wider that high (1.9 x 0.8 mm). Two postrostrals, wider than high; together with anterior lorilabials separate nasal scales from rostral. Nasal scales longer than wide (1.4 x 0.9 mm), dorsolateral in position. Nostril almost rounded in shape, occupying slightly less than half of nasal scale. Nasal scales in contact with nine scales (left) and eight scales (right). Internasal scales in two rows; two anterior, small, and pentagonal preinternasals; three posterior post-internasals, longer than wide, medial slightly larger than laterals. Two small postnasals behind each nasal. Ten frontonasals, irregular in shape, in two irregular rows. Nine prefrontals in two rows, five scales in front, four scales in back. Two scales conspicuously larger in each row, lateral in position in the first row, medial in the second row. Three frontal scales, median longer than wide, almost equal in size to prefrontals. Nine frontoparietals, irregular. Interparietal with a conspicuous parietal eye, oblong, surrounded by eight smaller irregular scales. Parietals smooth and irregular, variable in size. Eighteen circumorbitals on left side, twenty two on right side. Supraoculars small, irregular, numerous, 59 left, 46 right, five conspicuously larger, wider than high on each side. First canthal higher than wide, posterior canthal longer than wide, non overlapping first superciliary. A well marked but blunt canthal ridge. Six superciliaries on each side, overlapped. Loreals 9–8; flat to slightly convex. Loreals, preocular, and lorilabials forming a conspicuous concavity. Lorilabials in two-three rows, slightly bulged, becoming smaller below subocular, none wider than supralabials. Upper ciliary scales in two rows, those of inner row flat and quadrangular; those of outer row rectangular and conspicuously projecting. Lower ciliaries more similar in size and shape than upper ciliaries, some conspicuously projecting. Palpebral scale small, irregular, flat. Preocular small, quadrangular, with a keel. Subocular elongated (4.4 x 0.4 mm), with a distinct and sharp keel. Supralabials 8-8, last three on right side, distinct, two times longer than high. Temporal scales roughly quadrangular, higher than large. Supratemporals smaller than temporals, roughly rounded, a few almost granular. Nuchals slightly keeled, juxtaposed, rounded. Lateral nuchals small, almost granular, non-imbricated. Occipital scales small, irregular, flat, becoming granular distally. Auditory meatus oval, higher than wide (1.9 x 1.1 mm), surrounded above, behind, and below by granular scales. Pretympanic scales, rounded to obovate, non-projecting. Mental heptagonal (1.6 x 1.2 mm), wider than high, in contact with six scales: infralabials, postmentals, and sublabials. Infralabials flat 7–8, meeting sublabials at an acute angle. Chinshields slightly evident, two postmentals evident but following scales becaming similar to sublabials and gulars in the third row. First sublabials and sublabials in contact with infralabials, smaller than surrounding scales. Gulars imbricate, smooth, becoming rounded and notched distally. Longitudinal oblique and antegular folds distinct, gular and antehumeral well marked. Dorsal body scales obovate, subimbricated, with a blunt keel. Dorsal limb scales 2–3 times larger than dorsal body scales, rhomboidal to obovate, imbricate, and bluntly keeled. Suprabrachials nearly two times larger than suprantebrachials, with a more regular rhomboidal shape and keel. Supra-antebrachials becoming obovate near the insertion, a few with a small spine. Supracarpals and supradigitals smooth. Infrabrachials small, almost granular. Infraantebrachials 2–4 times larger than infrabrachials, non-granular. Infrabrachials oval to rounded, Juxtaposed near the infrabrachials, becoming progressively imbricated and obovate, some with a blunt keel, near the hand. Infracarpals blunt to well marked keel, imbricate, none tridentate. Subdigital lamellae of manus with three keels, numbering I:9, II:13, III:20; IV:20; V:12. Claws long and slender, slightly curved. Supracarpals smooth or with a blunt keel, supradigitals smooth. Infrafemorals and infratibials smooth, imbricated. Infratarsal keeled, strongly imbricated, none tridentate. Infradigitals unidentate, numbering: I:10; II:14, II:18, IV:24, V:14. Long and slender claws, slightly curved. Ventral scales lanceolate to rhomboidal, smooth, imbricated. Some scales with an apical notch. Ventral scales slightly larger than dorsal scales. Scales in the flanks between dorsal and ventral distinctly smaller. Scales in front, above and behind limb articulations small, granular to flat. Caudals imbricate, with a blunt but conspicuous keel, same size to the dorsal and ventrals, becoming smaller to the tip of the tail. Ventral caudals with a blunt keel. Scales of the cloacal apron slightly smaller that the ventral scales. Seven insconspicuous precloacal pores.

Coloration. Dorsal pattern on head, trunk, tail and limbs with brown rounded spots (4 to 9 scales in size) and speckles of cream, gray, tan, and reddish-brown on reddish background. Between 9 to 10 irregular transversal series of 5 to 7 spots between occiput and rump. Background coloration varies according to ambient light between a yellow-cream (full sun) to a red-brick tonality (in shade). Reddish-brown spots larger than other colored spots, sometimes white bordered anteriorly, posteriorly or both. Some larger creamy spots on dorsolateral areas of trunk. Head with brown spots smaller than in other areas of body; tail brown spots faintly larger than in limbs, head and trunk. Some clear lines faintly indicated on ciliar, supraocular, and longitudinal neck folds. Lateral areas of the body with larger brown spots on white background. Ventral areas immaculate cream-colored except in throat and lateral areas of chest and belly marked with brightly light brown to reddish-brown spots irregularly distributed. Some small, scattered blue iridescent scales are distributed on the dorsolateral areas of the body. In preservative same general coloration but faded, bright ventral spots become light gray, blue iridescent scales disappear.

Variation. Morphometric and scale variation is presented in Table 1 and 2 (with all other diagnostic features mentioned above), and dorsal and ventral color variation is depicted in Figure 2. As in other members of the *wiegmannii* group (except *L. wiegmannii*), intrapopulation variation in morphology is not conspicuous. Postfemoral patch not present in females and variable in size in males, between 18–25 scales. Dorsal background color usually similar to holotype, recently captured adult males have a brighter coloration. Variation most frequently seen is in the distribution and size of dorsal and ventral spots.

FIGURE 1. *Liolaemus cuyumhue* in life, lateral and ventral view of holotype (MACN 38981), adult male 51.2 mm in SVL.

TABLE 1. Variation in squamation and morphometric characteristics of paratypes of *Liolaemus cuyumhue*. Measurements are in mm, numbers for each variable indicate mean ± standard deviation, with range in parentheses. Precloacal pores, infra and supralabials scales are shown as ranges. .

Variable	Males (n = 9)	Females (n = 7)
SVL	52.8 ± 6.4(42.7–61.7)	55.3 ± 3.3(50.82–59.9)
Head length	12.5 ± 1.3(10.8–15.0)	12.6 ± 0.5(12.1–13.3)
Head width	10.8 ± 0.9(9.4–12.4)	10.7 ± 0.53(10.0–11.6)
Arm length	15.9 ± 1.8(13.4–17.9)	16.4 ± 0.44(15.5–16.9)
Tibial length	11.1 ± 1.10(9.3–12.3)	10.9 ± 0.48(10.0–11.5)
Foot length	19.1 ± 1.3(18.0–22.0)	16.0 ± 0.63(15.0–16.8)
Axilla-groin distance	21.6 ± 3.2(16.3–27.2)	24.7 ± 2.3(21.5–27.9)
Midbody scales	67.2 ± 2.4(64–71)	67.1 ± 1.0(66–69)
Dorsal scales	84.7 ± 3.7(78–90)	83.8 ± 2.4(82–88)
Ventral scales	78.5 ± 4.5(74–89)	81.4 ± 3.4(77–87)
Pre-cloacal pores	7–9	0
Infradigital lamellae (3rd to hand)	18.4 ± 0.7 (17–19)	17.6 ± 0.8 (17–19)
Infradigital lamellae (4th to foot)	23.2 ± 1.5 (22–26)	22.7 ± 1.1(21–24)
Supralabial scales	8–10	9–11
Infralabial scales	7–10	8–10

TABLE 2. Comparison of characters between the species of the *L. wiegmannii* clade. SAM = scales around midbody, DS = dorsal scales, PP = precloacal pores.

	Maximum SVL		SAM	DS	PP		Scapular marks	Dorsal sexual dichromatism	Iridescent blue scales	Source
	F	M			F	M				
L. arambarensis	56	60	60–66	57–64	3–4	4–7	no	evident	yes?	Verrastro *et al*. 2003
L. azarai	48.7	48.3	32–42	35–37	0–3	5–6	yes	evident	yes	Avila 2003, this study
L. cuyumhue	59.9	61.7	64–71	78–90	0	7–9	no	absent	yes	This study
L. lutzae	69	84	56–74	54–75	0	6	no	absent	no	Etheridge, 2000
L. multimaculatus	64	72	68–92	79–118	0	5–11	yes	absent	yes	Etheridge, 2000
L. occipitalis	60	70	67–79	75–86	0	7–10	no	absent	no	Verrastro *et al*. 2003
L. rabinoi	68	61	73–81	92–105	0	5–9	yes	absent	yes	Cei, 1974; Etheridge, 2000
L. riojanus	57	63	61–79	72–93	0–6	6–11	yes	absent	yes	Etheridge, 2000; Laspiur *et al*. 2006
L. salinicola	68	76	58–77	69–97	0	6–10	yes	absent	yes	Etheridge, 2000
L. scapularis	65	77	49–68	58–78	0–6	5–10	yes	absent	yes	Etheridge, 2000
L. wiegmannii	60	59.1	38–58	43–67	0–6	4–8	yes	strong	yes	This study

FIGURE 2. Dorsal and ventral color variation in the type series of *Liolaemus cuyumhue* (museum numbers are in diagnosis).

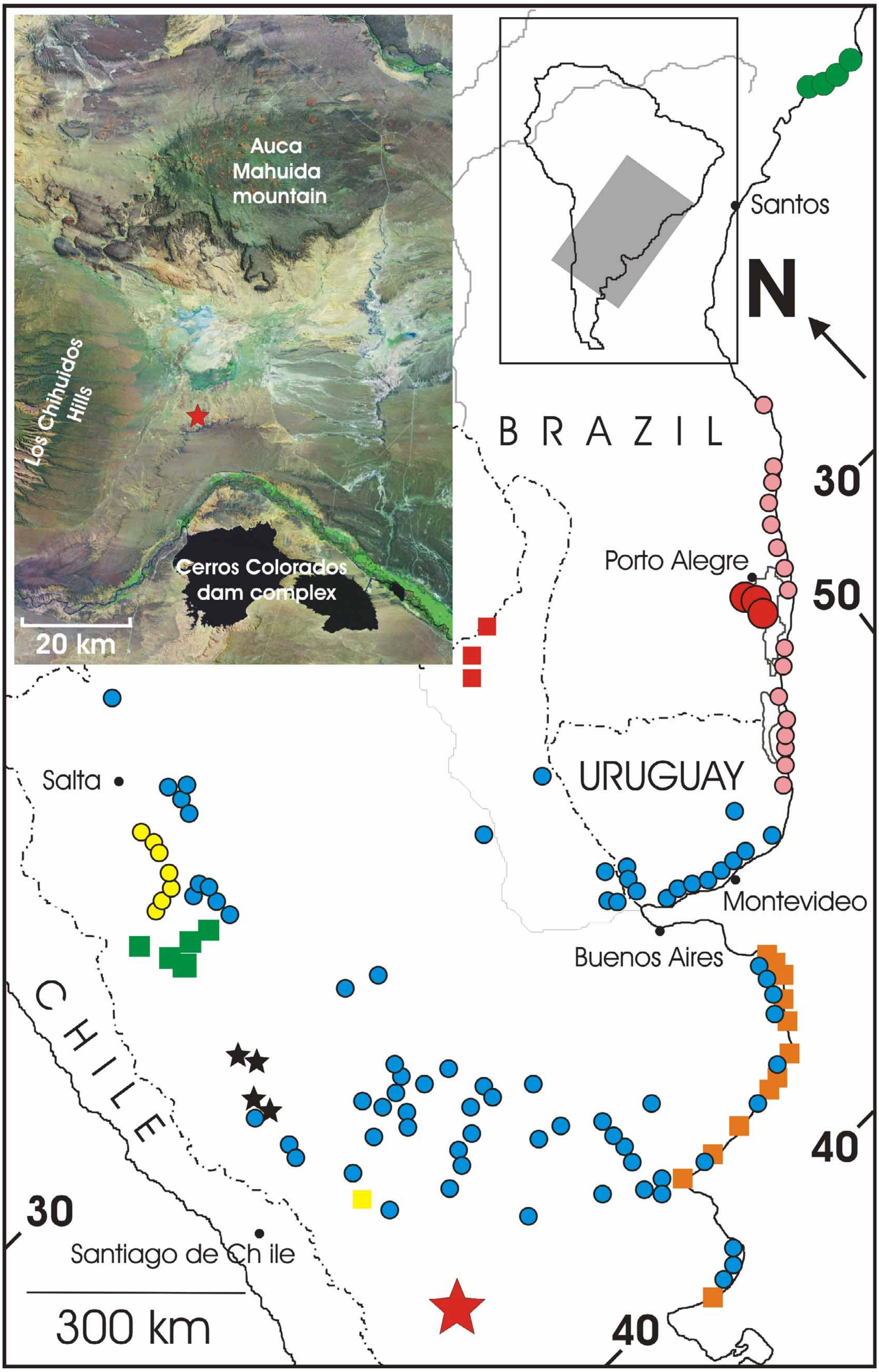

FIGURE 3. Known distribution of *wiegmannii* species group. Large red star: type locality of *Liolaemus cuyumhue*. Red squares, *L. azarai*; orange squares: *L. multimaculatus*; green squares: *L. salinicola*; green circles: *L. lutzae*; yellow circles: *L.scapularis*; red circles: *L. arambarensis*; pink circles: *L. occipitalis*; blue circles: *L.wiegmannii*; black stars: *L. riojanus*; yellow square: *L. rabinoi*. Inset: satellite image of the Añelo basin, a red star mark the type locality.

FIGURE 4. General view of the type locality of *Liolaemus cuyumhue*.

Sexual dimorphism. Females lack of the colored ventral spots characteristic of the males and the iridescent blue scales. The base of tail of males is expanded laterally, and cloacal opening is not rounded as is seen in females. Female lacks of the larger and obvious precloacal pores.

Etymology. Named in reference to the characteristics of the substrate of the type locality; cuyumhue is a Mapuche word meaning sandy place.

Geographic distribution. *Liolaemus cuyumhue* is known only from the type locality were the holotype and paratypes were collected, in the Añelo basin close to the Provincial Road 7, in Neuquén Province (Figs. 3, 4). Sand dune formations with suitable habitats for *L. cuyumhue* are restricted to the southern edges of the Añelo basin, but additional field work is necessary to explore other apparently suitable habitats north of this area. *Liolaemus cuyumhue* lives in marked isolation from other members of the *L. wiegmannii* group, the closest locality for *L. multimaculatus* is ~ 580 km SE (Vega and Bellagamba 1994); *L. wiegmannii* is found more than 300 km NE (Tiranti and Avila 1997), *L. rabinoi* was described for sandy areas around the Nihuil Dam in Mendoza province, more than 400 km N (Cei 1974, Etheridge 2000), and *L. riojanus* inhabit in dunes at least 700 km N (Cei 1979, Etheridge 2000). Field surveys carried out from 2000 to 2008 in dunes systems around the Añelo basin revealed other *Liolaemus* species different from any related to the *wiegmanni* group.

Natural history. *Liolaemus cuyumhue* is known from an isolated sand dune system in the region known as Bajo de Añelo, in eastern Neuquén. This is a depression between the Auca Mahuida Plateau and the Colorado and Neuquén rivers, with its lowest point reaching 223 m. The geological origin of the Añelo depression is attributed to karst activity, but sand dunes are probably remnants of old sea shore dunes (Uliana and Dellape 1981). The dunes are sparsely covered by clumps of *Sporobolus rigens*, *Neosparton darwinii*, *Larrea divaricata*, *Prosopis flexuosa* var *depressa*, and *Atriplex zampa*. *Liolaemus cuyumhue* is syntopic with other species of *Liolaemus*, including *L. grosseorum*, *L. mapuche*, *L. gracilis*, and in surrounding outcrops *L. austromendocinus*; other lizard species such as *Homonota fasciata*, *H. darwinii*, *Cnemidophorus longicaudus*, *Leiosaurus belli*, and *Pristidactylus* cf *fasciatus* are also found in sympatry. The holotype was collected at mid afternoon on a cloudy day and was the only specimen of this species observe that day, while individuals of other species were normally active. Paratypes were collected late in the afternoon after the substrate temperature was cooler. We did not observed bimodal activity but probably this type of activity is common in summer on very hot days. *L. cuyumhue* is insectivorous and presumably oviparous, as are other members of the *wiegmannii* group.

Individuals of *L. cuyumhue* were observed only on bare or sparsely vegetated dunes with extensive areas of open sand. They appear not to extend out into the more vegetated sandy flats or rocky areas that usually border the dunes. Field observations of *L. cuyumhue* were made in February and November 2003, February 2006, and January 2007. When first observed, most individuals were close to clumps of vegetation with a few observed basking on open areas between the clumps. Lizard observation was very difficult because their coloration usually matches soil color, and usually we detected them only when they were running from our approach. Their first escape behavior was to flee into the clumps and remain motionless on the surface. If pursuit continued, they would move to another location and again remain immobile on the surface. Only if pursued multiple times would lizards bury into the sand. We did not ever observe such a burial, but we presume that this behavior is likely very similar to the description made for *L. multimaculatus* (a closely related species) by Halloy *et al.* (1998). They usually "disappear" in a clump of vegetation with no evidence of a burrow entrance.

Liolaemus cuyumhue lives in a region were the oil and gas companies conduct some of the more intensive operations in Argentina; new rigs, tracks and roads are opened regularly; frequently modifying some areas with suitable habitats for *L. cuyumhue* that apparently do not cover large areas in the Bajo de Añelo. How the oil activity will affect this species must await further study. The entire *wiegmannii* group is threatened by human activities, urban and tourist development are rapidly fragmenting coastal sand dunes in Buenos Aires province, the habitat of *L. multimaculatus* (Vega *et al.* 2000); tourist activities also destroy the habitat of *L. lutzae* (Rocha and Bergallo 1992) and *L. occipitalis* (Di Bernardo *et al.* 2000); industrial agriculture (vineyards, olive groves), road construction and deforestation have destroyed extensive areas of habitat for *L.*

salinicola and *L. scapularis* (Avila, unpublished data); a large dam on the Rio Paraná probably destroyed large areas inhabited by *L. azarai* (Avila 2003); and *L. rabinoi* is considered by some authors as extinct, probably by habitat degradation as a result of human alteration after construction of El Nihuil Dam (Cei 1986, Etheridge 2000). We hope that this destiny will not be the future for our new species.

TABLE 3. Cytochrome-b uncorrected pairwise genetic distances; bold letters identify comparisons between *L. cuyumhue* and the two least genetically distant species.

Taxon 1	Taxon 2	Distance in %
L. riojanus	*L. multimaculatus*	1.23
L. wiegmannii 2	*L. wiegmannii 1*	1.51
L. cuyumhue	***L. multimaculatus***	**2.47**
L. riojanus	***L. cuyumhue***	**2.72**
L. wiegmannii	*L. wiegmannii 3*	2.84
L. wiegmannii 2	*L. wiegmannii*	4.03
L. wiegmannii	*L. wiegmannii 1*	4.20
L. wiegmannii 2	*L. wiegmannii 3*	4.52
L. wiegmannii 1	*L. wiegmannii 3*	4.81
L. wiegmannii	*L. azarai*	9.26
L. occipitalis	*L. lutzae*	9.26
L. scapularis	*L. multimaculatus*	9.51
L. riojanus	*L. wiegmanni 3*	9.51
L. wiegmannii 3	*L. multimaculatus*	9.75
L. scapularis	*L. cuyumhue*	9.75
L. riojanus	*L. scapularis*	9.75
L. azarai	*L. wiegmannii 1*	9.88
L. wiegmannii	*L. multimaculatus*	9.88

Phylogenetic affinities. *Liolaemus cuyumhue* is the only species of the *wiegmannii* group recorded from Neuquén province. The analyses of the separate gene partitions (Cyt-b, ND4, 12S and C-mos) showed some incongruences, but the majority were between the outgroups, and in most cases these relationships were not resolved and the outgroups formed a polytomy basal to the *wiegmannii* group. Most of the relationships among the ingroup taxa were consistent with the different partitions. The clades (*L. wiegmannii* complex + *L. azarai*) and (*L. cuyumhue* (*L. multimaculatus* + *L. riojanus*)) were recovered with the four genes. These two clades plus *L. scapularis* and *L. salinicola* formed a monophyletic group with the three mitochondrial genes. *Liolaemus lutzae* and *L. occipitalis* were recovered as sister taxa with the mitocondrial markers, but we did not have C-mos sequence for *L. lutzae* to evaluate this concordance. *Liolaemus pseudoanomalus* was recovered as the sister taxon of the *L. wiegmannii* group with all mitochondrial markers. Considering this high level of congruence within the ingroup we only present the phylogenetic tree obtained with the combined data set (Fig. 5). We found strong evidence for the monophyly of the *wiegmannii* group (posterior probability [pp] = 1.0 and MP bootstrap [MPb] = 75%). This result is congruent with the molecular hypothesis proposed by Schulte *et al*. (2000) and Cruz *et al*. (2005), and with the morphological hypothesis of Etheridge (2000). We also found some support for *L. pseudoanomalus* as the basal taxon of the *wiegmannii* group (pp=1.0), this relationship was also recovered by Cruz *et al*. (2005) and Schulte *et al*. (2000). The new species described here, *Liolaemus cuyumhue*, is nested within the *wiegmannii* group and is the sister taxon of the (*L. multimaculatus* + *L. riojanus*) clade with high support (pp=1.0; MPb=100%). Another monophyletic group recovered with high support is the *wiegmannii* complex + *L. azarai* (pp = 1.0, MPb = 100%). Also with high support (pp = 1.0, MPb = 100%) *Liolaemus lutzae* was recovered as the sister taxon of *L. occipitalis*; the same relationship was found by Schulte *et al*. (2000), but Etheridge (2000) found these two species more distantly related. *L. rabinoi* is probably related to *L. cuyumhue*; it has not been found after its original description in sand dunes around El Nihuil in Mendoza province, a locality 300 km N of Añelo sand dunes, and is probably extinct now (Etheridge, 2000). Our field survey of the type locality did not produce any lizards so tissues for molecular analysis are not available, rendering its phylogenetic relationships with other members of the *wiegmannii* group uncertain. *L. arambarensis* was previously confused with *L. wiegmannii* and Verrastro *et al*. (2003) suggested a close relationship with a clade formed by (*L. rabinoi* + (L. *multimaculatus* + *L. riojanus*)) based on morphological information provided by Etheridge (2000). Table 3 lists the uncorrected cytochrome b pairwise differences between all the taxa included in this study. Further research is needed to propose a well-supported hypothesis of the relationship of L. arambarensis within the *wiegmannii* group.

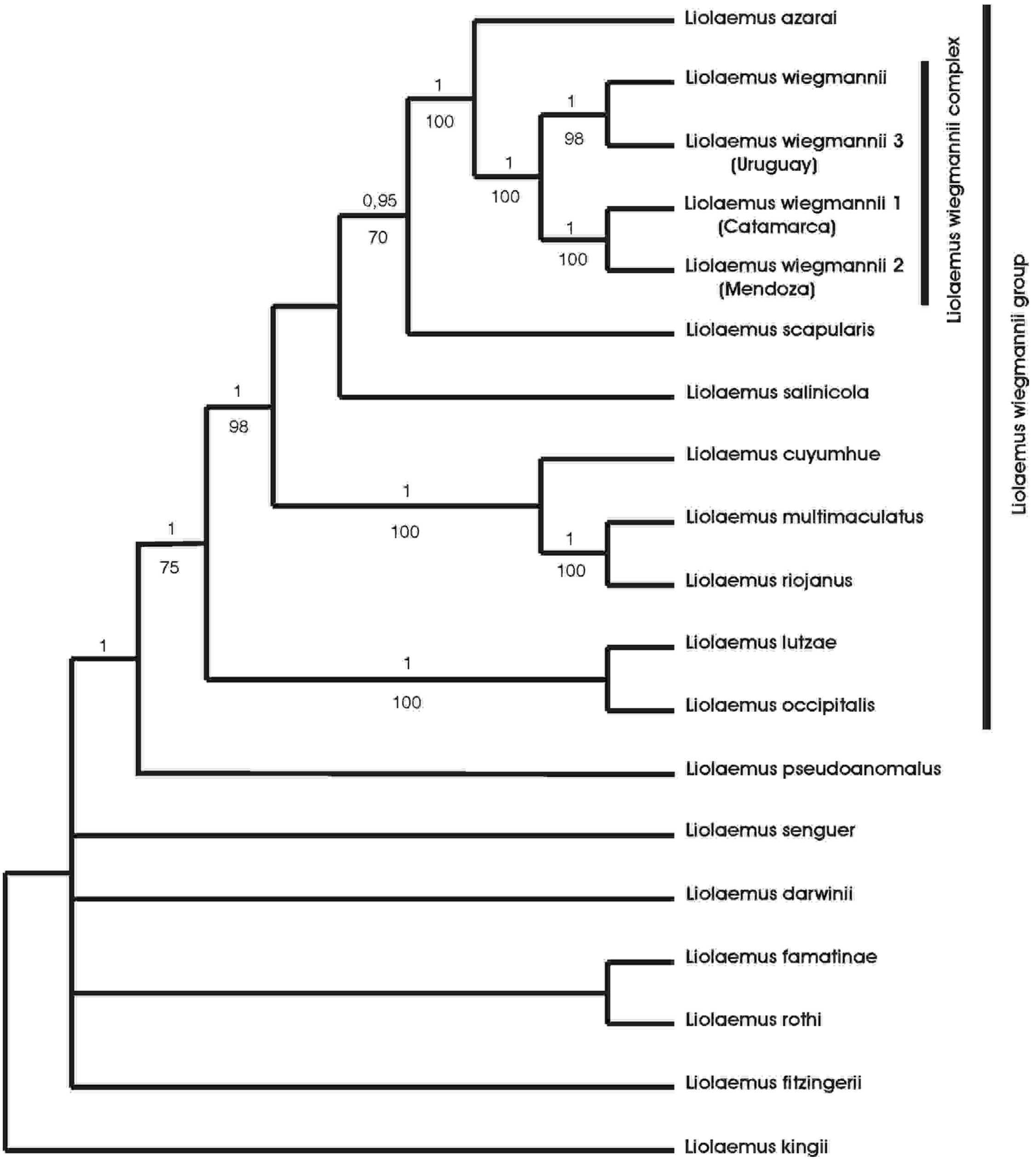

FIGURE 5. Phylogenetic relationships of *Liolaemus cuyumhue* with other species of the *wiegmannii* group as shown by the consensus Bayesian tree. Posterior probabilities and maximum parsimony bootstrap values are shown above and below branches.

FIGURE 6. From top to bottom: *Liolaemus cuyumhue*, *L. multimaculatus*, and *L. riojanus*.

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Appendix I. Specimens examined

Liolaemus azarai (*n* = 15): PARAGUAY: MISIONES: Yacyretá Island, Paraná River: UNNEC 5796–97, 5892–95. ARGENTINA: CORRIENTES: San Miguel Department: Curuzú Laurel (27° 50' S, 57° 30' W): UNNEC 562, 582–583, 585, 4332-35. San Roque Department: San Roque (28° 34' S, 58° 42' W): ZV-UNRC 2218. *Liolaemus lutzae* (*n* = 9): BRASIL: "Brasil," CENAI (o/n). RIO DE JANEIRO: Cabo Frío: FML 1287(7), MLP-S 920–21. *Liolaemus multimaculatus* (*n* = 50): ARGENTINA: BUENOS AIRES: Partido Claromecó: FML 1596(10). Partido Coronel Dorrego: MLP-S 137, 141–46, 155, 372. Partido General Alvarado: Miramar: MLP-S 138-39, 486-503. Partido General Lavalle: Las Toninas: MACN 33491–92. Lucila del Mar: MACN 32419. Partido San Antonio Norte: Cabo San Antonio: MACN 29705–08, 29714. Municipio Urbano Monte Hermoso: MLP-S 141–46, 149, 155, 157, 370–72. RIO NEGRO: Adolfo Alsina Department: Bahia Creek (41° 04' S, 63° 57' W): LJAMM 2559. *Liolaemus occipitalis* (*n* = 3): BRASIL: "Brasil," CENAI (o/n). BRASIL: Río Grande do Sul: Tramandaí: Praia Jardim Atlantico: FML 2618, 2620. *Liolaemus riojanus* (*n* = 32): ARGENTINA: LA RIOJA: "La Rioja": MLP-S 995. Independencia Department: 110.7 km S Villa Unión, on Ruta Provincial 26: FML 3005(18). San Martin Department: 5 km N Baldecito: 2626(4), 2378(1), 2876(8). *Liolaemus salinicola* (*n* = 37): ARGENTINA: CATAMARCA: Tinogasta Department: road between Tanton and Medanitos: FML 8441–42. Medanitos: FML 1886-87, 1907(4), 1909(10), 2079, 2101(5). 10 km N Taton (27° 28' S, 67° 35' W): LJAMM 2347–54, 2373–75. 4 km N Palo Blanco (27° 17' S, 67° 45' W): LJAMM 2379–80. *Liolaemus scapularis* (*n* = 68): ARGENTINA: CATAMARCA: Santa Maria Department: Campo Los Pozuelos, National Road 40, between km 894 and 904: FML 2022(18), 5 km E Santa Maria: FML: 2932(10). SALTA: Cafayate Department: Cafayate: Los Médanos: FML 1819(4), 1823(10), 2203(11), 2221(4), 2232(11). *Liolaemus wiegmannii* (*n* = 273): ARGENTINA: BUENOS AIRES: Partido Bahía Blanca: Bahía Blanca (38° 44' S, 62° 16' W): BYU 48117, MLP.S 2480, LJAMM 3100–2, MACN 1670–72; Ingeniero White (38° 47' S, 62° 16' W): MACN 24820. Partido Coronel Dorrego: Farola de Monte Hermoso, Monte Hermoso (38° 59' S, 61° 17' W): CENAI 850. Partido General Lavalle: Mar de Ajo (36° 43' S, 56° 41' W). MACN 25234; Santa Teresita (36° 33' S, 56° 41' W): CENAI 188; Laguna Chasicó, Campo de los Guijarros: MACN 31606–07. Partido Guaminí: Laguna Alsina (Estación Bonifacio) (36° 49' S, 62° 15' W): MACN 20938–40. Partido Patagones: Carmen de Patagones (40° 48' S, 63° 00' W): MACN 15191, 31620–22, 31762, 31876; Estancia El Médano, Carmen de Patagones (40° 48' S, 63° 00' W): MACN 31876; Bahía San Blas (40° 33' S, 62° 16' W): MACN 6406. CATAMARCA: Andalgala Department: Agua de las Palomas (27° 37' S, 66° 07' W): LJAMM 4299–300. La Paz Departament: Icaño (28° 55' S, 65° 19' W), Escuela Hogar Numero 4 – Ministerio de Educación: CENAI 117. CORDOBA: Punilla Departament: Los Cocos (30° 56' S, 64° 30' W): MACN 8919–22; Cruz Grande (30° 56' S, 64° 29' W): MACN 21443; La Cumbre (30° 59' S, 64° 30' W): MACN 22384–85, 24158-61, 31611-17; 2 km NE La Cumbre (30° 59' S, 64° 30' W). MACN 24634–36. Río Cuarto Departament: Río Cuarto (33° 08' S, 64° 22' W): ZV-UNRC 828, 1602; 20 km W Chaján (33°33' S, 65°01' W): ZV-UNRC 3638; Coronel Moldes (33° 38' S, 64° 33' W): ZV-UNRC 3644, 3690; Laguna Oscura (33° 53' S, 64° 52' W): ZV-UNRC 2475, 2478, 2504, 3074, 3082–84, 3086, 3090–91, 3093, 3097, 3123, 3125, 3129, 3131–32, 3139-40, 3154, 3159, 3165–66, 3169, 3175, 3177, 3180–81, 3186, 3207, 3209, 3214, 3217–19, 3224, 3229, 3231, 3233, 3235–36, 3238-40, 3242–47, 3249, 3250, 3252–58, 3262–70, 3273-78, 3280–88, 3453–59, 3493, 3497. San Javier Departament: Tilquicho (32° 11' S, 65° 13' W): ZV-UNRC 299, 301. ENTRE RIOS: Islas del Ibicuy Departament: Médanos (32° 25' S, 59° 04' W): CENAI 856, 858, 868. LA PAMPA: "Pampa Central": MACN 1474–80, 1482. Capital Departament: Colonia Inés y Carlota (36° 18' S, 63° 55' W): MACN 23257–59; airport, 3 km NE Santa Rosa (36° 37' S, 64° 17' W): MACN 23281, 23284; Santa Rosa (36° 37' S, 64° 17' W): CENAI 58(2). Catriló Departament: Lonquimay (36° 28' S, 63° 37' W): MACN 31187-96; 3 km SW Uriburu (36° 30' S, 63° 51' W): MACN 31197–205. Conelo Departament: Conelo (36° 00' S, 64° 36' W): MACN 6635, 6911–12, 6698. Guatraché Departament: "Don Amelio", Perú (37° 40' S, 64° 06' W): MACN 22035–36. Hucal Departament: Abramo (37° 54' S, 63° 51' W): MACN 34440. Loventué Departament: Loventué (36° 11' S, 65° 17' W): MACN 7193–94; Las Vertientes, 35 km SW Carro Quemado (36° 28' S, 65° 21' W): MACN 23263–65; Victorica (36° 12' S, 65° 27' W): CENAI 851. Lihué Calel Departament: Lihué Calel (38° 02' S, 65° 33' W): CENAI 840; Lihué Calel, (38° 02' S, 65° 33' W): MACN 35354. Mará Co Departament: General Pico (35° 40' S, 63° 46' W): MACN 30960–61. Utracan Department: National Road 35, Km 257, 6 km junction Padre Angel Buodo (37°14 ' S, 64°17' W): BYU48116, LJAMM 3200, MLP.S 2479. MENDOZA: La Paz Department: National Highway 146, Km 276, 74 km NE Monte Coman (34° 17' S, 67° 14' W). MLP.S 2499, LJAMM 4040–44. San Rafael Department: Provincial Road 179. 9,2 Km N junction Provincial road 179 and 190 (35º 26' S; 68º 04' W). MLP.S 2452, LJAMM 5039. RIO NEGRO: Adolfo Alsina Department: La Loberia Reserve, 60 Km SW Viedma (41º 09' S, 66º 34' W): LJAMM 5865. SAN JUAN: San Martín Department: San Martín, Calle Nacional s/n (31° 31' S, 68° 24' W): IMCN-UNSJ 103, 104. Angaco Departament: Angaco, Velazquez Street w/n, intersection of provincial routes 59 and 230 (31° 28' S, 68° 20' W): IMCN-UNSJ 105-07. SAN LUIS: Chacabuco Departament: 7 km N Naschel (32° 56' S, 65° 28' W) on National Highway 148: ZV-UNRC 662. Departamento Coronel Pringles: Saladillo (Río Quinto) (33° 12' S, 65° 51' W): CENAI 839. La Toma (33° 04' S, 65° 38' W): ZV-UNRC 1483–84, 4064. Provincial Road 10, 10 Km W La Toma (33º 02'S., 65º 40'W): LJAMM 5773. Departamento General

Pedernera: Estancia La Emboscada, El Morro (33° 13' S, 65° 29' W): MACN 10209(2); El Morro (33° 13' S, 65° 29' W): MACN 25055; 20 km W La Punilla (33° 09' S, 65° 05' W): ZV-UNRC 3655; Juan Jorba (33° 37' S, 65° 16' W): ZV-UNRC 3693; La Punilla (33° 09' S, 66° 05' O): ZV-UNRC 4098–99. Gobernador Dupuy Departament: Bagual (33° 09' S, 65° 35' W): MACN 15265. Junin Department: Provincial Road 20, Km 226, junction Lafinur (32º 04´ S, 65º 25´ W): LJAMM 1539. SANTA FE: Garay Departament: Colonia Mascias (Isla Garay) (30° 47' S, 60° 00' W): MACN 7846–47. TUCUMÁN: Burruyacú Departament: Agua Negra, Sierra de Medina: FML 769(4), 780, 823(6), 2393(8), 2393(2), 2571(2), 2577, 2704(3), 2721(7), 2801(3). BOLIVIA: SANTA CRUZ: Nueva Moka: MACN 15233.

Appendix II. Specimens used in molecular analysis

Liolaemus azarai: LG1092 – LG 1095; *Liolaemus cuyumhue* LJAMM 5753; *Liolaemus lutzae*: MZUSP 916862 – 916863; *Liolaemus multimaculatus*: LJAMM 4464; *Liolaemus occipitalis*: MTR Wo/N; *Liolaemus riojanus*: IMCN Wo/N; *Liolaemus salinicola*: LJAMM 2375; *Liolaemus scapularis*: MLP.S 2529; *Liolaemus wiegmannii*: MLP.S 2480; *Liolaemus wiegmannii* 1: BYU 48118; *Liolaemus wiegmannii* 2: MLP.S 2499; *Liolaemus wiegmannii* 3: LG 0759 (916880) – 916869. Outgroups: *L. senguer* LJAMM 2187; *L. darwinii* LJAMM 2410; *L. famatinae*: FML 9446; *L. fitzingerii* LJAMM 2876; *L. kingii* LJAMM 3040; *L. pseudoanomalus* LJAMM 2300; *L. rothi*: LJAMM 3091.

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ARTICLE

Vulnerability to global warming of the critically endangered Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*) from the Monte Desert, Patagonia Argentina

M. Victoria Brizio, Facundo Cabezas-Cartes, Jimena B. Fernández, Rodrigo Gómez Alés, and Luciano J. Avila

Abstract: The body temperature of lizards is strongly influenced by the thermal quality of microhabitats, exploiting the favourable environmental temperatures, and avoiding exposure to extreme thermal conditions. For these reasons, reptile populations are considered to be especially vulnerable to changes in environmental temperatures produced by climate change. Here, we study the thermal physiology of the critically endangered Añelo Sand Dunes Lizard (*Liolaemus cuyumhue* Avila, Morando, Perez and Sites, 2009). We hypothesise that (*i*) there is a thermal coadaptation between optimal temperature for locomotor performance of *L. cuyumhue* and its thermal preference; (*ii*) *L. cuyumhue* lives in an environment with low thermal quality; and (*iii*) a rise in environmental temperatures due to global warming will impose a decrement in locomotor speed represented by lower warming tolerance and narrower thermal safety margins, increasing their already high vulnerability. We recorded field body temperatures (T_{b}), preferred body temperatures (T_{pref}), the operative temperature (T_{e}), and the thermal sensitivity of locomotion at different body temperatures. Our results indicate that this lizard is not currently under environmental stress or exceeding its thermal limits, but that it is thermoregulating below T_{pref} to avoid overheating, and that an increase in environmental temperature higher than 3.5 °C will strongly affect the use of microhabitats with direct sun exposure.

Key words: climate change, vulnerable, *Liolaemus cuyumhue*, Añelo Sand Dunes Lizard, thermal sensitivity, locomotion, optimal temperature.

Résumé : La température du corps des reptiles est fortement influencée par la qualité thermique des microhabitats, l'exploitation de températures ambiantes favorables et l'évitement de conditions thermiques extrêmes. Pour ces raisons, les populations de reptiles sont considérées être particulièrement vulnérables aux variations des températures ambiantes découlant des changements climatiques. Nous étudions la physiologie thermique d'une espèce de lézard en danger critique, *Liolaemus cuyumhue* Avila, Morando, Perez et Sites, 2009. Nous postulons que (*i*) il y a coadaptation thermique entre la température optimale pour la performance locomotrice de *L. cuyumhue* et sa température de prédilection, (*ii*) *L. cuyumhue* vit dans un milieu de mauvaise qualité thermique et (*iii*) une hausse des températures ambiantes causée par le réchauffement planétaire entraînera une baisse de la vitesse de locomotion représentée par une tolérance plus faible au réchauffement et des plages de sécurité thermiques plus étroites, rehaussant la vulnérabilité déjà élevée de l'espèce. Nous avons enregistré la température du corps sur le terrain (T_{b}), les températures du corps de prédilection (T_{pref}), la température opérative (T_{e}) et la sensibilité thermique de la locomotion à différentes températures du corps. Nos résultats indiquent que ce lézard n'est présentement pas assujetti à un stress environnemental et que ses limites thermiques ne sont pas dépassées, mais qu'il fait preuve de thermorégulation pour se maintenir à des températures inférieures à sa T_{pref} afin d'éviter la surchauffe, et qu'une hausse de plus de 3,5 °C des températures ambiantes aura une forte incidence sur l'utilisation de microhabitats caractérisés par une exposition directe au soleil. [Traduit par la Rédaction]

Mots-clés : changement climatique, vulnérable, *Liolaemus cuyumhue*, lézard, sensibilité thermique, locomotion, température optimale.

Introduction

Ectotherms are not capable of producing and using metabolic heat for thermoregulation, and thus regulate their body temperature by behaviourally exploiting thermal resources (Bogert 1959). Through behavioural thermoregulation, ectotherms (and particularly reptiles) attempt to deal with the environmental conditions that can dramatically determine behavioural and physiological processes (Huey 1982; Van Damme et al. 1991; Angilletta et al.

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Fig. 1. Adult male (A) and habitat (B) of Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*). Colour version online.

2002*a*). As a result, the body temperature of reptiles is strongly influenced by the thermal quality of microhabitats, exploiting the favourable environmental temperatures, and avoiding exposure to extreme thermal conditions (Hertz et al. 1993; Besson and Cree 2010). For these reasons, reptiles are considered to be especially vulnerable to changes in environmental temperatures produced by climate change (e.g., Deutsch et al. 2008; El-Gabbas et al. 2016; Winter et al. 2016).

Many lizard populations across the world may be at risk of extinction due to the rapidly warming climate. In these populations, environmental temperatures increasingly exceed the thermal tolerances of lizards, limiting the activity, which translates ecologically into a constraint on available foraging and reproduction times (Grant and Dunham 1988; Huey et al. 2009; Sinervo et al. 2010; Kubisch et al. 2016; Kirchhof et al. 2017). However, the susceptibility of lizards to altered thermal niches depends on the interaction of many factors (Kirchhof et al. 2017), including availability of microhabitats, daily activity patterns, and foraging behaviour (e.g., Tingley et al. 2013; Böhm et al. 2016). A standard way to estimate the ecological consequences of raising temperature involves measuring how body temperature affects organismal-level performance (such as locomotion, digestive efficiency, or foraging rate; Huey and Slatkin 1976; Sinclair et al. 2016). Locomotion is an important temperature-dependent whole-organism functional performance trait of reptiles used in many ecologically relevant activities such as foraging, courtship, and escape from predators (Jayne and Bennett 1990; Pinch and Claussen 2003). Several authors have suggested that the action of natural selection over many generations would ensure that thermoregulatory behaviour and locomotion's thermal physiology have coevolved (Huey and Bennett 1987; Angilletta et al. 2006). The relationship between temperature and locomotor performance is generally described by a thermal performance curve (TPC) that allows one to estimate the optimal temperature for maximum performance (T_o) and the thermal performance breadth (e.g., B_{80}) (Gómez Alés et al. 2018; Cabezas-Cartes et al. 2019).

In particular, deserts are among the most extreme habitats inhabited by lizards due to the challenges imposed by thermal and hydric constraints (Labra et al. 2001; Lara-Resendiz et al. 2014; Kirchhof et al. 2017). Lizards can experience large temperature differences in these environments by simply moving from shade into open sunlight (Hertz 1992; Bauwens et al. 1996). Some diurnal desert lizards during the warmest seasons usually thermoregulate so that they maintain body temperatures below their preferred temperature (T_{pref}) values to avoid reaching their critical thermal maximum (CT_{max}; risk-avoidance hypothesis; Martin and Huey 2008). This strategy reduces the risk of overheating when there is low spatial thermal heterogeneity for behavioural thermoregulation (Labra et al. 2001; Lara-Reséndiz et al. 2015; Kirchhof et al. 2017).

The genus *Liolaemus* Wiegmann, 1834 is one of the most diverse genera of reptiles, represented by more than 262 recognised species of lizards (Olave et al. 2020), and its members can be found in a wide variety of environments (Medina et al. 2012). Species of the genus *Liolaemus* are known to present low variability in T_{pref} values, usually between 30 and 38 °C (Labra et al. 2009; Medina et al. 2012; Moreno Azócar et al. 2013; Cruz et al. 2014). However, thermoregulation or selection of different microenvironments seems to be flexible enough to deal with the environmental constraints in most species of the genus (Ibargüengoytía et al. 2010; Kirchhof et al. 2017; Stellatelli et al. 2020).

Within the subgenus *Eulaemus* Girard, 1858, morphological, behavioural, and molecular studies have resolved a clade of arenicolous lizards known as the *Liolaemus wiegmannii* group (Etheridge 2000; Olave et al. 2014; Villamil et al. 2019); it is also known as "the sand lizards' clade" of *Liolaemus* because of its specialisations for diving under the sand. The *wiegmannii* group includes 12 species of oviparous lizards (Villamil et al. 2019); some of them with a very restricted geographic distribution. Herewithin, we study the thermal physiology and the thermal sensitivity of locomotor performance in the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue* Avila, Morando, Perez and Sites, 2009), an insectivorous desert lizard, from the *wiegmannii* group (Fig. 1A). This species has been categorised as critically endangered by the International Union for the Conservation of Nature (IUCN) (Avila 2016). *Liolaemus cuyumhue* is endemic to an isolated Mediterranean aeolian sand dune system in the region known as Bajo de Añelo in the center-east of Neuquén province, Argentina (Avila et al. 2009). The known distribution of this species covers about 1000 km^2 (M.V. Brizio, unpublished data). Individuals of *L. cuyumhue* are observed only on bare or sparsely vegetated dunes with extensive areas of open sand (Fig. 1B). Besides its restricted distribution, the habitat of *L. cuyumhue* is constantly altered by intense grazing and oil and gas exploitation. This particular region is where oil companies conduct some of the more intensive operations in Argentina. New rigs, tracks, and roads are opened regularly, frequently modifying areas that are suitable for the species (Avila 2016).

In this paper, we aim to study the most relevant parameters of the thermal physiology of *L. cuyumhue* to estimate the thermal sensitivity of locomotor performance, the thermal quality of its habitat, and the effects of an increase in environmental temperature, due to climate change, predicted for the region where this lizard lives (based on IPCC 2014; Barros et al. 2015). We hypothesise that (*i*) there is a thermal coadaptation (Huey and Bennett

1987; Angilletta et al. 2006) between optimal temperature for locomotor performance of *L. cuyumhue* and its thermal preference; (*ii*) *L. cuyumhue* lives in an environment with low thermal quality; (*iii*) a rise in environmental temperatures due to global warming will impose a decrement in locomotor speed represented by lower warming tolerance and narrower thermal safety margins, increasing their already high vulnerability.

Materials and methods

Study site and fieldwork

The study was carried out in the Bajo de Añelo basin, located in the center-east of Neuquén province, Argentina (37.4°S to 38.5°S and 68.4°W to 69.8°W). The Bajo de Añelo basin comprises the lowest area of the province (230 m above sea level) and covers an area of 9000 km^2, placed within the Monte Desert region. The climate is temperate arid to semi-arid, with a mean annual temperature of 14.2 °C and a mean annual precipitation of 137.2 mm, occurring mainly in winter and spring (Busso and Bonvissuto 2009). The vegetation presents a marked physiognomic–floristic homogeneity, characterised by being a shrubby steppe with perennial foliage represented by Jarillas (genus *Larrea* Cav.) with little herbaceous cover (Fig. 1B) and scarcity of grasses and trees (Leon et al. 1998; Roig et al. 2009).

We captured 20 adult specimens of *L. cuyumhue* (8 females and 12 males) by lasso when they were active between the hours of 0800 and 2000 on 6 March 2020 (austral summer). Considering the critically endangered conservation status of the species, we worked with the minimum sample size needed for statistical significance. Our experimental design was planned to minimise the time spent in captivity and the stress suffered by the individuals.

Immediately after capture, T_b was measured (TES 1303 Electrical Electronic Corp., Taipei, Taiwan, China; ±0.03 °C digital thermometer) using a thermocouple (TES TP-K01, 1.62 mm diameter) inserted approximately 0.5 cm inside the cloaca. The temperature measurements were taken within 10 s of capture to prevent heat transfer from the operator's hands. We also recorded the substrate temperature (T_s) and the air temperature 1 cm above the ground (T_a) of the microenvironment where each lizard was captured. Each capture site was georeferenced with a GPS (Garmin eTtrex® Touch 35).

The day after capture, lizards were carried to the laboratory located at Centro Regional Universitario Bariloche (CRUB) in individual cloth bags. During experiments (5 days), lizards were kept individually at room temperature (20–22 °C) in a quiet site. After experiments, body mass (Pesola 10 g, ±0.3 g) and snout—vent length (SVL; digital calliper Lee Tools, ±0.02 mm) were measured and sex recorded (based on the presence of pre-cloacal pores in males). All the lizards were released in good condition at their exact capture sites.

Ethics approval

Lizards were cared for following the Canadian Council on Animal Care (CCAC) guidelines and the *Guide for the Care and Use of Laboratory Animals* (8th edition; National Academies Press, Washington, D.C., USA), as well as the regulations detailed in the Argentinean National Law N° 14346.

Preferred body temperatures

We measured preferred body temperatures (T_{pref}) the day after capture. Lizards were placed individually in an open-top terrarium (100 cm × 20 cm × 17 cm) with a thermal gradient (20–50 °C) produced by a 75 W incandescent light bulb in a lamp over one end of the terrarium. The body temperatures of lizards were measured every 10 s for 3 h with a temperature Data Acquisition Module (USB-TC08; OMEGA, Biel/Bienne, Switzerland) using miniature size insulated thermocouples (OMEGA® part No. 5SC-TT-T-40-72, diameter 0.076 mm). This thermocouple was fastened to the belly and to the base of the lizard's tail with hypoallergenic tape to keep the thermocouple in position during the experiment. For each individual, we estimated the mean T_{pref} and the minimum and maximum temperature set-points (T_{set}) as the central 50% of all body temperatures preferred in the laboratory.

Effects of body temperature on locomotor performance

We performed locomotor performance trials on a racetrack 7.5 cm wide and 1.20 m long, leading to a shelter. Photocells, positioned at 15 cm intervals along the track, signalled passing lizards to a laptop that calculated speed over each 0.15 m section. Two types of runs were considered in the analyses: (1) sprint runs (SR), defined as the speed reached between the first and the second photoreceptors (0.15 m), which is relevant for predator escape and prey capture, and (2) long runs (LR), defined as the speed between the first and the last photoreceptors (1.05 m), which indicated the locomotor capability of the lizard to perform activities such as foraging, territorial defence, and courtship (Cabezas-Cartes et al. 2014). Lizards ran three consecutive times at each experimental temperature, and only the maximum run speed (V_{max}) for SR and LR of the three repetitions was considered for the analyses. The lizards did not rest between the three consecutive trials, but they were always rested at least 4 h between the different temperature treatments.

Locomotor performance trials were carried out in an environmental chamber equipped with an air conditioner, heat lamps, electric heaters, and a thermostat to set the desired temperatures following the methodology of Cabezas-Cartes et al. (2019). Before and after each run, the lizard's T_b was measured using a thermocouple inserted 0.5 cm inside the cloaca (catheter probe TES TP-K01) and connected to a digital thermometer. Trials were conducted at five different T_bs (22 ± 1, 28 ± 1, 33 ± 1, 36 ± 1 °C, and 39.5 ± 1 °C) during three consecutive days. The order of each trial's temperature was established randomly. The T_bs for the treatments were chosen based on the following criteria: the median T_b in the field (33 °C) and the mean T_{pref} obtained in the laboratory for *L. cuyumhue* (36 °C). The T_b at 22 and 28 °C were included to define the shape of the curve. Also, we estimated performance at 39.5 °C to evaluate the locomotor performance at the mean T_{pref} + 3.5 °C. This is the environmental temperature increase anticipated by the end of this century at our study site based on the climatic assessment from IPCC (2014) and Barros et al. (2015).

Thermal tolerance

To determine the critical thermal minimum (CT_{min}), we place individually a subsample of eight lizards in a transparent plastic box (15 cm × 10 cm × 5 cm) in a refrigerator at −10 °C. T_b was measured every 30 s using a mini-infrared thermometer (DT-810 CEM) at a distance within 5 mm (Chukwuka et al. 2019). Lizards were observed throughout the experiment and we recorded and considered CT_{min} to be the T_b at which an individual was no longer able to right itself when placed on its back (Lowe and Vance 1955; Van Damme et al. 1991).

The same subsample of eight lizards was also used to determine critical thermal maximum (CT_{max}), the day after the CT_{min} experiments. Each lizard was placed in an open terrarium (with a diameter of 25 cm and 35 cm high) with an infrared 150 W lamp placed 40 cm overhead. The T_b was monitored every 30 s following the same methodology used in the CT_{min} experiments. Each lizard was carefully observed throughout the experiment and we recorded and considered CT_{max} to be the T_b at which an individual was unable to right itself when it was placed on its back. After reaching CT_{max}, each lizard was removed from heat source and cooled quickly to avoid overheating. None of the individuals died during the trials.

Operative temperatures, effectiveness of thermoregulation, and vulnerability to global warming

Operative temperatures (T_e) represent the null distribution of potential body temperatures expected in non-thermoregulating animals (Hertz et al. 1993). The T_e was measured using grey polyvinyl chloride (PVC) oval plastic models, 100 mm length and 20 mm diameter, to mimic an adult *L. cuyumhue*. The model was chosen to represent a living animal and was validated for the King's Tree Iguana (*Liolaemus kingii* (Bell, 1843)), a species of similar shape and size compared with *L. cuyumhue*, showing no differences between the model temperature and the live animal temperature (Wilcoxon's signed rank test: $Z = 0.558$, $P = 0.577$; simple linear regression: $R^2 = 0.992$, $F_{[1,47]} = 5440.99$, $P < 0.001$; F. Duran, unpublished data). Each model was connected to a thermistor connected to data loggers (HOBO Onset Computer Corporation, Bourne, Massachusetts, USA). The eight models were placed in areas where we usually find the species: sun models (two on the sand, one buried in the sand, and two buried under grass) and shadow models (two under dense and loose bush and one buried under shade). The data loggers were programmed to record temperatures every minute during the day of capture. In our analyses, we used the T_es recorded for 28 days between the hours of 0830 and 2000, which is the daily period of activity according to our 4 years of personal observations while working with this population.

To estimate thermoregulatory efficiency, we applied the methodology of Hertz et al. (1993), using the information on T_{pref} obtained in the thermal gradient and the availability of T_e in the natural environment. We calculate the d_b (thermoregulatory accuracy) as the absolute mean deviation of T_b from T_{set} for each individual. Then, we calculated the d_e as the mean thermal quality of the habitat from an organism's perspective. The d_e was estimated as the mean of the deviation of T_e from the T_{set} of each individual. Considering the high daily and hourly variations in temperature that characterises the Monte Desert climate, the T_e is highly dynamic. Hence, we used the mean value of obtained T_es considering all the models recorded from 1 h before each individual lizard was captured (sensu Cabezas-Cartes et al. 2019). Using the mean values of d_b and d_e, we calculated the effectiveness of thermoregulation (E) using the formula $E = 1 - (d_b/d_e)$ (Hertz et al. 1993), which integrates the mean degree to which *L. cuyumhue* experienced T_b outside the set-point range (d_b) and the corresponding d_e. When the E index approaches zero, the species is considered a thermoconformer, whereas when the E index approaches a value of one, the species can be considered a highly effective thermoregulator. If the E index is close to 0.5, then the species is considered a moderate thermoregulator (Hertz et al. 1993). Negative values of the E index are attributed to individuals that actively avoid thermally stable microhabitats (Huey and Slatkin 1976; Hertz et al. 1993). Finally, following Blouin-Demers and Weatherhead (2001), we measured the index of effectiveness of thermoregulation ($d_e - d_b$) to quantify the extent of departure from perfect thermoconformity.

In addition, we calculated two indices to estimate vulnerability to global warming. Firstly, we determined the warming tolerance (WT) index, which defines how much warming can be tolerated by an ectotherm before its performance is reduced to lethal levels, and is calculated as the difference between mean CT_{max} and mean T_e (sensu Deutsch et al. 2008; Logan et al. 2013). Secondly, we determined the thermal safety margin (TSM) for physiological performance as the difference between T_o and mean T_e, which gives an indication of how close the thermal optima of animals are to the current climatic temperature in their environment (Deutsch et al. 2008; Andrew et al. 2013).

Statistical analyses

To quantify the thermal sensitivity for locomotor performance, we used Table Curve 2 D version 5.01.2 software to create locomotor performance curves (TPCs) as functions of temperature during SR and LR. The values of CT_{min} and CT_{max} were used as the extreme values of the curves. We chose the model according to the adjusted R^2 (following Angilletta 2006). The best candidate model for the overall sample was fitted to each individual to estimate the V_{max}, the T_o (the T_b at which performance is maximal), and the performance breadth (B_{80}, the range of T_bs over which performance is greater than or equal to 80% of the V_{max}; sensu Ben-Ezra et al. 2008) of each individual for LR and SR. We used the statistical software RStudio version 1.2.1335 (R Core Team 2020) and Sigma Plot version 11.0 for statistical analyses and to generate figures, respectively. Relationships between T_b, T_s, and T_a were analysed by simple linear regressions. To compare samples from the same lizard, we used paired t tests or the non-parametric alternative Wilcoxon's signed rank test when the assumptions of parametric statistics were not met. Means are reported with ± standard errors (±SE). To analyse the effect of temperature on speed, we applied a linear mixed model (LMM) with a normal distribution; we performed post hoc pairwise comparisons (Tukey's test) between levels for the temperature effect.

Table 1. Median ± standard error (SE) and minimum and maximum temperature values of all models discriminated by microhabitat in which the model was located.

	Temperature (°C)	
Microhabitats	Median ± SE	Minimum and maximum values
On the sand (south–north)	37.0 ± 0.15	17.3–64.3
On the sand (east–west)	34.5 ± 0.16	14.5–62.2
Buried in the sun	37.4 ± 0.14	15.6–55.2
Buried under grass	34.6 ± 0.10	15.7–46.5
Under dense bush	29.4 ± 0.10	12.7–45.3
Under loose bush	32.6 ± 0.08	15.3–46.4
Buried under shade	27.5 ± 0.08	15.0–48.2

Results

Body measurements and their relationship with locomotor performance

The mean SVL of *L. cuyumhue* ($N = 20$) was 49.3 ± 4.32 mm and the median body mass was 4.1 g (range 3.3–8.7 g). There was no relationship between maximum speeds during SR or LR and SVL (linear correlation: $R_{SR} = 0.13$, $R_{LR} = 0.09$, $P > 0.5$) or body mass (linear correlation: $R_{SR} = 0.11$, $R_{LR} = 0.06$, $P > 0.5$).

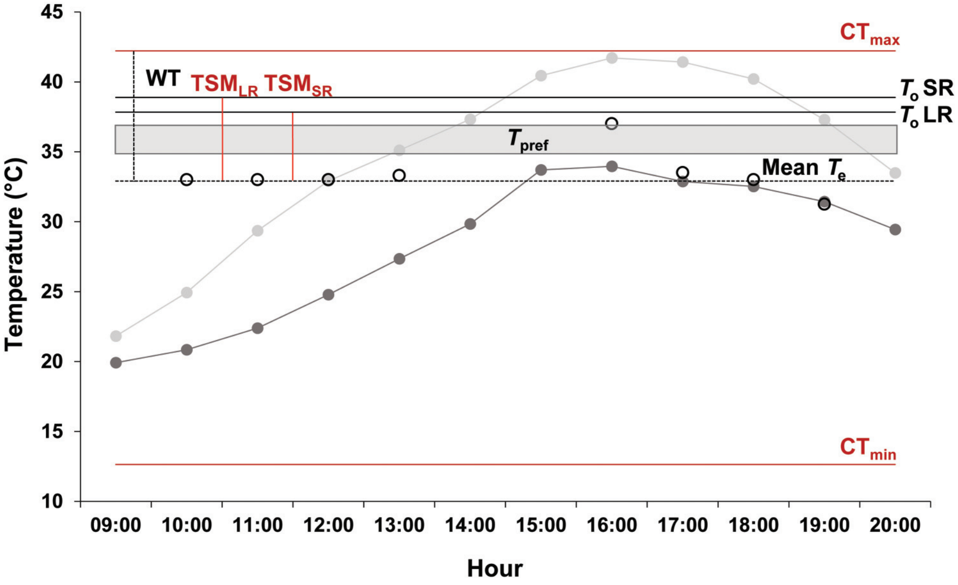
Field temperatures

The median T_b in the field was 33 °C (range 31–37 °C). Lizards were captured in microenvironments with a median T_a of 29 °C (range 20–39 °C) and a mean T_s of 38.2 ± 6.58 °C. There was a relationship between T_b and T_s (linear regression: $F_{[1,19]} = 8.02$, $R^2 = 0.27$, $P < 0.05$). The mean T_e was 32.9 ± 0.09 °C (Table 1). The median T_e of sun models was 35.3 ± 0.11 °C (range 15.7–51.1 °C; Fig. 2), whereas the median T_e of shadow models was 29.1 ± 0.09 °C (range 15.0–45.9 °C; Fig. 2).

Thermal performance curves

The relationship between T_b and maximum speed for the overall sample was best described by an asymptotic logistic curve of the non-linear family for SR (adjusted $R^2 = 0.45$; Fig. 3, lower panel) and LR (adjusted $R^2 = 0.57$; Fig. 3, upper panel). Lizards ran faster during SR than LR (median V_{max}SR = 1.19 m/s, V_{max}LR = 0.56 m/s; Wilcoxon's signed rank test: $W = 1$, $P < 0.001$; Fig. 3). However, the T_o was similar between SR and LR (median T_oSR = 37.8 °C, T_oLR = 38.9 °C; Wilcoxon's signed rank test: $W = 115$, $P = 0.21$; Fig. 3). Considering the thermal performance breadth at which 80% of maximal speed could be reached (B_{80}), there was no difference between SR and LR (B_{80}SR = 32.3–40.3 °C, B_{80}LR = 33.3–40.5 °C; Wilcoxon's signed rank test: $W = 85$, $P = 0.98$; Fig. 3). The

Fig. 2. Microenvironmental temperatures (T_e) of sun models (light grey line) and shadow models (dark grey line) during daily activity period of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*). The critical thermal maximum (CT_{max}), critical thermal minimum (CT_{min}), optimal temperature during SR (T_oSR) and LR (T_oLR), and the mean T_e are indicated by horizontal lines. Additionally, the warming tolerance (WT; broken vertical line) and thermal safety margin (TSM; red vertical lines) indices are shown, as well as the set-point range of the preferred temperature (T_{pref}; grey rectangle) and the mean body temperatures per hour of capture (T_b; open circles). Colour version online.



median B_{80} for SR was 8.2 °C (range 3.0–9.8 °C), whereas the median B_{80} for LR was 7.4 °C (range 1.9–11.8 °C).

Effects of temperature on running speed

Thermal performance curves showed an effect of temperature on the speed of *L. cuyumhue*. The sprint speed increased with temperature ranging from 22 to 39.5 °C (Figs. 3 and 4). Sprint speeds differed among trials (LMM: $F_{[4,76]}$ = 16.55, $P < 0.001$) (Fig. 4). The speed of long runs increased with temperature ranging from 22 °C to its maximum speed at 36 °C (Figs. 3 and 4). There were differences (LMM: $F_{[4,72]}$ = 23.43, $P < 0.001$) in speed among trials (Fig. 4).

Thermal physiology of *L. cuyumhue*, effectiveness of thermoregulation, and vulnerability to global warming

The mean T_{pref} of *L. cuyumhue* was 35.9 ± 1.43 °C with a set-point range of 34.8–36.8 °C (Fig. 2). For the interquartile range of T_{pref}, 80% of *L. cuyumhue* T_bs were below this range and 20% were within it. In the case of the T_e, 13.4% were within the T_{pref} interquartile range, 66.5% were below it, and 24% were above it (Fig. 2). The T_{pref} was similar to T_o for SR (SR — Wilcoxon's signed rank test: W = 137, P = 0.09); in contrast, T_o for LR was higher than T_{pref} (paired t test: t = 4.86, $P < 0.001$). The mean critical minimum and maximum temperatures were 12.6 ± 1.35 and 42.2 ± 1.24 °C, respectively. Our results may indicate that *L. cuyumhue* is a moderate thermoregulator during the end of the summer season (E = 0.64, d_b = 2, d_e = 5.52, $d_e - d_b$ = 3.52). The result for TSM and WT indices are shown in Table 2.

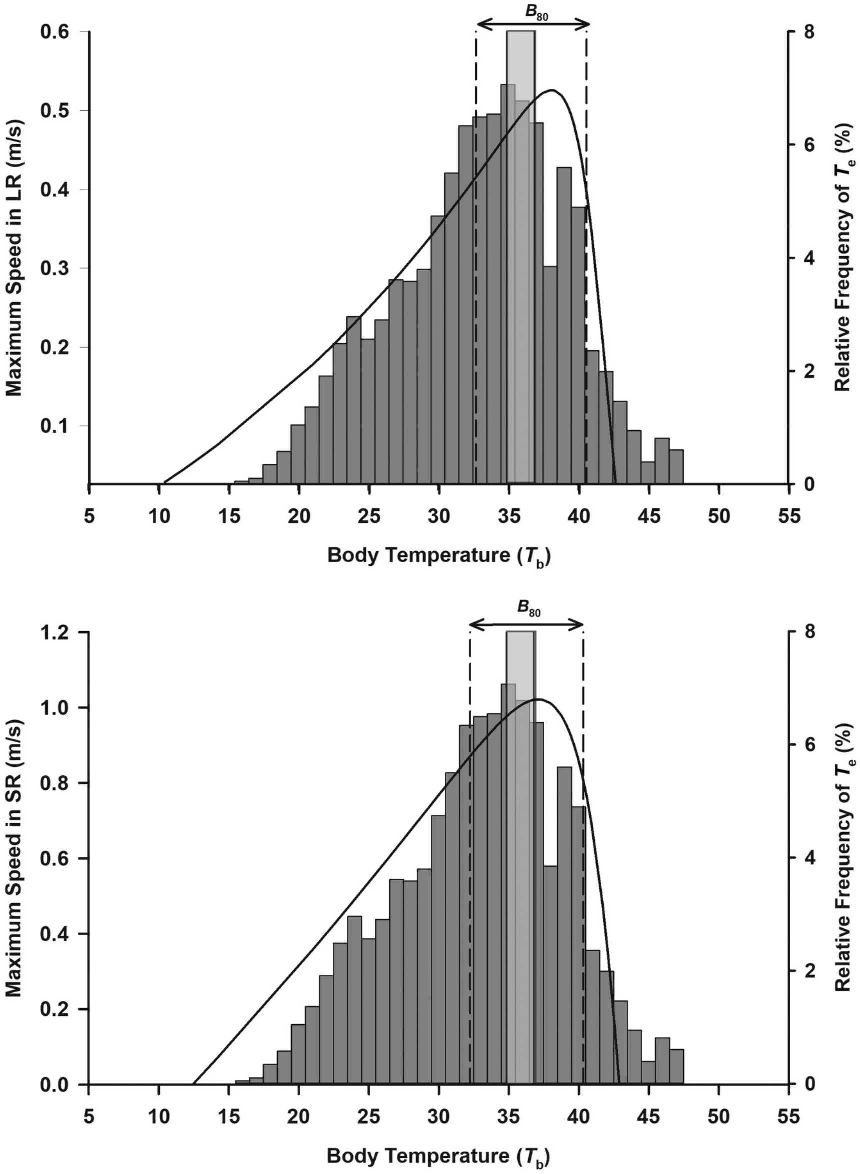
Discussion

This is the first study that describes locomotor performance and the possible effects of global warming in a species of the *wiegmannii* group, and particularly in the critically endangered *L. cuyumhue*. Our work suggests that *L. cuyumhue* is not currently under environmental stress or exceeding its thermal limits, but that it is thermoregulating below T_{pref} to avoid overheating, and that an increase in environmental temperature higher than 3.5 °C (predicted by the climate change models; Barros et al. 2015) will strongly affect the use of microhabitats with direct sun exposure.

The mean T_{pref} of *L. cuyumhue* (35.9 °C) is lower than the mean T_{pref} of other species of the *wiegmannii* group such as the Sand Dune Lizard (*Liolaemus multimaculatus* (Duméril and Bibron, 1837)) (37.2 °C; Stellatelli et al. 2020) and *Liolaemus wiegmannii* (Duméril and Bibron, 1837) (38.1 °C; Stellatelli et al. 2013), but is similar to the mean T_{pref} of *Liolaemus riojanus* Cei, 1979 (36.2 °C; Cruz et al. 2014). This result is in accordance with Rodríguez-Serrano et al. (2009), who suggested that thermal biology in the genus *Liolaemus* varies with an ecological gradient of ambient temperature. Thus, during summer, *L. cuyumhue* would likely reach a threshold beyond which the risks of overheating outweigh the benefits of thermoregulating to achieve their T_{pref}. Consequently, during the hottest period of the year, *L. cuyumhue* may prefer to stay in the shade, keeping body temperatures slightly below T_{pref} (like 80% of the individuals in this study) rather than expose itself to the direct sun, which could quickly increase T_b and reach lethal temperatures (Grant and Dunham 1988). This thermoregulatory behaviour has also been reported in the Husab Sand Lizard (*Pedioplanis husabensis* Berger-dell'mour and Mayer, 1989) of the Namib Desert (Kirchhof et al. 2017); it is opposite to the behaviour reported in the Sonoran Horned Lizard (*Phrynosoma goodei* Stejneger, 1893) of the Sonoran Desert, where T_b is never below T_{pref} (Lara-Resendiz et al. 2014). Furthermore, it is important to note that the T_{pref} is not an immutable variable, but it can vary temporally, spatially, and in different times of the life cycle of an organism (Andrews 1998; Stellatelli et al. 2013, 2020; Astudillo et al. 2019).

Regarding thermal sensitivity of locomotor performance, our results support the hypothesis that at least for sprint runs optimal temperature (36.9 °C) has coevolved with T_{pref}. This means that *L. cuyumhue* has an optimum adaptation for sprint runs, similar to the sympatric nocturnal gecko *Homonota darwinii* Boulenger, 1885 (Ibargüengoytía et al. 2007; Aguilar and Cruz 2010). However, T_o for long runs (38.3 °C) was higher than T_{pref}. In this sense, Martin and Huey (2008) found that there is a tight relationship between T_{pref} and T_o, but that thermal preferences should not necessarily match temperatures optimal for fitness. Consequently, total fitness over time might be maximised by centring thermal preferences at a temperature below T_o, as we observed in our results

Fig. 3. Thermal performance curves for long runs (LR; upper panel) and sprints (SR; lower panel) of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*). Vertical broken lines represent performance breadth (B_{80}) in SR and LR. Grey bars represent the percent frequency distribution of all operative temperatures (T_e) between activity hours. The light grey bar represents the set-point range of preferred body temperatures (T_{pref}) obtained in the laboratory.



for long runs. Also, it is important to point out that optimal temperatures will probably be different for digestion, bite force, reproductive processes, and other essential physiological performances with narrower optimal temperature ranges (Angilletta et al. 2002*a*).

Speed for long runs increased with temperature in almost all of the temperature treatments (Fig. 4), which is in contrast with Angilletta et al. (2002*b*), who found in Eastern Fence Lizard (*Sceloporus undulatus* (Bosc and Daudin, 1801)) that speed was not affected by temperature over a broad range, between 27.5 and 38 °C. In the case of sprint runs, the only difference was found between the trial at 22 °C and all the other temperatures; thus, it seems to be a wide range of body temperatures over which locomotor performance for sprint runs is high and similar (28–39.5 °C). Hence, *L. cuyumhue* select body temperatures that optimise sprint runs in a broad thermal range, which could provide an enhanced ability to escape from predators and optimise food acquisition, among other social activities (Fernández et al. 2011; Cabezas-Cartes et al. 2014; Gómez Alés et al. 2018). Miles et al. (2001) found similar results for Galápagos Lava Lizards (*Microlophus albemarlensis* (Baur, 1890)) that inhabit open areas with little shade (similar to our study site), where sprint speed is critical to avoid predators. Additionally, Kubisch et al. (2011) found that the sprint run is the type of run most often used and the most important for *Liolaemus pictus argentinus* Müller and Hellmich, 1939. Moreover, the speed for sprint runs was higher than the speed for long runs in other species of *Liolaemus* (Fernández et al. 2011; Kubisch et al. 2011; Gómez Alés et al. 2018). Preferences for sprints may respond not only to external environmental conditions, but also to physiological constraints, for example, the type of muscle fibre present in the hind-limb muscles, among others (Kingsolver and Huey 2003; Fernández et al. 2011; Fuller et al. 2011).

Regarding the effectiveness of thermoregulation (E = 0.64), *L. cuyumhue* may behave like a moderate thermoregulator during

Fig. 4. Box plots indicating median, 25th and 75th percentiles, and extremes of the maximum speeds of sprint (upper panel) and long runs (lower panel) of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*) at the five temperature treatments (22, 28, 33, 36, and 39.5 °C). Letters (a, b, c, d) indicate differences among temperature treatments (Tukey's post hoc test, $P < 0.05$).

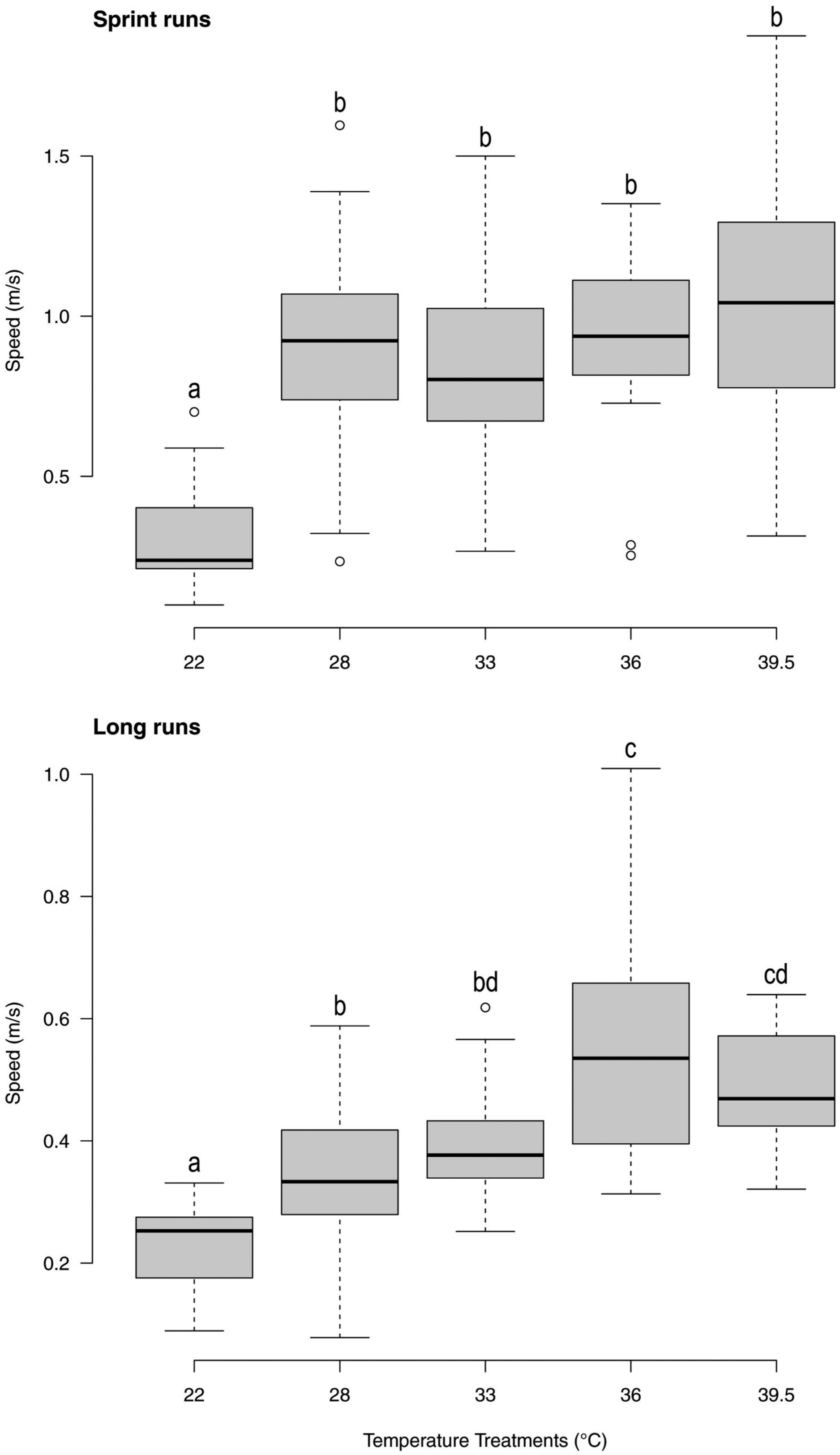


Table 2. Thermal safety margins (TSM) of sprint (SR) and long runs (LR) and the warming tolerance (WT) indices of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*) under different values of operative temperature (T_e; mean values of all the models, mean values of shadow models, and mean values of sun models).

	TSM_{SR} (°C)	TSM_{LR} (°C)	WT (°C)
$T_{e,mean}$	5.0	5.4	9.3
$T_{e,shadow}$	8.9	9.3	13.2
$T_{e,sun}$	2.6	3.0	6.9

the late summer season. The value of the thermal quality index (d_e = 5.52) is similar to the one calculated by Stellatelli et al. (2020) in populations of *L. multimaculatus*, which also live in dune environments with anthropogenic disturbances. It is important to note that in our study the T_bs were observed only in one day of late summer, and that they may change during the year, as seasonality has been recorded to be an important factor affecting body temperatures of temperate species of lizards (Stellatelli et al. 2018). The values of T_e show that the cost of thermoregulation is high in some microhabitats, and this could restrict vital activities such as searching for food, mating, avoiding predators, or engaging in social interactions (Huey and Slatkin 1976; Downes and Shine 1998). Selective microhabitat use, namely midday sheltering in vegetated patches, may allow evasion of critical maximum temperatures while enhancing the previously mentioned vital activities (Rocha 1995; Liz et al. 2019). According to Sartorius et al. (2002), xeric shrublands in deserts are ideal for lizard thermoregulation because the spatial scale of thermal variation is often small and movements between macrohabitats are not required to change thermal status. Also, specifically sand lizards select partially shaded sites in the warmest periods of the day and adopted raised postures to promote heat loss via air movement, in contrast to other species that move from open to shady areas to avoid overheating in the warmer periods of the day (Bujes and Verrastro 2008; Block et al. 2013; Maia-Carneiro and Rocha 2013). In this sense, for *L. cuyumhue*, the thermoregulatory behaviour and the use of microhabitats, specifically shaded ones, are the only way they could buffer the stressful conditions of the low thermal quality environment that they inhabit.

In reference to our last hypothesis, about the effect that global warming could have on *L. cuyumhue*, our results suggest that this species would be affected by this phenomenon. Despite the high warming tolerance index (WT = 9.31), the thermal safety margins show that if the latest IPCC predictions are correct (an increase of 3.5 °C between the years 2016 and 2035 for our study site), then *L. cuyumhue* will be forced to avoid microhabitats exposed to the sun to maintain its performance within optimal values. To survive, *L. cuyumhue* must rely on access to shelters during seasonal and daily extreme temperatures (Sunday et al. 2014); as a consequence, the time and space available for lizards to perform vital activities are expected to decrease (Sinervo et al. 2010; Logan et al. 2013). Recent studies suggest that ectothermic organisms from desert environments have a high extinction probability under current rates of global warming because it is unlikely that they will have a sufficiently rapid adaptive change in T_b to buffer from those changes in ambient temperature (Deutsch et al. 2008; Sinervo et al. 2010). In addition, Li et al. (2017) suggests that this risk differs among desert species, with higher risk for those having narrower thermal safety margins, as is the case of *L. cuyumhue* compared with the Mongolia Racerunner (*Eremias argus* Peters, 1869), the Multi-ocellated Racerunner (*Eremias multiocellata* Günther, 1872), and Przewalski's Toadhead Agama (*Phrynocephalus przewalskii* Strauch, 1876) from the Chinese Hobq Desert. Also, according to several authors, species from arid middle latitudes (20°S–40°S) may be more vulnerable to climate warming than tropical species because of the higher thermal variability in temperate zones, which increases the incidence of lethal temperatures (Clusella-Trullas et al. 2011; Vasseur et al. 2014; Kubisch et al. 2016), but this was not observed in our results. In this sense, the warming tolerance was lower and the thermal safety margin was similar in four tropical species of the genus *Anolis* Daudin, 1802 (WT = 3.1–7.8 °C, TSM = 1.5–5.5 °C; Logan et al. 2013) with those of *L. cuyumhue*.

Unfortunately, *L. cuyumhue* is already avoiding exposure to direct sun during the extreme temperatures of the day; therefore, given the future climate change scenario, the availability of suitable microhabitats for thermoregulation could be compromised, increasing its vulnerability. Currently, most distributions of *L. cuyumhue* suffer from high anthropogenic impact and from lack of any kind of protection for this essential environment, making our findings of its ability to cope with temperature threats particularly important. Therefore, accounting for its strict endemism, as well as the WT and TSM values in shade, we can point out the importance of microhabitats for the persistence of this species and consequently the importance of implementing urgent measures to protect the current suitable habitats that support populations of *L. cuyumhue*. In conclusion, similar to other studies, we show that the quality of the microhabitats is essential for the persistence of desert lizards (Flesch et al. 2017; Huey and Pianka 2018). Future research activities should be focused on studying basic aspects of the biology such as feeding, reproduction, and use of time space for the implementation of an appropriate management plan for this species. Also, studies of the physiological plasticity of this species as a short-term response to overcome global warming are necessary.

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CURRENT AND POTENTIAL DISTRIBUTION OF THE ENDANGERED ENDEMIC LIZARD *LIOLAEMUS CUYUMHUE*: IMPLICATIONS FOR CONSERVATION

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Abstract.—**To identify the threats a species is facing, the first step is to locate its populations and their distribution. When other ecological studies are not possible, knowing the distribution of a species and if possible, inferences about its density, can be enough to make informed management decisions for conservation priorities. In addition, with up-to-date knowledge of the geographic distribution, it is possible to carry out analysis of potential distributions through Ecological Niche Modelling (ENM). Here, we address for the first time the study of the distribution of a critically endangered lizard, the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*). We surveyed probable habitats of *L. cuyumhue*, estimated an index of population density in three areas where the species occurs, evaluated the nature of local habitat degradation in these areas, and interpolated its potential distribution. We surveyed 52 locations over the southernmost part of the Bajo de Añelo area and found *L. cuyumhue* at 16 sites. We also estimated differences in population density indexes among sites (Sites 2 and 1 and Sites 2 and 3), and among these, Site 2 had the highest population density of lizards and was characterized by more sources of disturbance. We confirmed that *L. cuyumhue* is an obligate endemic characterized by small populations, few occurrence records, and limited suitable habitats. We stress the need for urgent protection of all habitats that support isolated populations of this species.**

Key Words.—Añelo Sand Dunes Lizard; biogeography; ecological niche modeling; habitat suitability; niche

INTRODUCTION

There is extensive evidence of global decline in vertebrate populations (Gibbons et al. 2000; Light and Marchetti 2007; Beebee et al. 2009; Jones and Cresswell 2010; Hoffman et al. 2011). Approximately 200 vertebrates have disappeared in the past 100 y (Ceballos et al. 2017), and 15% of these species were reptiles (International Union for the Conservation of Nature 2021). Additionally, some studies suggest that between 15% and 44% of reptiles of the world are threatened with extinction (Böhm et al. 2013; Ceballos et al. 2015). Habitat loss, fragmentation, human overexploitation, introduced invasive species, emerging diseases, environmental pollution, and climate change all increase risks of population declines and extinctions (Bosch et al. 2007; Sinervo et al. 2010; Böhm et al. 2016).

Identification of threats to any species first requires locating its populations, and then assessing what factor(s) threaten the species. When detailed ecological studies are not possible, at least knowing the distribution of a species, and if possible, its abundance, can be enough to make informed management decisions for conservation priorities (Moreira-Muñoz et al. 2012; Guisan et al. 2013; Sunny et al. 2017; Rodríguez-Rodríguez et al. 2018). Further, knowledge of the species current and former geographic distribution allows assessment of potential distribution through Ecological Niche Modeling (ENM). Refinement of a species historical distribution may then permit a projection of possible future shifts in the species geographic range (Moreira-Muñoz et al. 2012). Modeling the potential geographic distributions of a species by relating observed occurrence localities to environmental data have been widely applied across a range of biogeographical analyses (Guisan and Thuiller 2005; Van Schinger et al. 2014; Yi et al. 2016; Zhao et al. 2020). This approach aims to estimate the realized coarse-resolution environmental requirements of a species, which can then be projected onto real-world landscapes to identify regions in which the requirements of the species are manifested (Saupe et al. 2012). Geographical regions presenting similar environments to where the species has been observed can thus be identified (Pearson et al. 2007). Consequently, ENM can

Figure 1. (A) Adult male and (B) habitat of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*). (Photographed by Victoria Brizio).

inform conservation decisions such as designing surveys for new populations and making spatial prioritization decisions for management actions, regulatory decision-making, and compliance, among other decisions (Sofaer et al. 2019; Simoes et al. 2020).

Here, we address for the first time the distribution of a critically endangered lizard species of the *Liolaemus wiegmannii* group (Etheridge 2000; Villamil et al. 2019); the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*; Fig. 1). This species is known only from two localities in a small, isolated sand-dune system in the Bajo de Añelo east-central region of Neuquén province, northern Patagonia, Argentina (Avila et al. 2009). It remains poorly known since its description, but a recent study of its thermal biology highlights its vulnerability to global warming (Brizio et al. 2021). Individuals of *L. cuyumhue* are observed only on bare or sparsely vegetated Mediterranean Aeolian dunes characterized by extensive areas of open sand (Fig. 1). The cryptic coloration and motionless behavior of the lizard, coupled with a very fast sand-diving behavior, enable it to avoid detection or escape possible predators. Across virtually all of it restricted distribution, the habitat of this species is degraded due to extensive livestock ranching (primarily Goats, *Capra hircus*, but some Cattle, *Bos taurus*, and Horses, *Equus caballus*), and poorly regulated gas and oil drilling (Mazzoni and Vazquez 2009). These are constant threats for *L. cuyumhue* and its habitat. New rigs, pipelines, power lines, and roads are opened regularly (Fig. 2), further modifying or destroying the few remaining suitable habitats (Avila 2016). The conservation of *L. cuyumhue* is of great concern (Avila 2016; Brizio et al. 2021) and an action plan that ensures the long-term viability of the species is urgently needed. In this study we: (1) surveyed the probable habitats of *L. cuyumhue* along the Bajo de Añelo regions to locate new populations/update its geographic distribution; (2) estimated an index of population density in three areas where the species occurs and evaluated the nature of local habitat degradation and potential threats in each of these areas; and (3) used occurrence records to interpolate the potential distribution of *L. cuyumhue*.

Materials and Methods

Study site.—We carried out our study in the Bajo de Añelo basin, located in the center-east of Neuquén province, Argentina (37.4° to 38.5°S and 68.4° to 69.8°W). The Bajo de Añelo Basin comprises the lowest area of the province (230 m elevation) covering an area of 9,000 km^2 within the Monte Desert Region (Roig et al. 2009). The climate is temperate arid to semi-arid, with a mean annual temperature of 14.2° C and a mean annual precipitation of 137.2 mm, occurring mainly in winter and spring (Busso and Bonvissuto 2009). The vegetation presents a marked physiognomic-floristic homogeneity, characterized by being a shrubby steppe with perennial foliage represented by shrubs in the genus *Larrea* with little herbaceous cover and a scarcity of grasses and trees (Leon et al. 1998; Roig et al. 2009).

Data collection.—We traveled to the Bajo de Añelo during the activity season of the lizard, from January 2003 through December 2020. We surveyed 52 locations, all of which were separated from each other by at least 1 km. We could not survey some private lands where oil and gas extractions were in progress. We surveyed only the low elevation Bajo de Añelo habitats, those between 230 to 600 m, higher elevations did not have the dune environments used by *L. cuyumhue*. We actively searched 1000–1700 in the spring and 0800–1200 and 1700–2000 in the summer.

We selected three sites to estimate the population status of *L. cuyumhue*, approximately 5 km apart from each other, with all with a confirmed presence based on the 52 surveyed locations. We placed eight cross pitfall traps at each site and spaced these about 25 m apart along the dunes. We checked each pitfall trap monthly throughout the spring and summer (20 September to 20 March) for three consecutive years. We toe-clipped all lizards with an individual ID number based on the

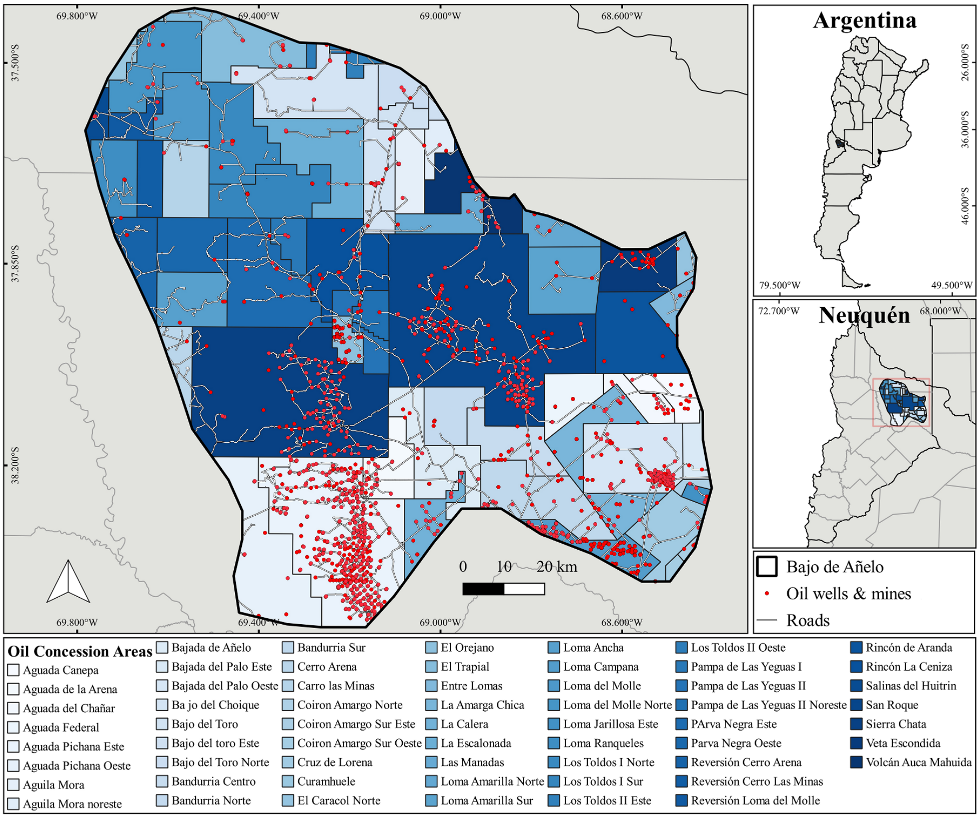

FIGURE 2. The study area Bajo de Añelo, Argentina, with the various oil concession areas shown in blue and oil wells and mines shown as red dots. (Data from http://hidrocarburos.energianeuquen.gov.ar/?page_id=1978)

code described by Woodbury (1956). Loss of a few toes does not have significant deleterious effects to terrestrial lizards (Borges-Landáez and Shine 2003). We calculated a standardized index of population density by dividing the total number of sighted lizards by the particular area (expressed as individuals[ind]/ha). We also recorded the following sources of disturbance at each site (as described by Rocha et al. 2009): (1) heavy traffic; (2) presence of limited oil well activity; (3) removal of sand and dune vegetation for oil activities; (4) presence of construction machinery on the dunes; (5) presence of vehicle tracks on the dunes; and (6) presence of cattle.

Data analysis.—We tested data for normality using the Shapiro-Wilk Test, and for homogeneity of variances using Levene's Test. To analyze the effect of site on lizard density, we used a Linear Mixed Model (LMM) with a normal distribution. We performed *post hoc* pairwise comparisons (Tukey's Test) between levels for the site effect. Using the locations of where we found lizards, we also estimated the Area of Occupancy (AOO), a measure of the area in which the species occurs, and the Area of Extension (AOE), a measure of the geographic range size of the species, using the GeoCAT (Geospatial Conservation Assessment Tool; Batchman et al. 2011).

To identify the potential distribution area of *L. cuyumhue*, we analyzed the presence data with the Wallace software (Kass et al. 2018), an R-based GUI ecological modeling algorithm to build, evaluate, and visualize models of niches and species distributions. This program is available as the R package Wallace on CRAN, with a development version on Github. We selected 16 environmental variables from WorldClim Bioclims, excluding the four layers that combine precipitation and temperature information into the same layer (Bio 8, Bio 9, Bio 18 and Bio 19; Table 1). The combinations we excluded have shown odd spatial anomalies in the form of odd discontinuities between neighboring pixels (Escobar et al. 2014). To avoid multicollinearity, we estimated the correlations among environmental variables (Appendix Table 1). Each variable from a highly correlated pair ($r^2 > 0.8$) was retained/rejected according to our knowledge. This led to retaining eight ecologically relevant variables (Table 1).

Because at the resolution of 1 km (30 arcseconds) all of our variables were correlated, we worked with the 5 km resolution (2.5 arcminutes), and to avoid spatial autocorrelation (i.e., locations close to each other exhibit more similar values than those further apart), we filtered all presence points that were < 5 km

Table 1. Environmental variables available at WorldClim Bioclims that we used for a correlation analysis. The variables highlighted in bold are the ones that were not correlated with each other and were used for the modeling.

Environmental Variables	
BIO1 =	Annual Mean Temperature
BIO2 =	**Mean Diurnal Range (Mean of monthly [max temp - min temp])**
BIO3 =	**Isothermality (BIO2/BIO7) (×100)**
BIO4 =	Temperature Seasonality (standard deviation ×100)
BIO5 =	Max Temperature of Warmest Month
BIO6 =	Min Temperature of Coldest Month
BIO7 =	**Temperature Annual Range (BIO5-BIO6)**
BIO10 =	**Mean Temperature of Warmest Quarter**
BIO11 =	Mean Temperature of Coldest Quarter
BIO12 =	**Annual Precipitation**
BIO13 =	Precipitation of Wettest Month
BIO14 =	Precipitation of Driest Month
BIO15 =	**Precipitation Seasonality (Coefficient of Variation)**
BIO16 =	**Precipitation of Wettest Quarter**
BIO17 =	**Precipitation of Driest Quarter**
ELEV =	Elevation

apart. We selected a modeling procedure based on the jackknife technique, appropriate for low numbers of observations (Pearson et al. 2007). Finally, we built the model through MAXENT with 10,000 iterations of data randomizations and selected the best fit following Warren and Seifert (2011) and Elith et al. (2011). We evaluated ENM performance with the Omission Rate (OR10%), the maximum test Area Under the Receiver Operator Curve (AUC_{Test}) for the averaged models, and the corrected Akaike Information Criterion (AICc).

Results

We found *Liolaemus cuyumhue* in 16 of the 52 surveyed locations (Fig. 3; Appendix Table 2), all of which were within 231 and 540 m elevation with an AOE of 730,827 km^2 and AOO of 16,000 km^2. The estimated population density indexes varied significantly across the three locations ($F_{2,40} = 5.29$, $P < 0.009$). We found significant differences between Site 2-Site 1 Tukey's *post hoc* test = -0.211, $P = 0.016$) and Site 2-Site 3 (Tukey's *post hoc* test = 0.196, $P = 0.026$). Site 2 supported the highest lizard density, 8.4 ind/ha, and had all disturbance sources except heavy traffic. Site 1 had the lowest density with 4.0 ind/ha, along with heavy traffic, presence of vehicle tracks on the dunes, and cattle as disturbance sources. Site 3 had a slightly higher density index than Site 1 of 4.3 ind/ha with only presence of vehicle tracks on the dunes and cattle as disturbance sources. The most important variables in determining habitat suitability of *L. cuyumhue* were isothermality (bio3), mean temperature of the warmest quarter (bio10), and precipitation of the wettest quarter (bio16; Table 2). The potential distribution map (Fig. 4) shows the highest probability (red) and zero probability (blue) habitable areas, and intermediate habitats (identified by the remaining colors).

Discussion

Our data show that the habitat of *L. cuyumhue* is restricted to small, isolated patches within a large area, heavily impacted by human activity. One unexpected result of this study is the surprisingly high density of lizards at one site (Site 2), which is embedded within the region with the highest number of disturbances. In contrast, the sister species, the Sand Dune Lizard (*L. multimaculatus*), endemic to coastal isolated sand dunes, has smaller populations within areas with high levels of degradation (Vega et al. 2000; Rocha et al. 2009; Kacoliris et al. 2011). Considering the presumably low quality of the Site 2 habitat, further study is needed to see if this region function as what is called an ecological trap (Heinrichs et al. 2018). Many ecosystems may provide habitats less than optimal for species populations (Railsback et al. 2003). As such, population density alone cannot be used to assess the conservation status of a species, and basic natural history data, demographic trends, and spatial dynamics are needed (Hawlena et al. 2010). Furthermore, density values for *L. cuyumhue* in Sites 1 and 3 were similar to those obtained for its sister species, *L. multimaculatus* (4.1–5.2 ind/ha; Kacoliris et al. 2009). Also, habitat mean thermal quality values (d_e) were also similar for the population densities of *L. cuyumhue* at Site1 (Brizio et al. 2021) and for *L. multimaculatus* at the Mar Chiquita Reserve (Stellatelli et al. 2020). These sister species are also morphologically and behaviorally very similar (Avila et al. 2009).

Different population densities are known in other closely related species of *Liolaemus*, including the Dune Lizard (*L. arambarensis*; 2–27 ind/ha; Martins et al. 2017), *L. wiegmannii* (no common name; 100 ind/ha; Martori et al. 1998), and the Sand Lizard (*L. lutzae*; 41–114 ind/ha; Rocha 1998). Additionally, population densities in other desert-dwelling lizards are generally lower; examples include several North American species: the Texas Horned Lizard (*Phrynosoma cornutum*; 5.0 ind/ha; Endriss et al. 2007); the Blunt-nosed Leopard Lizard (*Gambelia sila*; 16.0 ind/ha; Germano and Williams 2005); the Western Whiptail (*Aspidoscelis tigris*; 7.34 ind/ha; Furnas et al. 2019); the Common Side-blotched Lizard (*Uta stansburiana*; 3.88 ind/ha; Furnas et al. 2019); and the Zebra-tailed

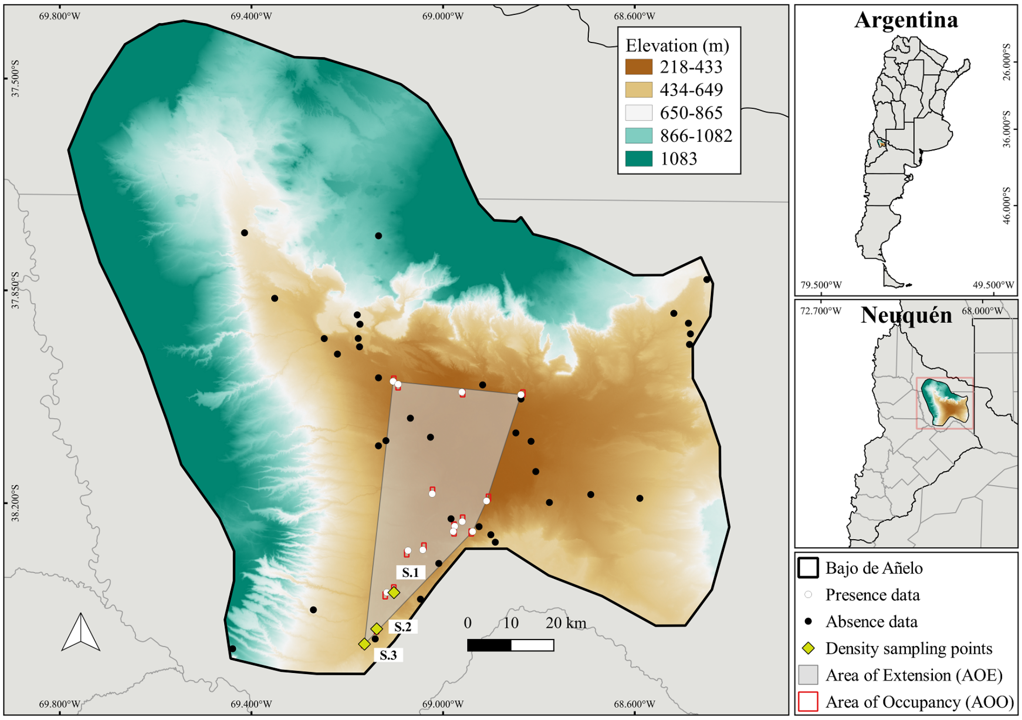

FIGURE 3. Distribution of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*) in Argentina. Black dots show all the surveyed locations, white dots presence data, S1, S2, S3 are the density sampling points, brown polygon shows the extension area (AOE; a measure of the geographic range size of the species), and the small red rectangles the occupancy area (AOO; a measure of the area in which the species occurs).

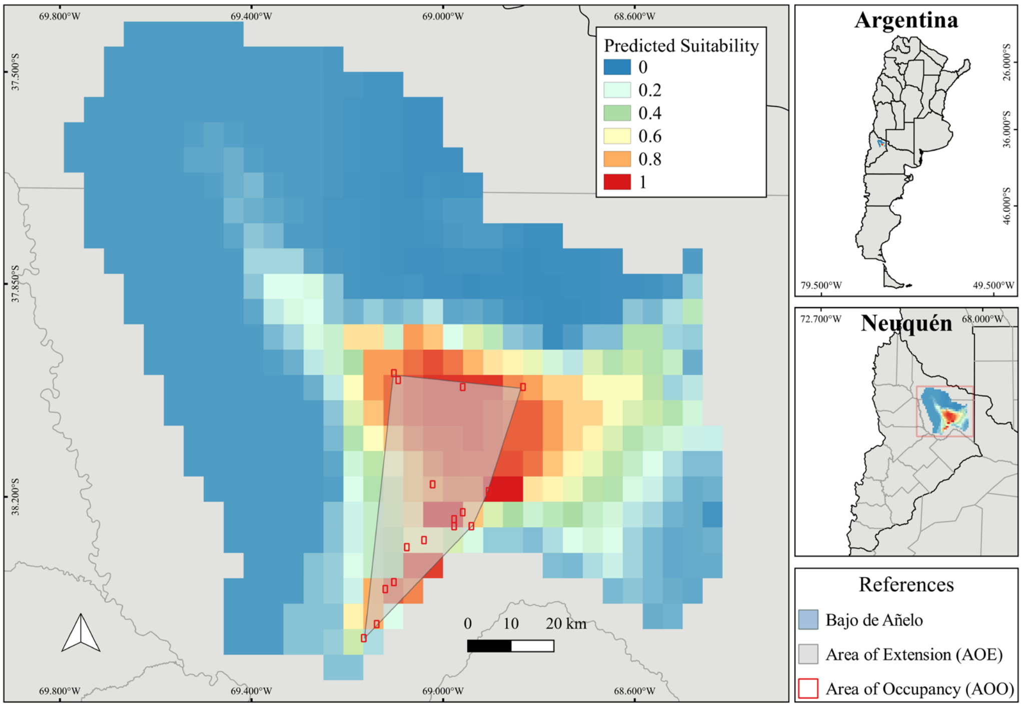

FIGURE 4. Predicted potential geographic distribution map of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*) in Argentina based on presence records (red rectangles) and climatic variables.

Table 2. Performance of the top 10 models of potential distribution of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*) with the selected model in bold. The models are named with the number of the regularization multiplier and the family functions that they belong: Hinge (H); Linear (L); or Quadratic (Q). The table shows the values of Omission Rate (OR10%), the maximum test Area Under the Receiver Operator Curve (AUC_{Test}) for the averaged models, the Standard Deviation for it (AUC_{Test} SD), and the corrected Akaike Information Criterion (AICc).

Models	OR10%	Average AUC_{Test}	AUC_{Test} SD	AICc	Parameters
2.5_fc.H	**0.222**	**0.960**	**0.032**	**96.871**	**3**
1_fc.L	0.333	0.968	0.026	99.014	4
3.5_fc.H	0.222	0.955	0.038	101.795	3
4_fc.LQ	0.222	0.938	0.059	103.217	2
4_fc.H	0.222	0.953	0.039	103.441	3
3.5_fc.L	0.222	0.938	0.059	103.728	2
4_fc.L	0.222	0.935	0.059	105.732	2
3_fc.LQH	0.222	0.955	0.037	106.365	4
3_fc.H	0.222	0.956	0.035	106.876	4
3.5_fc.LQH	0.222	0.953	0.038	109.441	4

Lizard (*Callisaurus draconoides*; 1.02 ind/ha; Furnas et al. 2019). These differences could be due to different phylogenetic histories, and/or intrinsic characteristics of North American desert ecosystems, such as precipitation, solar radiation, low soil fertility, and low productivity (Maestre et al. 2015; Hoover et al. 2020). Further, the biogeographic history and geographic extent of each desert may explain these density values (Agarwal et al. 2015), as well as anthropic activities. For example, Furnas et al. (2019) reported low densities for *C. draconoides* of 1.2 ind/ha in the Mojave Desert as a result of human activities (urban, agricultural, transportation, and mining-related development).

Despite the near-absence of natural history data for this species, we were able to collect basic absence/presence data for this study. There are a number of avenues for improving this work, however, should more data become available. Further, other factors not considered in our modeling (thermal envelopes, soil geomorphology, biotic interactions, geographic barriers, among others) imply that species rarely occupy all environmentally suitable habitats (Anderson et al. 2002; Svenning and Skov 2004; Araújo and Pearson 2005). For these reasons, niche-based distribution model data must be interpreted conservatively (Pearson and Dawson 2003; Soberón and Peterson 2004; Phillips et al. 2006), but bioclimate models can provide a useful starting point when applied to suitable species and at appropriate spatial scales. In many cases, like ours, these models provide the best available guide for policy making at the current time (Hannah et al. 2002). The potential distribution map for *L. cuyumhue* that we included shows the center of the highest predicted suitability area (red and orange colored) without any presence data. This corresponds to the lowest part of the Bajo de Añelo, where numerous channels drain from ravines to form salt flats and permanent lagoons (Basaldúa, 2018). The dune environments that *L. cuyumhue* inhabits are near these salt flats and lagoons, between the presence data points and the 0.2 predicted suitability. We consider these areas extremely important for conservation because they harbor a rich and unique diversity, not only of reptiles, but also for little-studied groups such as arthropods (Roig-Juñent et al. 2001), birds (Rundel et al. 2007), and mammals (Ojeda et al. 2002).

Because *L. cuyumhue* was not formally described before the start of gas and oil development in the region, we cannot know if it has already been impacted by these activities, but it is strictly endemic to these geographically restricted habitats and characterized by low population densities and few occurrences. We urge immediate protection of these small but unique habitats, as a recent study showed how rapidly habitat alteration in this dunes environment can lead to local extinction of specialist endemic species like the Shoulder Tree Iguana (*Liolaemus scapularis*; Cabrera 2021). Similarly, the distribution of a North American dune-dwelling Dunes Sagebrush Lizard (*Sceloporus arenicolus*) was negatively affected by oil and gas development (Smolensky and Fitzgerald 2011; Walkup et al. 2017). In another example, Vega et al. (2000) studied *L. multimaculatus* and the Graceful Tree Iguana (*L. gracilis*) before and after the construction of a road; 7 y after the disturbance, patches of vegetation destroyed by construction had not recovered, which accelerated soil erosion, followed by a notable decrease in the abundance of *L. multimaculatus.*

Given the above studies, we urge land protection as a priority to maintain a viable population size for this species, and its meta-population structure by protecting the connectivity of its so-called island habitats. Similar recommendations have been suggested for similar cases (Dixo and Metzger 2009; Kacoliris et al. 2019). Future research activities should focus on other basic life-history attributes, including feeding, reproduction, population viability, and habitat connectivity, as the scientific basis for implementation of appropriate conservation strategies for these unique habitats.

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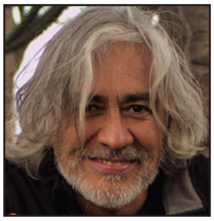

Daniel Roberto Pérez is a Professor of Restoration Ecology at the Universidad Nacional del Comahue (Argentinean Patagonia) and the Universidad del Centro de Argentina (Buenos Aires, Argentina). He conducts an interdisciplinary research group with a focus on recovery of degraded areas of the Monte Desert in Neuquén Province, Argentina. Although his current research has an emphasis on ecological, social, and cultural aspects of territories affected by severe disturbances, he has extensive field knowledge and work experience in arid zone fauna, with collaborations for the description of new species and distributions of lizards. (Photographed by Joaquín Pérez Carrió).

Mariana Morando is a Professor of Genetics and Evolution at the National University of Patagonia San Juan Bosco, Argentina. She has a degree in Biological Sciences from the Universidad Nacional de Río Cuarto, Argentina, and simultaneously earned a Master's degree at Brigham Young University (Provo, Utah, USA) and a Ph.D. at the Universidad Nacional de Tucumán, Argentina, on systematics, phylogeography, and other evolutionary aspects of lizards from Patagonia and northwestern Argentina. Mariana started as a CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas) researcher in 2006 and is a Senior Researcher of the Patagonian Herpetology Group. One of her interests is species delimitation and the role of hybridization in the evolutionary history of the highly diverse genus *Liolaemus*, taking into account the geological and climatic history of Patagonia. (Photographed by Luciano J. Avila).

Luciano Javier Avila has a degree in Biological Science from the Universidad Nacional de Río Cuarto and a Ph.D. from the Universidad Nacional de Tucumán, both in Argentina, and was Postdoctoral Fellow at Brigham Young University, Provo, Utah, USA. Luciano began his career as a Researcher from CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas) in 1998 and currently is the Director of the Research Centre Instituto Patagónico para el Estudio de los Ecosistemas Continentales (IPEEC-CONICET) in Puerto Madryn, Chubut Argentina. His research interests involve systematics, taxonomy, and species distribution of southern South American herpetofauna, mainly from Monte, Patagonia, and High Andes ecoregions, but he is interested in species limits, phylogenies, bioinventories, biogeography, spatial ecology, and diversity of lizards. (Photographed by Tadeo I. Avila).

Appendix Table 1. Results of the correlation analysis used to select environmental variables used to determine the distribution of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*) in Argentina. **S**ignificant correlations are in bold.

	BIO1	BIO2	BIO3	BIO4	BIO5	BIO6	BIO7	BIO10	BIO11	BIO12	BIO13	BIO14	BIO15	BIO16	BIO17	ELEV
BIO1	1.000	0.053	-0.758	**0.880**	**0.983**	**0.918**	0.695	**0.998**	**0.991**	0.132	-0.132	0.335	-0.367	-0.221	0.423	**-0.983**
BIO2	0.053	1.000	0.452	0.193	0.227	-0.217	0.655	0.077	0.012	0.540	0.418	0.494	0.016	0.391	0.483	0.101
BIO3	-0.758	0.452	1.000	-0.785	-0.667	-0.703	-0.378	-0.770	-0.717	0.006	0.410	-0.152	0.544	0.440	-0.235	**0.828**
BIO4	**0.880**	0.193	-0.785	1.000	**0.902**	0.644	**0.866**	**0.910**	**0.808**	0.341	-0.177	0.498	-0.584	-0.228	0.584	**-0.853**
BIO5	**0.983**	0.227	-0.667	**0.902**	1.000	**0.853**	0.799	**0.987**	**0.964**	0.222	-0.065	0.412	-0.362	-0.154	0.499	**-0.942**
BIO6	**0.918**	-0.217	-0.703	0.644	**0.853**	1.000	0.369	**0.893**	**0.956**	-0.141	-0.181	0.083	-0.181	-0.273	0.166	**-0.940**
BIO7	0.695	0.655	-0.378	**0.866**	0.799	0.369	1.000	0.730	0.617	0.560	0.093	0.639	-0.437	0.041	0.699	-0.596
BIO10	**0.998**	0.077	-0.770	**0.910**	**0.987**	**0.893**	0.730	1.000	**0.980**	0.162	-0.141	0.365	-0.404	-0.226	0.454	**-0.978**
BIO11	**0.991**	0.012	-0.717	**0.808**	**0.964**	**0.956**	0.617	**0.980**	1.000	0.060	-0.122	0.273	-0.294	-0.217	0.358	**-0.977**
BIO12	0.132	0.540	0.006	0.341	0.222	-0.141	0.560	0.162	0.060	1.000	0.718	0.595	0.091	0.726	0.620	-0.049
BIO13	-0.132	0.418	0.410	-0.177	-0.065	-0.181	0.093	-0.141	-0.122	0.718	1.000	0.119	0.728	**0.977**	0.111	0.193
BIO14	0.335	0.494	-0.152	0.498	0.412	0.083	0.639	0.365	0.273	0.595	0.119	1.000	-0.508	**0.093**	**0.932**	-0.236
BIO15	-0.367	0.016	0.544	-0.584	-0.362	-0.181	-0.437	-0.404	-0.294	0.091	0.728	-0.508	1.000	0.726	-0.534	0.353
BIO16	-0.221	0.391	0.440	-0.228	-0.154	-0.273	0.041	-0.226	-0.217	0.726	**0.977**	0.093	0.726	1.000	0.089	0.274
BIO17	0.423	0.483	-0.235	0.584	0.499	0.166	0.699	0.454	0.358	0.620	0.111	**0.932**	-0.534	0.089	1.000	-0.331
ELEV	**-0.983**	0.101	**0.828**	**-0.853**	**-0.942**	**-0.940**	-0.596	**-0.978**	**-0.977**	-0.049	0.193	-0.236	0.353	0.274	-0.331	1.000

Appendix Table 2. Coordinates of the sampling points with confirmed and unconfirmed presence of the Añelo Sand Dunes Lizard (*Liolaemus cuyumhue*).

Point	Longitude	Latitude	Presence
1	-68.96000	-38.23028	YES
2	-69.02278	-38.18469	YES
3	-69.10433	-37.99994	YES
4	-69.16417	-38.43139	YES
5	-68.90933	-38.19638	YES
6	-68.96078	-38.01753	YES
7	-68.83739	-38.02177	YES
8	-69.09376	-38.00466	YES
9	-68.93836	-38.24660	YES
10	-69.13862	-38.40606	YES
11	-69.10039	-38.34532	YES
12	-69.11733	-38.34626	YES
13	-69.04240	-38.27668	YES
14	-69.07313	-38.27760	YES
15	-68.97569	-38.23788	YES
16	-68.97885	-38.24653	YES
17	-69.00900	-38.29881	NO
18	-69.43928	-38.43850	NO
19	-69.14169	-38.42242	NO
20	-69.27075	-38.37483	NO
21	-69.04719	-38.35741	NO
22	-68.89103	-38.26406	NO
23	-68.90033	-38.25180	NO
24	-68.92495	-38.23855	NO
25	-68.98342	-38.22564	NO
26	-68.77811	-38.19886	NO
27	-68.58930	-38.19208	NO
28	-68.69173	-38.18589	NO
29	-68.80653	-38.14815	NO
30	-69.13489	-38.10583	NO
31	-68.81638	-38.09850	NO
32	-69.11931	-38.09742	NO
33	-69.02633	-38.09173	NO
34	-68.84814	-38.08466	NO
35	-69.06825	-38.06047	NO
36	-68.83739	-38.02894	NO
37	-68.91744	-38.00572	NO
38	-69.13483	-37.99401	NO
39	-69.22055	-37.95501	NO
40	-69.17439	-37.94306	NO
41	-68.48568	-37.93914	NO
42	-69.17719	-37.92919	NO
43	-68.48375	-37.92175	NO
44	-68.48786	-37.90422	NO
45	-69.17919	-37.89044	NO
46	-68.51833	-37.88797	NO
47	-68.44942	-37.83222	NO
48	-69.13472	-37.76000	NO
49	-69.41440	-37.75512	NO
50	-69.35146	-37.86316	NO
51	-69.17350	-37.90586	NO
52	-69.24806	-37.92944	NO

Resumen trabajo 1

En este trabajo se realiza la descripción formal desde el punto de vista científico de la nueva especie. El grupo *wiegmannii* de *Liolaemus* incluye *L. arambarensis*, *L. azarai*, *L. lutzae*, *L. occipitalis*, *L. multimaculatus*, *L. rabinoi*, *L. riojanus*, *L. salinicola*, *L. scap*ularis, *L. wiegmannii*, y las especies aquí descritas. Utilizamos secuencias mitocondriales cyt-b, 12S y ND4, y las regiones del gen nuclear C-mos para inferir la filogenia de la mayoría de las especies del grupo *wiegmannii*. Describimos una nueva especie que está estrechamente relacionada con *L. multimaculatus* y *L. riojanus*, pero se puede distinguir por una coloración dorsal diferente, ausencia de manchas supraescapulares y menor tamaño. *Liolaemus cuyumhue* sp. nov. Vive en marcado aislamiento geográfico con respecto a otras especies estrechamente relacionadas del grupo *wiegmannii*.

Resumen trabajo 2

En este trabajo se estudia la ecología térmica de la lagartija de arena. La temperatura corporal de las lagartijas está fuertemente influenciada por la calidad térmica de los microhábitats, aprovechando las temperaturas ambientales favorables, y evitando la exposición a condiciones térmicas extremas. Se considera que las poblaciones de reptiles son especialmente vulnerables a los cambios en las temperaturas ambientales producidos por el cambio climático cambio. Aquí, estudiamos la fisiología térmica del lagarto de las dunas de arena de Añelo (*Liolaemus cuyumhue*), en peligro crítico de extinción (Avila, Morando, Pérez y Sites, 2009). Nuestra hipótesis es que (i) existe una coadaptación térmica entre la temperatura óptima para el rendimiento locomotor de *L. cuyumhue* y su preferencia térmica; (ii) *L. cuyumhue* vive en un ambiente con calidad térmica; y (iii) un aumento de las temperaturas ambientales debido al calentamiento global impondrá una disminución de la velocidad representada por una menor tolerancia al calentamiento y márgenes de seguridad térmica más estrechos, lo que aumenta su ya alta vulnerabilidad. Se registraron las temperaturas corporales de campo (Tb), temperaturas corporales preferidas (Tpref), la temperatura operatoria (Te), y la sensibilidad térmica de la locomoción a diferentes temperaturas corporales. Nuestros resultados indican que este lagarto no se encuentra actualmente bajo estrés ambiental o superando sus límites térmicos, pero que se termorregula por debajo de Tpref para evitar el sobrecalentamiento, y que un aumento de la temperatura ambiental superior a 3,5 °C afectará fuertemente el uso de los microhábitats con exposición directa al sol.

Resumen trabajo 3

En este trabajo se realiza una revisión de la distribución geográfica conocida para la especie. Para identificar las amenazas a las que se enfrenta una especie, el primer paso es localizar sus poblaciones y su distribución. Cuando otros estudios ecológicos no son posibles, conocer la distribución de una especie y, si es posible, inferencias sobre su densidad, puede ser suficiente para tomar decisiones informadas de manejo para las prioridades de conservación. Además, con un conocimiento actualizado de la distribución geográfica, es posible realizar análisis de distribuciones potenciales a través de la Modelización de Nichos Ecológicos (ENM). Aquí, abordamos por primera vez el estudio de la distribución de un lagarto en peligro crítico de extinción, el lagarto de las dunas de Añelo (*Liolaemus cuyumhue*). Estudiamos los hábitats probables de *L. cuyumhue*, estimamos un índice de densidad poblacional en tres áreas donde se encuentra la especie, evaluamos la naturaleza de la degradación del hábitat local en estas áreas e interpolamos su distribución potencial. Se estudiaron 52 localidades en la parte más austral del área del Bajo de Añelo y se encontró *L. cuyumhue* en 16 sitios. También estimamos diferencias en los índices de densidad poblacional entre sitios (Sitios 2 y 1 y Sitios 2 y 3), y entre estos, el Sitio 2 tuvo la mayor densidad poblacional de lagartijas y se caracterizó por tener más fuentes de perturbación. Confirmamos que *L. cuyumhue* es un endémico obligado caracterizado por poblaciones pequeñas, pocos registros de ocurrencia y hábitats adecuados limitados. Hacemos hincapié en la necesidad de proteger urgentemente todos los hábitats que sustentan poblaciones aisladas de esta especie.

Resumen trabajo 4

En este trabajo se realiza un nuevo estudio de las relaciones filogenéticas del grupo de lagartijas arenícolas *Liolaemus wiegmannii* dentro del cual se encuentra la lagartija de la arena de Añelo, *Liolaemus cuyumhue*.

Los algoritmos basados en coalescencia, junto con el acceso a datos de todo el genoma, se han convertido en herramientas poderosas parala evaluación de las cuestiones relativas a la diversificación reciente o rápida, así como la delimitación de los límites de las especies en ausencia de monofilia recíproca. En el sur de América del Sur, la diversificación de los lagartos *Liolaemus* durante el Pleistoceno está bien documentado y se ha atribuido a los cambios climáticos que caracterizaron este período de tiempo reciente. Los cambios climáticos pasados tuvieron duros efectos en latitudes extremas, incluida la Patagonia, pero cambios de hábitat en latitudes intermedias de América del Sur también se han registrado, incluyendo la expansión de los campos de arena sobre el norte de Patagonia y Pampa. En este trabajo, aplicamos un enfoque coalescente para estudiar la diversificación del complejo de especies de *Liolaemus wiegmannii*, un clado morfológicamente conservador que habita en suelos arenosos el noroeste y centro-sur de Argentina, y la costa sur de Uruguay. Utilizamos de cuatro marcadores de secuencia estándar (ADN mitocondrial y tres loci nucleares) junto con los datos de ddRADseq inferimos límites de especies y un árbol filogenéticamente calibrado del complejo *L. wiegmannii* con el fin de evaluar la influencia ciclos de expansión/retracción de arena del Cuaernario en la diversificación del grupo. También se evaluó la independencia evolutiva del recientemente descripto *L. gardeli* e infirimos su posición filogenética en relación con *L. wiegmannii*. Encontramos pruebas contundentes de seis especies candidatas alopátricas dentro de *L. wiegmannii*, que se diversificaron durante el Pleistoceno. La gran glaciación patagónica (~1 millón de años antes del presente) probablemente dividió el complejo de especies en dos grupos principales: uno compuesto por linajes asociados a formaciones sedimentarias subandinas, y el otro relacionado mayoritariamente con campos de arena en la Pampa y el norte de la Patagonia. Nuestra hipótesis es que la especiación temprana dentro de *L. wiegmannii* fue influenciado por la expansión de las dunas de arena en todo el centro de Argentina y Pampa. Por último, *L. gardeli* es sostenido como un linaje distinto anidado dentro del complejo *L. wiegmannii*.

Point	Longitude	Latitude	Presence
1	-68.96000	-38.23028	YES
2	-69.02278	-38.18469	YES
3	-69.10433	-37.99994	YES
4	-69.16417	-38.43139	YES
5	-68.90933	-38.19638	YES
6	-68.96078	-38.01753	YES
7	-68.83739	-38.02177	YES
8	-69.09376	-38.00466	YES
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10	-69.13862	-38.40606	YES
11	-69.10039	-38.34532	YES
12	-69.11733	-38.34626	YES
13	-69.04240	-38.27668	YES
14	-69.07313	-38.27760	YES
15	-68.97569	-38.23788	YES
16	-68.97885	-38.24653	YES
17	-69.00900	-38.29881	NO
18	-69.43928	-38.43850	NO
19	-69.14169	-38.42242	NO
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21	-69.04719	-38.35741	NO
22	-68.89103	-38.26406	NO
23	-68.90033	-38.25180	NO
24	-68.92495	-38.23855	NO
25	-68.98342	-38.22564	NO
26	-68.77811	-38.19886	NO
27	-68.58930	-38.19208	NO
28	-68.69173	-38.18589	NO
29	-68.80653	-38.14815	NO
30	-69.13489	-38.10583	NO
31	-68.81638	-38.09850	NO
32	-69.11931	-38.09742	NO
33	-69.02633	-38.09173	NO
34	-68.84814	-38.08466	NO
35	-69.06825	-38.06047	NO
36	-68.83739	-38.02894	NO
37	-68.91744	-38.00572	NO
38	-69.13483	-37.99401	NO
39	-69.22055	-37.95501	NO
40	-69.17439	-37.94306	NO
41	-68.48568	-37.93914	NO
42	-69.17719	-37.92919	NO

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44	-68.48786	-37.90422	NO
45	-69.17919	-37.89044	NO
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47	-68.44942	-37.83222	NO
48	-69.13472	-37.76000	NO
49	-69.41440	-37.75512	NO
50	-69.35146	-37.86316	NO
51	-69.17350	-37.90586	NO
52	-69.24806	-37.92944	NO

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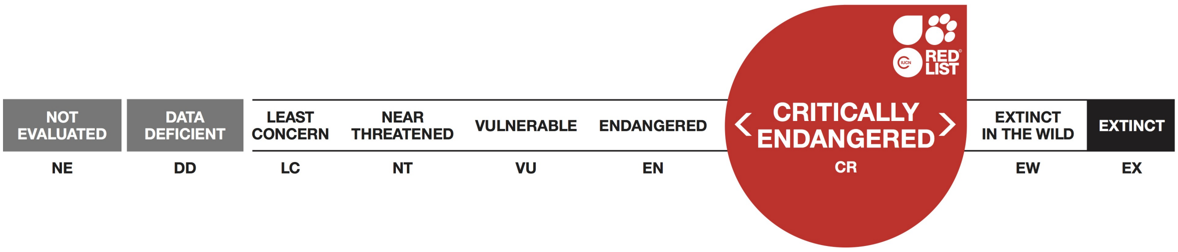
Liolaemus cuyumhue

Assessment by: Avila, L.



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Citation: Avila, L. 2016. *Liolaemus cuyumhue. The IUCN Red List of Threatened Species 2016*: e.T56052426A56052434. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T56052426A56052434.en

Taxonomy

Kingdom	Phylum	Class	Order	Family
Animalia	Chordata	Reptilia	Squamata	Liolaemidae

Taxon Name: *Liolaemus cuyumhue* Avila, Morando, Perez & Sites, 2009

Assessment Information

Red List Category & Criteria:	Critically Endangered B1ab(iii)+2ab(iii) ver 3.1
Year Published:	2016
Date Assessed:	November 12, 2014

Justification:

This species is listed as Critically Endangered because it is known only from the type locality in a small sand dune system and there is intensive oil and gas exploration and exploitation that is causing continuing decline in the extent and quality of its habitat.

Geographic Range

Range Description:

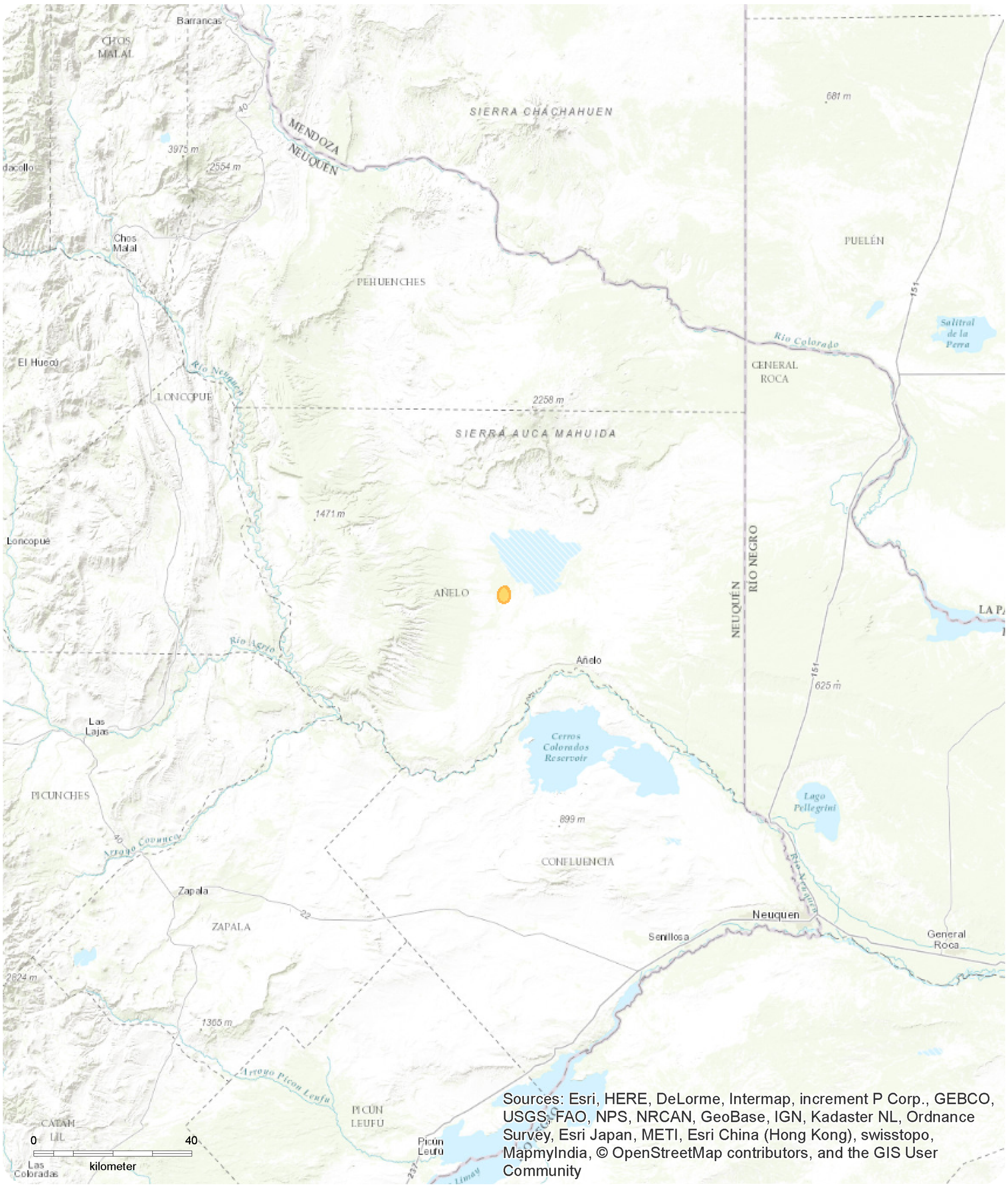
Liolaemus cuyumhue is known only from the type locality in Añelo basin close to the Provincial Road 7, in Neuquén Province (Avila *et al*. 2009). The holotype was collected at 259 m and one of the paratypes at 260 m (Avila *et al*. 2009). The area of occupancy is estimated to be around 5 km^2, the extent of the dune system.

Country Occurrence:

Native: Argentina (Neuquén)

Distribution Map

Liolaemus cuyumhue



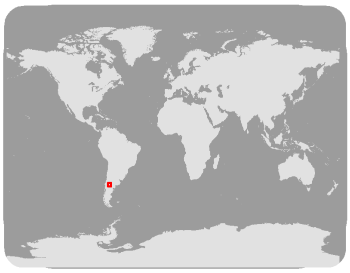
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

NE DD LC NT VU EN CR CRITICALLY ENDANGERED EW EX

Range

🟧 Extant (resident)

Compiled by:
NatureServe; IUCN
(International Union for
Conservation of Nature)



Population

There are no data on population size and trends for this species. It is a rare species.

Current Population Trend: Unknown

Habitat and Ecology (see Appendix for additional information)

Liolaemus cuyumhue is known from an isolated sand dune system in the region known as Bajo de Añelo, in eastern Neuquén. The dunes are sparsely covered by clumps of *Sporobolus rigens*, *Neosparton darwinii*, *Larrea divaricata*, *Prosopis flexuosa* var *depressa*, and *Atriplex zampa*. Individuals of *L. cuyumhue* are observed only on bare or sparsely vegetated dunes with extensive areas of open sand. They appear not to extend out into the more vegetated sandy flats or rocky areas that usually border the dunes. It is insectivorous and presumably oviparous, as are other members of the *wiegmannii* group (Avila *et al*. 2009).

Systems: Terrestrial

Use and Trade

There is no known use of or trade in this species.

Threats (see Appendix for additional information)

Liolaemus cuyumhue lives in a region were the oil and gas companies conduct some of the more intensive operations in Argentina; new rigs, tracks and roads are opened regularly; frequently modifying some areas with suitable habitats for *L. cuyumhue* that apparently do not cover large areas in the Bajo de Añelo (Avila *et al*. 2009, Abdala *et al*. 2012).

Conservation Actions (see Appendix for additional information)

This species is categorized as Vulnerable in Argentina (Abdala *et al*. 2012). The species is not known to occur in protected areas.

Credits

Assessor(s):	Avila, L.
Reviewer(s):	Bowles, P.
Facilitators(s) and Compiler(s):	NatureServe

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Citation

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External Resources

For Images and External Links to Additional Information, please see the Red List website.

Appendix

Habitats

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Habitat	Season	Suitability	Major Importance?
3. Shrubland -> 3.8. Shrubland - Mediterranean-type Shrubby Vegetation	-	Suitable	-
8. Desert -> 8.2. Desert - Temperate	-	Suitable	-

Threats

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Threat	Timing	Scope	Severity	Impact Score
3. Energy production & mining -> 3.1. Oil & gas drilling	Ongoing	Whole (>90%)	Unknown	Unknown
	Stresses:	1. Ecosystem stresses -> 1.2. Ecosystem degradation		

Conservation Actions in Place

(http://www.iucnredlist.org/technical-documents/classification-schemes)

Conservation Actions in Place
In-Place Land/Water Protection and Management
Occur in at least one PA: No

Additional Data Fields

Distribution
Estimated area of occupancy (AOO) (km²): 5
Estimated extent of occurrence (EOO) (km²): 5-99
Number of Locations: 1
Lower elevation limit (m): 259
Upper elevation limit (m): 260
Habitats and Ecology
Continuing decline in area, extent and/or quality of habitat: Yes

The IUCN Red List Partnership

The IUCN Red List of Threatened Species™ is produced and managed by the IUCN Global Species Programme, the IUCN Species Survival Commission (SSC) and The IUCN Red List Partnership.

The IUCN Red List Partners are: BirdLife International; Botanic Gardens Conservation International; Conservation International; Microsoft; NatureServe; Royal Botanic Gardens, Kew; Sapienza University of Rome; Texas A&M University; Wildscreen; and Zoological Society of London.

Sugerencias y acciones de conservación

Se deberían realizar mayores estudios sobre el estado de sus poblaciones, biología y grado de amenaza que presentan el ambiente que habita. Asimismo se debería realizar una campaña de educación ambiental en las áreas donde habita esta especie, a fin de desmitificar mitos, enseñar las verdaderas cualidades y peligro que corre esta especie.

Liolaemus cinereus Monguillot, Cabrera, Acosta & Villavicencio, 2006

Acosta, J. C.

Categoría 2012

INSUFICIENTEMENTE CONOCIDA

Categoría anterior en Argentina

No Evaluada

Categoría UICN

No Evaluada

Justificación

Especie recientemente descripta. Su distribución es desconocida sólo se ha encontrado en el sector sur del Parque Nacional San Guillermo, provincia de San Juan, (Junta de Palca y margen norte del cauce del río Blanco, salida de la quebrada Alcaparrosa). Sólo se han encontrado 3 individuos en ambientes típicos de Monte, por encima de los 2000 m s.n.m. Lagarto de pequeño tamaño (60 a 65 mm, LHC), microhábitat con grava y suelo arenoso, con escasa vegetación.Su biología es completamente desconocida (Acosta *et al.,* 2007).

Liolaemus cuyumhue Avila, Morando, Perez & Sites, 2009

Avila, L. J.; Morando, M.

Categoría 2012

VULNERABLE

Categoría anterior en Argentina

No Evaluada

Categoría UICN

No Evaluada

Justificación

Especie endémica de distribución muy restringida, habita exclusivamente dunas vivas encontradas en algunas áreas del denominado Bajo de Añelo, en el Departamento Añelo, provincia de Neuquén, (aprox. 38° 11’ S, 69° 01’ W, 259 m s.n.m.). Su densidad es baja y con requerimientos ecológicos muy específicos. La región donde se distribuye se encuentra en una zona de cada vez mayor actividad humana por el desarrollo de la industria petrolera y el desarrollo de obras que pueden destruir el hábitat de la especie.

Sugerencias y acciones de conservación

Extender el Área Natural Protegida Auca Mahuida hacia el sur de sus actuales límites para incluir áreas de distribución de la especie. Informar a los actores principales de los cambios ambientales, empresas petroleras y gobierno, de la existencia de este endemismo y sugerir acciones de conservación.