



Conservation assessments in climate change scenarios: spatial perspectives for present and future in two *Pristidactylus* (Squamata: Leiosauridae) lizards from Argentina

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Abstract

The consequences of global climate change can already be seen in many physical and biological systems and these effects could change the distribution of suitable areas for a wide variety of organisms to the middle of this century. We analyzed the current habitat use and we projected the suitable area of present conditions into the geographical space of future scenarios (2050), to assess and quantify whether future climate change would affect the distribution and size of suitable environments in two *Pristidactylus* lizard species. Comparing the habitat use and future forecasts of the two studied species, *P. achalensis* showed a more restricted use of available resource units (RUs) and a moderate reduction of the potential future area. On the contrary, *P. nigroiugulus* uses more available RUs and has a considerable area decrease for both future scenarios. These results suggest that both species have a moderately different trend towards reducing available area of suitable habitats, the persistent localities for both 2050 CO₂ concentration models, and in the available RUs used. We discussed the relation between size and use of the current habitat, changes in future projections along with the protected areas from present-future and the usefulness of these results in conservation plans. This work illustrates how ectothermic organisms might have to face major changes in their availability suitable areas as a consequence of the effect of future climate change.

Key words: Ectotherms, Habitat use, Niche modeling, Climate scenarios, Conservation areas

Introduction

Climate change on a global or regional scale generates large variations in physiology and phenology of the organisms, while species may exhibit changes in their distribution, interspecific interactions, in the structure and composition of communities (Hughes 2000; Walther *et al.* 2002). The climate alterations and global distribution of the current climate is likely to shift in the course of this century, and possibly some weather patterns disappear while others emerge (Williams *et al.* 2007). Future projections predict that climate change will occur mostly in temperate regions, including an average increase in global temperature and decreased precipitation (Christensen *et al.* 2007; Allison *et al.* 2009). The consequences of these climate shifts can already be seen in several physical and biological systems (Menzel *et al.* 2006; Meehl *et al.* 2007; Scheffer *et al.* 2009), and these effects could change the distribution of suitable areas for a wide variety of organisms by the end of this century. The changes in distribution of suitable areas for the species presence, increase or decline the risk of extinction of many taxa (Parmesan & Yohe 2003; Thomas *et al.* 2004; Attorre *et al.* 2007), especially those with a restricted geographical distribution (Gibson *et al.* 2010; Penman *et al.* 2010).

An additional aspect that can negatively affect the future is the status of current conservation, so that if species are currently threatened they may be plausible to suffer further negative changes in the conservation status (Marini *et al.* 2010). The persistence of populations of organisms under future climate scenarios depends on whether the adaptive or dispersion abilities which allow species to track or detect suitable habitat conditions in other environments (Martínez-Meyer *et al.* 2004; Tingley *et al.* 2009). The taxa without any of these skills in relation to the rapid changes likely to become extinct (Peterson *et al.* 2005); because of this, biodiversity can decline and leave

ecological opportunities available to general or highly opportunistic species which usually possess the skills and abilities to thrive and expand geographically (Malcolm *et al.* 2002; Loarie *et al.* 2009).

Ectothermic organisms and particularly reptiles are experiencing severe reductions or confirmed extinctions of populations worldwide (Sinervo *et al.* 2010), with confirmed species extinctions (Honegger 1981; IUCN 2015) and it is estimated that ~19 % (range 15-36 %) of all world taxa are considered under the endangered species category (Böhm *et al.* 2013, 2016). The current decline in reptiles is considered a global problem with complex local causes and related to climate change (Kujala *et al.* 2013), and habitat alteration and fragmentation caused mainly by human activities (Thomas *et al.* 2004; Böhm *et al.* 2013). Lizards are particularly vulnerable to climate change and habitat destruction because of their reproductive strategies and low dispersion capacity (Zajitschek *et al.* 2012). Therefore, displacement and contraction of the appropriate climatic-environmental areas represents a major threat to the conservation of lizards species with little physiological adaptability (*e.g.*, Huey *et al.* 2012; Ceia-Hasse *et al.* 2014).

The potential effects of climate change can be assessed by developing models that provide working hypotheses to support research and conservation strategies (El-Gabbas *et al.* 2016; Jones *et al.* 2016). Previous works on lizards from temperate (Vera-Escalona *et al.* 2012; Nori *et al.* 2016) and cold environments (Bonino *et al.* 2015; Breitman *et al.* 2015) in Patagonia, have shown changes in the distributional ranges by comparing modeled present niche versus other temporary scenarios. In the particular case of the lizards of temperate-cold environments, it is essential to prioritize species and populations in situ monitoring, with the aim of supporting conservation decisions, but also to assess whether the actual effects correspond to those provided by the models (Kubisch *et al.* 2015).

Regional and local factors can determine patterns by which communities of organisms are assembled, and the resulting degree of similarity or difference between localities with similar environments (Chase 2003). Lizards are an object of optimal study to test the climate changes effects, as this group of ectotherms organisms is very susceptible to climate change (Kubisch *et al.* 2015) and they some taxa are included in conservation status within the risk categories (Abdala *et al.* 2012). In this study, we evaluated the potential effects of climate change projected for 2050 in two *Pristidactylus* species lizard using ecological niche modeling (ENM, *sensu* Townsend Peterson & Soberón 2012). Additionally, various ecological aspects of *Pristidactylus* species remain today insufficiently known (*e.g.*, its ability to spread), so this study will provide relevant information at the regional level for their conservation. The projection of the present modeled distributions coupled with comparisons versus a 35 future medium-term model (Merow *et al.* 2013), allow to obtain solid evidence on which possible conservation actions are available and to face modulated shifts by climate change (Fitzpatrick & Hargrove 2009). We selected two species ecologically and geographically distant to obtain accurate georeferenced records and tested the potential effects of future climate change in their distribution ranges. We used as target for this study *Pristidactylus achalensis* (Gallardo 1964) and *P. nigroiugulus* (Ceia *et al.* 2001), employing records from herpetological collections of Argentina and online database resources.

The objectives of this study for these taxa were i) to determine which resource units from the environmental variables used were more influential in their distribution; and ii) evaluate the current distribution through habitat suitability models, and assess future spatial changes projecting these conditions into two scenarios CO₂ concentration for 2050. From the comparison of the present and future modeled distributions (modulated by climate change), we explored the following distributional issues: 1 - The area availability of suitable habitats for these *Pristidactylus* species between the present-2050 scenarios; and 2 - The number of locations without a potentially suitable area in the future models. If the habitat suitability models for current populations differ with future models, a conservation priority could be established for areas or populations for the studied *Pristidactylus* species.

Material and methods

Studied species and localities data. The *Pristidactylus* genus has 10 species geographically ranging from 31° S of Argentina and Chile to the central region of Patagonia Argentina (Vidal Maldonado & Labra Lillo 2008; Minoli & Avila 2011; Minoli *et al.* 2015). In addition, occurrences of these lizards are considered rare and/or difficult to record (Ceia *et al.* 2001). These species live in very different environments, such as temperate-cold environments with sandy or rocky soils, forests subantarctic and in mesophilic environments (Ceia 1986). Most species are

relatively large and robust (~100 mm. snout-vent), diurnal, carnivorous and oviparous (Cei 1986). Within this genus, *P. achalensis* distribution is restricted exclusively to grassland high environments (1800-2000 msnm; Sinsch *et al.* 2002) with rocky substrate (Etheridge & Williams 1985) in central Argentina. This environment is located in an extensive touristic usage area and this taxon is considered under the “vulnerable” category (Abdala *et al.* 2012). On the other hand, *P. nigroiugulus* recently classified as “not threatened” (Abdala *et al.* 2012), has the widest geographic range for this genus, inhabit areas associated with basaltic plateaus and presents wider range of latitude-altitude (Cei *et al.* 2001).

We used 53 georeferenced presence localities (17 for *P. achalensis* and 36 *P. nigroiugulus*) from 142 individual records for these species (see Appendix 1). We obtained this information from the herpetological collection of reptiles (LJAMM-CNP) from Instituto Patagónico para el Estudio de los Ecosistemas Continentales – Centro Nacional Patagónico – CONICET (Puerto Madryn, Chubut, Argentina), literature records (Etheridge & Williams 1985; Avila 1994; Cruz *et al.* 1999; Cei *et al.* 2001; Sinsch *et al.* 2002; Salas *et al.* 2004) and additional verified data from Global Biodiversity Information Facility (GBIF 2015). Species sampling, observations and collecting events tend to be clustered around accessible roads and fields. This may give the possibility of inflating modeling results by including localities that are not spatially independent and does not present environmental variation between them (Dormann *et al.* 2012). In order to minimize potential geographic-sampling bias, we considered a locality for each species to any record separated from another presence with at least 5 km distance (Pearson *et al.* 2007). Based on the substantial local variation in climatic and altitude conditions that exists in both implemented extents (as shown in our environmental layers), we consider that localities separated by at least 5 km exhibit sufficient potential variation as to be considered spatially independent. This approach with a buffer distance allow to reduce errors associated, such as using low number of records and other geographical bias (i.e., the unknown error in the accuracy of geographic coordinates for presence data taken from records of museums, over-sampled sites and roads, etc.). We incorporated only records with no exact or available geographic locations, when was possible to assign approximate coordinates according to the detailed descriptions of locations as they appear in the records of museums and literature. We reviewed the historical presence records from all the analyzed collections.

Climate and environmental data. We modeled the habitat suitability for each studied species considering a soil layer (Dijkshoorn *et al.* 2005), the 19 bio-climatic variables for current conditions (~1950-2000) and a variable altitude from the data base WorldClim 1.4 – Global Climate (<http://www.worldclim.org>). We used ACCESS1-0 CMIP5 (2015) layers for modeling 2050 scenarios with 45 and 85 RCP concentrations, through a database downscaled and calibrated (bias corrected) using WorldClim 1.4 as baseline 'current' climate (WorldClim – Global Climate Data 2015). All used layers had a resolution of 30 arc-seconds (~1 km²). The IPCC performs simulations of the climate system response to increasing levels of greenhouse gases based on different assumptions about the size of the projected population, technological developments and socio-economic trends. The RCP85 scenarios projected relatively large changes based on the most recent observations, which suggested that climate change will be more severe than expected (Meehl *et al.* 2007; Rahmstorf *et al.* 2007; Smith *et al.* 2009). The RCP45 scenario projected an intermediate climate change, based on projections of a world with intermediate population and economic growth (Meehl *et al.* 2007).

We estimated the accessible area (M; *sensu* Barve *et al.* 2011) considering the ecological traits, environmental features and potential historical distribution to generated an extent for each species. We used these extent sizes to clip the environmental layers and generated 5000 random points for each species. We extracted the pixel values for each bio-climatic variable for both species from these random points and we used them to create a subset of variables. In order to obtain a representation of both types of climatic variables (Barbet-Massin & Jetz 2014), we divided them in two groups: 1—precipitation and 2—temperature. We evaluated the number of variables to use implementing an initial test Jackknife (Pearson *et al.* 2006). Then, for each variable group we performed a Spearman correlation test (threshold selected > 0.75) to avoid collinearity (Debandi *et al.* 2012; Dormann *et al.* 2013; Kershaw *et al.* 2013) and additionally a selection criterion with biological significance to the studied species (Rissler & Apodaca 2007; Debandi *et al.* 2012) related to the active months period for these studied species. We performed all correlation analysis with Ggally 1.0.1 R package (Schloerke *et al.* 2016).

Habitat use model in present scenario. We used an habitat definition *sensu* Hall *et al.* (1997), as the resources and conditions present in an area which produce occupancy by a given organism. Our aim was to study the habitat selection to identify the environmental characteristics (e.g., altitude, temperature) that make a place suitable for these *Pristidactylus* species. We reduced each study area into discretized resource units (RU), which

correspond to the pixels of a raster map (Manly *et al.* 2002), characterized by several environmental variables. Each available RU was characterized by an availability weight describing how the RU is available to the species (Calenge & Basille 2008). We considered a P-dimensional space of variables as the ecological space, and each RU is characterized by a measure on each environmental variable and corresponds to a point in this space. We defined the RUs with the bio-climatic variables previously selected and were considered useful to study habitat use (Basille *et al.* 2008). We analyzed the habitat use with The General Niche-Environment System Factor Analysis (GNESFA), which provides a very flexible framework to tackle this kind of exploration (see, Calenge & Basille 2008). Within this framework, we performed a Factor Analysis of the Niche, Taking the Environment as the Reference (FANTER) to identify bimodal niches, considering only the utilization weights as the “focus distribution” equivalent to habitat use (see, Calenge & Basille 2008; Caruso *et al.* 2015). We performed all habitat use analysis with “adehabitatHS 0.3.12” (Calenge 2015) R package.

Ecological niche models. We generated correlative models (Townsend Peterson *et al.* 2016) of ecological niche modeling (ENM) using MaxEnt (3.3.3k version; 2016) algorithm, which seeks maximum entropy density through a robust estimation requiring only records of presence (Phillips *et al.* 2006; Phillips & Dudík 2008; Elith *et al.* 2011) and supports a low number of localities (Pearson *et al.* 2007; van Proosdij *et al.* 2016). We calculated with this software the relationship between the current presence of each species and environmental variables, and projected them into the two future scenarios for CO₂ concentrations (2050 RCP45 and 2050 RCP85). We ran MaxEnt using the selected subset for each species of bio-climatic and altitude variables with the default configurations, except for: 10 replicates, 1000 Maximum iterations, “10 percentile training presence logistic threshold” as selected threshold for each average model.

We evaluated the ENMs performance with true skill statistic (TSS) for model’s replicates (Allouche *et al.* 2006; Lobo *et al.* 2008) and Area Under the Receiver Operator Curve (further abbreviated to AUC; Phillips *et al.* 2006; Elith *et al.* 2011) for the averaged models. TSS takes into account both omission and commission errors and success as a result of random guessing, hence this evaluation model is not affected by prevalence and also is not affected by the size of the validation set (Allouche *et al.* 2006). The TSS values ranges from -1 to +1, where +1 indicates perfect agreement and values of zero or less indicate a performance no better than random (Allouche *et al.* 2006), and we considered these values as model performance indicators: < 0.05–0.05 no agreement, 0.06–0.39 = poor, 0.40–0.55 = fair, 0.56–0.70 = good, 0.71–0.85 = very good, 0.86–0.99 = excellent, 0.99–1 = perfect (following Monserud & Leemans 1992). The AUC is a measure of rank-correlation and high AUC values indicates that sites with high predicted suitability values tend to be areas of known presence and locations, whereas a model with lower prediction values tend to be areas where the species is not known to be present (absent or a random point). An AUC score of 0.5 means that the model is as good as a random guess, so we considered AUC range values to interpret model performance *sensu* Araújo *et al.* (2005): excellent ≥ 0.90 ; good ≥ 0.80 ; fair ≥ 0.70 ; poor ≥ 0.60 ; fail ≤ 0.50 .

Given the importance of the substrate for thermoregulation in this genus (Labra 1995; Vidal Maldonado & Labra Lillo 2008), and based on that the few publications of the studied species analyzed data from soil habitat (Avila *et al.* 2003) and obtained some results of relationships between reproduction ratios and temperature (Sinsch *et al.* 2002), we considered to employ of a soil layer to clip the average models output (present and 2050 RCP45-RCP85). We used the average model for each studied scenario and clipped the area intersected with the soil layer, taking into account only the type of soils in which the localities were registered. Then, we projected the current modeled conditions into the 2050 RCP45 and RCP85. Finally, we created binaries maps of suitable and unsuitable areas for each scenario.

Spatial analyses and potential effects on species populations. We used the suitable habitat from the final output models to quantified their area in km², and latitude longitude (minimum-maximum-range) extent for each species and scenario. From these surfaces, we intersected and calculated the percentage contained within the perimeter of a protected area currently existing. We analyzed the “future persistence” (*Fp*) as a simple intersection between localities and thresholded suitable areas. We archived this, evaluating the coincidence of present known localities with potentially suitable environment in the 2050 (RCP45 and RCP85) models. This spatial analysis for future scenarios is algebraically equivalent to $Fp = \text{current} * 2050 \text{ (RCP45, RCP85)}$; where *Fp* can be 0 = absence or 1 = presence (see, Zank *et al.* 2014). This might be interpreted as a rigid and conservative estimate of a potential persistence, since we did not considered areas of recolonization after a potential disappearance of suitable environment. Since there is almost no published literature on the spatial ecology of these species, our analyzes

were based on the assumption that none of these lizards would be able to disperse to new potentially suitable areas within the time period of the model. These assumptions were considered due to lack of ecological information on its dispersal ability and adaptability to all the bio-climatic variables considered in the models. This kind of assumptions are commonly associated with forecasting modeling niche techniques (Araújo & Pearson 2005; Elith & Leathwick 2009). However, this assumption could be considered as plausible within a relatively short time frame (35 years), the spatial extent of this study and its relation to the size of these lizard species.

We performed all spatial analyses and maps with “raster 2.5-2” (Hijmans 2015b), “maptools 0.8-39” (Bivand & Lewin-Koh 2016), “sp 1.2-2” (Pebesma & Bivand 2016), “rgdal 1.1-7” (Bivand *et al.* 2016), “geosphere 1.5-1” (Hijmans 2015a), “rgeos 0.3-17” (Bivand & Rundel 2016) R packages.

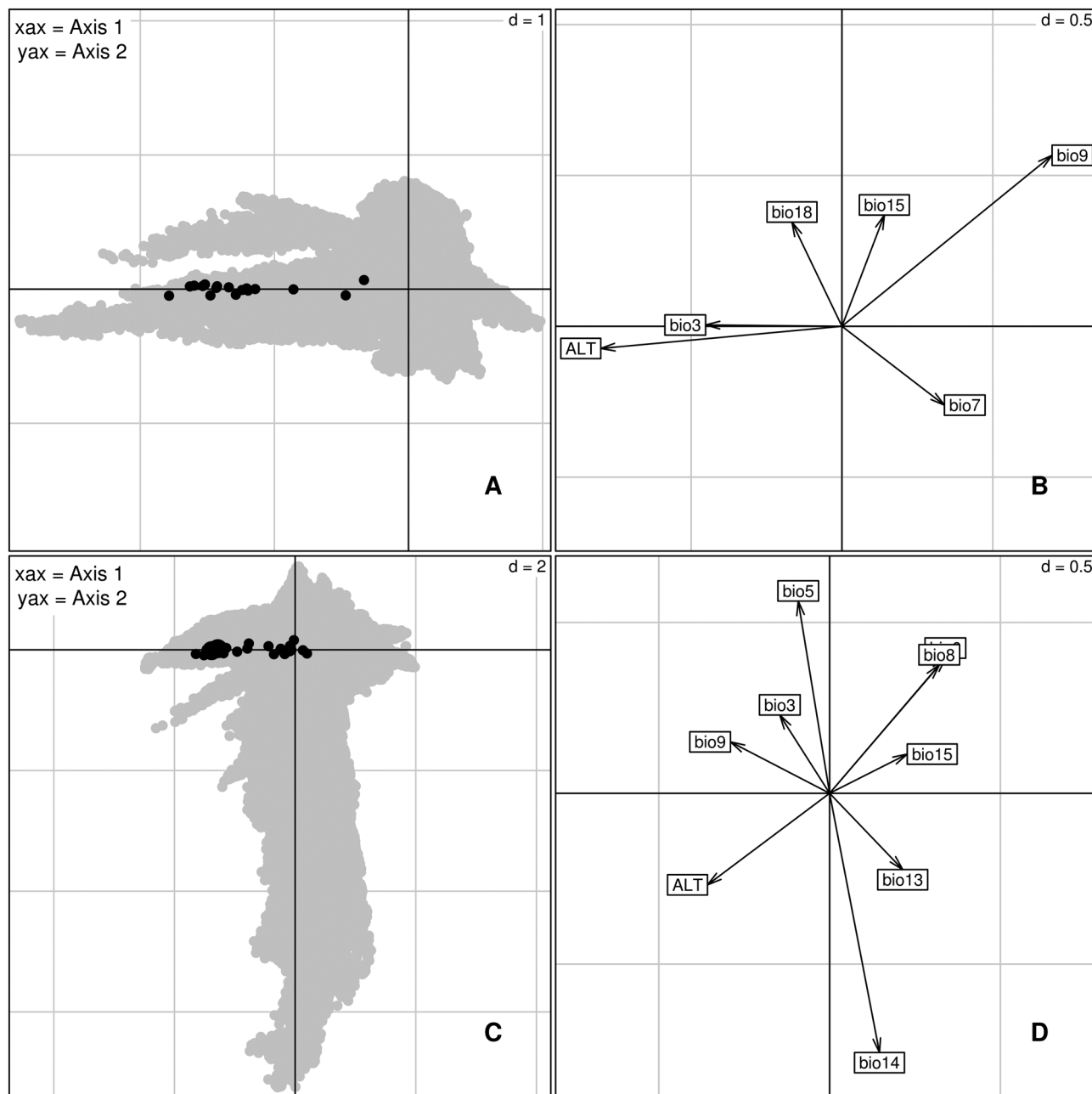


FIGURE 1. General Niche-Environment System Factor Analysis (GNESFA) and Factor Analysis of the Niche, Taking the Environment as the Reference (FANTER) for *Pristidactylus* species. Left column: grey points show the distribution of the RUs (here the pixels) on the axes found by the analysis and black points correspond to the RUs used by the species. Right column: correlations between the environmental variables and the axes. References: *P. achalensis* A–B; *P. nigroiugulus* C–D.

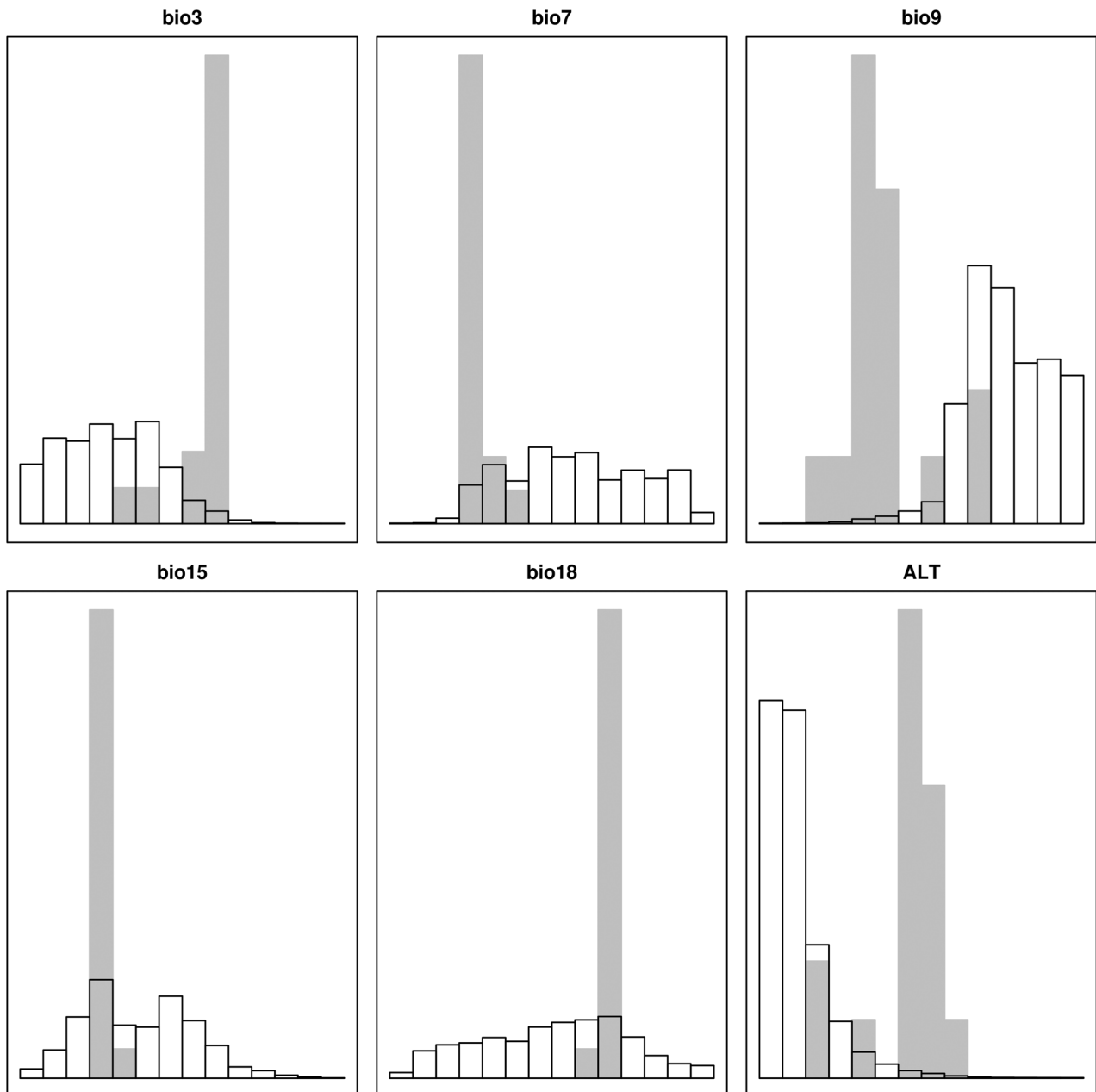


FIGURE 2. RUs histograms for *P. achalensis*. The white columns show the distributions of available RUs, whereas grey columns show the distributions of used RUs.

Results

Habitat use models. Considering the bio-climatic correlation analysis outcome, we selected for all analyses these environmental variables for each species: *P. achalensis*, bio3 (Isothermality = $(\text{bio2} / \text{bio7} * 100)$), bio7 (temperature annual range = $\text{bio5} - \text{bio6}$), bio9 (mean temperature of driest quarter), bio15 (precipitation seasonality), bio18 (precipitation of warmest quarter); and altitude, and bio3, bio5 (maximum temperature of warmest month), bio6 (minimum temperature of coldest month), bio8 (mean temperature of wettest quarter), bio9, bio13 (precipitation of wettest month), bio14 (precipitation of driest month), bio15 and altitude for *P. nigroiugulus*. Based on the eigenvalues obtained from the GNESFA "Focus = utilization" algorithm, we selected the first and the last component for both species. The FANTER results showed that the used RUs were distributed in a particular range of the first factorial axis and confirmed that this analysis found an interesting direction in the ecological space (Fig. 1). The grey points showed the distribution of the RUs on the axes found by the analysis, while the

black points correspond to the used RUs by the species (Fig. 1A-C). The eigenvalues showed a clear pattern only for the first axis for the two species (*P. achalensis* component 1 = 18.85, component 6 = 0.003; *P. nigroiugulus* component 1 = 3.83, component 9 = 0.004). *P. achalensis* (Fig. 1B) showed for the first component high correlation values with altitude (cor = -0.80), bio9 (cor = 0.70), and bio3 (cor = -0.45); and *P. nigroiugulus* (Fig. 1D) presented first component correlated with altitude (cor = -0.36), bio9 (cor = -0.29), bio6 (cor = 0.33) and bio8 (cor = 0.32). *P. achalensis* showed areas of utilization (Fig. 1A) characterized by high values for altitude and isothermality, and these used RUs were negatively correlated to low values of mean temperature of driest quarter or temperature annual range (Fig. 1B). The areas of utilization for *P. nigroiugulus* showed (Fig. 1C) high values for altitude, mean temperature of driest quarter, and these used RUs were negatively correlated to low values of minimum temperature of coldest month or mean temperature of wettest quarter (Fig. 1D). The distributions of available/used RUs for *P. achalensis* showed a high frequency of use of RUs (Fig. 2), especially in precipitation variables (bio15, bio18). Moreover, *P. nigroiugulus* showed values of RUs used more homogeneous and a higher frequency of use for temperature variables bio 5 and bio 9 (Fig. 3).

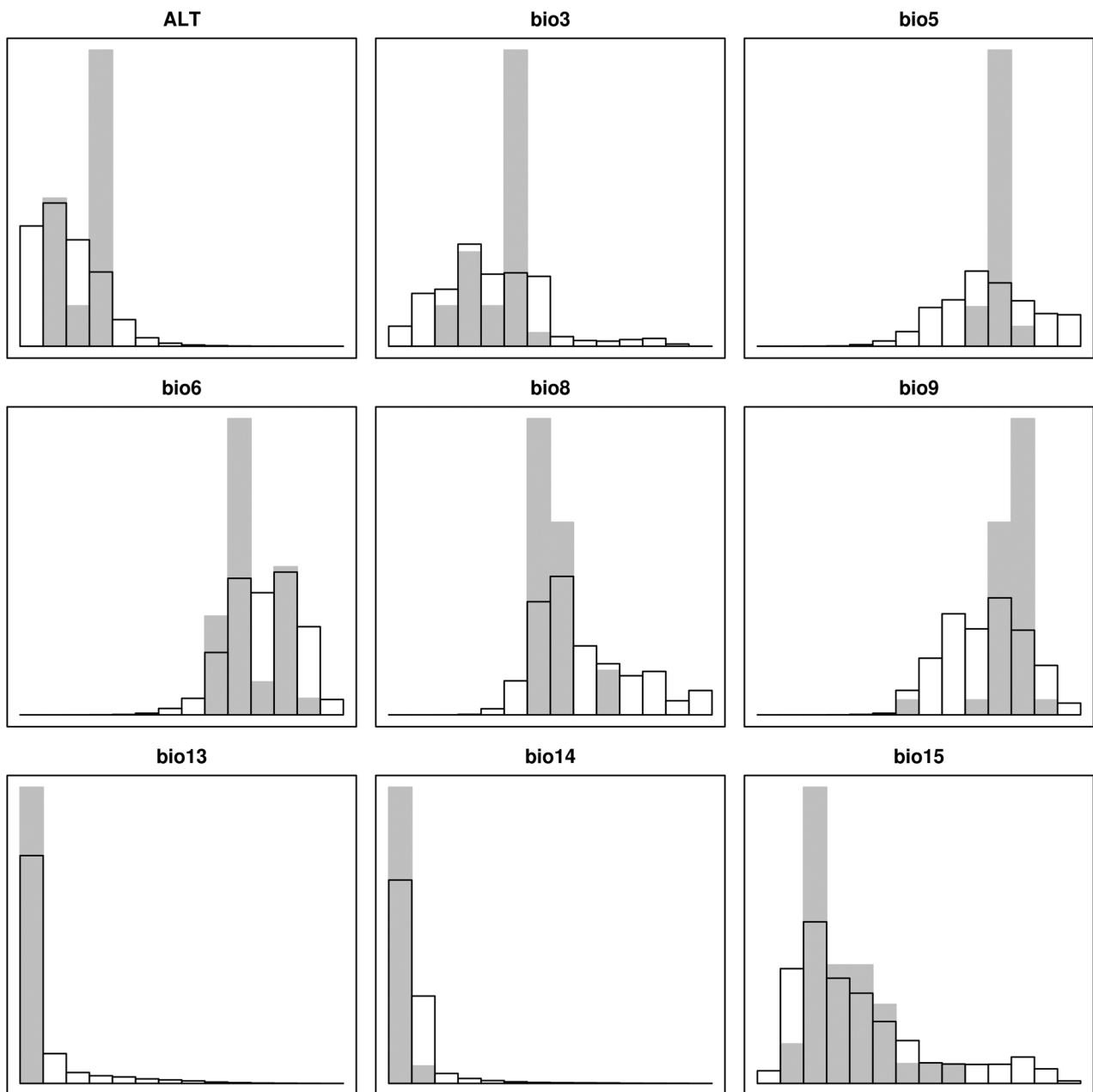


FIGURE 3. RUs histograms for *P. nigroiugulus*. The white columns show the distributions of available RUs, whereas grey columns show the distributions of used RUs.

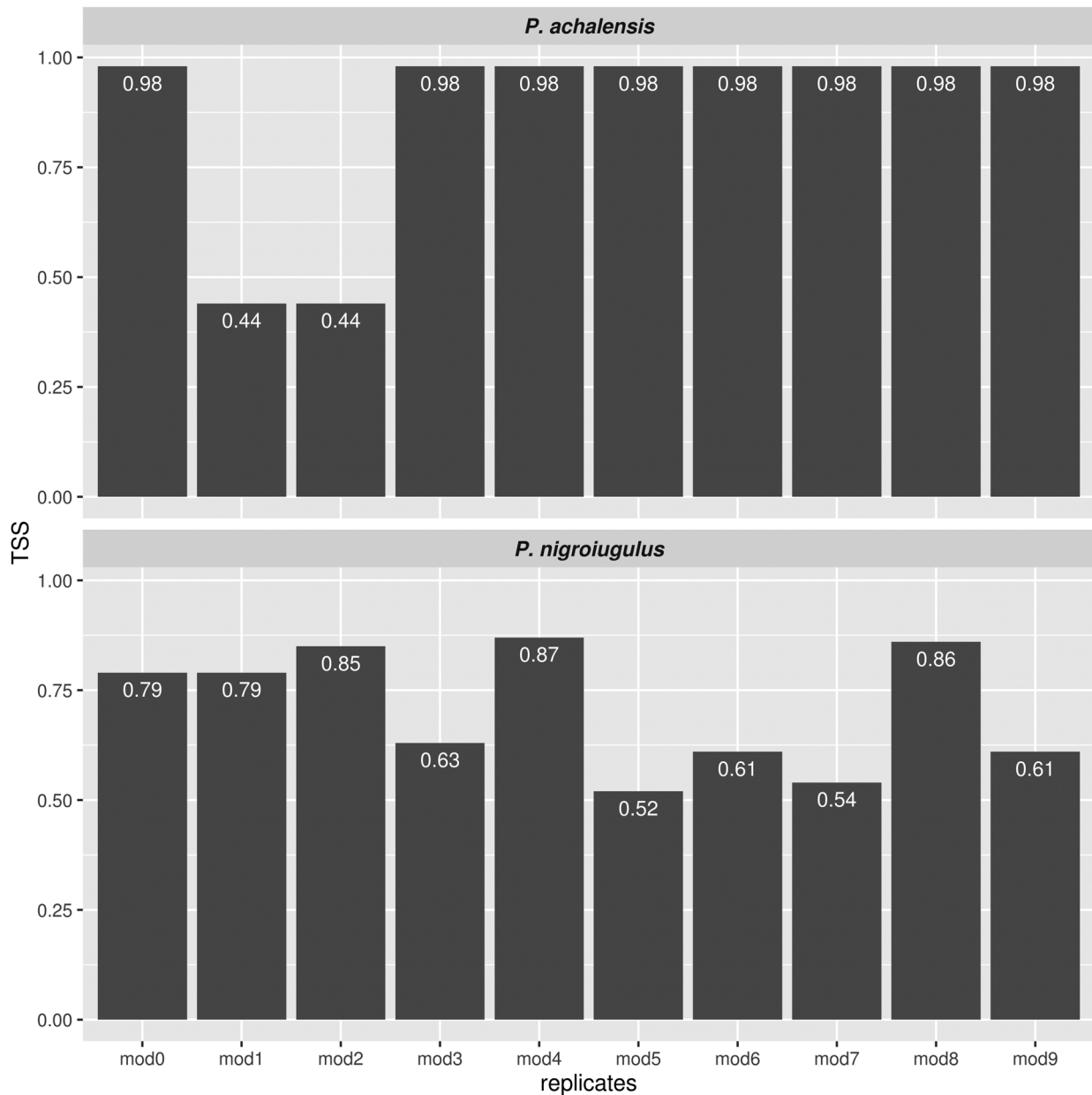


FIGURE 4. True skill statistic (TSS) performed on the replicates for each species. References: mod, number of model replicate; values close to 1 indicates perfect agreement, values near zero indicates a performance no better than random.

ENM, spatial analyses and potential future effects. The replicates performance through TSS indicated models fitted above “fair” or “good”, with relatively high values for most of the replicates in both species (Fig. 4). The average test AUC for the replicate runs for *Pristidactylus achalensis* was 0.922 (\pm 0.058 SD) and 0.984 (\pm 0.029 SD) for *P. nigroiugulus*. The suitable climate area in present scenario was 50,08.55 km² for *P. achalensis* (Fig. 5A) and 71,957.34 km² for *P. nigroiugulus* (Fig. 5D). For 2050 scenarios, the *P. achalensis*’ area decreased 19.06 and 46.53 % for 2050 RCP45 (Fig. 5B) and RCP85 (Fig. 5C) respectively (Table 1). The future models for *P. nigroiugulus* indicated a decrease of 21.95 % for 2050 RCP45 (Fig. 5E) and 46.49 % for RCP85 (Fig. 5F; Table 1). Both species did not showed future considerable differences in changes of latitude or longitude (Table 1). Regarding the relationship between the suitable area and the surface of protected areas, *P. achalensis* models showed for the current scenario 33 % (16,52.88 km²; Fig. 5A) of adequate areas contained in Pampa de Achala and Parque Nacional El Condorito, 32.67 % (16,36.43 km²; Fig. 5B) for 2050 RCP45 and 30.48 % (15,26.62 km²; Fig. 5C) for 2050 RCP85. The *P. nigroiugulus* models, presented for the current scenario 0.99 % (715.29 km²; Fig. 5D) of adequate areas contained in Área Natural Protegida Somuncurá, and none for 2050 RCP45 or RCP85.

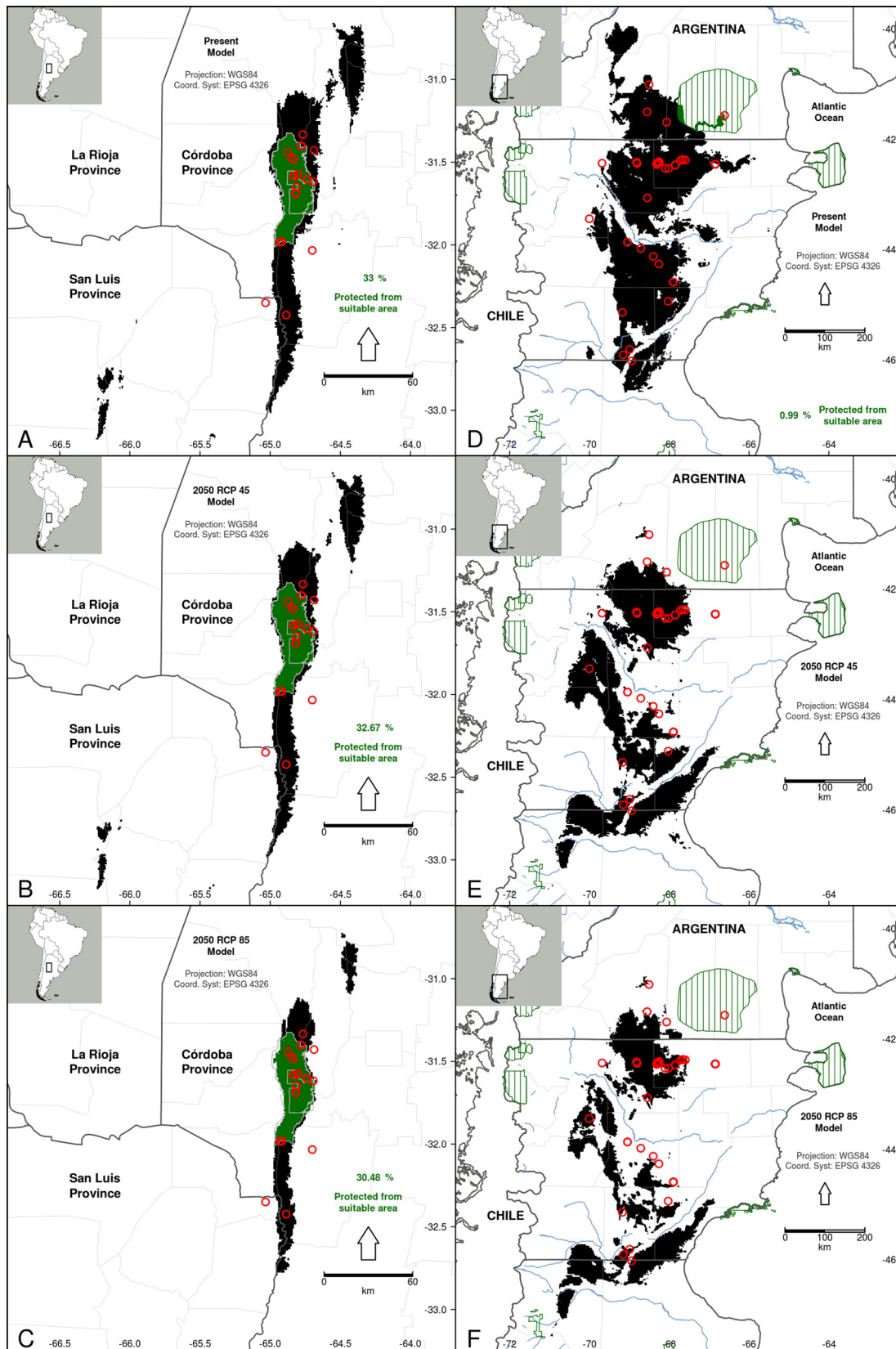


FIGURE 5. Area models for suitability habitat from the averaged replications output for: *P. achalensis*, A) Present model = 5008.55 km², B) Model for 2050 RCP 45 = 4054.00 km², C) Model for 2050 RCP 85 = 2677.83 km²; *P. nigroiuugulus*, 2) Present model = 71957.34 km², E) Model for 2050 RCP 45 = 56162.45 km², F) Model for 2050 RCP 85 = 38501.27 km². References: Country / province names, protected areas perimeters dashed-green lines, protected areas intersected with suitable areas filled in solid green, localities in red dots, and defined accessible area (M) in the upper left box.

The MaxEnt models for both 2050 CO₂ concentrations showed that the climatic conditions at a number of known presence sites may no longer be suitable for the persistence of both species (Table 1). The *Fp* for *P. achalensis* showed a relative small number of current locations below the threshold for future presence RCP85 (17.65 %; Table 1). On the contrary, *P. nigroiugulus* significantly reduced the number of presence records currently known that would find suitable conditions for 2050 rcp45 with 11 (30.56 %) localities and 14 (38.89 %) for RCP85 (Table 1).

TABLE 1. Spatial analysis performed on output models for each time scenario and CO₂ concentration. References: C.A % = percentage of change from previous scenario, NLL = northern latitudinal limit, SLL = southern latitudinal limit, Lat.R = latitudinal range, C.T. = change difference from latitudinal present range, WLL = western longitudinal range, ELL = eastern longitudinal range, Lon.R = latitudinal range, C.L. = change difference from present longitudinal range, Nv. Locs = localities with no suitable habitat.

	<i>P. achalensis</i>			<i>P. nigroiugulus</i>		
	Present	2050 rcp45	2050 rcp85	Present	2050 rcp45	2050 rcp85
Area (km ²)	5,008.55	4,054.00	2,677.83	71,957.34	56,162.45	38,501.27
C.A. %	-----	-19.06	-46.53	-----	-21.95	-46.49
NLL	-30.66	-30.73	-30.66	-39.88	-40.43	-40.87
SLL	-33.18	-32.79	-33.18	-46.58	-47.43	-47.38
Lat.R	-2.52	-2.06	-2.52	-6.70	-7.00	-6.51
C.T.	-----	-0.46	0.00	-----	0.30	-0.19
WLL	-66.24	-64.98	-66.23	-70.08	-71.03	-70.97
ELL	-64.32	-64.38	-64.33	-65.38	-66.75	-66.87
Lon.R	-1.93	-0.60	-1.91	-4.70	-4.28	-4.10
C.L.	-----	-1.33	-0.02	-----	-0.42	-0.60
Nv. Locs	2 (11.76 %)	2 (11.76 %)	3 (17.65 %)	3 (8.33 %)	11 (30.56 %)	14 (38.89 %)

Discussion

Habitat use models. This paper reports the first analysis of the variables determining the habitat use distribution of any *Pristidactylus* species in Patagonia and central Argentina, and our results confirmed the usefulness of this comprehensive approach to identify the factors affecting the ecological niche of two scarcely registered taxa. The specialization is a measure of habitat selection on a particular direction of the ecological space and is defined as the ratio of the variance of availability weights divided by the variance of the utilization weights (Basille *et al.* 2008). All species of this genus have relatively few known localities, but nevertheless our results consistently showed how a clear ecological direction of how the environmental variables affects these species' ecological niche. Comparing the habitat use between these two species, *P. achalensis* showed a more restricted use available RUs than *P. nigroiugulus*. The results of *P. achalensis* for habitat use showed the importance of altitude and Isothermality and low values of temperature, coupled with the use of available RUs could be interpreted as a narrow niche (Calenge & Basille 2008). This finding characterized and supported the prior knowledge of *P. achalensis* restricted distribution to high grassland environments located in the high hill formations (Sinsch *et al.* 2002). On the other hand, the broadest distributed species *P. nigroiugulus* were also characterized by altitude, but differed in high values of temperature and a higher use of available RUs.

These metrics are useful and relevant to wildlife managers and governmental authorities, because they allow the identification of the key habitats or factors limiting the use or distribution of species in a given area. These analyses are also an effective tool to analyze presence-only data, which are the most frequent source of spatial information available for elusive species.

Species distribution models. The species distribution in the geographic space underlies on different factors and not exclusively on bio-climatic variables (Peterson *et al.* 2005; Soberón & Peterson 2005). Despite this and consistently with previous studies in ectotherms, our results showed a general trend towards reducing the

potentially suitable area (Araújo *et al.* 2006; Bonino *et al.* 2015) and the number of present locations which will find a future suitable environment (Zank *et al.* 2014). Comparing the future forecasts among the studied species, *P. achalensis* showed a less reduction of the potential future area than *P. nigroiugulus*, which presented a major reduction of the potential future area and a high *Fp* progressive decrease. Although the studied taxa live in geographically distant environments and ecologically different, our findings supported the hypothesis that the suitable area will decrease as the result of exposure to future climate change. Although the differences between the results of the two species may be due to possible sampling bias (Syfert *et al.* 2013), the distribution employed here is all currently known for these taxa.

The potential barriers from reptiles are well documented in reptiles (Barbosa *et al.* 2012; Sahlean *et al.* 2014) and some lizards distribution could be influenced by presence of rivers as limits in the geographical range (Sillero & Carretero 2013). The most important finding in the geographic space context, was the future potential fragmentation of the *P. nigroiugulus*, which currently has a broader distribution range. The decreased of future potentially suitable areas for this species around a natural barrier (in this case, the area between Chubut and Chico rivers) were higher than elsewhere, but had also increased the suitable area in southern sector for 2050 models. However, potential expansions considered as “advantageous” for the species should be taken with caution as there are multiple factors (e.g., anthropized changes, such as oil extraction, cultivated soils, dams, desertification) that could play a decisive role in these shifts to materialize (Bastos *et al.* 2005; Nori *et al.* 2013). The major finding for *P. achalensis* was at the north of San Luis province, which might be a possible commission area. Recently, we performed surveys in this sector with the intention of validate the models output, and we detected environments with similar ecological conditions to Córdoba high grasslands. We consider that new field surveys are needed because this is one of the sectors that would be lost in the 2050 scenarios.

Although, future impacts of climate change keep a moderate uncertainty level being influenced by interactions and effects of biotic, abiotic, and dispersal considerations (Townsend Peterson *et al.* 2016), the robustness of decision-making can be improved by quantifying the risks and trade-offs associated with climate scenarios (Kujala *et al.* 2013). The limited knowledge of these species’ dispersion combined with the great fragmentation and degradation of the environments they inhabit (Ares *et al.* 1995; Aguiar *et al.* 1996; Bisigato & Bertiller 1997; Cesa & Paruelo 2011), leads us to think that some of the new suitable climate spaces predicted in our results remains uncertain whether they can be occupied or not in the future (Araújo *et al.* 2006; Araújo & New 2007; Colwell & Rangel 2009). These constraints of employed models may show an overestimating the forecast of the gain in the suitable climate spaces, which increase the uncertainty of their predictions (Radosavljevic & Anderson 2014).

Final considerations. In the last two decades many authors have done review works of concepts (Soberón & Nakamura 2009; McInerny & Etienne 2012a, 2012b, 2012c; Rangel & Loyola 2012; Townsend Peterson & Soberón 2012), advantages and disadvantages of correlative, mechanistic and process-oriented models (Townsend Peterson *et al.* 2016). On the other hand, some authors propose blurry boundaries between these approaches (Dormann *et al.* 2012), and consider that these three approaches do overlap and interconnect (e.g., correlative niche estimates being used in process-oriented approaches). However, additional advantages of using correlative models that we have implemented is to analyze a wider range of dimensions that define the niche the object of study, but the biggest disadvantage is not being able to evaluate physiological thresholds as mechanistic models (Townsend Peterson *et al.* 2016). Until present, there have been numerous publications which used ENM as a tool to predict future changes in the distribution of suitable environments and their use in conservation actions (Schwartz 2012; Lemes *et al.* 2014; Ruete & Leynaud 2015; Allen & Lendemer 2016; Jones *et al.* 2016). However, the future challenge in these studies should be perform methods or analysis very well explained in order to be repeatable, and also obtain quantified results on how and how much the climate change affects species distribution.

The usage of our results and predictions may materialize, but should require constant field surveys and implementing registration of sites with new data of confirmed presences and absences. These potential suitable environments in present-future scenarios should be considered to be contained in protected areas coupled with dynamic controls of known and/or new populations (Schwartz 2012), and in combination with current habitat use analysis (Caruso *et al.* 2015) can be a robust framework to achieve successful actions for the conservation of these species in a medium-term future.

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APPENDIX 1. Specimens and localities examined with voucher numbers (if available), species name and geographical coordinates used in this study.

Specimen	Species	Latitude	Longitude	Source / Collector
iNaturalist research-grade observations 85009	<i>Pristidaactylus achalensis</i>	31°26'43.2"S	64°41'15.0"W	GBIF trackable data
MACN-He 38592	<i>Pristidaactylus achalensis</i>	31°37'03.0"S	64°42'35.9"W	GBIF trackable data
ZV-UNRC 2977, 2976	<i>Pristidaactylus achalensis</i>	32°02'06.0"S	64°42'00.0"W	Avila 1994
Amphibian and reptile specimens 127078, 127079, 127080, 127081, 127082, 127083, 127084, 127085, 127086	<i>Pristidaactylus achalensis</i>	31°36'13.1"S	64°44'10.8"W	GBIF trackable data
without acronym specified	<i>Pristidaactylus achalensis</i>	31°20'60.0"S	64°46'00.0"W	Ref. Etheridge & Williams 1985
Amphibian and reptile specimens 127065, 127066, 127067, 127068, 127069, 127070	<i>Pristidaactylus achalensis</i>	31°24'07.3"S	64°47'43.1"W	GBIF trackable data
Amphibian and reptile specimens 127071, 127072, 127073, 127074, 127075, 127076, 127077, 186509, 186510, 186511, 186512	<i>Pristidaactylus achalensis</i>	31°34'27.3"S	64°48'12.1"W	GBIF trackable data
MACN-He 10913, 10914, 10915	<i>Pristidaactylus achalensis</i>	31°39'03.6"S	64°49'43.8"W	GBIF trackable data
MACN-He 9466, 27468, 27469, 27470, 27471, 27472, 27473, 27474, 27475, 27476, 27477, 27478, 27479, 27480, 27481, 28391, 29156, 29157, 32779, 32780, 34250, 34251, 34252, 36150, 36151, 36152, 39222, 39987, 39988, 39989	<i>Pristidaactylus achalensis</i>	31°41'19.8"S	64°49'07.7"W	GBIF trackable data
Amphibians & Reptiles 204868, 6324003, 204869, 6324004; Herps 132518, 132519; Herp R-154235, 170451, 170452, 170453; KUH 182067, 182068	<i>Pristidaactylus achalensis</i>	31°35'59.9"S	64°50'59.9"W	GBIF trackable data
Herp R-33584	<i>Pristidaactylus achalensis</i>	31°29'60.0"S	64°50'60.0"W	GBIF trackable data
MACN-He 4369	<i>Pristidaactylus achalensis</i>	31°28'16.6"S	64°51'58.6"W	GBIF trackable data
without acronym specified	<i>Pristidaactylus achalensis</i>	31°26'23.0"S	64°53'30.0"W	Sinsch et al 2002
MACN-He 40044, 40278	<i>Pristidaactylus achalensis</i>	32°25'26.1"S	64°53'10.2"W	GBIF trackable data
MACN-He 23369, 32686, 32687	<i>Pristidaactylus achalensis</i>	31°59'52.9"S	64°55'03.2"W	GBIF trackable data

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APPENDIX 1. (Continued)

Specimen	Species	Latitude	Longitude	Source / Collector
without acronym specified	<i>Pristidactylus achanensis</i>	31°59'60.0"S	64°56'60.0"W	Ref. Etheridge & Williams 1985
UNRC-ECO 781-2	<i>Pristidactylus achanensis</i>	32°21'00.0"S	65°02'06.0"W	Salas et al 2004
LJAMM-CNP 3308	<i>Pristidactylus nigroiugulus</i>	41°34'57.2"S	66°37'45.0"W	N. Frutos, M. Kozykariski & L. Camporro
CH-IADIZA 288, 290; IBA-UNC R1477; JAS-DC 594; JMC-DC 1196; JMC-DC 1197; MACN 37092, 37093; MCZ R182882, R182883	<i>Pristidactylus nigroiugulus</i>	42°27'03.5"S	66°51'45.4"W	Scolaro and Upton
LJAMM-CNP 5505	<i>Pristidactylus nigroiugulus</i>	42°23'35.4"S	67°36'42.9"W	L.J. Avila, C.H.F. Pérez, M. Morando & K. Dittmar
LJAMM-CNP 5666	<i>Pristidactylus nigroiugulus</i>	42°22'03.8"S	67°39'22.0"W	L.J. Avila, C.H.F. Pérez, M. Morando & K. Dittmar
LJAMM-CNP 5638, 5639	<i>Pristidactylus nigroiugulus</i>	42°23'55.3"S	67°43'44.8"W	L.J. Avila, C.H.F. Pérez, M. Morando & K. Dittmar
LJAMM-CNP 5603, 5604, 5605	<i>Pristidactylus nigroiugulus</i>	42°28'05.6"S	67°51'01.9"W	L.J. Avila, C.H.F. Pérez, M. Morando & K. Dittmar
LJAMM-CNP 3900, 3901, 3902, 3903, 3904	<i>Pristidactylus nigroiugulus</i>	44°35'20.3"S	67°54'47.2"W	L. J. Avila & C.H.F. Pérez
LJAMM-CNP 5508	<i>Pristidactylus nigroiugulus</i>	42°32'44.3"S	68°01'00.6"W	L.J. Avila, C.H.F. Pérez, M. Morando & K. Dittmar
LJAMM-CNP 3888	<i>Pristidactylus nigroiugulus</i>	44°56'07.6"S	68°02'01.0"W	L. J. Avila & C.H.F. Pérez
LJAMM-CNP 3382	<i>Pristidactylus nigroiugulus</i>	41°41'22.8"S	68°04'05.4"W	L.J. Avila, N. Frutos & M. Kozykariski
LJAMM-CNP 5669	<i>Pristidactylus nigroiugulus</i>	42°32'37.1"S	68°06'01.6"W	L.J. Avila, C.H.F. Pérez, M. Morando & K. Dittmar
LJAMM-CNP 3839	<i>Pristidactylus nigroiugulus</i>	42°25'01.8"S	68°15'57.7"W	N. Frutos, M. Kozykariski, L. Camporro & M.F. Breitman
LJAMM-CNP 3409	<i>Pristidactylus nigroiugulus</i>	42°24'18.8"S	68°15'27.1"W	M. Kozykariski & N. Frutos
LJAMM-CNP 3897	<i>Pristidactylus nigroiugulus</i>	44°16'33.8"S	68°16'34.4"W	L. J. Avila & C.H.F. Pérez
LJAMM-CNP 6254	<i>Pristidactylus nigroiugulus</i>	42°25'16.2"S	68°17'37.4"W	L.J. Avila & N. Frutos
LJAMM-CNP 6903, 6904	<i>Pristidactylus nigroiugulus</i>	42°25'27.4"S	68°17'08.8"W	N. Frutos & M. Kozykariski
LJAMM-CNP 6757	<i>Pristidactylus nigroiugulus</i>	42°25'24.7"S	68°17'15.8"W	N. Frutos & M. Kozykariski
LJAMM-CNP 6762	<i>Pristidactylus nigroiugulus</i>	42°26'30.3"S	68°17'22.9"W	N. Frutos & M. Kozykariski
LJAMM-CNP 3417	<i>Pristidactylus nigroiugulus</i>	42°26'43.6"S	68°18'11.5"W	M. Kozykariski & N. Frutos

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APPENDIX 1. (Continued)

Specimen	Species	Latitude	Longitude	Source / Collector
LJAMM-CNP 3840, 3841, 3842, 3843	<i>Pristidaectylus nigroingulus</i>	42°27'44.9"S	68°19'42.6"W	N. Frutos, M. Kozykariski, L. Camporro & M.F. Breitman
LJAMM-CNP 3406	<i>Pristidaectylus nigroingulus</i>	42°27'12.5"S	68°19'49.7"W	M. Kozykariski & N. Frutos
LJAMM-CNP 6760, 6761	<i>Pristidaectylus nigroingulus</i>	42°27'24.7"S	68°19'50.3"W	N. Frutos & M. Kozykariski
IBA-UNC 784	<i>Pristidaectylus nigroingulus</i>	44°07'05.0"S	68°24'05.9"W	J. M. Cej, L. Cej, and R. Ferreyra
LJAMM-CNP 3090	<i>Pristidaectylus nigroingulus</i>	41°01'01.2"S	68°30'23.0"W	L. J. Avila & C.H.F. Pérez
LJAMM-CNP 12179	<i>Pristidaectylus nigroingulus</i>	43°04'02.5"S	68°33'52.0"W	L.J. Avila, M. Kozykariski & M.F. Breitman
LJAMM-CNP 3089	<i>Pristidaectylus nigroingulus</i>	41°30'07.2"S	68°33'16.3"W	L. J. Avila & C.H.F. Pérez
IBA-UNC 934	<i>Pristidaectylus nigroingulus</i>	43°59'40.8"S	68°43'51.4"W	J. M. Cej, L. Cej, and R. Ferreyra
LJAMM-CNP 6045	<i>Pristidaectylus nigroingulus</i>	42°26'24.6"S	68°48'20.0"W	L. J. Avila & C.H.F. Pérez
LJAMM-CNP 6104, 6105	<i>Pristidaectylus nigroingulus</i>	42°25'50.8"S	68°49'17.5"W	L. J. Avila & C.H.F. Pérez
LJAMM-CNP 14908	<i>Pristidaectylus nigroingulus</i>	46°01'00.9"S	68°57'41.0"W	L.J. Avila & M. Morando
LJAMM-CNP 15333	<i>Pristidaectylus nigroingulus</i>	45°48'28.8"S	68°60'32.9"W	L. Elizalde
MHNG 2146-39, 2146-40	<i>Pristidaectylus nigroingulus</i>	43°52'52.1"S	69°03'05.0"W	by A. Kovacs in Cej, Scolari, & Videla, 2001
LJAMM-CNP 14934	<i>Pristidaectylus nigroingulus</i>	45°54'28.4"S	69°09'00.9"W	L.J. Avila & M. Morando
LJAMM-CNP 15588	<i>Pristidaectylus nigroingulus</i>	45°08'02.1"S	69°10'23.9"W	M.A. Gozalez Marin, C.H.F. Pérez & L.J. Avila
UNMDP 525	<i>Pristidaectylus nigroingulus</i>	42°26'60.0"S	69°41'60.0"W	Cruz et al. 1999
LJAMM-CNP 13090	<i>Pristidaectylus nigroingulus</i>	43°26'23.9"S	70°00'00.7"W	L.J. Avila, M. Kozykariski, M.F. Breitman & R. Martinez