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Potential biodiversity map of lizard species in Southern Patagonia: environmental characterization, desertification influence and analyses of protection areas

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Abstract. The distribution of biodiversity at the landscape level is shaped by biotic, abiotic and anthropogenic factors. Biodiversity maps provide the basis for defining management and conservation strategies that can minimize human impacts. The objective was to elaborate a map of potential biodiversity of lizards based on habitat suitability maps of individual species in Santa Cruz (Argentina). Also, we analysed desertification influence and the representativeness of the current network of protected areas on the lizard biodiversity. For this, we used a database of eight lizard species and we explored 41 potential explanatory variables to develop habitat suitability maps, which were combined to obtain one single map of the potential biodiversity. We analysed the outputs in a GIS project using the marginality and the specialization indexes and the normalized difference vegetation index of each species. Also, we characterized the potential biodiversity using the following variables: desertification, ecological areas and current network of protected areas. We detected differences in the occupied niches for the different species throughout the landscape. The map of potential biodiversity uncovered hotspots of biodiversity in the north-east study area, where the prevalence of unique climatic conditions showed a dry steppe and a high degree of desertification due to the human impacts (e.g. livestock). These results can be readily used as a support system for conservation and management strategies at different scale levels in areas with higher human impacts or to develop new protection areas.

Keywords: climatic and topographic variables, conservation, ENFA, habitat suitability, human impacts, reptiles.

Introduction

The distribution of species is shaped by historical, environmental and biotic-interactions (Bonino et al., 2015; Godsoe, Franklin and Blanchet, 2017), as well as anthropogenic impacts at the landscape level (Mangiacotti et al., 2013; Badiane, Matos and Santos, 2017). Evaluations of biodiversity provide basic ideas to develop management and conservation projects that can minimize human impacts (Breitman et al., 2015). There are many studies related to modelling potential biodiversity at global and regional scales in areas with large quantities of reliable long-term data (Ferrier 2002; Naidoo et al., 2008) and during the last few years in areas with scarce data based mainly on remote sensing (Martínez Pastur et al., 2016). In this sense, modelling potential biodiversity examines the associations between the general environmental characteristics and the occurrences of a particular species (Guisan and Zimmermann, 2000; Hirzel et al., 2002; Soberón and Peterson, 2005). The species distribution models allow us to project the geographic distribution of a species into new, unexplored regions, or into scenarios of future or past climatic conditions (Bonino et al., 2015; Breitman et al., 2015; Kubisch et al., 2015). Furthermore, this can be used as a proxy to assess the effectiveness of the current networks of protected areas and to identify sites that are potentially suitable for reintroductions (Newbold, 2010; Corbalán et al., 2011). Also, predictive models have provided knowledge and understanding of the ecology and behaviour of studied taxa, which could support

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management and conservation planning (Böhm et al., 2013).

Southern Patagonia is one of the last remote wild places on Earth, with high endemism and conservation priorities (Corbalán et al., 2011). This region presents a great variability of environments, from *Nothofagus* forests to arid steppe ecosystems (Peri et al., 2016). Biodiversity specialists and conservation planners have classified the ecoregion as vulnerable and included within the Global 200 priority areas for conservation (Olson and Dinerstein, 2002). Only 29 lizard species occurred in the area, where 19 belong to *Liolaemus lineomaculatus* section and where the other species belong to recent arrival lineages (Breitman et al., 2014). These lizard groups presented several endemic species and few scientific studies related to their ecology and conservation status (Ibargüengoytía et al., 2010; Corbalán et al., 2011; Fernández et al., 2011; Bonino et al., 2015; Breitman et al., 2015; Kubisch et al., 2015). Reptiles constitute a group of conservation concern, because they are ectotherms with small distribution ranges, and are often associated with specific microhabitats which make them especially vulnerable to habitat disturbances (Gibbons et al., 2000; Böhm et al., 2013). However, their representation is very low within the current network of protected areas in Southern Patagonia (Chébez et al., 2005; Corbalán et al., 2011, 2013).

Livestock (cattle and sheep) is the main economic activity in the area, which generate greater changes in the natural ecosystem, increasing the desertification processes across the region (Del Valle et al., 1998; Peri et al., 2016). Land-use change caused by agriculture and grazing activities in natural ecosystems can greatly affect terrestrial biodiversity by modifying vegetation assemblages and ecosystem functions (Howland et al., 2014; Martínez Pastur et al., 2017). Such structural alteration may lead to local extinction of specialist species of lizards or species replacement (Larson, 2014). A better understanding of species ecology is useful for conservation and management strategies at different spatial scales with human impact (Mangiacotti et al., 2013; Howland et al., 2014). For this, the objective was to elaborate a map of potential biodiversity (MPB) of lizards based on the potential habitat suitability (PHS) of eight species in Santa Cruz province (Argentina). Additionally, we aim to: (i) characterize each species based on their environmental requirements, (ii) characterize the potential threat of desertification processes on the lizard potential biodiversity, and (iii) analyse their representativeness in the current network of protected areas (national parks and provincial reserves).

Methods

The study was carried out in Santa Cruz province (Argentina) (46°00′ to 52°30′S, 66°00′ to 73°00′W) covering 243,943 km^2 (fig. 1A). Total inhabitants is 320,469 (year 2015) living in 37 localities (cities and small towns). Lakes were located at the base of the Andes Mountains and main rivers flow from W to E to the Atlantic Ocean (fig. 1B). Ice fields and the mountains (N to S direction) define relief and climate, generating a rainfall gradient from W to E (fig. 1C). The main ecological areas are dominated by grasslands (dry, humid and sub-Andean) and shrub-lands, while *Nothofagus* forests and alpine vegetation occupy a narrow fringe along the mountains (fig. 1D). Finally, National Parks and Provincial Reserves mainly preserve forest ecosystems close to the Andes Mountains, however, some reserves were created to preserve unique landscapes (e.g Bosques Petrificados de Jaramillo National Park) or biodiversity values (e.g. Monte León National Park) (fig. 1E).

To make the map of the potential biodiversity (MPB) of lizards in Santa Cruz province, we follow the methodology proposed by Martínez Pastur et al. (2016). We used a database of lizards based on 351 locations since 1998 to 2014 (Cruz et al., 2005; Ibargüengoytía et al., 2010; Fernández et al., 2011; Breitman et al., 2014), and we selected eight species based on their highest occurrence (>20 locations) that belong to three families: (i) one genera with six species belongs to Liolaemidae (*Liolaemus lineomaculatus*, *L. escarchadosi*, *L. sarmientoi*, *L. kingii*, *L. bibronii* and *L. fitzingerii*), (ii) one species belongs to Leiosauridae (*Diplolaemus bibronii*), and (iii) one species belongs to Phyllodactylidae (*Homonota darwinii darwinii*). For the modelling, we explored 41 potential explanatory variables (supplementary table S1), which were rasterized at 90×90 m resolution grid, like other studies about species distribution maps (Martínez Pastur et al., 2016; Rosas et al., 2017) using the nearest neighbour resampling technique on ArcMap 10.0 software (ESRI 2011). Climatic variables ($n =$

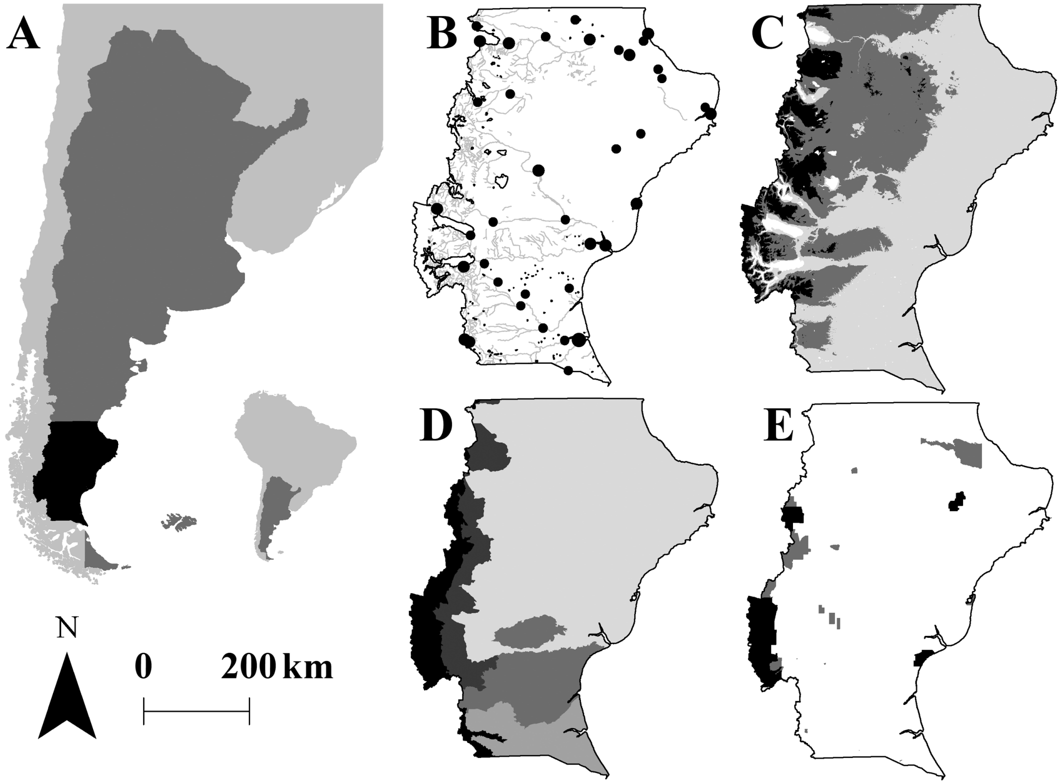

Figure 1. Characterization of the study area: (A) location of Argentina (dark grey) and Santa Cruz province (black); (B) towns (big dot = capital city, middle dots = towns >3000, small dots = towns <3000 inhabitants), lakes and main rivers; (C) relief (grey = <400, dark grey = 400-1000, black = >1000 m.a.s.l.); (D) main ecological areas (light grey = dry steppe, grey = humid steppe, medium grey = shrub-lands, dark grey = sub-Andean grasslands, black = forests and alpine vegetation) (modified from Oliva, Gonzalez and Ruial, 2004), and (E) protection areas (grey = provincial reserves, black = national parks).

21) (Hijmans et al., 2005) included temperature and precipitation, characterized as annual, monthly and seasonal, as well as global potential evapo-transpiration and global aridity indexes (Zomer et al., 2008). The topography variables ($n = 8$) were defined using the shuttle radar topography mission (Farr et al., 2007) which produced high-resolution digital elevation model. With these images we defined altitude, aspect and slope, where aspects were calculated as both sine and cosine function of the north magnetic direction (E-W and N-S) (Jenness, 2007). Also Euclidean distances to towns, lakes, rivers and main routes were calculated using shapes obtained from SIT Santa Cruz (Sistema de Información Territorial, http://spm.sitsantacruz.gob.ar). Finally, the landscape metrics ($n = 12$) explored were: (i) vegetation covers (five layers), (ii) forest landscape metrics (three layers) derived from Fragstats software (McGarigal, Cushman and Ene, 2012), (iii) the normalized difference vegetation index (NDVI) (ORNL DAAC 2008), (iv) net primary productivity (NPP) of year 2015 (Zhao and Running, 2010), (v) desertification index (Del Valle et al., 1998), (vi) and soil carbon content (Peri et al., 2018). The final variables used for modelling PHS of each lizard species were selected based on the lower Pearson´s correlation indices obtained when paired analyses of each variable were conducted.

Using Environmental Niche Factor Analysis (ENFA) (Hirzel et al., 2002), we performed a series of spatially explicit potential habitat suitability (PHS) models for each lizard species in the Biomapper 4.0 software (Hirzel, Hausser and Perrin, 2004). ENFA compares the eco-geographical predictor distribution for a presence data set consisting of locations where the species has been detected with the predictor distribution of the whole study area (Hirzel, Helfer and Metral, 2001). ENFA calculates a measure of habitat suitability based on an analysis of marginality (how the species' mean differs from the mean of all sites in the study area) and environmental tolerance (how the species' variance compares with the global variance of all sites) or specialization (tolerance^{-1}) (Martinez Pastur et al., 2016). We used a distance of geometric-mean algorithm to perform the PHS, which provides a good generalization of the niche (Hirzel and Arlettaz, 2003). The resulting PHS maps had scores that varied from 0 (minimum) to 100 (maximum habitat suitability), and we evaluated the model by a cross-validation process (Boyce et al., 2002; Hirzel et al., 2006) through: (i) the Boyce index (B) which indicates how consistent are the model predictions with the presences distribution in the evaluation dataset (−1 to 1), (ii) the proportion of validation points (P), (iii) the continuous Boyce index (Bcont), (iv) the absolute validation index (AVI) defined as the proportion of validation cells with habitat suitability (0 to 1), and (v) the contrast validation index (CVI) defined as AVI-AVI>50 which indicates how much the model differs from a random model (0.0 to 0.5) (Hirzel and Arlettaz, 2003; Hirzel, Hausser and Perrin, 2004; Hirzel et al., 2006). For further comparisons, the PHS maps were reclassified as: unsuitable area (<50%) and three qualities (low, medium and high) containing equal quantity of pixels. Beside this, we characterize and compare the PHS of each lizard species through: (i) their marginality and specialization values, and (ii) the occurrence according to the normalized difference vegetation index (NDVI). Finally, we combined the eight PHS maps into the GIS, obtaining a map of potential biodiversity (MPB) of lizard species for Santa Cruz province. As well as the PHS maps, the MPB was reclassified as: low potential biodiversity (1-21%), medium potential biodiversity (22-37%), and high potential biodiversity (38-100%), where the limits also were defined into three classes containing an equal quantity of pixels. We employed the output of the MPB to characterize the three quality habitat classes through: (i) their climate and topographic variables comparing to the whole study area, (ii) their occurrence in different ecological areas (based on Oliva, Gonzalez and Ruial, 2004), (iii) their potential trade-offs with the desertification processes (Del Valle et al., 1998), and (iv) their occurrence inside and outside the protected areas (national parks and provincial reserves).

Results

Seven variables were selected for modelling of PHS for lizard species based on the lower values of Pearson's correlation indices obtained when paired analyses were conducted among the 41 variables (supplementary table S2): five related to climate (annual mean temperature – AMT, minimum temperature of the coldest month – MINCM, mean annual precipitation – AP, precipitation of coldest quarter – PCQ, and global potential evapo-transpiration – EVTP), one related to topography (elevation – ELE), and one related to vegetation (normalized difference vegetation index – NDVI). Nevertheless, some of these variables presented high influence among them. Climate variables presented correlation indexes between 0.25 and 0.99, and some of them were greatly influenced by the topography variable (e.g. temperature was influenced by the elevation with a correlation index of 0.85). The landscape variable (NDVI) presents correlation indexes between 0.45 and 0.67 when contrasted with the other variables.

From modelling, the seven described variables fit the distribution of the first group of lizard species (*Liolaemus lineomaculatus*, *L. escarchadosi*, *L. sarmientoi*, *L. kingii*), while a second group (*L. bibronii*, *L. fitzingerii*, *Diplolaemus bibronii*, *Homonota darwinii darwinii*) only included four of the selected variables (AMT, AP, EVTP and NVDI). The studied lizard species presented one predominant geographic location (north, general, or south) across the study area. Using a GIS project and the occurrence points of each lizard species, we can see that most of them presented a northern distribution (*L. kingii*, *L. bibronii*, *L. fitzingerii*, *D. bibronii*, *H. darwinii darwinii*), while two presented a southern (*L. escarchadosi*, *L. sarmientoi*) and one a general distribution (*L. lineomaculatus*). For the PHS modelling, we employed the first four axes, where the explained information was close to 100% (supplementary table S3). The models showed good validation statistics: (i) the Boyce index varied between 0.10 and 0.37, and this index indicates that the model predictions are consistent with the presence distribution of the field observation dataset, (ii) $P(B = 0)$ index varied between 0.33 and 0.60 and Bcont(20) index between −0.04 and 0.20, and these indexes indicate a good statistics for the cross validation analyses of the models, and (iii) AVI varied between 0.46 and 0.68, and CVI between 0.31 and 0.49 which indicate that the model predictions were consistent with the evaluation datasets since 50% of evaluation records were enclosed in the core area (supplementary table S4).

The PHS maps of the eight lizard species (supplementary figure S1) presented significant differences, but are coincident with the observed distribution of locations sites. Some species presented a smaller potential habitat

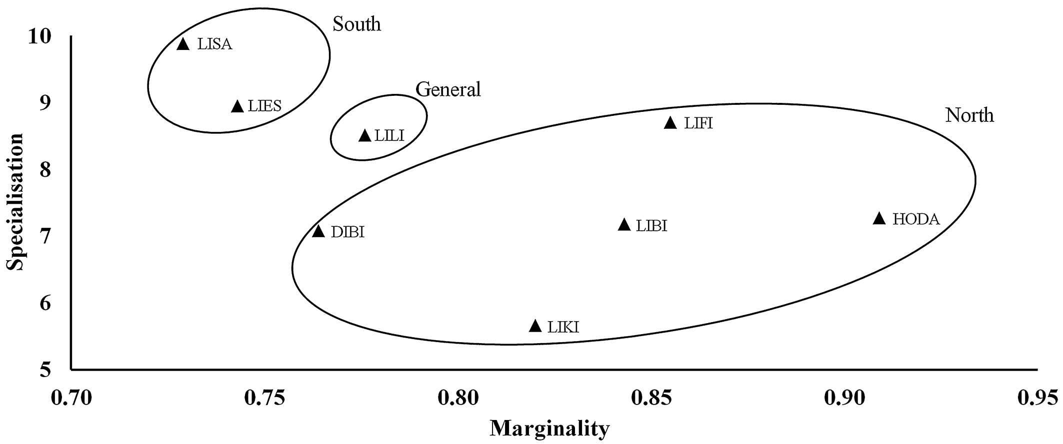

Figure 2. Specialization (low species' variance compared to global variance of the data base) vs. marginality (large difference of species' mean compared to the mean of the data base) of the studied species, which were grouped according to predominant geographic distribution (North, General, South) inside the study area (see supplementary material). Species code means: LIBI = *Liolaemus bibronii*, LIFI = *L. fitzingerii*, LIKI = *L. kingii*, LILI = *L. lioneomaculatus*, LISA = *L. sarmientoi*, LIES = *L. escarchadosi*, DIBI = *Diplolaemus bibronii*, and HODA = *Homonota darwinii darwinii*.

area (e.g. *L. bibronii*, *L. fitzingerii* and *H. darwinii darwinii*), while others presented larger potential habitat areas (e.g. *L. lineomaculatus* and *L. sarmientoi*). Also, some species presented similar values of marginality and specialization (fig. 2) and similar NDVI ranges where the potential habitat suitability occurred (fig. 3). In general, the species with northern distribution (*L. kingii*, *L. bibronii*, *L. fitzingerii*, *D. bibronii*, *H. darwinii darwinii*) presented the highest marginality (0.76 to 0.91) and the lowest specialization (5.7 to 8.8), where 90% of the habitat occurred between 0.11 and 0.20 NDVI. The species with the southern distribution (*L. escarchadosi*, *L. sarmientoi*) presented the lowest marginality (0.73 to 0.74) and the highest specialization (8.9 to 9.9), where 90% of the habitat occurred between 0.11 and 0.30 NDVI. Finally, the most generalist species (*L. lineomaculatus*) occupied an intermediate position between both groups, where marginality was 0.78 and specialization was 8.5, and 72% of the habitat occurred between 0.11 and 0.20 NDVI.

The eight PHS maps were combined into a GIS to obtain a single map of potential biodiversity (MPB) for lizards. This classified map showed (fig. 4) that the highest potential lizard biodiversity can be observed mainly in north-east areas, while medium potential included areas from the middle-north Santa Cruz province to the south. The lowest potential areas were observed in the west, where mountain and forest areas occurred. However, some higher potential areas occurred in the wetlands across large rivers and close to lakes in the mountain regions with more temperate and humid places.

The first analysis of environmental characterization of the MPB classified the habitat quality across climatic and topographic gradients (table 1). Temperature (AMT) influenced potential biodiversity by increasing the habitat quality, e.g. mean value for the study area was 7.8°C, while in low and optimum habitat was 6.3°C and 9.5°C respectively. The other related temperature variables followed the same pattern (MDR, TS, MAXWM, MINCM, TAR, MTDQ, MTWAQ, and MTCQ), except for the mean temperature of the wettest quarter (MTWEQ) where maximum values were found in medium quality habitats. Beside this, isothermality (ISO) decreased when habitat quality increased (47.0% to 46.1% from low to high quality habitats). Rainfall (AP) also influenced potential biodiversity by decreasing the quality when precipitation increases (254.6 mm.yr^{-1} in low and

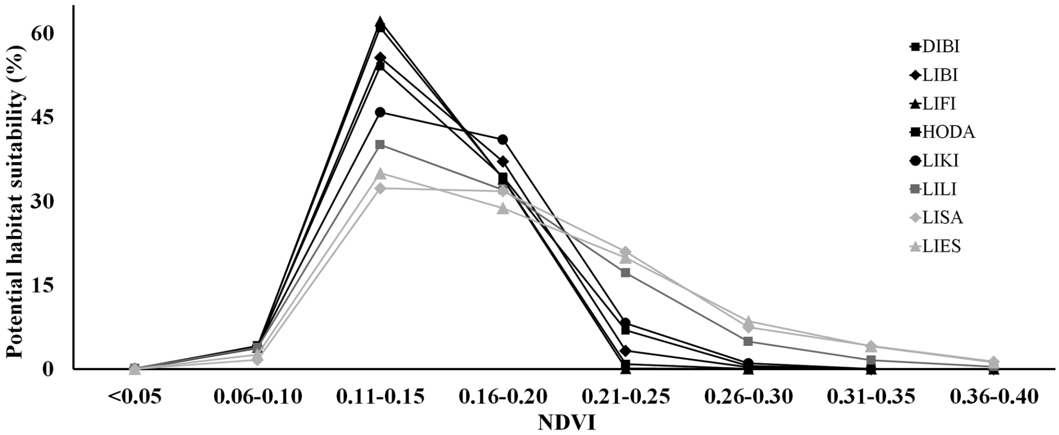

Figure 3. Variation of potential habitat suitability (PHS) of lizard species according to the normalized difference vegetation index (NDVI) and their predominant geographic location (North = black, General = grey, South = pale grey). Species code means: LIBI = *Liolaemus bibronii*, LIFI = *L. fitzingerii*, LIKI = *L. kingii*, LILI = *L. lioneomaculatus*, LISA = *L. sarmientoi*, LIES = *L. escarchadosi*, DIBI = *Diplolaemus bibronii*, and HODA = *Homonota darwinii darwinii.*

200.5 mm.yr^{-1} in high quality habitats). The other related rainfall variables followed similar patterns (PWEM, PDM, PS, PWEQ, PDQ, PWAQ, PCQ), where lower quality greatly differentiate from medium-high quality habitats. Climatic indexes (EVTP and GAI) followed the combined patterns of temperature and rainfall, where MPB values increased with the evapotranspiration (lower at 745.5 mm.yr^{-1} and high at 879.8 mm.yr^{-1}) and decreased with the aridity (lower at 0.4 and higher at 0.2). Finally, habitat quality decreased with elevations (optimum at 281 m.a.s.l.) and slope (better habitat quality occurred at gentle slopes).

The second analysis of environmental characterization of the MPB classified the habitat quality occurrence across the different degrees of desertification and categories of ecological areas (see fig. 1D), which determined that the best quality habitats occurred in the dry steppe in areas where desertification processes increased (table 2). 68.7% of the MPB occurred in the dry steppe (19.3% low, 33.0% medium and 47.7% high) and 12.4% in the shrub-lands (39.0% low, 57.2% medium and 3.8% high). 7.8% of the MPB was in humid steppe (59.2% low, 40.8% medium and 0.0% high), while 8.1% of the MPB was in sub-Andrean grasslands (93.0% low, 5.3% medium and 1.7% high) and 2.9% of the MPB was in forest and alpine vegetation (100% low). Also, 91% of MPB occurred in areas with moderate to very severe desertification, where 51% was in moderate and moderate to severe desertification (low 53.6%-33.6%, medium 38.7%-37.5%, high 7.6%-28.9%), and 40% was in severe and very severe degradation (low 18.0%-8.7%, medium 32.7%-32.4%, high 49.3%-58.9%).

The last analysis showed the occurrence of the MPB quality habitat inside of the current network of protected areas (see fig. 1D), where only 3.2% of the total habitable area for lizards (228,098 km^2) occurred inside the protection areas network (4.6% of the low, 2.4% of the medium and 2.8% of the high quality areas) and 96.8% occurred outside (table 3). Considering the total protected area of the MPB, the national parks protect 32.9% and the provincial reserves represent the other 67.1% of the total area.

Discussion

The interest to understanding species distribution at the landscape level, and changes due to human impact has increased during

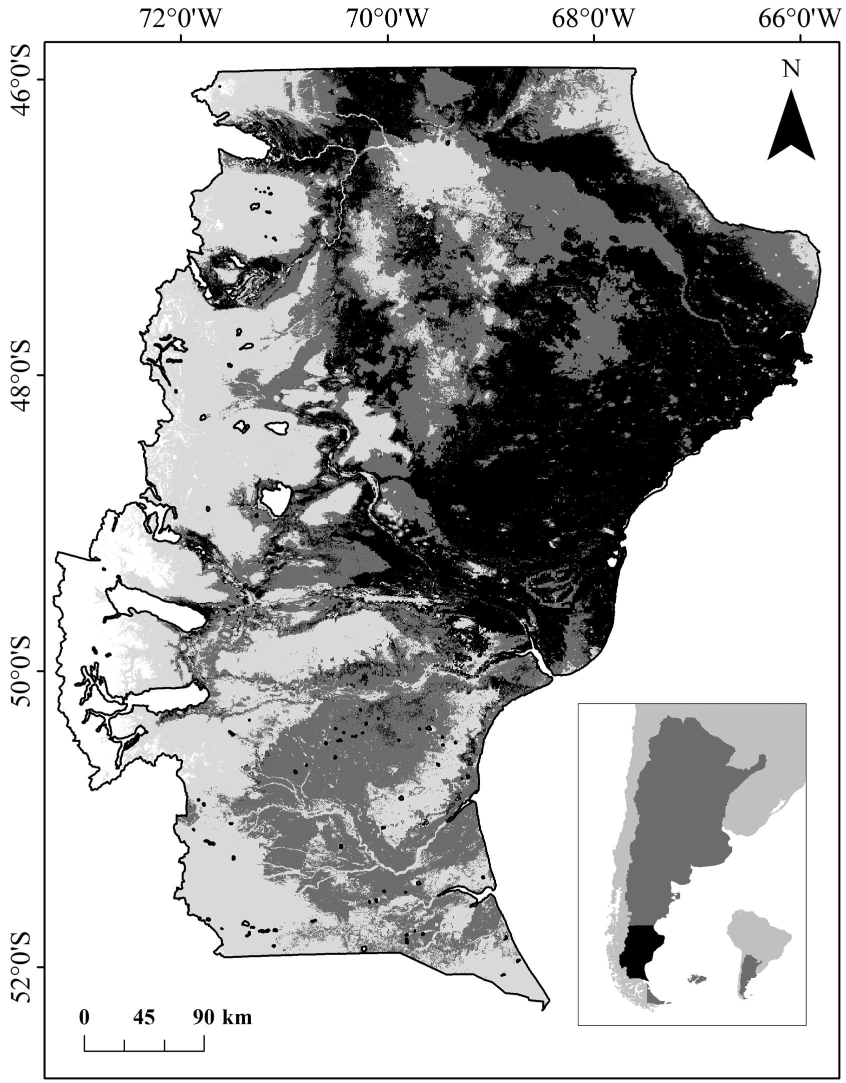

Figure 4. Map of potential biodiversity (MPB) of lizard species in Santa Cruz province. Low potential = pale grey (1-21%), medium potential = grey (22-37%), high potential = black (38-100%).

the last decades (Bonino et al., 2015; Badiane, Matos and Santos, 2017; Godsoe, Franklin and Blanchet, 2017). The structural alteration of habitats may affect species and their relative abundance, population structure and dynamics (Mangiacotti et al., 2013; Howland et al., 2014; Larson, 2014). In this context, potential habitat suitability (PHS) models based on ENFA (Hirzel et al., 2002) had been largely used for several studies around the world (e.g. Sillero et al., 2009) and Patagonia (Martínez Pastur et al., 2016). This is an easy methodology to be applied in areas with low data environmental availability and for studies that analyze the ecological niche based only in presence data (Guisan and Zimmermann, 2000; Soberón and Peterson, 2005). The presence-only data was used when no planned and systematic surveys exist (Hirzel et al., 2006; Anderson, 2012). This can generated potential disadvantages to be considered in the modelling: (i) The risk of over-fitting probably increases due to auto-correlation among environmental

Table 1. Characterization (mean and standard deviation) of the climatic and topographic variables analysing the map of potential biodiversity (MPB) of lizard species classified according to their values: total means the entire province, low (1-21%), medium (22-37%) and high (38-100%) potential quality classified according to the modelling.

Variable	Total	Low	Medium	High
AMT	7.8 (2.4)	6.3 (2.3)	8.2 (1.6)	9.5 (0.8)
MDR	10.3 (0.6)	10.1 (0.6)	10.5 (0.5)	10.6 (0.4)
MAXWM	19.6 (3.2)	17.6 (2.9)	20.2 (2.2)	21.8 (1.1)
MINCM	−2.7 (2.2)	−3.9 (2.3)	−2.4 (1.7)	−1.2 (1.3)
TAR	22.2 (1.8)	21.5 (1.7)	22.6 (1.5)	23.0 (1.1)
MTWEQ	5.7 (2.9)	5.8 (3.1)	6.7 (3.0)	5.0 (2.2)
MTDQ	9.8 (3.7)	8.7 (3.3)	10.2 (3.9)	11.3 (2.8)
MTWAQ	13.20 (2.83)	11.5 (2.7)	13.8 (2.0)	15.2 (0.9)
MTCQ	−2.65 (2.19)	0.6 (2.1)	2.1 (1.4)	3.3 (0.9)
ISO	46.4 (0.2)	47.0 (0.2)	46.5 (0.2)	46.1 (0.1)
TS	4.5 (0.4)	4.3 (0.4)	4.6 (0.4)	4.7 (0.2)
AP	245.9 (181.4)	254.6 (109.0)	186.2 (31.1)	200.5 (26.3)
PWEM	30.2 (18.9)	31.7 (12.4)	23.8 (4.9)	25.1 (3.3)
PDM	13.6 (12.5)	13.5 (7.1)	9.7 (1.9)	11.0 (2.3)
PWEQ	79.8 (53.2)	83.7 (35.5)	61.1 (13.2)	67.0 (10.8)
PDQ	46.4 (41.1)	46.5 (22.4)	33.6 (5.7)	37.1 (6.1)
PWAQ	53.6 (42.9)	53.5 (24.2)	41.2 (11.1)	43.9 (9.4)
PCQ	67.3 (46.0)	68.7 (31.7)	51.3 (13.2)	58.1 (10.9)
PS	24.4 (6.6)	25.0 (7.3)	24.8 (6.4)	24.6 (5.2)
EVTP	807.9 (101.6)	745.5 (93.9)	827.9 (73.7)	879.8 (35.0)
GAI	0.3 (0.4)	0.4 (0.2)	0.2 (0.0)	0.2 (0.0)
ELE	468.8 (383.8)	646.2 (429.6)	383.9 (245.1)	281.3 (187.8)
SLO	5.0 (5.8)	5.7 (5.9)	4.0 (3.5)	3.6 (3.1)

AMT = annual mean temperature (°C), MDR = mean diurnal range (°C), MAXWM = maximum temperature of warmest month (°C), MINCM = minimum temperature of coldest month (°C), TAR = temperature annual range (°C), MTWEQ = mean temperature of wettest quarter (°C), MTDQ = mean temperature of driest quarter (°C), MTWAQ = mean temperature of warmest quarter (°C), MTCQ = mean temperature of coldest quarter (°C), ISO = isothermality (%), TS = temperature seasonality (°C), AP = mean annual precipitation (mm.year^{-1}), PWEM = precipitation of wettest month (mm.year^{-1}), PDM = precipitation of driest month (mm.year^{-1}), PWEQ = precipitation of wettest quarter (mm.year^{-1}), PDQ = precipitation of driest quarter (mm.year^{-1}), PWAQ = precipitation of warmest quarter (mm.year^{-1}), PCQ = precipitation of coldest quarter (mm.year^{-1}), PS = precipitation seasonality (%), EVTP = global potential evapo-transpiration (mm.year^{-1}), GAI = global aridity index, ELE = elevation (m.a.s.l.), SLO = slope (degrees).

variables. Nevertheless, potential errors can be relatively constant when worked with more than one species (Munguía et al., 2008; Breitman et al., 2015). And, (ii) some species can be over-sampled in easily accessible areas and under-represented in remote areas. This spatial autocorrelation problem were mainly cited for presence/absence models, however, it is possible to implement one spatial filter for presence-only to reduce autocorrelation (Veloz, 2009). This is possible to implement when the database have enough presence point, but in our study, the available number of observations were limited (between 20 to 55 observations per species). For this, in our study we analysed the human related variables (e.g distance to localities and routs), expecting a high correlation if the data were biased with those human related variables (Phillips et al., 2009). In our study, these variables were not significant for the modelling, thus low autocorrelation errors related to this problem are not to be expected.

The requirement-based concept of the ecological niche (Grinnell, 1917) links the fitness of individuals to the environment that they inhabit (Allouche et al., 2008; Hirzel and Le Lay, 2008). Distribution maps for reptiles are based mainly on climate, topography and vegetation type variables (Bonino et al., 2015; Breitman

Table 2. Percentage occupied by the qualities according to the map of potential biodiversity (MPB) of lizard species classified by the occurrence in different categories of ecological areas (see fig. 1D) and intensities of desertification (see Del Valle et al., 1998). Where low (1-21%), medium (22-37%) and high (38-100%) potential quality were classified according to the modelling.

Type	Variable	Total	Low	Medium	High
Ecological area	Dry steppe	68.7%	19.3%	33.0%	47.7%
	Humid steppe	7.8%	59.2%	40.8%	0.0%
	Shrub-lands	12.4%	39.0%	57.2%	3.8%
	Forests and alpine vegetation	2.9%	100.0%	0.0%	0.0%
	Sub-Andean grasslands	8.1%	93.0%	5.3%	1.7%
Desertification	Water bodies, forest, ice caps and snow cover	3.3%	89.8%	5.3%	4.9%
	Slight degradation	5.0%	82.1%	12.0%	5.9%
	Moderate degraded or desertification	14.6%	53.6%	38.7%	7.6%
	Moderate to severe desertification	36.4%	33.6%	37.5%	28.9%
	Severe desertification	27.6%	18.0%	32.7%	49.3%
	Very severe desertification	13.0%	8.7%	32.4%	58.9%

Table 3. Percentage and area (km^2) occupied by the qualities according to the map of potential biodiversity (MPB) of lizard species classified by the occurrence and their protection status: provincial reserves (PR), national parks (NP) (see fig. 1E). Where low (1-21%), medium (22-37%) and high (38-100%) potential quality were classified according to the modelling.

		Total	Low	Middle	High
Model (km^2)		228098.6	74513.5	77798.9	75786.2
Unprotected		96.8%	95.4%	97.6%	97.2%
Protected	Total	3.2%	4.6%	2.4%	2.8%
	NP	32.9%	41.6%	31.4%	19.8%
	PR	67.1%	58.4%	68.6%	80.2%

et al., 2015; Kubisch et al., 2016). The PHS-based studies have traditionally addressed the niche issues of single species, and few studies addressed issues of species assemblage (Hirzel and Le Lay, 2008; Martínez Pastur et al., 2016). In this framework, we combined eight PHS of lizards to characterize the potential biodiversity in Southern Patagonia.

The PHS models responded to the phylogenetic lizard classification (Pyron, Burdrink and Wiens, 2013). The first group belonged to the *L. lineomaculatus* section (Breitman et al., 2011), where *L. lineomaculatus* presented a generalist distribution, while *L. escarchados*i and *L. sarmientoi* had the southernmost distribution, and *L. kingii* had the northernmost distribution. These results were coincided with the current distribution proposed by Breitman et al. (2015). Also in that study, they suggested that *L. escarchadosi* and *L. sarmientoi* are closely related species with shared areas with *L. kingii*. These distributions among species related to phylogenetic relationships can be supported by the morphological data and molecular evidence (Breitman et al. 2011). *Liolaemus lineomaculatus* section inhabits extremely heterogeneous landscapes that have directly affected by several glacier cycles since the Miocene (Breitman et al., 2012). The second group presented more recent lineages and low nucleotide diversity (Avila, Morando and Sites, 2006; Morando et al., 2007). The PHSs maps of *L. bibronii*, *L. fitzingerii*, *Diplolaemus bibronii*, *Homonota darwinii darwinii* showed a northern distribution and Breitman et al. (2014) indicated that the presence of these species in this area is a result of a recent geographical expansion. The presence of lizard species in extreme temperatures showed possible physiological adaptations at molecular and cellular levels (Angilletta, 2009), e.g. in *L. bibronii*, one of the southernmost oviparous of *Liolaemus* (Medina and Ibargüengoytía, 2010), and in *Homonota darwinii darwinii*, the southernmost gecko species (Weeks and Espinoza, 2013).

In this southernmost latitude of southern hemisphere inhabits 29 species of lizards (Breitman et al., 2014) from steppe in the north to wetlands near to the mountain in the south. Nevertheless, lizards cannot achieved high corporal temperatures in these extremely cold environments (Ibargüengoytía et al., 2010) because of the short daily and seasonal activity periods The MPB showed the highest biodiversity in the northeast area, where environmental conditions were a dry steppe with several intensities of desertification due to livestock production (Del Valle et al., 1998; Peri et al., 2016). This economic activity can have a profound influence on reptiles by changing the structural complexity of grasslands (Howland et al., 2014; Larson, 2014). Nevertheless, not all lizards decline in areas experiencing vegetation loss (Attum et al., 2006), e.g. due to desertification. In fact, these degraded areas can be of great importance for conservation purposes of some lizard species, changing richness and abundance at the landscape level (Zeng et al., 2014). Medium potential biodiversity included areas towards west and south, where a few species had been surveyed in the southernmost distribution (Breitman et al., 2015). Finally, the lowest potential occupied the western areas, where the ecological areas are dominated by sub-Andean grasslands, forest and alpine vegetation and the conditions of desertification are minimal. These areas with low potential biodiversity support the idea that it is possible to find new species or populations in these few explored landscapes (Breitman et al., 2014). These climatic conditions may limit the distribution of the species or their habitats range (Bonino et al., 2015; Kubisch et al., 2015). However, some species (*L. sarmientoi and L. magellanicus*) will achieve a high performance in a wide range of low temperature conditions (Fernández et al., 2011).

Patagonia presents a great variability of environments (Peri et al., 2016) where arid steppe ecosystems have been assessed as a region with high endemism (Corbalán et al., 2011) and high conservation values (Olson and Dinerstein, 2002). In these areas, lizards have been considered important for many studies about conservation and ecology (Ibargüengoytía et al., 2010; Corbalán et al., 2011; Fernández et al., 2011; Bonino et al., 2015; Breitman et al., 2015; Kubisch et al., 2015). Nevertheless, in Southern Patagonia the current network of protected areas is not very effective to protect lizards. According to our results only 3.2% of the MPB occurred inside the protection areas network in Southern Patagonia. Nevertheless, Corbalán et al. (2011) found that 31% of lizard species are protected in the whole of Patagonia. However, only 49% of the endangered reptiles are protected in national parks in Argentina (Chébez, Rey and Williams, 2005) while, in this study national parks protect 32.9% and provincial reserves represent the other 67.1% of the MPB.

Conclusions

Habitat suitability models improve our understanding of the ecology of species at different landscape levels, and also this tool can be used to support different hypotheses of phylogenetic studies. These models allow us to develop a map of potential biodiversity (MPB), which was related to climate, topographic and landscape variables. This map can be used to understand how lizard biodiversity is affected by environmental impacts in Southern Patagonia, where livestock caused a high degree of desertification areas. Also, the map can be used to support decision making for new management strategies to improve the current conservation efforts of the arid ecosystem where lizards represent a significant biomass and have an important role in trophic nets. The obtained results also can contribute to future research to: (i) delineate the ecological requirements of species and their limiting factors; (ii) understand biogeography and dispersal barriers; (iii) support a new phylogenetic hypothesis; (iv) predict climate change effects. Also, the identification of biodiversity hotspots can be used to: (v) identify land-use conflicts and analyze the effect of human impacts and (vi) define new conservation plans and reserves.

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