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Assessing conservation priorities of xenarthrans in Argentina

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Abstract In this study, we combine species distribution models with a reserve selection approach to assess the degree of representation of xenarthrans in the existing protected area network of Argentina, and to identify conservation priority areas that may help expand the current system. Species distribution models were developed from species' occurrence records using a maximum entropy algorithm. Maps of species distributions were produced for 15 of the 16 species currently present in the country. To assess the performance of the existing protected area network in representing all modeled species, and to identify priority areas to expand the current reserve system, we used the software Zonation. Overall, all species modeled are represented in the existing protected area network. However, the percentage of their ranges covered by protected areas is very low (average = 6.7%; range = 1.7–17.6%). To represent at least 5% of the distribution of each species, 8.8% of the country's area would be needed, and species with restricted ranges have the greatest increase in representation in this scenario. When 10% of the country is set aside for conservation, species representation increases considerably, again favoring range-restricted species. Most of the areas identified as conservation priorities are under strong anthropogenic pressures, including deforestation, agricultural expansion, and hunting. Our analysis provides a preliminary assessment of conservation priorities for the xenarthrans of

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Argentina, and we hope will serve as guideline to focus future conservation assessments at more refined scales.

Keywords Argentina · Priority areas · Protected area network · Species distribution models · Systematic conservation planning · Xenarthrans

Introduction

The current pace at which species and habitats are being lost requires urgent and effective conservation measures. In order to delineate conservation priorities, we need to accurately know the geographic distribution of the species. However, conservation biologists are usually confronted with very limited data on the distribution and abundance of many species, particularly those that are very rare (Hernandez et al. 2006; Thorn et al. 2009). Moreover, resource limitations generally preclude systematic surveys for many taxonomic groups, making it difficult to assess species representation in protected areas and establishing conservation priorities (Pawar et al. 2007). In the past decade, the use of ecological niche models has become a very powerful tool to infer species distribution for answering questions in ecology, evolution, biogeography, epidemiology, and conservation biology (Guisan and Thuiller 2005 and references therein). Ecological niche models attempt to predict species distributions by relating species locality records to environmental variables (Guisan and Zimmermann 2000; Guisan and Thuiller 2005). Combined with reserve selection algorithms, they can be used in conservation planning to identify areas or landscapes that are of conservation concern (Sánchez-Cordero et al. 2005; Fuller et al. 2006; Pawar et al. 2007; Sarkar et al. 2009).

The xenarthrans is a group composed by sloths, armadillos, and anteaters. It is presumably the only group of mammals originated in South America (see Delsuc et al. 2002) and all extant species are found within specific regions of Latin America (Aguiar and Fonseca 2008). Only one species, the nine-banded armadillo (*Dasypus novemcinctus*), has successfully colonized much of the southern US in the last 200 years (Taulman and Robbins 1996). Current molecular evidence indicates that the xenarthra represent one of the four major clades of placental mammals, and potentially a basal offshoot of the founders of the eutherian line (see Delsuc and Douzery 2008). This fact makes the xenarthrans a very important conservation target because unique evolutionary lineages contribute disproportionately to the earth's genetic diversity (Avise 2005). There are 31 living species: six sloths, four anteaters, and 21 species of armadillos, representing a small fragment of a much more diverse fossil assemblage that includes such well-known oddities as the giant ground sloth and glyptodonts (see MacKenna and Bell 1997). Of these, 18 species have been cited for Argentina, although the presence of two species remains doubtful. Indeed, the only two collecting localities of *Bradypus variegatus* are from the early 1900s and it has not been collected since, whereas morphological evidence for the identification of the two specimens of *Dasypus septemcinctus* collected in northern Argentina is not conclusive.

A recent analysis of the global conservation status of all world mammals indicates that almost 20% of the xenarthrans are in one of the IUCN threatened category, and that a same percentage is near threatened (Schipper et al. 2008). However, xenarthrans have not received the same attention as other, more charismatic groups, such as carnivores and cetaceans (Aguiar and Fonseca 2008). In Argentina, the local Red List assessment has identified a higher percentage (38%) of species in any of the endangerment categories

(Diaz and Ojeda 2000). Indeed, of the 18 species cited for the country, six are either critically endangered, endangered or vulnerable, four are near threatened, one is possibly extinct (*Bradypus variegatus*), two do not have enough information to make an evaluation (*Dasypus yepesi* and *Chaetophractus nationi*), and five do not present any conservation risk (Diaz and Ojeda 2000).

In this study, we combine species distribution models with a reserve selection approach to assess conservation priorities of the xenarthrans of Argentina. Our objectives were twofold: to assess the performance of the current protected area system at representing the target species, and to identify potential conservation areas to expand the existing network.

Materials and methods

Data

We collected point locality data from natural history museum collections, published literature, and field data collected by one of the authors (A.M.A) for 16 of the 18 species once cited for Argentina. All records were assigned geographic coordinates using national and international gazetteers (e.g. Geographic Military Institutes of Argentina, NIMA-GeoNET Names Server). In total, we obtained 944 unique records for all species, ranging from 3 to 236 (Table 1).

Nineteen bioclimatic variables and elevation, each at a resolution of 2.5×2.5 arc-minutes (approximately 4.65×4.65 km^2 at the equator), were obtained from the WorldClim database (http:\\www.worldclim.org; Hijmans et al. 2005). These variables are derived from temperature and precipitation data for the 1950–2000 time period. Additionally, we derived slope and aspect from elevation data. All 22 layers were clipped to include the entire boundary of Argentina (Fig. 1). Although using many environmental

Table 1 Species names, number of records for each species (*N*), and Extent of occurrence in km^2

Species	*N*	Extent of occurrence (km^2)
Cabassous chacoensis	12	418253.04
Cabassous tatouay	9	29965.19
Calyptophractus retusus	3	Not modeled
Chaetophractus nationi	9	52604.05
Chaetophractus vellerosus	112	583766.28
Chaetophractus villosus	236	733988.50
Chlamyphorus truncatus	53	231724.85
Dasypus hybridus	88	463159.45
Dasypus novemcinctus	58	243033.20
Dasypus yepesi	9	58543.42
Euphractus sexcinctus	44	208705.01
Myrmecophaga tridactyla	46	282136.97
Priodontes maximus	21	165526.56
Tamandua tetradactyla	56	213585.73
Tolypeutes matacus	76	378917.07
Zaedyus pichiy	112	553841.50

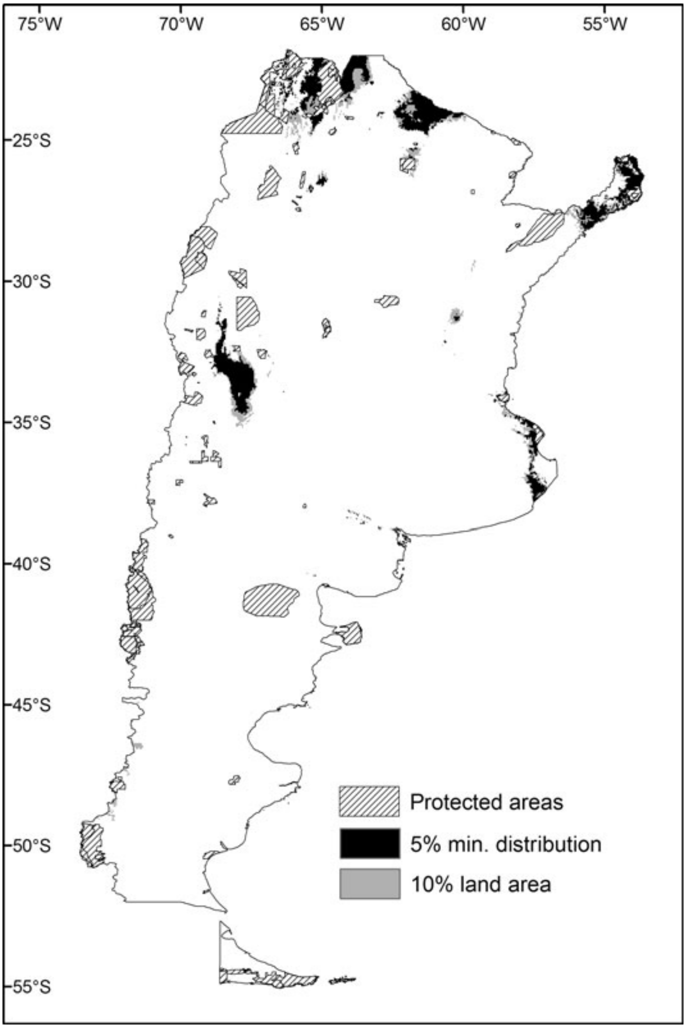


Fig. 1 Protected areas (in *diagonal hatch*) and conservation priority areas for representing the xenarthrans of Argentina. In *black* are the areas identified by the scenario with the goal of protecting at least 5% of the distribution of all species. In *gray* are the areas identified by the scenario with the goal of protecting 10% of the total area of the country

layers may tend to overfit the models (Phillips et al. 2006), we believe it is more conservative when using the models for conservation planning purposes.

Digital maps of protected areas for Argentina were obtained from the Argentine Secretary for the Environment (Secretararía de Medio Ambiente de Argentina). We included all protected areas under the National System of Protected Areas (Adminstración de Parques Nacionales), as well as Biosphere Reserves and designated Provincial parks. A few Provincial parks are represented only by their point locality because of their small area and were not included in the analysis. We considered protected all those pixels of $2.5' \times 2.5'$ that have their centroid included within any of the protected area polygons.

Because many of the locality data are historic data, we used the Global Land Coverage dataset (GLC2000; Eva et al. 2004) to restrict the species distribution maps obtained from the species distribution models (SDMs). This takes into account the changes in land cover that may have occurred since the collection of the species. Based on the expert opinion of one of the authors (A.M.A), we excluded all land cover classes that were not deemed suitable for the viability and persistence of the species. The classes that were excluded were: intensive agriculture, mosaic agriculture/degraded vegetation, mosaic agriculture/degraded forests, barren/bare soil, and deserts. Given that not all species are affected in the same way by the different land uses, the restriction of the SDMs was performed independently for each species. Finally, land cover data classified as urban, water bodies, and permanent snow/ice were masked from the analysis.

Species distribution models

Species distribution models were run with the software package Maxent (version 3.2.19) (Phillips et al. 2006). We selected Maxent because it has been shown to perform very well with presence-only data (Elith et al. 2006), and with relatively small sample sizes (Hernandez et al. 2006, 2008). Maxent uses a statistical mechanics approach called maximum entropy for characterizing probability distributions from incomplete information (Phillips et al. 2006). Maxent estimates the probability distribution of maximum entropy (the distribution that is most spread-out, or closest to uniform) of the occurrence points across the study area given the constraint that the expected value of each environmental predictor variable under this estimated distribution matches its empirical average (average values for the set occurrence data) (Hernandez et al. 2006; Phillips et al. 2006).

The Maxent algorithm was run using the default parameters including a maximum of 500 iterations with a convergence threshold of 0.00001, and 10,000 randomly generated background localities. We used the logistic output which provides an estimate between 0 and 1 of probability of presence of the modeled species. Species locality data were first filtered so that there was only one record per pixel. We modeled all species that have $\geq$8 point locality data. This excluded only one species (*Calyptophractus retusus*) that is known from only three localities in Argentina (Table 1). Several studies have shown that very reliable models can be obtained with low number of occurrences provided that appropriate model validation techniques are employed (Pearson et al. 2007; Kremen et al. 2008). Accordingly, we used very stringent criteria to validate all models. First, all species were modeled 100 times, randomly selecting 75% of the points to generate the models and the remaining 25% to test them. For each of the 100 model runs, we used the testing points to calculate the area under the curve (AUC) for the receiver operating characteristic. The area under the curve reflects the proportion of both correctly and incorrectly classified predictions over a range of probability thresholds (Pearce and Ferrier 2000) and is positively correlated with the predictive ability of the model (Manel et al. 2001). From the 100 model runs, we were able to calculate the mean AUC value and 95% Confidence Intervals. Second, for a species to be included in the reserve selection analysis, the lower limit of the 95% Confidence Interval of the mean AUC had to be >0.75. According to Elith et al. (2006), models that have an AUC value >0.75 have a useful amount of discrimination. Because species with <11 point localities have <100 number of training and testing combinations for calculating the 95% Confidence Intervals (Kremen et al. 2008), we used the actual number of possible combinations. Finally, for all species that met these criteria, we calculated a mean habitat suitability map by averaging all 100 runs for each species.

Evaluation of existing protected areas and reserve selection analysis

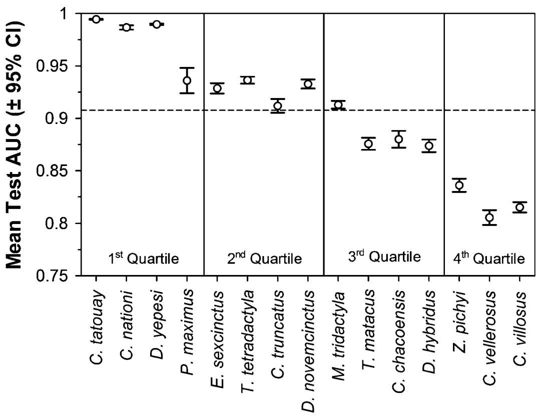
To assess the performance of the existing protected area network in representing all modeled species, and to identify priority areas to expand the current reserve system, we used the software Zonation v 2.0 (Moilanen and Kujala 2008). The advantage of Zonation is that it operates using large grids of probabilistic data as input files, providing a direct link between species distribution modeling software and spatial conservation prioritization. In addition, Zonation allows for the inclusion of species of special interest (SSI; species that cannot be modeled because they are known only from a few localities). The Zonation algorithm generates a hierarchical prioritization of the conservation value of a landscape (Moilanen et al. 2005). The algorithm iteratively removes the least valuable cells from the landscape while minimizing marginal loss of conservation value. The cell removal order is recorded and it can be used later to identify the top 1, 5, 10%, etc. fraction of the landscape in terms of conservation value (Moilanen 2007). Zonation has three different removal rule options: core-area Zonation, additive benefit function, and target-based planning (see Moilanen (2007) and Moilanen and Kujala (2008) for a detailed description and the differences among these removal rules). Here, we used the core-area Zonation removal rule which emphasizes locations with high occurrence levels for each species separately, and attempts to retain as much of the core distribution of the species as possible (Moilanen 2007; Moilanen and Kujala 2008). The software also allows for the identification of the landscape that will contain at least a determined proportion of the geographic distribution of all species. Additionally, the existing reserve network can be included in the analysis to assess the degree of protection from current protected areas.

We ran the Zonation algorithm including the existing reserve network to assess the level of protection that the studied species currently have. At present, the Argentine protected area system covers approximately 6% of the country. To identify conservation priority areas for expanding the existing reserve network, we assessed two different scenarios. The first one included an area that would represent at least 5% of the geographic distribution of each species. The range size for each modeled species was defined as the sum of habitat suitability scores across the entire area. We included only the suitability probabilities above the minimum probability value of an existing training presence, averaged over all 100 runs for each species. Because species' geographic ranges vary widely, we divided them in quartiles, with the first quartile including the 25% most geographically restricted species, and the fourth quartile the 25% most widely distributed species. The second scenario was related to the conservation target proposed by the Convention on Biological Diversity (CBD 2004), which implies the effective protection of 10% of a region or country. Accordingly, we assessed the level of protection that would be achieved for each species when 10% of the Argentine territory is set aside for conservation. In all cases, the only species that could not be modeled because of low number of presence data was included as a species of special interest (SSI) in the prioritization analysis.

Results

The average AUC value for all 15 species was 0.908 (range: 0.805–0.994; Fig. 2), and the average 95% Lower Confidence Interval for all species was 0.902 (range: 0.798–0.994). Because of the high AUC values, all species passed the criteria imposed in order to be included in the reserve selection process. In general, narrowly distributed species (i.e. in the lowest quartiles) have higher values of AUC than widely distributed ones (Fig. 2),

Fig. 2 Mean AUC value and 95% confidence intervals for each species. Species are arranged by quartiles depending on their total geographic distribution. The *dotted horizontal line* represents the average AUC value across all species



which is consistent with the findings of other studies (Segurado and Araújo 2004; Elith et al. 2006; Hernandez et al. 2008).

In general, all the species modeled are represented in the existing reserve network. However, the only species that was not modeled because of low sample size is not covered by any protected area. The current reserve network protects an average 6.7% of the distribution of all species (range: 1.7–17.6). With the exception of *Priodontes maximus*, species with smaller geographic distributions (i.e. in the first quartile) are better represented in the existing protected areas (Fig. 3). The species with the lowest percentage (1.7%) of its range under protection is *Chlamyphorus truncatus*.

To achieve the goal established for the first proposed scenario (i.e. represent at least 5% of all species' ranges), an area equivalent to the 8.8% of the country would be needed. The areas selected are mostly concentrated in central western and eastern Argentina, and in the northern western, central, and eastern portions of the country (Fig. 1). On average, 16.6% (range: 5–52.6) of all species' geographic distributions are represented in protected areas in this scenario (Fig. 3). The species in the first and second quartiles are the ones that show a greater increase in the percentages of their ranges that would be under protection (Fig. 3).

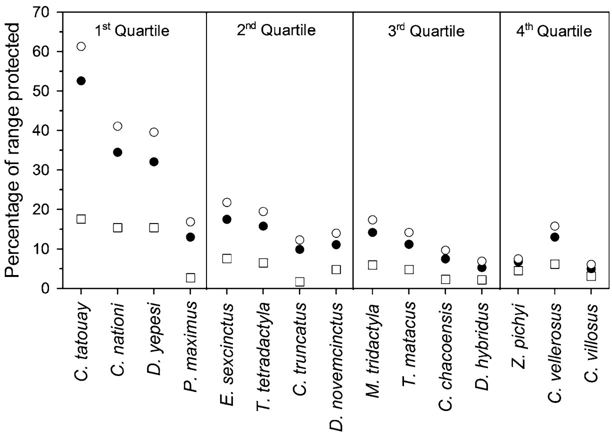


Fig. 3 Percentage of the geographic range protected for each species when the existing protected area network and the two different scenarios are analyzed. Species are arranged by quartiles depending on their total geographic distribution

When 10% of the country is set aside for conservation (second scenario), the average percentage of all species' geographic ranges in protected areas is 20.3% (range 6.1–61.3; Fig. 3). Again, species with narrower distributions (i.e. first and second quartiles) show a greater increase in the percentages of their ranges that would be protected. In general, the areas selected represent an expansion of the ones selected in the first scenario (Fig. 1).

Discussion

This is the first study that assesses conservation priorities for xenarthrans in Argentina. Our results show that almost all species of armadillos and anteaters present in the country are represented within the existing reserve network. However, the level of representation is very low for most of the species. This is particularly important for rare or geographically restricted species, which are more prone to become endangered in the near future because they are more vulnerable to stochastic events and anthropogenic activities. Furthermore, species with small geographic distributions tend to be rare in terms of local abundance as well (Gaston et al. 1997). This may be the case of the smallest species of armadillo, the pichiciego (*Chlamyphorus truncatus*), which is the species with the lowest percentage of its range represented in protected areas, and is a very rare, cryptic species, endemic to central western Argentina. Although some species in the first quartile have a higher percentage of their ranges represented in protected areas, it may not be sufficient to sustain viable populations in the long term.

Protecting at least 5% of the geographic distribution of all modeled species implies increasing the protected area system by only 2.8% of the country's area. This increase may not seem very significant but it represents a great boost in the protection of restricted-range species. Indeed, in this scenario, species in the first and second quartiles would have at least 10% of their range under protection. In fact, most of the areas highlighted as priority for conservation are directly related to the presence of restricted-range species, although they also cover some widespread species. Thus, the area identified in the Selva Paranaense ecoregion (north eastern Argentina) would mainly protect *Cabassous tatouay*, *Tamandua tetradactyla*, and *Dasypus novemcinctus*; the area in the Chaco ecoregion (north central Argentina) would increase the protection of *Priodontes maximus*; the areas in the Yungas and Puna ecoregions (north western Argentina) would serve to protect *Dasypus yepesi*, *Euphractus sexcinctus*, *Tamandua tetradactyla*, and *Chaetophractus nationi*; and the area in the Monte ecoregion (central western Argentina) would help protect *Chlamyphorus truncatus*. The area in the Pampas ecoregion (central eastern Argentina) would increase the protection of more widespread species, such as *Chaetophractus vellerosus*, *C. villosus*, and *Dasypus hybridus*. The second scenario (i.e. protecting 10% of the country's area) represents an increase in area of 1.2% with respect to the first scenario and, with the exception of two small areas in southwestern Argentina, it does not add new priority areas to the ones selected in the first scenario; it only expands upon the areas selected in the first scenario.

Most of the areas of conservation concern identified in our study are under strong anthropogenic pressures. Recent studies have shown an increase in deforestation rates in the last three decades in the Chaco ecoregion due to agricultural expansion (Grau et al. 2005; Boletta et al. 2006). According to Grau et al. (2005), approximately 20% of the forests were converted to agriculture between 1972 and 2001. Conversion of native forests to farmland is also a major concern in the Yungas and Panaraense ecoregions. During the period 1970–2000 the percentage of land converted to agriculture in the Yungas region doubled from 5.5 to 11% (Somma 2006). The Pampas ecoregion has been, for a long time now, the prime land for intensive agriculture and livestock grazing in Argentina and very little remains of its native habitats. In the Monte ecoregion, about 60% of the land area has been subjected to extensive livestock grazing (Guevara et al. 2009). It is uncertain how these activities affect most of the species of armadillos and anteaters, but it is very likely that habitat degradation and fragmentation may be taking a toll on many of their populations. The only published study (Abba et al. 2007) reported that, in the Pampas region of Argentina, two out of three species of armadillos use native habitats and avoided cultivated areas. Habitat degradation, however, is not the only threat that humans are imposing on these species, as some are heavily hunted both for food and for sport (Fonseca and Aguiar 2004). In addition, two species of armadillos (*Chaetophractus nationi* and *C. vellerosus*) are intensively harvested in northern Argentina and Bolivia for the construction of charangos, guitar-like musical instruments that are popular in the Andean culture (Fonseca and Aguiar 2004).

In areas that lack comprehensive data on species distribution, predictive distribution modeling is an innovative alternative approach for estimating the potential occurrence of species (Guisan and Thuiller 2005; Rodríguez et al. 2007). In combination with systematic conservation planning approaches, they can become powerful tools to identify conservation priority areas (Peralvo et al. 2007; Pawar et al. 2007; Kremen et al. 2008; Sarkar et al. 2009). However, there are some caveats to the use of species distribution models in conservation planning. First, predictive distribution models are only a hypothesis of the presence of the species in favorable or suitable areas and do not take into account biogeographical, historical, or biotic factors (Guisan and Thuiller 2005; Rondinini et al. 2006). Here, by using stringent criteria for validating the models, we ensured that only reliable models are included in the reserve selection process. Second, the use of species distribution models for conservation planning introduces the risk of false positive errors (Rondinini et al. 2006) that can lead the reserve selection algorithm to select sites where the species may actually be absent. However, this error is ameliorated by the use of the core-area algorithm in Zonation, which retains the areas of the distribution where there is highest probability of occurrence of the species. Third, the areas identified by Zonation represent large portions of contiguous land and it is very improbable that the totality of these areas can be allocated for conservation, mainly because most of these lands are likely owned by private landowners. The goal of this study, however, is to highlight the areas of conservation concern for anteaters and armadillos, so that they can help conservation managers in their decisions. If biodiversity targets are to be met, conservation should take place both inside and outside protected areas. To achieve this, appropriate social and economic incentives should be provided (Figgis 2004) in addition to innovative management of agricultural systems that are friendlier to biodiversity (McNeely and Scherr 2001).

Our analysis provides new insights into conservation priorities for armadillos and anteaters in Argentina. Although a very important group from the conservation point of view, these species represent a mere 5% of the total mammal species of Argentina. Further studies are under way to include the rest of the mammal species, as well as other vertebrate groups (i.e. birds, reptiles and amphibians). This study is a preliminary attempt towards identifying conservation priority areas for vertebrate species in Argentina.

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