

Estimating potential geographic ranges of armadillos (Xenarthra, Dasypodidae) in Brazil under niche-based models

Estimation de la distribution géographique potentielle des tatous (Xenarthra, Dasypodidae) au Brésil à partir de modèles basés sur les niches écologiques

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Introduction

The order Xenarthra is restricted to the Neotropical region and includes armadillos, sloths and anteaters. These taxa originated in the Cretaceous period approximately 80 million years ago (Sarich 1985, Delsuc et al. 2001, Delsuc et al. 2004), and constitute one of the most diverse and abundant groups of recent and fossil mammals (Paula Couto 1979). Xenarthra species occur mainly in South America and might have colonized North America after the formation of the Panama Isthmus during the late Tertiary period (Engelmann 1985).

The order Xenarthra is currently divided into three infraorders: Pilosa (sloths), Vermilingua (anteaters) and Cingulata (armadillos) (Nowak 1991, Wilson and Reeder 1993). Xenarthrans have been poorly studied, despite their importance in the history of mammals. Phylogenetic analyses reinforce the ancestral position of Xenarthra, which, with the Afrotheria clade, represent the basal lineages of placental mammals (Madsen et al. 2001, Murphy et al. 2001). This suggests that the current four families of Xenarthra encompass a great amount of the evolutionary history of mammals, making conservation of this order a priority for biodiversity maintenance (Purvis et al. 2000, Mace et al. 2003).

Armadillos are the most widespread taxa of the order Xenarthra, ranging from the United States to Argentina (Nowak 1991). Armadillos also constitute the largest family (Dasypodidae) of the order, with eight genera and 21 species (Eisenberg and Redford 1999). Brazil harbors a considerable richness of this group, with five genera and 10 species, including one species restricted to the country – *Tolypeutes tricinctus* Linnaeus, 1758. Despite this, information on the occurrence of armadillo species in Brazil is fragmented in publications on populations from specific regions or localities (Carter 1983, Carter and Encarnação 1983, Marinho-Filho et al. 1997, McDonough et al. 2000, Anacleto and Marinho-Filho 2001, Prada and Marinho-Filho 2004). Geographic ranges of armadillos have been estimated and mapped using information from species records (Wetzel 1982, 1985, Emmons and Feer 1990, Eisenberg and Redford 1999), but no recent studies have considered information on geographic ranges combined with data on biotic and abiotic factors for a whole data set. This combination allows a more accurate estimate of the potential extent of the occurrence of each species.

Abstract

Dasypodidae is the largest family of the order Xenarthra, with eight genera and 21 species. The geographic ranges of 10 species of armadillos in Brazil were analyzed together with environmental variables, such as topography and climate, using the GARP program. Maps were generated using the 20 best models per species and predicted the occurrence of eight of the 10 species in the Cerrado biome, indicating that the central region of Brazil is an important area for the preservation of armadillo species. Thus, using niche modeling it is possible to better map the geographic ranges of species, to use these maps to optimally establish priority areas for species conservation and to understand overall biodiversity patterns.

Keywords: armadillos; Brazil; Cerrado; genetic algorithm; geographic range.

Résumé

La famille des Dasypodidae est la plus grande de l'ordre des Xenarthra avec 8 genres et 21 espèces. La distribution géographique de 10 espèces de tatous a été analysée à l'aide de variables environnementales de topographie et de climat, en utilisant le programme GARP. Les cartes ont été générées à l'aide des 2 meilleurs modèles et l'occurrence de 8 des 10 espèces dans le Cerrado a été prédite. Ceci indique l'importance de cette zone du centre du Brésil pour la préservation des espèces de tatous. Ainsi, grâce à la modélisation des niches il est possible de mieux cartographier la distribution géographique des espèces et de les utiliser pour établir de façon plus optimale des zones prioritaires pour la conservation et pour mieux comprendre les patrons de biodiversité.

Development of such estimates has been favored by the recent availability of detailed ecological and climatological data, as well as by the development of optimization and modeling algorithms and programs that create range models with reasonable prediction ability. The use of these niche modeling tools allows a better understanding of regional biodiversity patterns and, consequently, improvements in the implementation of many conservation actions, such as the selection of priority areas and biodiversity corridors.

Several methods have been adopted for the creation of these models, such as multivariate statistics (Austin and Meyers 1996, Corsi et al. 1999), multiple logistic regression and discriminant analysis, and artificial intelligence based on genetic algorithms (Stockwell 1999). Among these methods, the genetic algorithm for rule-set prediction (GARP) has been considered a particularly robust and efficient optimization technique (Stockwell and Peterson 2002) that allows the prediction of geographic ranges for species in poorly sampled or unknown regions (Peterson et al. 2004).

This study aimed to estimate the potential geographic ranges of the 10 armadillo species that occur in Brazil. Sites of records of species available in the literature and obtained through fieldwork were used to define ecological niche models using GARP. The results are discussed in terms of establishing priority areas for the conservation of armadillo species in Brazil.

Material and methods

The program GARP (<http://biodi.sdcs.edu>) is a genetic algorithm developed by Stockwell and Noble (1991) that combines the analytical abilities of several individual methods, such as BIOCLIM and logistic regression, optimized for a set of rules. GARP tries to find non-random relationships between data on species occurrence and environmental variables at recorded sites, producing models of the potential geographic ranges of the species (Stockwell and Noble 1991). Among the numerous interpretations of ecological niche (Grinnell 1917, Elton 1927, Hutchinson 1965), the concept of fundamental niche is used in GARP modeling. According to this concept, a niche might be defined as a set of ecological and environmental conditions in which the species is able to survive. It might be represented by a multidimensional space when the species is not restricted through competition with others (Hutchinson 1965).

GARP works with sets of rules of logic inference that indicate the presence or absence of a species in a region (Stockwell and Noble 1991). Specifically, half of the data are randomly selected for development of the rules (training data), whereas the other half are used to evaluate the accuracy of the rules (test data). An algorithm is applied to the training rules to evaluate the accuracy of the model in terms of the two errors likely to occur in estimation: omission (when an area of occurrence of the species is not predicted) and commission (when the prediction includes an area not occupied by the species). Omission is considered intrinsic when accuracy is evaluated from the training data, or extrinsic when testing data are used

(Anderson et al. 2003). Each half is then sampled with 1250 substitutions, generating data for presence and absence (pseudo-absence) for a given locality. These presence-absence data are related to the environmental variables, generating a set of rules that define these associations by a process of self-evaluation according to a zero omission error. These rules are then modified and re-evaluated using the same criterion, generating an evolution of the rules that will tend to maximize the relationship between occurrence and a given set of environmental conditions, creating a bioclimatic envelope.

Thus, the program can run for a previously defined number of iterations, allowing model improvement. It can also stop when the addition of new rules has no appreciable effect on the accuracy measure (convergence), i.e., the difference between the current and the previous rule-set. The final rule-set, or ecological-niche model, is then projected onto a digital map. Previous studies showed that GARP has fine predictive ability with relatively few data points, ranging from 10 and 20 records (Peterson et al. 2002).

We used the above procedures to model the geographic range of 10 armadillo species in Brazilian biomes (Amazon, Caatinga, Cerrado, Pantanal, Atlantic Forest and Pampa): *Cabassous tatouay*, *C. unicinctus*, *Dasypus hybridus*, *D. kappleri*, *D. novemcinctus*, *D. septemcinctus*, *Euphractus sexcinctus*, *Priodontes maximus*, *Tolypeutes matacus* and *T. tricinctus*. The taxonomy followed Wilson and Reeder (1993). For these 10 species, we obtained 929 occurrence points, widely distributed throughout their geographic ranges (Figure 1). These data points were compiled from the literature and from the scientific collection of the University of Mato Grosso (Appendix 1).

In the optimization, we ran GARP 200 times for each species (2000 iterations for each run), setting the convergence limit to 0.001, a 0% extrinsic omission error and 10% commission error. We used variables of topography (altitude) and climate, including precipitation, total precipitation for the driest 3-month period, the coefficient of variation for monthly precipitation, total precipitation for the most rainy 3-month period, mean temperature for the coldest 3-month period, coefficient of variation for monthly temperature, mean temperature for the hottest 3-month period, mean annual temperature, minimum and maximum. The data sets refer to a 25-year period (1965–1990) and are available in the DIVA-GIS program (www.diva-gis.org). In a preliminary analysis, these variables, defined at a resolution of 10' (approx. 16.7 km), resulted in a better prediction of the geographic ranges of the species when compared with the resolution levels and variables originally available in GARP.

We ran 200 models for each species and, following the standard procedures, selected the 20 best models (i.e., the best subset) generated for each species and imported then into a GIS platform (Arc View). Models in the best subset were summed and mapped, allowing a visual inspection of regions with high levels of model overlap, which are presumably the regions with a higher chance of species occurrence. We used a map with four classes to represent the number of models (0, 1–8, 9–16 and 17–20) used to estimate the geographic range for each species.



Figure 1 Distribution of 929 sites of occurrence of 10 armadillo species that occur in the six Brazilian biomes.

Richness maps were generated by summing geographic ranges for each species and conservatively considering for each species only the regions that were assigned by nine models or more. This choice was based on the fact that regions in which species occurrence is based on a small number of models in fact do not have real records, and probably present a commission error. More importantly, since we are working only with Brazilian species, this range overlap and potential richness estimate is valid only within this region.

Results

The species with the highest numbers of recorded sites were *Dasypus novemcinctus* and *Euphractus sexcinctus*, while *Tolypeutes matacus* had the lowest (Table 1). Considering occurrence based on records, the geographic ranges of the 10 species were primarily concentrated in northeastern Brazil. There is also a gap for the Amazon region, particularly the central Amazon, where only three species (*C. unicinctus*, *D. kappleri* and *P. maximus*) were recorded. The high concentration of sites of occurrence in the Caatinga region is due to recent information presented in the Workshop “Avaliação e Ações Prioritárias para a Conservação da Biodiversidade da Caatinga” (Silva et al. 2004).

The genus *Cabassous* was widely distributed across the six Brazilian biomes, but the Caatinga and Pampa showed low potential for its occurrence (Figure 2). *C. tatouay* showed high likelihood of occurrence in the Cerrado, Pantanal and Atlantic Forest. *C. unicinctus* had a potential geographic range that included the Amazon,

Cerrado, and Pantanal, plus a small region of the Atlantic Forest.

The potential geographic range of the *Dasypus* species showed distinct associations with specific environmental conditions (Figure 3). *D. hybridus* had the most restricted potential range, with predicted occurrence in the Pampa and a small portion of the Atlantic Forest. The predicted range of *D. kappleri* was concentrated in the Amazon, but also along the Cerrado border. *D. novemcinctus* and *D. septemcinctus* were potentially distributed in Cerrado and Caatinga biomes, with a gap of occurrence in the Amazon, the Pampa and part of the Atlantic Forest.

E. sexcinctus (Figure 4) was also potentially distributed in Cerrado, Pantanal, Caatinga and Atlantic Forest biomes. The genus *Tolypeutes* was predicted for the Caatinga, the Cerrado and a restricted area of Atlantic Forest and Pantanal biomes (Figure 4). Within this genus, *T. tricinctus* is a threatened species endemic to Brazil (Table 1). In the modeling process, its geographic range was basically restricted to the Caatinga and a narrow and adjacent zone of Cerrado. *T. matacus* had a potential range in the Atlantic Forest and, with a lower number of models (1–8), was predicted for the Pantanal.

The potential range of *P. maximus* encompassed a considerable portion of Brazil, except in the Caatinga and Pampa (Figure 4). For this threatened species (Table 1), Cerrado, Pantanal and part of the Atlantic Forest were its potential biomes.

The species richness map (Figure 5) based on range maps generated by GARP showed the highest richness values for the Cerrado and the Atlantic Forest (both with eight species) and the Pantanal (seven species). The Caatinga was predicted to harbor five species. The Pam-

Table 1 Number of sites of occurrence of armadillo species that occur in Brazil, with threat categories: near threatened (NT), least concern (LC) and vulnerable (VU) (Fonseca and Aguiar 2004), and biomes: Atlantic Forest (AF), Amazon (Am), Caatinga (Ca), Cerrado (Ce), Pantanal (Pa) and Pampa (Pm).

Species	Common name	Points	Biomes	Categories
<i>Tolypeutes matacus</i> Desmarest, 1804	Southern three-banded armadillo	16	Ce, Pa	NT
<i>Dasypus hybridus</i> Desmarest, 1804	Southern lesser long-nosed armadillo	25	AF, Pm	NT
<i>Cabassous tatouay</i> Desmarest, 1804	Greater naked-tailed armadillo	29	Am, Ce, Ca, AF, Pm	LC
<i>Dasypus kappleri</i> Krauss, 1862	Greater long-nosed armadillo	39	Am	LC
<i>Cabassous unicinctus</i> Linnaeus, 1758	Naked-tailed armadillo	52	Am, Ce, Pa, Ca, AF	LC
<i>Priodontes maximus</i> Kerr, 1792	Giant armadillo	56	Am, Ce, Pa, AF	VU
<i>Dasypus septemcinctus</i> Linnaeus, 1758	Seven-banded long-nosed armadillo	78	Am, Ce, Ca, AF	LC
<i>Tolypeutes tricinctus</i> Linnaeus, 1758	Ball armadillo	80	Ca, Ce	VU
<i>Euphractus sexcinctus</i> Linnaeus, 1758	Yellow armadillo	254	Am, Ce, Pa, Ca, AF, Pm	LC
<i>Dasypus novemcinctus</i> Linnaeus, 1758	Nine-banded armadillo	300	Am, Ce, Pa, Ca, AF	LC

pa was the biome with lowest potential for the occurrence of armadillos (only one species).

Discussion

Data quality

Our modeling procedure is based on local records of multiple species, and these data are not usually available in the specialized literature. In many instances, there are only crude descriptions of the extent of occurrence of the species, not infrequently dealing with geopolitical (countries, states, provinces or municipalities) units. The exact place of collection or sighting is rarely reported, and we indeed found only 929 spatially unique points for 10 species from a total of 74 data sources.

The niche-modeling approach used here, which generates polygons based on occurrence records, will be more accurate as long as a relatively large number of records widely distributed within the species geographic range are available. Previous methodological papers using GARP showed that the procedure works relatively well even with a low number of points (10–20) (Peterson et

al. 2002). Thus, in our data set, some heterogeneity of accuracy in the modeling procedure is expected because of the variation in the number and quality of records obtained for each species. For example, for *D. novemcinctus*, which is the best-studied armadillo, we obtained a large number of records, whereas for species such as *T. matacus*, *D. hybridus* and *Cabassous tatouay* there are relatively few records. However, considering the statistical properties of GARP, we believe that these differences are not significant and do not qualitatively affect our conclusions.

Another important issue is the quality of the records themselves. The use of sources that were more refined and based on direct scientific search for armadillo species is more frequent in our data set, although in some cases (e.g., some records from Caatinga) there is a mix of direct and indirect records for some species. This may add some error to the process for some species when data are based, for example, on interviews with local people, which may introduce taxonomic problems. When using data from secondary literature, it is not possible to individually separate these records from those based on direct observations or sampling of a species. However, once again, these data sources are relatively few in our

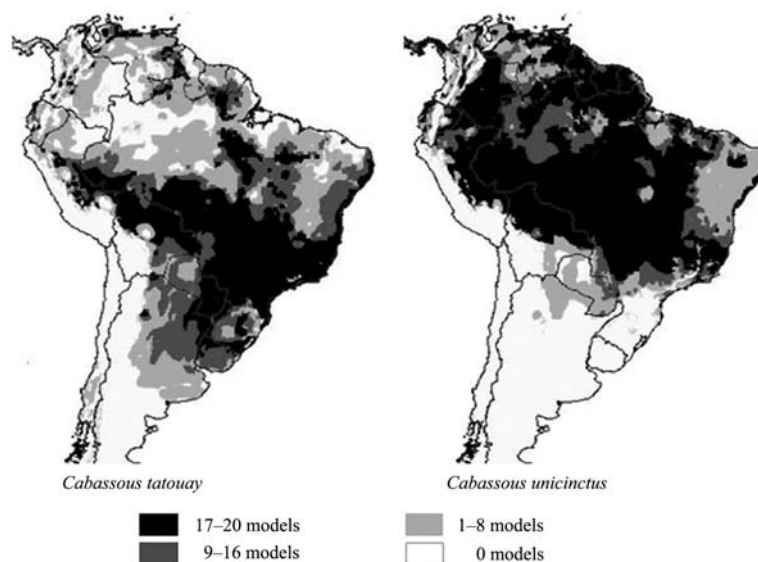


Figure 2 Model of the potential distribution of *C. tatouay* and *C. unicinctus* in Brazil. The scale of colors (black to white) represents the number of models for the occurrence of each species (see materials and methods for details).

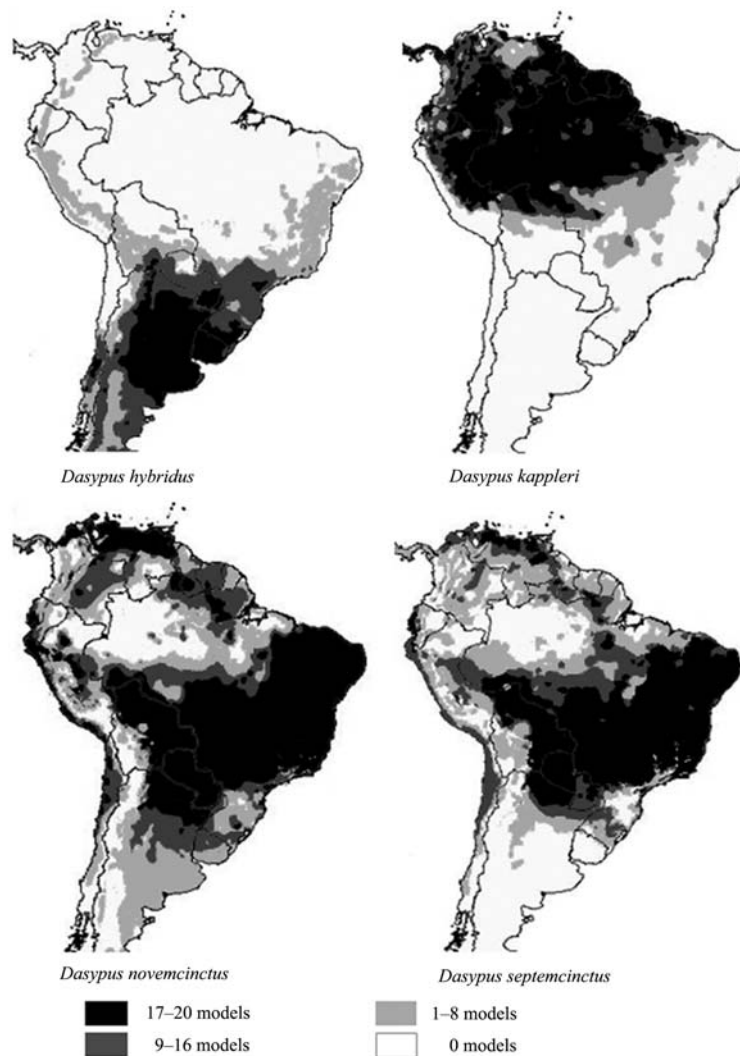


Figure 3 Model of the potential distribution of *D. hybridus*, *D. kappleri*, *D. novemcinctus* and *D. septemcinctus* in Brazil. The scale of colors (black to white) represents the number of models for the occurrence of each species (see material and methods for details).

data set and consequently it is not expected that they qualitatively affect our main conclusions.

Potential ranges defined by GARP

Comparison of the most recently available data on the extent of the occurrence of armadillos (Fonseca and Aguiar 2004) with those obtained here using GARP reveals some curious aspects. The polygons formed by connecting occurrence records and generating the extents tend to encompass a broad range of environments and, consequently, simplify the complexity of potential interactions between occurrence and environmental conditions at more local scales. On the other hand, GARP modeling indicates regions with more suitable environmental conditions for species, usually at much more refined spatial scales. For example, in the geographic range of *C. tatouay*, a large portion of north-east Brazil was added, but in the GARP map this region, despite being marked, has a small overlap of models, suggesting that occurrence there is not predicted in all models. This result corroborates empirical knowledge about this species, because *C. tatouay* was recorded

only twice in this region, with only one record in the Caatinga (Santos et al. 1994) and the other in the northern extreme of the Cerrado (Eisenberg and Redford 1999).

Species ranges are limited by environmental conditions (Holt et al. 2003). In the niche modeling of armadillos, it was noted that some species showed specific ecological tolerances. For example, *D. kappleri* was restricted to Amazonia, *T. tricinatus* to the Caatinga, and *D. hybridus* to the Pampa. *D. kappleri* prefers forested areas and has been found in the Amazonian and Orinoco basins (Eisenberg and Redford 1999).

T. tricinatus has been considered endemic to the Caatinga (Wetzel 1985, Redford 1994, Santos et al. 1994), and the lack of records led to the suspicion that it was extinct in nature (Cole et al. 1994). However, it was recently found in the Caatinga (Cardoso da Silva and Oren 1993) and the Cerrado (Marinho-Filho et al. 1997). The range predicted for this species reinforces the potential presence of this species in these two biomes. Overall, the genus *Tolypeutes* has been poorly studied, and *T. matacus* was poorly sampled in Brazil, with only one record for the Fazenda Acurizal, Pantanal in Mato Grosso do Sul (Schaller 1983).

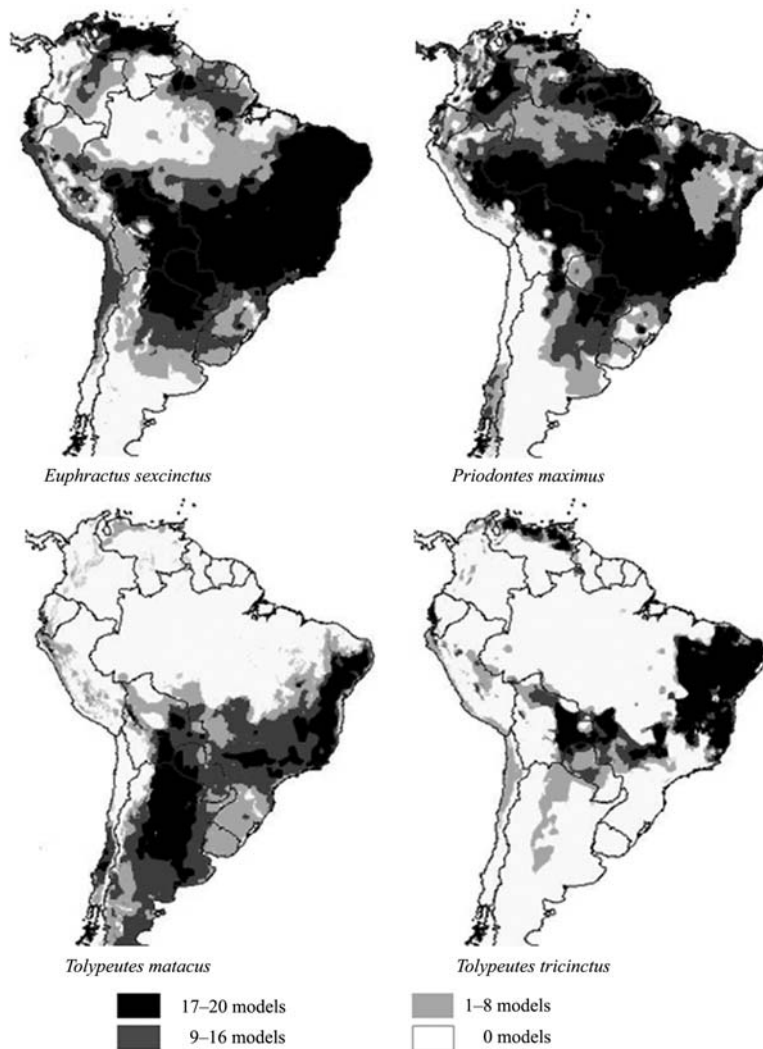


Figure 4 Model of the potential distribution of *E. sexcinctus*, *P. maximus*, *T. matacus* and *T. tricinctus* in Brazil. The scale of colors (black to white) represents the number of models for the occurrence of each species (see material and methods for details).

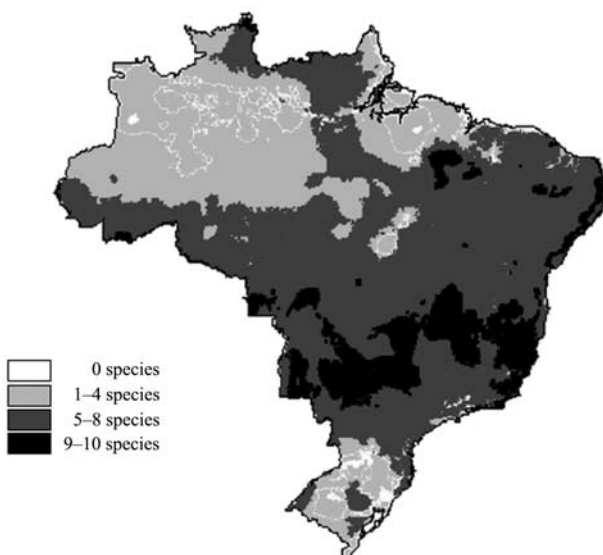


Figure 5 Species richness map for armadillos that occur in Brazil. The scale of colors represents the number of species.

The predicted range of *D. hybridus* was restricted to southern Brazil, broadly occurring in open areas of Pampa (Silva 1984, Eisenberg and Redford 1999). There is a single record from southeastern Brazil in São Paulo state (Jorge et al. 1985).

C. unicinctus was predicted to occur throughout Brazil. This species uses a wide range of habitats, varying from wet areas in the Atlantic Forest (Loughry and McDonough 1997) to dry areas in the Cerrado (Encarnaç o 1986) and even rarely in forests (Encarnaç o 1986, Emmons and Feer 1990). This species is most often sighted during diurnal foraging activities. Modeling its range would likely be improved if the occurrence data were sub-divided to distinguish the subspecies *C. u. unicinctus*, which occurs from Peru to French Guiana through northern Brazil, from the subspecies *C. u. squamicaudis*, which is smaller (approx. 2 kg) and occurs from Bolivia to Peru and Brazil. However, there are no data on the localities of occurrence of these subspecies, although it is known that they are sympatric along the Rio Amazonas-Solim es in the Amazonian basin (Wetzel 1985). There are few records of *C. unicinctus* in the Amazon and, despite its absence in forests, it might occur in

the diverse range of vegetation types of this biome, such as Cerrado disjunctions, palm forests, bamboo patches and varzea forests.

Although *C. tatouay* is considered common and present in a number of parks and protected areas in Brazil (Fonseca and Aguiar 2004), it is rarely seen and we only have a small number of detailed records of occurrence. This may be partially explained by its low ecological density and fossorial habits (Eisenberg and Redford 1999). According to GARP modeling, the potential range of this species encompasses the Cerrado and Atlantic Forest.

D. novemcinctus is the most widely distributed armadillo species, occurring from South America to the United States (Taulman and Robbins 1996). It and *D. septemcinctus* prefer forested areas, but *D. septemcinctus* may also be found in open and disturbed areas (Eisenberg and Redford 1999, McDonough et al. 2000). *D. septemcinctus* is more likely to be found than *D. novemcinctus*, probably because of its relatively higher abundance, its diurnal foraging habits and its small body mass (1.5 kg), which does not place it as a frequent target of hunters.

In the Atlantic Forest, *D. novemcinctus* was found in disturbed vegetation surrounding forest fragments, possibly moving between forest fragments (McDonough et al. 2000). The same behavior was observed for *P. maximus*, in the Cerrado (Anacleto, personal observation). In places where *D. novemcinctus* is hunted, it is much more difficult to approach active animals in order to catch them, and this behavior was not observed in the US, where only natural predators pursue these armadillos (Loughry and McDonough 1998). Indeed, *D. novemcinctus* is expanding its range in the United States (Taulman and Robbins 1996), where it does not suffer negative direct effects from human action (hunting) (Humphrey 1974). It is curious that in Brazil, hunting and habitat loss are reducing the abundance of *D. novemcinctus*, which is shifting some alimentary habits (taboos) of human populations. *D. novemcinctus* is appreciated for its white and highly flavored meat, but it is now being replaced by other species as a food source. In Mato Grosso, local hunters are now targeting the abundant *E. sexcinctus*, which was formerly refused for human consumption due to the perception of its habit of carrion feeding (Anacleto, personal observation).

E. sexcinctus has high tolerance for habitat disturbance and is often found in Cerrado pasturelands (Anacleto, personal observation). The subspecies were not considered in this analysis due to a lack of information. Five subspecies are recognized, with three of them occurring in Brazil: *E. s. setosus*, from Ceara to southern Brazil; *E. s. flavimanus*, from Rio Grande do Sul to Goiás and Mato Grosso; and *E. s. sexcinctus*, in the lower Amazon (Cabrera 1958). It is likely that the high number of records for this species reflect its conspicuousness.

P. maximus had a broad potential range in Brazil, mainly in Cerrado, Pantanal and part of the Atlantic Forest biomes. These biomes have been severely fragmented, but were ancestral habitats for *P. maximus*. Indeed, Cabrera and Yepes (1940) considered the Cerrado and Pantanal (more specifically Goiás and Mato Grosso states) as areas of high density for this species. Ruschi

(1954) recorded three individuals in a forest area in Espírito Santo. Although no recent records by scientists exist, sightings by locals have been reported in this area (Chiarrello 1999).

It is likely that errors of commission occur in models that consider climatic and ecological data at large scales, as the natural cover of some areas might have been severely modified in recent times. Thus, to obtain more precise estimates of geographic ranges, besides increasing information on occurrence locations, it is essential to generate environmental maps with recent and specific information about the biomes. These could include, for example, the type of soil use and native vegetation cover, which would be related to the environmental variables used for the modeling.

More detailed taxonomic information is necessary for improved modeling processes. In the case of *C. unicinctus* in the Amazon, it will be necessary to indicate the subspecies found in a given locality. The same should be adopted for *E. sexcinctus*. Eisenberg and Redford (1999) estimated the range of *E. sexcinctus* to the north of the Amazonas River, but did not comment on its occurrence in this area. Silva et al. (2001) and Silva and Nunes (2001) reduced the dimensions of this isolated area with records from the Caatinga region to Amapá. It is likely that the records are of *E. s. sexcinctus* and that, considering the potential geographic range, this isolated area shows favorable environmental conditions for the occurrence of this species. This was not predicted for other Amazonian regions.

To a great extent, this problem occurs because armadillos are difficult to see and the morphological similarity between some sympatric species might lead to equivocal identifications. For example, in the case of field records, young *C. tatouay* and *D. novemcinctus* might be confused with adults of *C. unicinctus* and *D. septemcinctus*, respectively. As some species are diurnal, others are nocturnal, and some have strong fossorial habits, obtaining reliable records of occurrence requires specific methodologies for each species.

In terms of species richness, the Amazon region, covering approximately 49% of the Brazilian territory (IBGE 2004) and harboring the most diverse fauna in the Neotropical region (Voss and Emmons 1996), was characterized by our models as an area with climatic conditions less suitable to the occurrence of armadillos. However, a different outcome might have been obtained if this extensive biome had been better sampled.

The Cerrado and Atlantic Forest biomes included more ranges for armadillo species, which is in accordance with other biological data (these biomes are considered biodiversity hotspots; Myers et al. 2000). The Cerrado is the second largest Brazilian biome, and was the ecosystem predicted to harbor eight of the 10 species analyzed. Atlantic Forest was also predicted to have high species diversity, although this was generated with a smaller number of range models. Our results highlight the importance of the central region of Brazil for the conservation of armadillo species. However, the native vegetation has been intensively converted to cultivated fields by agribusiness (Machado et al. 2004). This rate of habitat

destruction is much faster than the rate of production of scientific research on armadillos.

Conservation implications

Armadillos are also threatened by human actions such as deforestation (Redford 1992, McDonough and Loughry 2005) and illegal hunting (Redford 1987, 1992, Loughry and McDonough 1998, Cullen et al. 2000). These problems can modify the habits of the armadillos and in some instances help to explain the modeling patterns observed.

The armadillo species have distinct ecological requirements that might lead to difficulties in planning their conservation programs. Since 1996, only two species that occur in Brazil (*T. tricinatus* and *P. maximus*) have been considered threatened with extinction (Fonseca and Aguiar 2004). These two species are the only armadillos considered officially threatened in Brazil (Fonseca and Chiarello 2003). The scant information on the biology and geographic range of *T. matacus*, *C. tatouay*, *C. chacoensis* and *D. hybridus* makes it difficult to accurately ascertain their conservation status according to IUCN criteria.

Some species appear to be locally extinct. *P. maximus* is nearing extinction in the whole Atlantic Forest biome, but particularly so in São Paulo, Rio de Janeiro and Espírito Santo (Biota 2006, MMA 2006). In Minas Gerais state the conservation status of this species is perhaps slightly better due to the presence of larger expanses of Cerrado vegetation and large conservation areas such as the National Parks of Grande Sertão Veredas, Sempre Vivas and Serra da Canastra (A. Chiarello, personal communication). A similar situation occurs with *Cabassous* spp. in the south and southeast of Atlantic Forest. In Paraná state, data are deficient regarding *C. tatouay* and *C. unicinctus* is considered vulnerable in São Paulo state (Biota 2006, MMA 2006). In Minas Gerais, these two species were also classified as vulnerable (BDT 2006). There are no recent records for *D. hybridus* in São Paulo state, suggesting extinction at a more regional level. This could also be due to a misclassification problem, since this species is closely related to the other species in the genera and only a single record was previously noted for the state (Jorge et al. 1985). In general, the genus *Dasypus* does not appear in regional lists of endangered species and only *D. septemcinctus* appears in the list for Paraná state (Atlantic Forest), being classified as data deficient (MMA 2006).

Conclusion

Our study shows that ecological niche modeling might be an important computational tool to supplement traditional field studies. Our data can be used for the formulation of public policies specific for the different Brazilian biomes through the selection of areas to be protected or recovered for the conservation of higher species richness. In addition to predicting the geographic ranges of each species, this analysis allows reflection on the biology and natural history of armadillos, and highlights the importance of the Cerrado as a hotspot where

political and management actions are urgently needed to effectively protect these xenarthran species.

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Appendix 1: Data sources used for species point occurrence

Bibliography

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