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Assessment of *Cerdocyon thous* distribution in an agricultural mosaic, southeastern Brazil

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Abstract

Crab-eating fox, *Cerdocyon thous*, is a habitat generalist species relatively common throughout its range inhabiting most environments owing to its low habitat requirements. Because no information is available for anthropogenic habitats, this study aimed to describe the species occurrence in a highly fragmented and heterogeneous landscape in southeastern Brazil. *C. thous* was surveyed in 95 study sites in four main land covers (native forest, eucalyptus forest, sugar cane and pasture) from April to September 2006. Presence records (n=28) and landscape variables (land cover, heterogeneity, stream and forest fragment distance, elevation and slope) were used for modeling in Maxent. The bootstrapping method was used for sampling 70% of the dataset for training and 30% for testing models. The species was equally distributed in all types of land cover, although it was more frequent in the sugar cane areas and more associated with forest fragments and heterogeneous habitats. The potential distribution model predicted forest patches and its surroundings as highly suitable for the species. It also predicted part of the sugar cane matrix as highly suitable, probably related to prey availability. Results suggested that the anthropogenic landscape studied encompasses many suitable habitats for species occurrence, resulting in the necessity to assess its potential role in vertebrate communities.

Keywords: agroecosystem; habitat generalist species; Maxent; potential distribution; track survey.

Introduction

The crab-eating fox, *Cerdocyon thous* (Linnaeus 1766) is a medium-sized nocturnal carnivore widely distributed in the Neotropical region. The species is relatively common throughout its range from Colombia and south Venezuela, into Brazil, Paraguay, northern Argentina and Uruguay (Berta 1982), inhabiting most habitats including marshland, savanna, cerrado, caatinga, scrubland, woodland, dry and semideciduous forest, gallery forest and Atlantic forest, among others (Courtenay and Maffei 2008, Di Bitetti et al. 2009).

Cerdocyon thous is an insectivore/omnivore and is able to use environments disturbed by human activities owing to its opportunist and generalist habits (Facure and Monteiro-Filho 1996, Facure et al. 2003, Bueno and Motta-Junior 2004, Jácomo et al. 2004, Dotta and Verdade 2007, Courtenay and Maffei 2008, Rocha et al. 2008). The generalist diet of *C. thous* includes fruits, plants, vertebrates and invertebrates, in addition to human rejects (Facure et al. 1996, Juarez and Marinho-Filho 2002, Jácomo et al. 2004, Rocha et al. 2004, Gatti et al. 2006a,b, Pedó et al. 2006, Rocha et al. 2008).

Habitat fragmentation, usually defined as a landscape-scale process involving both habitat loss and the breaking apart of habitats, has positive and negative effects on biodiversity (Fahrig 2003). Habitat generalist species should benefit from environments that are heterogeneous (in space and/or time) (Kassen 2002, Marvier et al. 2004). As Marvier et al. (2004) indicated, habitat destruction, fragmentation and short-term disturbances all favor invasion by habitat generalists. Considering the little information available for *Cerdocyon thous* occurrence and its potential to adapt to anthropogenic habitats, this study aimed to describe the species occurrence in a highly fragmented and heterogeneous agricultural landscape in southeastern Brazil. Ecological niche modeling was used as a tool to elucidate the potential distribution of the species in this landscape.

Materials and methods

Study area

The study area was at the Corumbataí river basin (1710 km^2), located in the middle-east part of São Paulo state 22°04′–23°41′ S, 47°26′–47°56′ W; Figure 1). It comprises eight municipalities and has approximately 530,000 inhabitants. The most important river is the Corumbataí river, which starts flowing in the cuesta zone, reaching Piracicaba river after crossing Rio Claro city, the most important municipality in the basin (Garcia et al. 2006).

The topography of the region is moderate undulated. The elevation on the springs of the Corumbataí river is nearly 1058 m and at the discharge nearly 470 m (Garcia et al. 2006). After intensive and lasting processes of landscape modifications, approximately 12% of original Atlantic Forest remains in highly fragmented conditions (Valente and Vettorazzi 2003). Only approximately 14% of forest fragments are up to 100 ha. Larger forest fragments are located mainly on the elevated areas in the west portion of the river basin. The landscape mosaic is heterogeneous encompassing mixed cultivated areas, urban areas, pasture, forest remains and eucalyptus forest. Sugar cane (~26%) and artificial pasture (~44%) are the main land uses in the Corumbataí river basin (Valente and Vettorazzi 2003, Figure 1). This area is under frequent and high levels of human disturbance, owing mainly to agriculture and urban development.

Species survey

Cerdocyon thous was surveyed in 95 study sites: 23 in sugar cane (SC), 26 in pasture (PA), 27 in native forest (NF) and 19 in eucalyptus forest (EF), selected from the stratified sampling approach considering the four main land covers in the river basin. After stratification systematic points were centered in all map polygons by GIS software (ArcView 3.3, ESRI, CA, USA), representing possible study sites. All possible study sites were checked before sampling, and those on which track survey could be feasible were selected. The species occurrence by track survey was recorded on a 350-m transects in dirt trails early in the morning (06:00–10:00 h) at once, in each study site. All tracks were measured, photographed and correctly identified by mammal specialists. They were also checked according to Becker and Dalponte (1991) and Borges and Tomas (2004). All records were made by the same observer from April to September 2006.

Environmental variables

Ten environmental variables were considered in this study, six continuous and one categorical, with four classes of land cover (Table 1). Among these, the heterogeneity (i.e., landscape diversity) merits some consideration. Two different levels of heterogeneity were evaluated by Shannon's landscape diversity index (McGarigal and Marks 1994): (a) a landscape heterogeneity map quantified by an interpolated grid by the inverse of distance weight (IDW) of systematic points 250 m distant from each other, and (b) local heterogeneity measures for each sample site quantified by the proportion of land cover within a 250-m and 1000-m radius. A landscape heterogeneity map was generated to be included in the modeling and a local heterogeneity measure was calculated as an attribute of the sample site, considering the

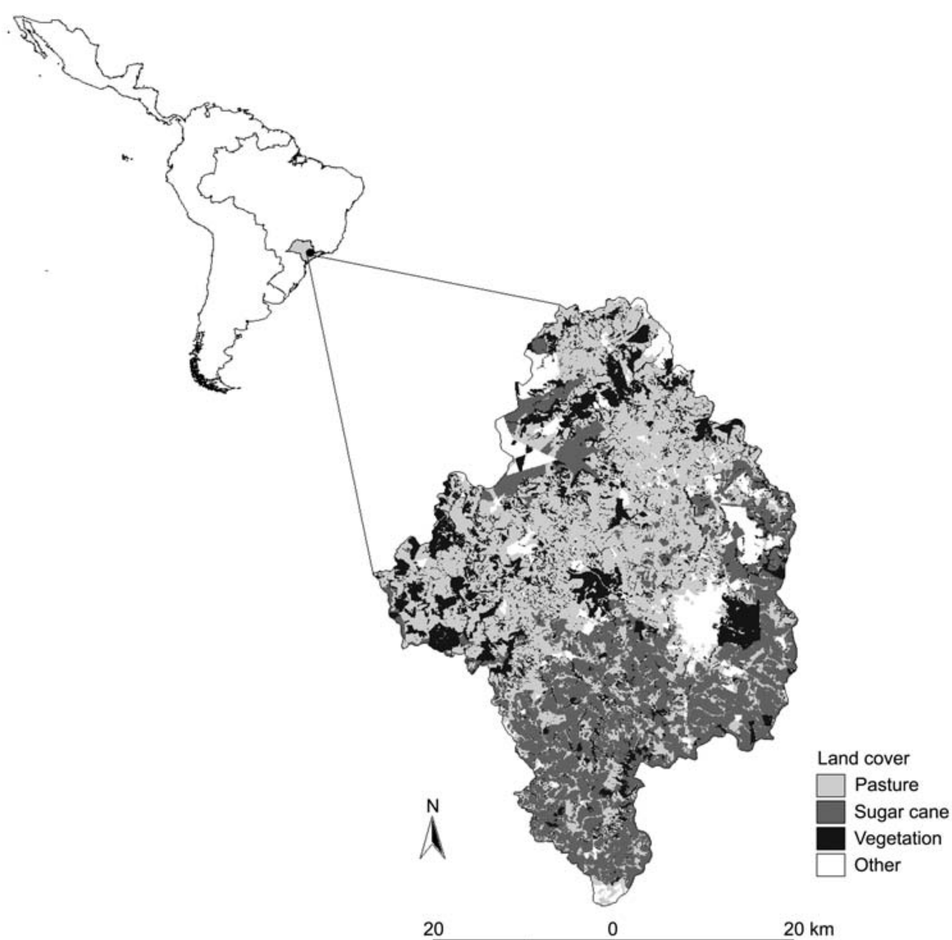

Figure 1 Location of Corumbataí river basin in São Paulo State, southeastern Brazil with main land uses/land covers.

Table 1 Environmental variables used to describe and to predict *C. thous* occurrence at the Corumbataí river basin, southeastern Brazil.

Variables	Description
Land cover	Four categorical variable of land cover (pasture, sugar cane, vegetation, other)
Landscape heterogeneity	Landscape diversity
Local heterogeneity	Diversity measure within 250 m radius and 1000 m radius
Forest fragment distance	Gradient distance in meters from forest fragment
Distance from streams	Gradient distance in meters from the closest main stream
Elevation	Elevation in meters
Slope	Terrain slope (%)

surrounding diversity. The distance of 250 m between systematic points for map interpolation was considered adequate to generate the landscape heterogeneity map, because shorter distances did not include the land cover variability and larger ones did not provide a good estimate of diversity values. The difference between the calculated local heterogeneity measure and that estimated by the interpolation was analyzed using the t-test with no statistical difference between mean values (t=-0.03, gl=1998, p=0.975). For local heterogeneity measurements the 250-m radius was chosen to be comparable with the one used in the interpolation whereas the 1000-m radius was chosen to provide an area close to the one estimated as the species home range, approximately 3 km^2 on average (Courtenay and Maffei 2008).

Ecological niche modeling

Presence records and nine variables (land cover with four classes, landscape heterogeneity, forest fragment distance, distance from stream, elevation and slope) were used for modeling in Maxent (AT&T Labs-Research, Florham Park, NJ, USA) (Phillips et al. 2006, Phillips and Dudík 2008) with independent data setting; 70% of the dataset for training and 30% for testing models (Pearson 2007). The datasets were sampled by the bootstrapping method with ten random partitions with replacement. All runs were set with a convergence threshold of 1.0 E^{-5} with 500 iterations, with 10,000 background points (Maxent software default).

Data analysis

The observed frequency of occurrence of *Cerdocyon thous* was compared with that expected among land covers by the χ^2-test. The relation between the species presence and landscape variables (local heterogeneity, forest fragment distance, distance from streams, elevation and slope) was clarified with a principal components analysis biplot graph (Gabriel 1971).

Model performance evaluation was assessed by AUC (area under curve), a probability that a randomly chosen presence site will be ranked above a randomly chosen absence site (Phillips and Dudík 2008). The best model was the one with the highest AUC value. Threshold-independent assessment for the minimum value associated with the test dataset was used to avoid commission error converting the best predictive model into a binary map with suitable and unsuitable areas for *Cerdocyon thous*.

Results

Cerdocyon thous occurred in 29.47% (n=28) of the sampling study sites. The species was equally distributed in all land cover sampled (χ^2=2.778, df=3, p=0.427), although it was more frequent in sugar cane areas (35.71%). The occurrence of *C. thous* was not related to any specific landscape variable (Figure 2), although 42.86% of presence records were at less than 100 m from forest fragments. Presence records were slightly associated with more heterogeneous areas near forest fragments.

The potential distribution model predicted approximately 44% of the anthropogenic river basin as suitable for *Cerdocyon thous* occurrence (36.38% sugar cane, 27.63% pasture, 22.12% native forest and 12.51% eucalyptus forest), excluding urban areas, perennial fields and pasture and sugar cane far from forest area (Figure 3). Highly suitable areas for *C. thous* occurrence encompassed vegetation (native and eucalyptus forest) and its surroundings, and some portions of sugar cane plantations. Distance from forest fragments (35.3%) and distance from streams (25.2%) were the highest contributor variables for model prediction. The environmental variable with the highest gain when used in isolation was distance from forest fragments, which therefore appears to have the most useful information by itself. This variable was also the one that most decreases the gain when omitted, suggesting to have the most information that is not present in the other variables. Average AUC was 0.688±0.042 and the AUC value for the best model was 0.797. Threshold assessment for the minimum value associated with the test dataset (0.450) with 0% test omission rate was used for discriminating suitable from unsuitable areas for the species. Model validation with test subset was statistically significant (p=0.0008).

Discussion

Cerdocyon thous occurred in forest habitat (native and eucalyptus forests), open habitat (pasture) and cultivated areas (sugar cane) characterizing the species as a habitat generalist and emphasizing its potential to occur in altered environments. As stated by Courtenay and Maffei (2008) *C. thous* readily adapts to deforestation, agricultural and horticultural development (e.g., sugar cane, eucalyptus, among others) and habitats in regeneration. It is probable that this species takes advantage of using these new landscape elements for displacement and foraging.

The agricultural landscape mosaic could have favored the species occurrence in this region. Habitat generalist species

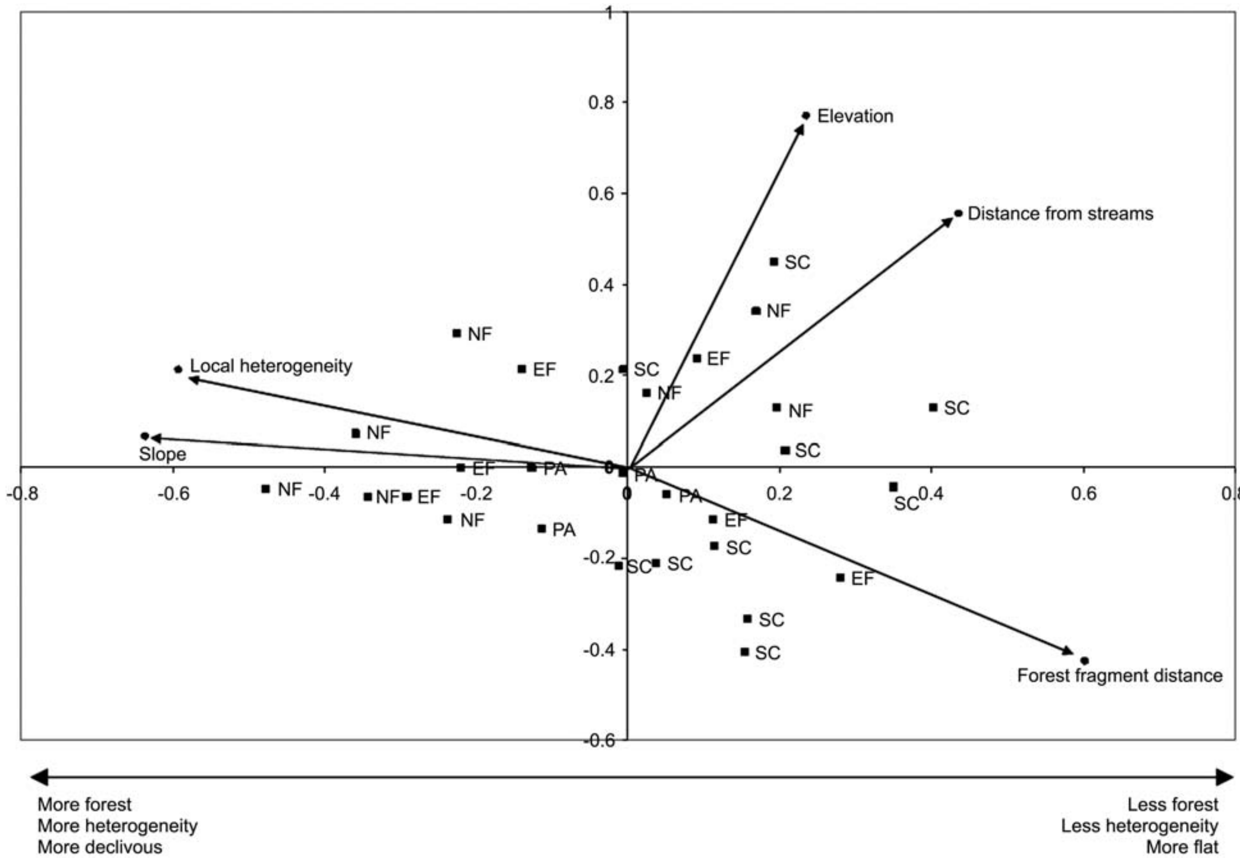

Figure 2 Biplot graph of principal components explaining the presence of *Cerdocyon thous* in relation to environmental variables at the Corumbataí river basin, southeastern Brazil (SC, sugar cane; PA, pasture; NF, native forest; EF, eucalyptus forest). The percentage of variance explained by axis 1 is 37.2% and by axis 2 is 25.6%.

might present a tendency for expansion of range distribution, colonizing new potential habitats in dynamic landscapes (Marvier et al. 2004). They could even survive in very small patches because they can also utilize resources in their surroundings (Andrén 1994). Therefore, because most of the diet of sympatric carnivores such as *Cerdocyon thous*, *Lycalopex vetulus* (hoary fox), *Procyon cancrivorus* (raccoon) and *Chrysocyon brachyurus* (maned wolves) overlap (Juarez and Marinho-Filho 2002, Bueno and Motta-Junior 2004, Jácomo et al. 2004, Gatti et al. 2006b), ecological segregation, resource competition and partitioning should be investigated in anthropogenic landscapes.

The higher frequency of records in sugar cane and also the high suitability of this land use for the species occurrence (as revealed by the Maxent model) is probably related to prey availability. The high abundance of small mammals in sugar cane in the same region found by Gheler-Costa (2006) could probably explain the high incidence of the species in these places. Dotta and Verdade (2007) also found higher abundance of *Cerdocyon thous* in sugar cane in the region, probably owing to the same reason. The suitability of sugar cane was higher in areas closer to forest fragments.

The predictive model also revealed the native and eucalyptus forests as highly suitable for the species occurrence. The association of the species to the fragment proximity clarified by the biplot graph and the model suggested the importance of this landscape component to the species occurrence, possibly also serving for shelter during the day. *Cerdocyon thous* has also been recorded in eucalyptus plantations by Lyra-Jorge et al. (2008) and Dotta and Verdade (2007). Silviculture, as indicated by Rocha et al. (2008), should be used by *C. thous* for foraging.

The AUC score obtained for this model was considered satisfactory. In this valuable contribution for the large-scale model comparison Elith et al. (2006) found 64% of the best models for each species with AUC values >0.75 and an additional 14% with AUC values between 0.7 and 0.75. They agree these AUC scores indicate that predictions based on presence-only data can be sufficiently accurate to be used in conservation planning and in numerous other applications in which estimates of species distribution are relevant. Many discussions had permeated the misleading use of AUC values as an indicator of model performance (e.g., Lobo et al. 2008, Peterson et al. 2008). Despite some of the limitations imposed on the performance of ROC analysis, it has been widely used to assess the accuracy of predictive distribution models.

Some explanations could justify the AUC value found in this study. First, the area being considered in this study is inside of the distribution range of *Cerdocyon thous*. Most of

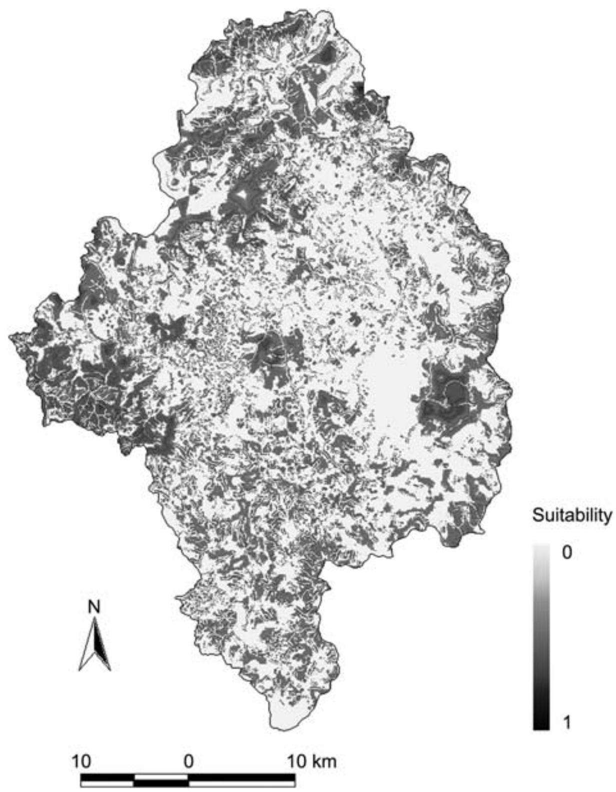

Figure 3 Maxent model of environmental suitability areas for *C. thous* occurrence at the Corumbataí river basin, southeastern Brazil (AUC=0.797 and threshold=0.450).

the high accurate models (i.e., high AUC score) presented in the ecological niche literature present, in general, broad geographical extent, different from the approach used here. As indicated by Lobo et al. (2008) increasing the geographical extent outside the area where the species is predicted as present entails obtaining higher AUC scores. Second, *C. thous* is a typical habit generalist species (Courtenay and Maffei 2008) probably leading to a lower accurate model. Some papers have demonstrated that environmentally or geographically restricted species appeared to be modeled with greater accuracy than more common and generalist species (McPherson et al. 2004, Elith et al. 2006, McPherson and Jetz 2007, Tsoar et al. 2007). Finally, the environmental gradients of the landscape could also have decreased the AUC value as a result of conflicts situations in the algorithm solution.

The incorporation of landscape variables (heterogeneity and gradient distance from fragments) in ecological niche modeling was innovative and was shown to be relevant to explain the occurrence of the species in the scale considered (30 m resolution). In such circumstances, the diversity of the land use should play an important role in species occurrence, owing probably to the availability of habitats and also resources. In addition, forest fragment distance could provide useful information for the model if the distribution of points was associated with land use, but not well represented by the land use value in the presence record (e.g., presence records in the fragment edge).

Carnivores can vary in their responses to fragmentation being sensitive to fragmentation (e.g., disappearing as habitat patches became smaller and more isolated), as well as being enhanced by fragmentation (e.g., increasing abundance in highly fragmented sites) or being tolerant to fragmentation (e.g., little to no effect of landscape variables on their distribution and abundance) (Crooks 2002). Marvier et al. (2004) emphasize that ecological generalist species tend to be invaders because they are more successful at establishing, spreading, and attaining high population densities. The estimative of population size, habitat use and selection should be considered in further studies for *Cerdocyon thous* in the region.

In conclusion, this study highlights the potential of adaptation of *Cerdocyon thous* to human-made landscapes because the Maxent model predicted much of the river basin as a suitable area for the species. Results suggested that the highly fragmented and heterogeneous landscape studied encompasses many suitable habitats for *C. thous* occurrence raising the necessity to assess the potential role of this species in vertebrate communities. In addition, its potential for range expansion should be evaluated because landscape modification, e.g., sugar cane plantation and cattle ranching might represent new suitable habitats for foraging species.

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