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Different land use types influence Red-browed Amazon (*Amazona rhodocorytha*) ccurrence in Southeastern Brazil

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Abstract: The habitat loss is the main threat for many parrot species worldwide. However, the disturbed environments can influence the occurrence of the species positively or negatively, depending on its structure and potential use as an alternative environment. Therefore, this work aims to determine the relationship between land use types and the occurrence of the threatened Red-browed Amazon, identifying the land use types related to species' occurrence and the direction of these relationships. Seven land use types were significantly associated with the species' occurrence: Primary/Secondary Advanced/Medium Natural Forest, Secondary Natural Vegetation, Pasture, Outcrop/Bare Soil, Mangroves, Rivers and Urban Areas. We found that some land use types that are structurally different from the original environments (Pasture, Outcrop/Bare Soil and Urban Areas) positively affected the occurrence of the species. The relationship between intensity of occurrence and highly anthropized land use types, suggests a plasticity of the species in habitat use that may be contributing to the maintenance of Red-browed Amazon populations in highly disturbed habitats. Therefore, we proposed that the management of disturbed areas, along with usual conservation strategies (e.g., conservation of forest remnants, restoration of degraded areas), could contribute to Red-browed Amazon conservation.

Key words: anthropized environments, Atlantic Forest, conservation, Neotropical, threatened species.

INTRODUCTION

The Red-browed Amazon (*Amazona rhodocorytha*) is a typical representative of the forests of eastern Brazil (Atlantic Forest), and its occurrence is currently restricted to a few areas in the states of Rio de Janeiro, Espírito Santo, Bahia, Alagoas, and eastern Minas Gerais (BirdLife International 2017, Klemann-Junior et al. 2008a). This vulnerable species is threatened due to habitat loss and illegal capture (BirdLife International 2017, Klemann-Junior et al. 2008a, b). Furthermore, it is assumed that the replacement of forests by disturbed environments, mainly open habitats such as pasture and agricultural areas, is the main threat to this parrot and negatively affects the occurrence of the species (BirdLife International 2017, Klemann-Junior et al. 2008a, b).

The Atlantic Forest covers the Brazilian coast almost continuously, extending from southern Brazil to eastern Paraguay and northeast Argentina (Tabarelli et al. 2005). This forest, one of the most threatened biodiversity hotspots in the world (Myers 1988, Myers et al. 2000), has been replaced since the early 16th century by landscapes with vegetation structures highly different from that of the original forests — e.g., coffee plantations, sugar cane plantation, pastures (see Tabarelli et al. 2005). This increasingly and accelerated process of deforestation resulted in a loss of more than 80% of the forest by 2018 (Fundação SOS Mata Atlântica & Instituto Nacional de Pesquisas Espaciais 2019).

Habitat loss is a main cause of rising extinction rates worldwide (Tilman et al. 1994, Purvis et al. 2000, Brook et al. 2008, Loehle & Eschenbach 2012, Pimm et al. 2014). This process has led to fragmentation of the Atlantic Forest, reducing the Red-browed Amazon feeding and reproduction sites, and limiting their dispersal between fragments. Such fragmentation, together with the reduction of forest cover, contributes to the increase in rates of local extinction as the dispersal between fragments becomes limited (Andren 1994). Associated with these landscape changes, Red-browed Amazon populations are depleted by the illegal capture of individual parrots (see Regueira & Bernard 2012, TRAFFIC 2011), an increasing problem caused by the ease of access to and greater human presence in the already reduced habitat of the species.

The mixture of natural and altered environments can be viewed as a mosaic of units, with variable impact on different organisms (Antongiovanni & Metzger 2005, Umetsu & Pardini 2007, Umetsu et al. 2008, Prevedello & Vieira 2010). This mosaic directly affects the presence or absence and abundance of individuals. Thus, the conversion of natural areas into altered areas causes changes in fauna and flora composition (Reidsma et al. 2006), mainly because of expansions or contractions in species' distributions, but also due to the introduction of exotic species. In sum, the interaction between the environmental changes and the tolerance of the species to these modifications determines which species will go extinct locally and which will be introduced or have their distributions enlarged (Morris & Heidinga 1997, Baskin 1998, McKinney & Lockwood 1999).

The matrix of disturbed areas — which is composed of environments not primarily intended for the conservation of natural ecosystems, ecological processes, and biodiversity (Lindenmayer & Franklin 2002) — is thought to be important for the occurrence (Pickett & Cadenasso 1995, Umetsu et al. 2008) and abundance of organisms (Renjifo 2001, Rodewald 2003). The vegetation structure of the matrix is currently seen as a relevant aspect of the landscape, especially in human-impacted areas (Ricketts 2001, Vandermeer & Carvajal 2001, Umetsu et al. 2008, Prevedello & Vieira 2010). In addition, it is accepted that these environments affect ecological processes in heterogeneous landscapes (Stouffer & Bierregaard 1995, Bender & Fahrig 2005, Fischer et al. 2005, Haynes et al. 2007, Prevedello & Vieira 2010).

The relevance of the anthropized environments also differs among species, relative to the biology of the organisms (Umetsu et al. 2008) and to its usefulness as an alternative environment (e.g., Sieving et al. 1996, Bender & Fahrig 2005). In addition, there is a general pattern whereby altered habitats that are more structurally similar to the original vegetation allow for greater connectivity (Prevedello & Vieira 2010). Thus, although the size and isolation of natural forest fragments are the main determinants of biodiversity parameters for a landscape, the structural characteristics of the anthropized environments also affect the composition of the fauna and flora (Prevedello & Vieira 2010).

Although many studies have focused on the effects of land use types on individuals or communities, few have studied the effects on populations (Prevedello & Vieira 2010). Moreover, of the studies addressing populations, only a small fraction evaluated the influences of the land use types on the occurrence of species (Prevedello & Vieira 2010). This species-specific information is extremely important, as it allows management strategies to consider the impact of the matrix composition on species conservation, when planning actions that affect the landscape. Therefore, this work aims to determine the relationship between land use types and the occurrence of the threatened Red-browed Amazon, identifying the land use types related to species' occurrence and the direction (i.e., positive or negative) of these relationships.

MATERIALS AND METHODS

Study site

Espírito Santo is a state in southeastern Brazil, located between 17º53' and 21º18'S and 39º39' and 41º53'W and entirely within Brazil's Atlantic Forest biodiversity hotspot (Myers 1988, Myers et al. 2000). Its vegetation was drastically reduced during the human colonization process, placing this state among the most heavily modified in the country, with less than 13% of areas being well-preserved (5812 km^2 of 46095 km^2; Fundação SOS Mata Atlântica & Instituto Nacional de Pesquisas Espaciais 2019). This haphazard occupation and exploitation in Espírito Santo turned the landscape into a mosaic of environments, consisting of a mixture of different land use types, including both altered and natural areas (Table SI – Supplementary Material).

Considering that the Red-browed Amazon occurs in well-preserved areas (Silveira & Brettas 2015), mainly in the valleys of large rivers and plateau forests ("Tabuleiro" forests; Juniper & Parr 2003, Klemann-Junior et al. 2008a, b), a rapid and ongoing population decline is suspected on the basis of habitat destruction and fragmentation (BirdLife International 2017). Habitat loss throughout the entire distribution area of the Red-browed Amazon (Brown & Brown 1992), along with their capture for the national and international pet trade, have made this species the most threatened parrot in Brazil (see BirdLife International 2017).

Data gathering and analysis

We obtained the coverage of the land use types in the study area from the land use mapping carried out by Geobases/Aracruz Celulose AS (1999). Considering the date of the images used for mapping (1996/1997; Geobases/Aracruz Celulose AS 1999) and the final date of the Red-browed Amazon occurrence data collection (2006), we updated the land use map using 15-m spatial resolution Landsat5 satellite imagery from 2005/2006 (Table SI; land use types in shapefile format available in doi:10.6084/m9.figshare.9917840). Complementarily, considering that the species occurs at lower altitudes and that altitude is a main factor in Red-browed Amazon occurrence (Klemann-Junior et al. 2008b), we used mean altitude — calculated from altitudinal data produced in raster format (1-km spatial resolution; Farr et al. 2007) — in all analyses.

The names of the land use types used in the entire text are as follows: Agriculture (areas used for planting coffee, sugar cane, banana, cocoa, black pepper, and other crops), Eucalyptus Plantation, Flooded Areas (natural and artificial wetlands), Herbaceous/Beach "Restinga" (herbaceous vegetation that occurs in sandy soils parallel to the shoreline), Mangroves (vegetation with marine-river influence, typical of estuarine regions), Outcrop/Bare Soil, Pasture (grass planted areas, used for livestock; presence of sparse fruit and non-fruit trees), Primary/Secondary Advanced/Medium Natural Forest (climax forests or forests in middle or advanced successional stages), Rivers, Secondary Natural Vegetation (forests in early successional stages), Shrub/Tree "Restinga" (shrub and tree vegetation that occurs in sandy soils parallel to the shoreline), and Urban Areas (mix of areas with different uses and occupation intensities, such as residential areas, commercial areas and parks; presence of urban afforestation with fruit and non-fruit tree species).

The occurrence data of Red-browed Amazons used in the analyses comprises 1200 records gathered from 2004 to 2006 (Klemann-Junior et al. 2008b; records in shapefile format available in doi:10.6084/m9.figshare.9917846). To obtain the records, the entire Espírito Santo state was sampled with the same methodology (see Methods in Klemann-Junior et al. 2008b for details), resulting in a map of Red-browed Amazon occurrence for the study area (Fig. 1). To avoid bias in the data used, caused by under- or oversampling between different regions on the state, we did not use other record sources.

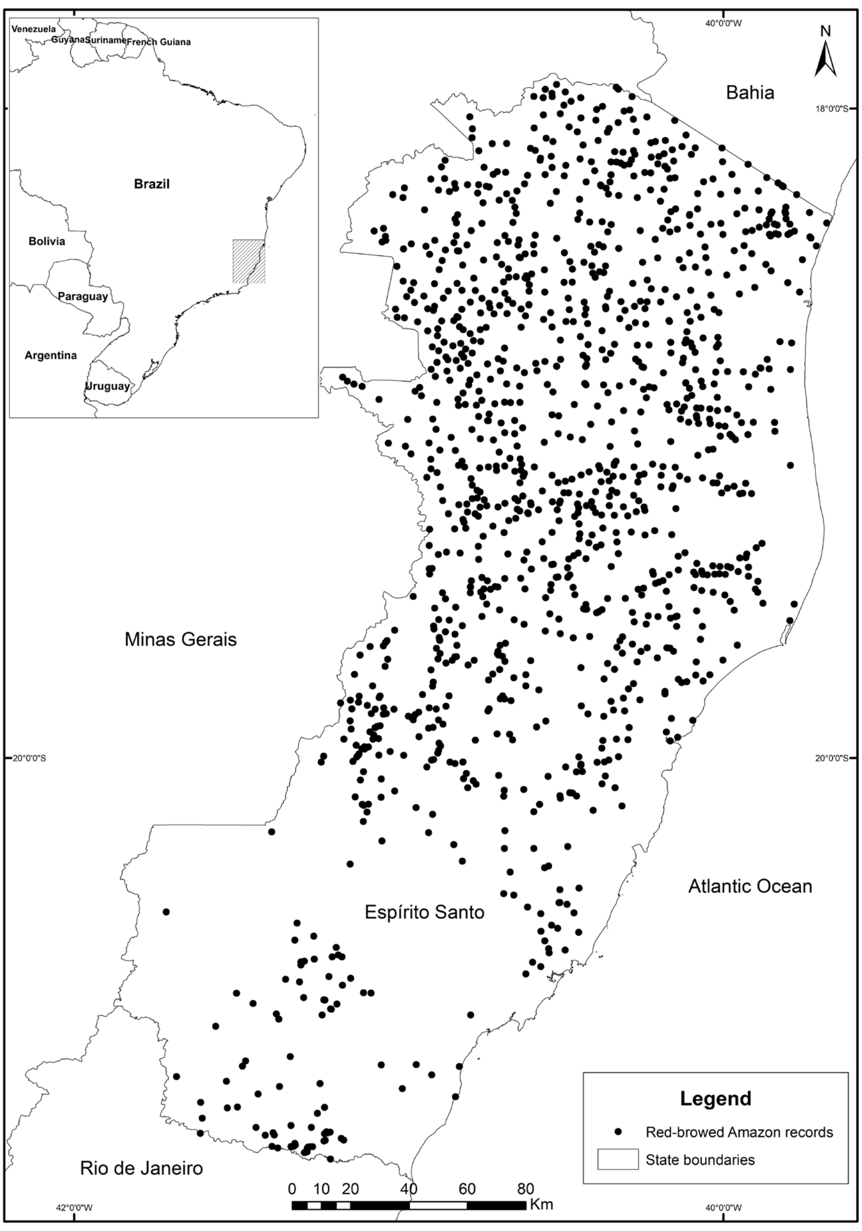

Figure 1. **Points of occurrence of the Red-browed Amazon obtained in Espírito Santo state (Brazil) during 2004-2006 (information extracted from Klemann-Junior et al. 2008b, records in shapefile format available in doi:10.6084/m9.figshare.9917846).**

We used a geographic information system (GIS) framework to perform area calculations and delimit the sampling units in the study area (i.e., 2003 cells with 25 km^2 each, covering the entire Espírito Santo state). Using GIS, we calculated mean altitude and total area of each land use type for each sampling unit. Afterward, by superimposing the occurrence data of Red-browed Amazon on the cells, we counted the number of occurrence points per sampling unit (quadrat counting).

Some land use types are present in restricted and/or concentrated distributions in specific regions of the study area, making many cells with zero value for that land use type. This pattern prevents effective analysis of how variation in the area of that land use type affects species occurrence. Therefore, we calculated the percentage of cells where each land use type is present, and we treated as dichotomous (i.e., present or absent) the land use types present in less than 50% of cells. On the other hand, we treated as continuous the land use types present in 50% or more of the sample units, using the total area of each land use type in each cell for the analyses.

To investigate the point pattern of the records of the Red-browed Amazon in the study area, we used the package Spatstat (Baddeley & Turner 2005) in software R (R Core Development Team 2012). We examined the intensity of occurrence, defined as the number of points of occurrence expected per unit of area (Baddeley 2010), and its dependence on land use types and altitude.

Assuming that point processes do not usually represent spatially homogeneous distributions, diverse factors are expected to relate to the spatial distribution of points (Bivand et al. 2008). In addition, point observations of the Red-browed Amazon in the study area were not homogeneous: they were more concentrated in some regions than in others, conferring a grouped or non-homogeneous distribution. As a result, we modeled the intensity of occurrence as a generic function that varies spatially.

We estimated the generic function for intensity parametrically by the smoothing technique of quadrat counting, which assumes that the intensity of the point process is a function of a covariate (Z). Thus, in any location μ, where $\lambda(\mu)$ is the intensity of the point process and $Z(\mu)$ is the value of the covariate, it is assumed that $\lambda(\mu) = \rho[Z(\mu)]$, where ρ is the function to be investigated and shows how the intensity of the points depends on the value of the covariate (Baddeley 2010).

Assuming a non-homogeneous Poisson process, we fitted a model to the spatial point pattern of species occurrence, with intensity dependent on the covariates, expressed as $\lambda(\mu) = \exp[\beta 0+\beta 1Z(\mu)]$ (Baddeley 2010). In the equation, $\lambda(\mu)$ is the intensity of the point process as a log-linear function, $\beta 0$ and $\beta 1$ are parameters, and $Z(\mu)$ is the value of the covariate or a function of the value of the covariate at location μ (Baddeley 2010). We used a cubic spline interpolation to interpolate with maximal smoothness the function of the covariates.

To identify which covariates were significantly related to the occurrence of the species, we fitted separate bivariate models with occurrence intensity given by a log-linear function of altitude and each land use type. We tested the land use covariates in the bivariate models using *z*-test, and we considered the significant covariates (significance level of 0.05) related to the occurrence of the species. Including the covariates related to species occurrence in a multivariate model, we used *z*-test to identify and exclude the covariates not significant in the multivariate model. In order to identify the model with the best fit, we used backwards stepwise regression (Draper

& Smith 1981, Hocking 1976, SAS Institute 1990), starting with a model containing all the candidate covariates (i.e., significant covariates in the bivariate models) and comparing Akaike information criterion (AIC) values (Akaike 1974) obtained by excluding the covariates one by one.

Considering that models with a difference in AIC of <2 have the same fit, we eliminated from the model the covariates whose exclusion reduced the AIC, or increased it by <2. The order of exclusion followed the ratio between estimate and standard error, so we excluded from the model first the covariates with high values, indicating relatively low variability. We used the same criterion to identify the number of degrees of freedom for the function of each covariate that produced the multivariate model with the best fit.

From the multivariate model, we identified the land use types related to the occurrence of the species and the direction (i.e., positive or negative) of these relationships. We analyzed the relationships between the covariates and the occurrence of the Red-browed Amazon from the point of view of the biology of the species (e.g., behavior, feeding requirements, environment preference, etc.).

RESULTS

Of the 12 land use types analyzed, we considered seven as dichotomous (Table I) and found eight related to the occurrence of the Red-browed Amazon in Espírito Santo state (Table I). The model with the best fit included altitude and the following covariates significantly related to species occurrence: Primary/Secondary Advanced/Medium Natural Forest, Secondary Natural Vegetation, Pasture, Outcrop/Bare Soil, Mangroves, Rivers, and Urban Areas (Table II). In addition, in the best-fit multivariate model, the effects of the dichotomous and continuous covariates on the occurrence of the species varied from positive to negative and from linear to curvilinear with six degrees of freedom (Table II, Fig. 2).

The relationship between the occurrence of the species and altitude shows that the intensity of occurrence was greater in regions with lower altitudes, reaching its peak between 0 and 200 m above sea level, and then decreasing with increasing altitude (Fig. 2c, Table II). In addition to altitude, of the seven significant covariates in the multivariate model, we found six that were positively related to species occurrence (i.e., Primary/Secondary Advanced/Medium Natural Forest, Secondary Natural Vegetation, Pasture, Outcrop/Bare Soil, Rivers, and Urban Areas) and one negatively related (Mangroves; Table I).

The intensity of occurrence of Red-browed Amazon increased in the presence of Rivers (Table I), and with an increase in the amount of natural forest environments in the sample units (i.e., Primary/Secondary Advanced/Medium Natural Forest and Secondary Natural Vegetation, Fig. 2a-b, Table I). Similarly, three land use types with vegetation structure highly different from the original habitat of the species also presented a positive relationship with Red-browed Amazon occurrence (i.e., Pasture, Outcrop/Bare Soil, and Urban Areas; Fig. 2d-e, Table I).

On the other hand, the intensity of occurrence of Red-browed Amazon decreases in sample units with the presence of Mangroves (Table I). The other covariates (i.e., Agriculture, Eucalyptus Plantation, Flooded Areas, Herbaceous/Beach "Restinga", and Shrub/Tree "Restinga") did not have significant relationships with the occurrence of the Red-browed Amazon (Table I).

Table I. **Covariates with the percentage of cells with zero value and statistics obtained from the non-homogeneous Poisson process (with intensity of the point pattern λ a log-linear function of the covariates) for the covariates included in the best-fit model that explain the Red-browed Amazon occurrence in the Espírito Santo state during 2004-2006. An asterisk indicates land use types treated as dichotomous (present or absent). df = degrees of freedom; SE = standard error; *z*-test = Statistical significance obtained with the *z*-test; - = values not calculated (covariates that did not enter in the final multivariate model).**

Covariates	Cells with zero value (%)	df	Estimate	SE	*z*-test
Agriculture	47.73	-	-	-	-
Altitude	0.00	3	-7.41	1.12	< 0.001
Eucalyptus Plantation	74.19*	-	-	-	-
Flooded Areas	78.73*	-	-	-	-
Herbaceous/Beach “Restinga”	93.41*	-	-	-	-
Mangroves	97.35*	-	-1.00	0.39	< 0.01
Outcrop/Bare Soil	24.41	4	0.26	0.10	< 0.05
Pasture	4.64	2	0.02	0.01	< 0.05
Primary/Secondary Advanced/Medium Natural Forest	6.24	6	1.12	0.24	< 0.001
Rivers	63.21*	-	0.17	0.07	< 0.05
Secondary Natural Vegetation	8.09	4	0.42	0.19	< 0.05
Shrub/Tree “Restinga”	93.51*	-	-	-	-
Urban Areas	85.37*	-	0.18	0.08	< 0.05

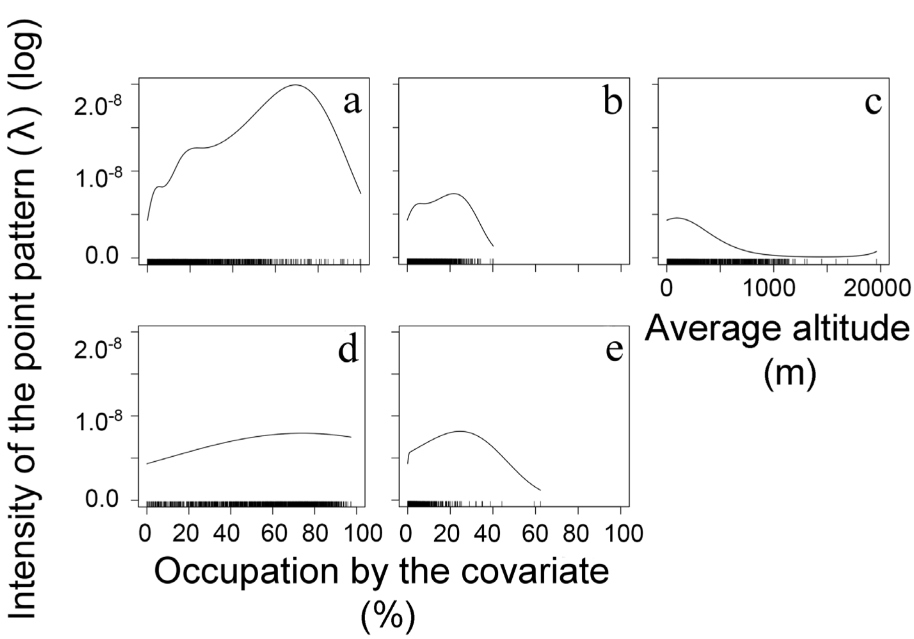

Figure 2. **Effect of the percentage of area covered by a particular land use type on the occurrence of the Red-browed Amazon in Espírito Santo state (intensity of the point pattern λ), in the best-fit model with a non-homogeneous Poisson process, using a log-linear function of the covariates. a) Primary/Secondary Advanced/Medium Natural Forest; b) Secondary Natural Vegetation; c) Altitude; d) Pasture and e) Outcrop/Bare Soil. Each bar (|) on the *x*-axis represents a sampling unit.**

Table II. Best-fit model that explains Red-browed Amazon occurrence in the Espírito Santo state, found through backward stepwise regression. Fit was achieved with a non-homogeneous Poisson process, with intensity of the point pattern (λ) a log-linear function (~) of the covariates. bs = B-spline; df = degrees of freedom.

Model
~bs(Altitude, df = 3) + bs(Primary/Secondary Advanced/Medium Natural Forest, df = 6) + bs(Secondary Natural Vegetation, df = 4) + polynom(Pasture, df = 2) + bs(Outcrop/Bare Soil, df = 4) + Mangroves + Rivers + Urban Areas

DISCUSSION

Our results, by showing the relationship between different land use types and the intensity of occurrence of Red-browed Amazon, suggest a pattern of habitat use that differs from what was expected for this endangered species of the Atlantic Forest (see Sigrist 2006, Klemann-Junior et al. 2008a, b). The positive relationship between intensity of occurrence and highly anthropized land use types (e.g., Outcrop/Bare Soil, Pasture, and Urban Areas), along with reports of the use of these environments for feeding (Klemann-Junior et al. 2008a, b), suggest a plasticity of this species both in habitat use and in the use of resources available in the habitats (see Renton et al. 2015). This plasticity (i.e., the ability to adapt to changing environments and pressures) may be contributing to the maintenance of Red-browed Amazon populations in regions where forests were largely replaced by non-forested environments (see Saunders 1990, Bucher & Aramburú 2014).

The land use types characterized by non-native plant species or by low-height native vegetation are expected to have negative (see Berkunsky et al. 2017) or no effect on Red-browed Amazon occurrence. In agreement with this expectation, we found a nonsignificant relationship between the occurrence of the Red-browed Amazon and the land use types Agriculture, Eucalyptus Plantation, Flooded Areas, Shrub/Tree “Restinga”, and Herbaceous/Beach “Restinga” (Table I). Similarly, Mangroves had a negative influence on the intensity of occurrence of the Red-browed Amazon. Therefore, although available information suggests that the species uses this environment in certain periods of the year (Forshaw & Cooper 1973), our results indicate that the Red-browed Amazon does not regularly use Mangroves. Thus, the potential use of this habitat by the species warrants further investigation.

Considering the current information on the biology of the species, the plains of large rivers (Rivers) are the species’ main areas of occurrence (Klemann-Junior et al. 2008b). Likewise, forests are the original environment of this parrot (Sigrist 2006, Klemann-Junior et al. 2008a, b) and are expected to be significantly, positively related to species occurrence. We confirmed, in our study, the positive influence of Primary/Secondary Advanced/Medium Natural Forest, Secondary Natural Vegetation, and Rivers on the intensity of occurrence of the Red-browed Amazon. In addition, we confirmed the relationship between species occurrence and altitude (Sigrist 2006, Klemann-Junior et al. 2008a, b), with a reduction in the intensity of occurrence as the altitude increases. These patterns reinforce the importance of forest remnant conservation and degraded area restoration for the conservation of this forest-inhabiting species, accordingly with the most important parrot conservation actions directed toward the Neotropical region (Berkunsky et al. 2017). Moreover, these actions will be more effective for Red-browed Amazon conservation if they are applied in regions located less than 300 m above sea level (see Klemann-Junior et al. 2008a, b).

The positive relationship between anthropized land use types (e.g., Outcrop/Bare Soil, Pasture, and Urban Areas) and the intensity of Red-browed Amazon occurrence suggest that environments structurally different from the original habitat of the species may have a positive effect on its intensity of occurrence. These altered environments, in combination with forest remnants, can therefore be important for maintaining parrot populations, providing additional sources of food (e.g., exotic or native fruit trees, see Galetti 1993, Vaughan et al. 2006, Klemann-Junior et al. 2008a, b) and reproduction sites (e.g., hollows in isolated trees, see Snow 1976, Koenig et al. 2007). This suggests that to evaluate the importance of the matrix for a species, in addition to the structural similarity between the altered environment and the original one (Prevedello & Vieira 2010), more detailed aspects of the composition of the vegetation should be considered (Dunning et al. 1992, Brotons et al. 2003). Furthermore, it is important to analyze the composition of the matrix to plan landscape strategies for species conservation (e.g., creation of protected areas or ecological corridors) (Rodewald & Yahner 2001, Rodewald 2003).

Similar to other Neotropical parrot species, the conservation of forest remnants and the restoration of degraded areas are the most important conservation actions for the Red-browed Amazon (see Berkunsky et al. 2017). Nevertheless, as a complement to the protection and management of natural environments, the positive influence of Pasture, Outcrop/Bare Soil, and Urban Areas on species occurrence suggests that the management of disturbed areas could also benefit the Red-browed Amazon. The incentive to plant fruit trees as well as the maintenance of large native or exotic trees in disturbed areas can provide sources of food and additional reproduction sites for this vulnerable parrot. Such a strategy has low cost and low social and economic impact, and along with the usual strategies (e.g., conservation of forest remnants, restoration of degraded areas) for the conservation of forest-dependent species threatened by habitat loss, it could contribute to Red-browed Amazon conservation.

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SUPPLEMENTARY MATERIAL

Table SI

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