# Diet specialisation reduces the occupancy of cocoa agroforests by diurnal raptors

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# Diet specialisation reduces the occupancy of cocoa agroforests by diurnal raptors

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## Summary

Habitat loss and fragmentation, especially due to agriculture expansion, pose the main threats to biodiversity conservation. While some species are able to survive and proliferate in human-modified habitats (winner species), others are highly dependent on well-preserved habitats, being more vulnerable to extinction (losers). Many raptors can be considered loser species due to their high trophic position, large home ranges, and low reproductive rates. Consequently, this group is frequently used to reflect the environmental quality of habitats and the biodiversity status of communities. Here we describe the diurnal raptor assemblages found in shaded-cocoa agroforests (*cabrucas*) of Southern Bahia, Brazil, and the determinants of raptor occupancy in this system. We systematically surveyed diurnal raptors in 16 *cabruca* sites using complementary sampling methods – active search, playback, and point-count – and modeled species occupancy using covariates related to vegetation structure, landscape, management intensity, and biological traits (body mass, trophic level, and diet specialisation). We found a high number of species (at least 18) as able to use *cabrucas* and a negative relationship between species occupancy and the degree of diet specialisation. Thus, our results suggest that *cabrucas* have a high potential to mitigate the effects of forest loss and fragmentation on diurnal raptors, but this system alone may not support complete assemblages of this group. It highlights the need for the maintenance of forest remnants in the landscapes to increase species diversity at a regional scale and to assure the conservation of this group in Southern Bahian Atlantic Forest.

## Introduction

Anthropogenic habitat loss and change are rapidly expanding worldwide (Venter *et al.* 2016, Watson *et al.* 2016), causing the loss, fragmentation and structural modification of natural habitats of many forest species. Species tolerance to habitat changes depends on their ecological flexibility to deal with the new conditions, such as alterations to the microclimate and vegetation structure, and this flexibility will strongly determine their ability to survive in human-modified habitats (Swihart *et al.* 2003, Tabarelli *et al.* 2012).

Among birds, raptors are expected to be highly affected by habitat disturbance due to their high trophic position in food webs, large home ranges, and low reproductive rates (Carrete *et al.* 2009). For example, raptors have shown to be underrepresented in agricultural lands where high inputs of pesticides are applied, since bioaccumulation and magnification of such substances impact on top predators (Espín *et al.* 2016). Consequently, this group is often used to indicate the biodiversity status of biological communities (Sergio *et al.* 2006, 2008) and the quality of the surrounding environment (Rodríguez-Estrella *et al.* 1998).

Three orders of diurnal raptors (Cathartiformes, Accipitriformes, and Falconiformes), encompassing 102 species, are found in the Neotropics (Remsen *et al.* 2017). Seventy-five species occur in Brazilian territory (Piacentini *et al.* 2015) and about 76% of these inhabit the Atlantic Forest (Ferguson-Lees and Christie 2006), one of the most threatened biomes in the world which is currently reduced to about 12% of its original extent (Ribeiro *et al.* 2009). The Corredor Central da Mata Atlântica (Central Atlantic Forest Ecological Corridor) is a region within this biome that combines a large extent of forest remnants with a high level of biodiversity (Galindo-Leal and Câmara 2003). Within this corridor, there are some Important Bird and Biodiversity Areas (IBAs), such as the Southern Bahia region (Bencke *et al.* 2006), where three of the six species of Accipitriformes that are threatened in Brazil can be found: the Crested Eagle *Morphnus guianensis*, the Harpy Eagle *Harpia harpyja* and the White-necked Hawk *Buteogallus lacernulatus* (MMA/ICMBio 2016). In Southern Bahia, much of the original forest was converted into cocoa *Theobroma cacao* plantations, mostly cultivated under the "*cabruca*" system (Landau *et al.* 2008). In *cabrucas*, the understorey is replaced by cocoa trees that grow under the canopy of predominantly native forest trees partly retained when cocoa is planted, plus trees that regenerated or have been planted later (Alves 1990).

*Cabruca* has been considered a wildlife-friendly system (Schroth *et al.* 2011) because it supports a significant portion of the native fauna (Cassano *et al.* 2009). Despite the vertical structural simplification compared to forests, *cabrucas* are much more complex than other farmlands such as annual crops (Alves 1990), thus acting as a suboptimal habitat for species from different taxonomic groups (Cassano *et al.* 2009). To our knowledge, there is no study specifically developed to investigate the use of *cabrucas* by raptors. Understanding how raptors are being affected in agricultural lands - particularly in conservation priority areas such as Southern Bahia - is a research priority in Brazil's National Action Plan for the Conservation of Birds of Prey (Soares *et al.* 2008). Also, the specific response of raptor species to environmental degradation gradients is still poorly understood in the Neotropics (Carrete *et al.* 2009), calling for new field data.

Since the carnivorous mammal fauna is very depauperate in Southern Bahia region (Cassano *et al.* 2012), raptors end up being the major (and sometimes the only) predators regulating populations of many species, including some native endangered species such as the Golden-headed Lion Tamarin, *Leontopithecus chrysomelas* (Oliveira and Dietz 2011). Predator-prey relationships can be unbalanced and sometimes lead to the local extinctions of prey in human-modified habitats (Irwin *et al.* 2009). Therefore, understanding the abundance and diversity of raptors using *cabrucas* is important to evaluate the trophic structure and the stability of biological communities in this agrosystem. This study aimed to describe the diurnal raptor assemblages of *cabrucas* from Southern Bahia and to identify features of this system that could determine occupancy by raptors. We expected a positive relationship between raptor occupancy and habitat structural complexity (Thiollay 1985, Jullien and Thiollay 1996), specifically: *cabrucas* with better-connected canopy, high-density, taller and large-diameter shade trees, as well as a lower density of cocoa trees and a low management intensity, would have a higher chance of being occupied by raptors. We also expected the percentage of vegetation cover in the landscape to positively affect raptor occupancy in *cabrucas* (Jullien and Thiollay 1996).

We added some biological traits such as body mass, dietary requirements, and use of vertical strata, to predict raptor occupancy in *cabruca* sites. We expected a lower occupancy of (1) species with higher dependence on intermediate forest strata, since these are replaced by cocoa trees in *cabrucas* (Johns 1998); (2) larger species, since they usually occur at low population densities and have large home ranges, being more sensitive to habitat disturbance (Gaston and Blackburn 1995); and (3) species with higher energetic requirements and dietary specialisation, since they are expected to be less tolerant to changes in the availability of food resources (Terraube *et al.* 2011).

## Methods

### *Study area*

The surveys occurred between August 2014 and May 2015, a period that includes the breeding season for most raptor species in Atlantic Forest (Mañosa *et al.* 2003, Zorzin 2011), and when these predators are expected to behave more conspicuously, increasing their detectability (Seymour *et al.* 2010, Monsalvo 2012). Also, according to field records, migratory species such as the Swallow-tailed Kite *Elanoides forficatus* and the Plumbeous Kite *Ictinia plumbea* can be found in the study region during the major part of this period (https://en.wikiaves.com/).

Sixteen *cabruca* sites separated by at least 11 km (mean 52 km; range 11–114 km) were surveyed, covering 11 municipalities (~ 4,000 km$^2$) in the cocoa-growing region of Southern Bahia, Brazil (Figure 1). The dominant vegetation is tropical lowland rainforest (Oliveira-Filho and Fontes 2000), the mean annual temperature is 24°C and rainfall averages 2,500 mm/yr, with no marked seasonality (Mori *et al.* 1983).

### *Data collection*

#### Species dataset

A subset of 46 species potentially occur in the study region (http://www.listavermelhabahia.org.br/; http://www.iucnredlist.org/; Del Hoyo *et al.* 2017). Taxonomy follows Remsen *et al.* (2017). For all of them, we compiled information in the literature about (1) diet preferences (proportional consumption of each food category: vertebrates, invertebrates, and fruits); (2) body mass (in grams); (3) percentage of foraging time in each stratum (ground, understorey, mid-high, canopy, and air); (4) degree of sensitivity to habitat disturbance (low, medium or high); (5) relative abundance throughout the range (uncommon, fairly common, common, or patchily distributed); and (6) conservation status according to IUCN ('Vulnerable', 'Near Threatened', 'Endangered', or 'Critically Endangered'). We derived two indexes based on diet preferences: (1) trophic level – the sum of the proportional consumption of each food category weighted by its energetic value, assuming a decreasing energy content from vertebrates to invertebrates to fruits; and (2) dietary specialisation – the number of different food categories in species dietary. Species list, ecological information, details about indexes calculation, and literature references are available in the online supplementary material (Tables S1 and S2).

#### Field survey

The field methodology was adapted from Granzinolli and Motta-junior (2008). A combination of active search, playback and point-counts were performed in each *cabruca* site by the same observer with the help of a field assistant. All sampling was carried out in two visits between 06h00 and 12h00, a period during which most species of diurnal raptors are active (Thiollay 1989, Mañosa *et al.* 2003), avoiding days with rain and strong wind due to a possible decrease in species detectability (Jones 2000).

Using Landsat images with 30 m resolution obtained from Google Earth (Google Inc. 2016), we designed two parallel linear transects of 800 m separated by 400 m in each *cabruca* site (Figure 2). Between 06h00 and 09h00, the active searches and playbacks were carried out in these transects, focusing on species which predominantly occur in forested habitat, such as the Crested and Harpy Eagles and the Forest-falcons *Micrastur* spp., plus soaring species that have not started their flight activities yet, such as the Grey-headed Kite *Leptodon cayanensis* and the Hawk-eagles *Spizaetus* spp. (Thiollay 1989). The active search was performed by walking through these transects at a constant velocity while identifying species using 10 x 50 binoculars and a digital voice recorder to record vocalisations whenever possible.

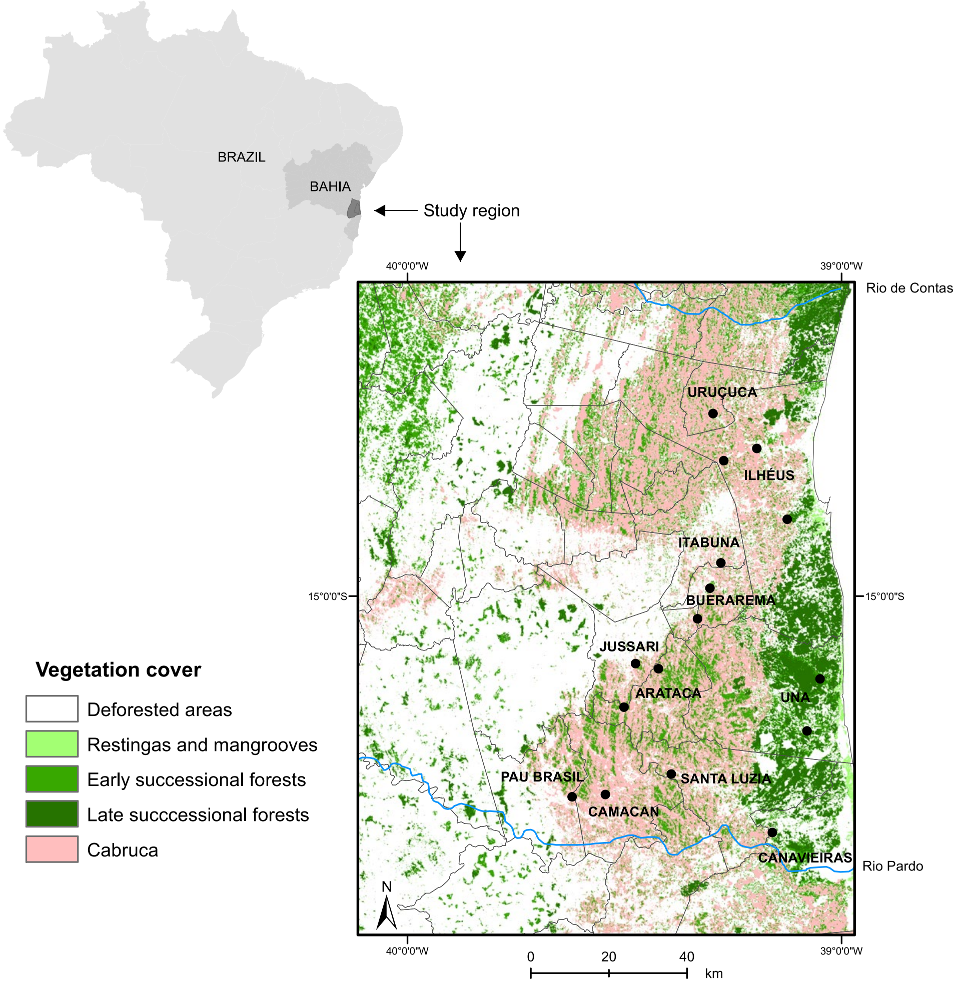

Figure 1. Vegetation cover in the study region and the location of the 16 *cabruca* sites surveyed in this study (black circles). Vegetation classification followed Landau *et al.* (2008).

Playback was performed to a set of species that are known to respond well to this technique: the Grey-headed Kite, Barred Forest-falcon *Micrastur ruficollis*, Collared Forest-falcon *M. semitorquatus*, Bicolored Hawk *Accipiter bicolor* and Black Hawk-eagle *Spizaetus tyrannus* (Zorzin 2011, JABM pers. obs.). This method consists of playing a recording of the species' vocalisation to attract individuals and stimulate intra-specific responses. Often playback resulted in inter-specific responses as well. Playback was performed at two opposite points of the sampling grid (Figure 2), separated by a mean linear distance of 665 m ± 160 SD, a placement that is consistent with those used by previous studies (Carvalho Filho *et al.* 2008/2009, Vázquez-Pérez *et al.* 2009). We used recordings available on Wiki Aves (http://www.wikiaves.com/), preferentially those made in the study region and avoiding aggressive vocalisations and pair duets. Using the aforementioned recorder coupled with a portable speaker, the recordings of all focal species were played in a pre-established order that took into account both body size and aggressive behavior, considering that large and fierce species could repel smaller ones (Mosher *et al.* 1990). Each vocalisation was played continuously for 3 min, holding the speaker at

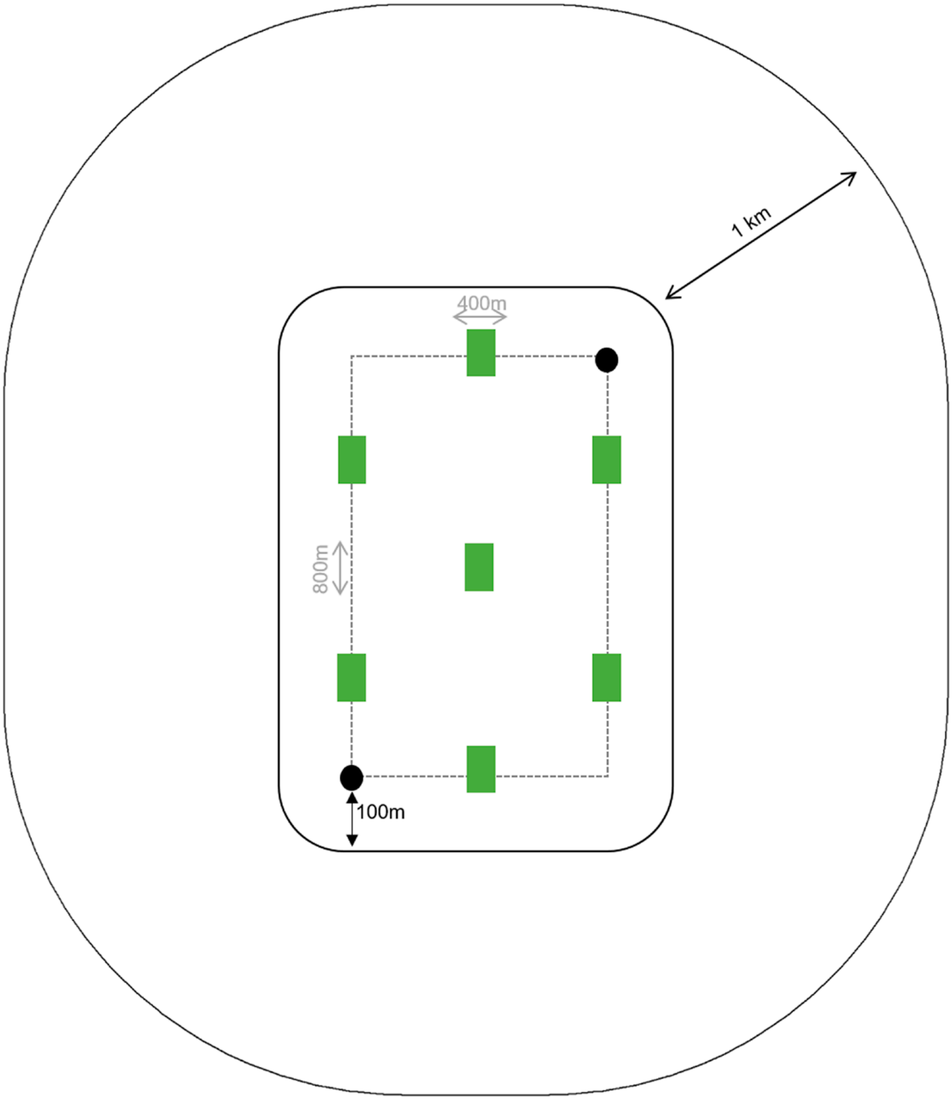

Figure 2. Scheme of the sampling grid designed in each *cabruca* site showing the linear transects (dashed gray line) where the active searches were performed, the location of the playback points (black circles) and the vegetation plots (gray rectangles). The transects are located at least 100m distant from fragment's edge and the vegetation cover was estimated within the area delimited by the 1-km radius.

approximately 2 m above the ground and rotating it over 360° at a constant speed, followed by a 3-min on-site wait.

Most raptors, such as the hawks *Buteogallus* spp. and the Mantled Hawk *Pseudastur polionotus*, often start soaring when thermals are well-formed, so the best period to perform the point-count methodology is between 09h00 and 12h00 (Thiollay 1989, Mañosa *et al.* 2003). During this period, we recorded all individuals visually or through their vocalisations from a fixed location. Point-counts for raptors are typically located in high places that offer a wide view of the canopy, such as tops of hills adjacent to the study area (Mañosa *et al.* 2003). Such an approach was used whenever possible, but in six *cabruca* sites the relief was very flat so we located two complementary point-counts at the edge of the *cabruca* (~100 m from the edge and 690 ± 170 m apart from each other) and remained for 1h30 min at each point.

Except for single point-counts, the starting sampling point of each method was alternated on the second visit to ensure that species with different peaks of activity could be detected at all points (Jones 2000). Since most Atlantic Forest fragments are smaller than the mean territory sizes of Neotropical raptors (Thiollay 1989, Zorzin 2011), repeated detections of the same species at the same site were attributed to the same individual unless when more than one individual was observed simultaneously.

## Habitat characterisation

In each *cabruca* site, seven 200-m$^2$ plots were placed at interspersed points of the sampling grid (Figure 2). Six features related to vegetation structure and *cabruca* management were collected in these plots, resulting in eight explanatory variables to be used in data analysis: (1) shade tree density; (2) mean shade tree diameter; (3) mean canopy height; (4) mean canopy connectivity; (5) heterogeneity of the vertical strata; (6) cocoa tree density; (7) shading level and (8) management intensity (Table S3). For the statistical analysis, we created an abundance index for each variable so that each of them was represented by a unique value per area. This index is the sum of the values obtained for each variable per plot.

Responses of diurnal neotropical raptors to forest fragmentation usually occur between the scales of 500 m and 1 km (Zorzin 2011). Based on the Landsat images, we created a buffer defined by a 1-km radius from the extreme points of the sampling grid (Figure 2) where we estimated the percentage of vegetation. Clearings within the buffers were visually identified and their area was subtracted from the total area of the buffer. This estimate included both *cabruca* and native forest due to the difficulty of accurately differentiating it in the images. Spatial analyses were performed on Quantum GIS 2.18.2 (www.qgis.org) using its interface with Google Earth (Google Inc. 2016). The distance measurements were made with the Raster Package (Hijmans *et al.* 2016) in R 3.3.1 (R Core Team 2016).

### *Data analysis*

Occupancy modeling was performed in the program Mark version 8.x (White and Burnham 1999) to evaluate the influence of several variables on raptor occupancy. We used the single-season multi-species method to model the occupancy ($\Psi$) and detectability ($p$) of all species simultaneously, assuming an imperfect detection (Mackenzie *et al.* 2002). In this approach, 'species' and 'visits' represent the sample units and occasions, respectively (see chapter 9 of Mackenzie *et al.* [2006] for more details). For each species, a detection history was created based on the two independent visits per sampling method, which resulted in six occasions per species/site. This analysis included only the subset of species detected at least once at one of the sampling areas.

Single-season modeling assumes that the population is closed to changes in occupancy during the season (Mackenzie *et al.* 2006). Given that raptor home ranges are probably larger than all of our sampling areas (Thiollay 1989), this assumption may not have been achieved. To deal with this problem, we interpreted the estimated occupancy as the proportion of the area 'used' by the species rather than the true occupancy (Mackenzie *et al.* 2006). The detectability was interpreted as the probability of detecting the species when it is present in the area *and* using the sampling unit during the survey, assuming that movement of species through their home range is random (see similar interpretations in Keane *et al.* 2012 and Kalan *et al.* 2015).

Habitat features, landscape metrics, and biological traits were used as covariates to model $\Psi$ and $p$ in a series of competing models. Prior to analyses, we assessed their pairwise correlations through a Spearman correlation test using the R Stats package (R Core Team 2016), and excluded those with correlation ≥ 0.60, that is: percentage of foraging in intermediate strata (negatively correlated with body mass; $r$ = -0.63); percentage of foraging in air (positively correlated with percentage of foraging in the canopy; $r$ = 0.67); percentage of shade (positively correlated with canopy connectivity; $r$ = 0.60 and vertical stratification; $r$ = 0.66); and canopy height (positively correlated with canopy connectivity; $r$ = 0.84) and diameter of shade trees ($r$ = 0.64)]. We assessed the multicollinearity among the remaining variables through the Variance Inflation Factor (VIF) using the CAR package of R (R Core Team 2016). Since no variable had VIF > 4, we kept all of them for the analyses.

We finished with seven covariates to model $p$: (1) sampling method; (2) body mass; (3) percentage of foraging in the canopy; (4) canopy connectivity; (5) vertical strata heterogeneity; (6) shade tree density; and (7) cocoa tree density. We expected that: sampling methods would differ in species detectability; larger species would be more easily detected than smaller ones; species could be more or less easily detected depending on its preferred foraging strata; canopy connectivity, vertical heterogeneity, shade tree density, and cocoa density could interfere with visual obstruction and sound propagation, thus affecting species detectability during active searches and playbacks. We modeled $\Psi$ as a function of 10 covariates: (1) shade trees density; (2) shade trees diameter; (3) canopy connectivity; (4) vertical strata heterogeneity; (5) management intensity; (6) cocoa tree density; (7) vegetation cover; (8) body mass; (9) trophic level; and (10) specialisation degree. We also included models where $p$ and $\Psi$ were held constant.

Since we were more interested in determining the importance of covariates rather than in the final estimates of $\Psi$ and $p$, we built a model set based on all possible additive covariate combinations (Doherty *et al.* 2012), totalling 3,215 competing models. Then we calculated the cumulative AIC$_c$ weight ($w_+$) for each covariate to interpret their relative importance, and the final estimate of $\Psi$ was averaged among all competing models (Burnham and Anderson 2002). We investigated the fit of the most general model (the model with the greatest number of parameters) by estimating the overdispersion parameter *c-hat* using 10,000 bootstrap samples (Mackenzie and Bailey 2004) in the program PRESENCE 11.7 (http://www.mbr-pwrc.usgs.gov/software/presence.shtml).

## Results

### Raptor assemblages in cabrucas

A total sampling effort of 64 playback points (four per area), 91h11min of active search (mean effort: 5h40 per area; range: 4h48–6h45) and 96h of point-count (6h per area), resulted in the record of 18 species plus unconfirmed records of three species (Table S4). Some species for which we did not perform playbacks, as *Buteo* hawks, responded to the vocalisations of other species, therefore increasing their detectability (Table S5). Although we did not systematically survey for the smaller New World vultures – the Turkey Vulture *Cathartes aura*, Lesser Yellow-headed Vulture *C. burrovianus*, and Black Vulture *Coragyps atratus* - they were observed in all *cabruca* sites with all survey methods. Considering their constant presence in almost all sampling units and the difficulty in estimating their abundance, we decided not to include them in the analyses.

Among all recorded species, 44% (11 spp.), 48% (12 spp.), and 8% (2 spp.) are considered to be slightly, moderately and highly sensitive to habitat disturbance, respectively (*Parker III et al.* 1996). The most common species in our survey - ordered from the most to the less abundant - were the Southern Caracara *Caracara plancus*, the Zone-tailed Hawk *Buteo albonotatus*, the Laughing Falcon *Herpetotheres cachinnans*, and the Roadside Hawk *Rupornis magnirostris*. With the exception of the Zone-tailed Hawk - which is classified as uncommon, patchily distributed, and moderately sensitive to habitat disturbances - the aforementioned species are all considered to be common and slightly sensitive to habitat disturbance. The highly sensitive species detected in this study were the Black-and-white Hawk-eagle *Spizaetus melanoleucus* (recorded in four sites), and the Mantled Hawk *Pseudastur polionotus* (recorded in 10 sites).

The recorded species vary a lot in their dependence on forested habitats. The Collared Forest-falcon *Micrastur semitorquatus*, a forest-dependent species that uses mainly the low forest strata to forage, was recorded in two *cabruca* sites. Both records were made near regenerating forest plots, in places with a high density of shade trees. At the opposite extreme, the Savanna Hawk, *Buteogallus meridionalis*, a species that is typical of open areas, was observed during point counts in pastures near *cabruca* sites.

Some evidence of reproductive activity were observed during surveys, such as breeding pairs from six species (Black-and-white Hawk-eagle, and Black Hawk-eagle, Great Black-hawk *Buteogallus urubitinga,* Mantled Hawk, Southern Caracara, and Zone-tailed Hawk), juveniles of three species (Gray-lined Hawk, Roadside Hawk and King Vulture), and a family group of the Zone-tailed Hawk (two adults and one juvenile) foraging in the canopy near the edge of a *cabruca*.

### *Habitat characterisation*

The structure of the *cabrucas* varied significantly among sites, with a mean ± SD density of 623 ± 182 cacao trees/ha, and 182 ± 60 shade trees/ha (Table S6). Mean ± SD diameter of shade trees is 37.2 ± 30.7 cm, mean ± SD canopy height is 15.6 ± 2.6 m and mean ± SD shading level is 73 ± 10%. Hunting signs (traps, hunters and/or firearm blows) and logging signs (chainsaw noises and stumps) were recorded in 10 and nine of the 16 areas, respectively. The vegetation cover ranged between 73% and 96%.

### *Occupancy modeling*

The most parsimonious model had a low $AIC_c$ weight ($w+ = 0.08$), reflecting the high number of competing models and a high degree of uncertainty about the best-ranked models (Table 1). There is no evidence of overdispersion ($\chi^2 = 73.37$; $P = 0.12$; $c\text{-}hat = 1.28$). Although the detectability of diurnal raptors was higher with the point-count method ($P = 0.24$; 95% CI: 0.19, 0.32) compared to the others ($P_{both} = 0.13$; 95% CI: 0.09, 0.18), the sampling method did not significantly affect detectability (Table 2). Detectability decreases as both the percentage of foraging in the canopy ($w+ = 0.97$) and the density of shade trees ($w+ = 0.82$) increase (Table 2; Figures 3 and 4), and there is a significantly negative correlation between occupancy and dietary specialisation ($w+ = 0.60$; Table 2; Figure 5). The model-averaged estimate of $\Psi$ was 0.66 (95% CI: 0.42; 0.84).

## Discussion

In this study we described the diurnal raptor assemblages found in *cabrucas* of Southern Bahia, Brazil. We used occupancy modeling to investigate the role of vegetation structure, management intensity, landscape context, and biological traits in determining raptor occupancy in this agroecosystem. A significant percentage of the species expected to occur in the study region (~40%) was recorded in our study sites, and they have a high probability of occurrence in *cabruca* sites. It does not necessarily mean that *cabrucas* can assure the conservation of these species, but considering the high degree of deforestation and habitat loss in this region, *cabrucas* can act as a suboptimal habitat and assist in the persistence of diurnal raptor populations. Despite this promising perspective, there is a tendency towards impoverishment of communities in this system from the decrease of specialists.

### *Raptor assemblages in cabrucas*

At least 18 (possibly 21) diurnal raptor species occur in the *cabrucas* of Southern Bahia. Most of these are considered to be naturally common, but species such as the Grey-headed Kite, Mantled Hawk, and Zone-tailed Hawk, which are classified as 'uncommon' by Parker III *et al.* (1996),

Table 1. Results for the 10 top-ranked models of occupancy ($\Psi$) and detection ($p$) probabilities of diurnal raptors in 16 *cabrucas* of Southern Bahia, Brazil. '$\text{AIC}_c$' is the Akaike information criterion corrected for small samples, '$\Delta\text{AIC}_c$' is the difference between the $\text{AIC}_c$ value of each model and the top-ranked model, '$\text{AIC}_c\text{W}$' is the Akaike weight, and 'Dev' is the deviance (model adjustment).

| Model | $\text{AIC}_c$ | $\Delta$ $\text{AIC}_c$ | $\text{AIC}_c\text{W}$ | Dev |
|---|---|---|---|---|
| {$\Psi$(DIE+TRO) $p$(FOR+DEN)} | 1013.39 | 0.00 | 0.08 | 1001.05 |
| {$\Psi$(BOD) $p$(FOR+DEN+BOD)} | 1013.72 | 0.33 | 0.07 | 1001.38 |
| {$\Psi$(DIE) $p$(FOR+DEN)} | 1014.08 | 0.68 | 0.06 | 1003.84 |
| {$\Psi$(DIE+MAN) $p$(FOR+DEN)} | 1014.12 | 0.73 | 0.06 | 1001.78 |
| {$\Psi$(DIE+BOD) $p$(FOR+DEN)} | 1015.12 | 1.73 | 0.03 | 1002.78 |
| {$\Psi$(DIE+DEN) $p$(FOR+DEN)} | 1015.14 | 1.75 | 0.03 | 1002.80 |
| {$\Psi$(BOD+MAN) $p$(FOR+DEN)} | 1015.35 | 1.96 | 0.03 | 1003.01 |
| {$\Psi$(DIE+COC) $p$(FOR+DEN)} | 1015.49 | 2.09 | 0.03 | 1003.15 |
| {$\Psi$(DIE+CON) $p$(FOR+DEN)} | 1015.57 | 2.18 | 0.03 | 1003.24 |
| {$\Psi$(DIE) $p$(FOR+DEN+BOD)} | 1015.61 | 2.21 | 0.03 | 1003.27 |

DIE = dietary specialisation; DEN = shade tree density; FOR = percentage of foraging in the canopy; BOD = body mass; MAN = management intensity; COC = cocoa tree density; and TRO = trophic level.

were actually very frequent in our surveys. It is important to emphasise that such a classification is being used to allow comparison with other studies since we believe this is the only classification available for all Neotropical raptors to date. We recognise that it may suffer some limitations since it does not consider regional variations in factors that strongly determine species abundance. Anyway, since no systematic surveys of raptor assemblages have been made in forests from this region, we cannot conclude if the aforementioned species are particularly common in *cabruca*, or in the study region as a whole. However, as they are

Table 2. Cumulative $\text{AIC}_c$ weight for covariates used to model occupancy ($\Psi$) and detection ($p$) probabilities of diurnal raptors in 16 *cabrucas* of Southern Bahia, Brazil. The covariate effects (ß parameters) were derived from the most parsimonious model including each covariate. LL and UL represent the lower and upper limits of the confidence interval (95%), respectively.

| Covariate | Cumulative | ß parameters | | |
|---|---|---|---|---|
| | $\text{AIC}_c$ Weights | Estimate | LL | UL |
| **Detection ($p$)** | | | | |
| % of canopy foraging | 0.97 | **-0.02** | **-0.03** | **-0.01** |
| density of shade trees | 0.82 | **-5.99** | **-8.43** | **-3.55** |
| body mass | 0.17 | -0.72 x $10^{-3}$ | 0.00 | -0.41 x $10^{-3}$ |
| canopy connectivity | 0.11 | -0.01 | -0.04 | 0.03 |
| vertical stratification | 0.10 | -0.83 x $10^{-3}$ | -0.02 | 0.03 |
| method – active search | 0.07 | -0.24 | -0.90 | 0.43 |
| method - playback | 0.07 | -0.03 | -0.68 | 0.63 |
| density of cocoa trees | 0.05 | 0.10 | -1.01 | 1.20 |
| **Occupancy ($\Psi$)** | | | | |
| dietary specialisation | 0.60 | **1.12** | **0.29** | **1.95** |
| body mass | 0.43 | 0.00 | -0.83 x $10^{-3}$ | 0.01 |
| management intensity | 0.18 | 0.11 | -0.03 | 0.26 |
| canopy connectivity | 0.16 | -0.03 | -0.11 | 0.05 |
| trophic level | 0.11 | 1.42 | -0.31 | 3.16 |
| density of shade trees | 0.10 | -3.7 | -10.75 | 3.34 |
| vertical stratification | 0.07 | 0.02 | -0.04 | 0.09 |
| dbh of shade trees | 0.07 | 0.00 | -0.04 x $10^{-3}$ | 0.01 |
| density of cocoa trees | 0.06 | 1.40 | -1.99 | 4.78 |
| % of vegetation cover | 0.04 | 0.82 | -0.17 | 1.81 |

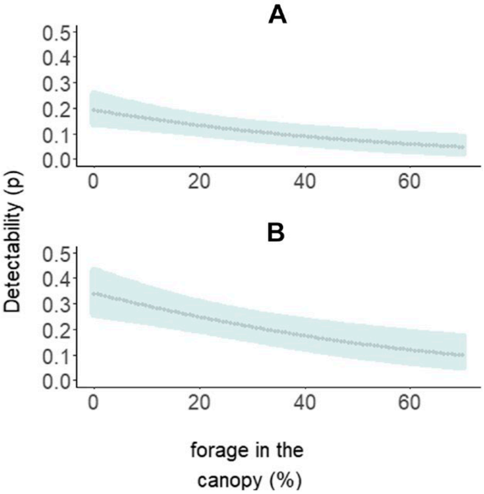

Figure 3. Relationship between diurnal raptor detectability and species' percentage forage in the canopy using three sampling methods: active search and playback (both represented in graph A), and point-count (B). Dotted lines and shaded areas represent the predicted values and the 95% confidence intervals, respectively.

frequently sighted throughout this region (even foraging in urban areas, in the case of the Zone-tailed Hawk; JABM pers. obs.), we believe that they can indeed be fairly common in Southern Bahia.

More than half of the recorded species are classified as moderately or highly sensitive to habitat disturbance, such as the Black-and-white Hawk-eagle and the Mantled Hawk. In fact, some authors have been questioning this classification by claiming that species-specific responses to habitat alterations depend on the disturbance context (Sergio *et al.* 2008; Alexandrino *et al.* 2016).

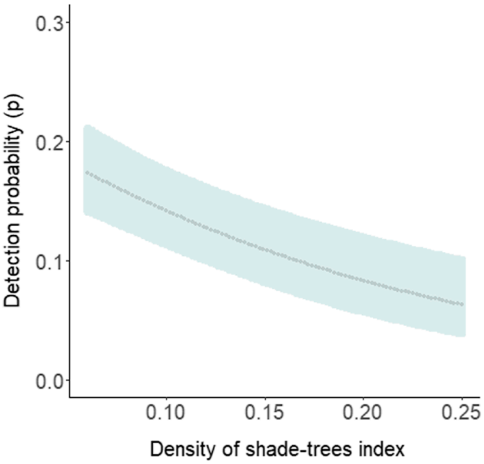

Figure 4. Diurnal raptor occupancy probability as a function of the density of shade trees in *cabruca* sites. The dotted line represents predicted values and the shaded areas the 95% confidence intervals.

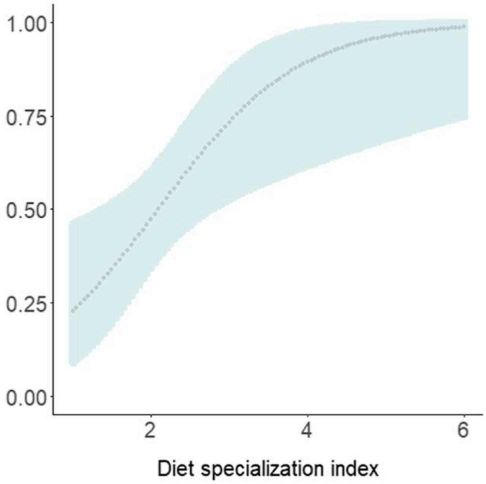

Figure 5. Diurnal raptor occupancy probability as a function of the diet specialisation index (= the number of food items in species diet). A high index value means a low degree of dietary specificity. The dotted line represents predicted values and the shaded areas the 95% confidence intervals.

As the classification proposed by Parker III *et al.* (1996) did not specify the type and intensity of disturbance under consideration, conclusions may have been based on habitats with levels of disturbance more intense than those observed in *cabrucas*.

We did not record any globally threatened species, and only one 'Near Threatened' species, the Mantled Hawk, in the *cabruca* sites. The commonness of this species in *cabruca* is supported by unpublished reports from the Serra Bonita reserves complex in Camacan, located within the study region (JABM pers. obs.). An earlier study has found the Mantled Hawk to be extremely affected by forest fragmentation (Zorzin 2011), thus a high tolerance to *cabrucas* may reveal an important role of this agroecosystem on mitigating the detrimental effects of forest fragmentation.

The observation of juveniles and breeding pairs from many species in *cabruca* sites was a very interesting and promising finding because it suggests they may be breeding there. However, specific studies on this topic are needed to confirm if these species are actually nesting in *cabrucas* since it would contradict the high-quality requirements proposed for raptor breeding sites (Joenck *et al.* 2011, Canuto *et al.* 2012). There are some nesting records of Neotropical accipitrids such as the Short-tailed Hawk and the Harpy Eagle in areas that do not match such high-quality demands (Silva 2007, Monsalvo 2012), suggesting that a re-evaluation of this topic is necessary at least for some hawks and eagles (Monsalvo *et al.* 2018).

The failure to detect some species from the potential dataset may be partly explained by their high dependence on specific habitat types. The Snail Kite *Rostrhamus sociabilis* for example, is most commonly associated with wetlands, and the Long-winged Harrier *Circus buffoni* prefers open areas (Thiollay 2007). An adult pale-morph male of the latter species was occasionally observed while flying above a *restinga* (vegetation on the sandbanks) confirming their presence in the region despite the absence of records in the *cabruca* sites. A group of Swallow-tailed Kites, a migratory species that reproduces in the Atlantic Forest, was also occasionally recorded foraging under a pasture in the proximities of a *cabruca* site. To our knowledge, this is the first published record of this species in this region, and although we did not detect any individual within *cabruca* sites, such record suggests an ability to forage in landscapes totally dominated by this system. The same conclusion applies to our records of the Savanna Hawk, a common species in altered landscapes (Thiollay 2007).

The largest species from our potential dataset (the Crested and Harpy Eagles) are among the rarest Neotropical raptors (Thiollay 2007) and were also not recorded in our surveys. However, there are recent records of both species near and within our study region (Sánchez-Lalinde *et al.* 2011, Araújo *et al.* 2015, Suscke *et al.* 2016), including the observation of Harpy Eagles foraging in *cabrucas* from the Serra Bonita reserves complex between 2012 and 2013, and the recent record of nesting in that same area (JABM unpublished. data). Considering the rarity of such species, an increased survey effort would be necessary to best estimate their occupancy in *cabruca* sites.

### *Determinants for raptor occupancy in cabrucas*

Our analysis suggests that the availability of food resources may play a key role in determining the assembly of raptor communities in *cabrucas*. Despite the certain degree of habitat complexity and heterogeneity that is preserved in *cabrucas*, this system is indeed simplified compared to forests, so the overall prey availability is expected to be lower (August 1983). Consequently, specialists may be less likely to occupy *cabrucas* than species with more diversified diet. Previous studies have already shown that specialist species are strongly affected by habitat disturbance and may be excluded from altered habitats, which tend to be dominated by generalists (Ferrer-Sánchez and Rodríguez-Estrella 2014). Thus, although *cabrucas* may represent a suboptimal habitat for a significant number of diurnal raptor species, this system alone may not support complete assemblages of raptors.

Finally, although we failed to find any significant effect of habitat and landscape features on raptor occupancy, our results should be interpreted under the regional context. The *cabruca* sites surveyed in this study preserve a high density of shade trees, which is typical of traditional *cabrucas* in this region (Schroth *et al.* 2015). There may be a critical density of trees, below which significant impacts on raptor occupancy may be observed, and it is therefore possible that the study did not include *cabrucas* with such a low density of trees. Assuming this possibility is particularly important due to the current scenario in Southern Bahia of encouragement of *cabruca* management intensification. A state decree published by the Bahia Government in 2014 (N° 15.180; article 19) has sanctioned the management intensification of *cabrucas* by allowing the reduction in shade tree density to very low levels (40 trees per ha). If implemented, it will promote a huge change and will likely decrease habitat heterogeneity in *cabruca* (Benton *et al.* 2003). Unfortunately, we cannot predict how raptors will respond to the changes that will occur in habitat features such as canopy connectivity or the diameter of shade trees. However, since a minimum level of habitat complexity and heterogeneity is necessary to support species-rich bird communities in altered habitats (Abrahamczyk *et al.* 2008, Philpott *et al.* 2008), raptor assemblages may not be sustained in very intensified *cabrucas*, as already shown in other types of farmland (Donald *et al.* 2001, Carrete *et al.* 2009).

## Conservation implications and recommendations

This study is a first attempt to understand the role of *cabrucas* for diurnal raptor conservation in Southern Bahia. We found a significant number of diurnal raptor species are able to use *cabrucas*, and evidence that some species may even be breeding in these areas. However, there is a tendency towards impoverishment of communities through the reduction in dietary specialists' occupancy. These findings emphasise the importance of considering human-modified habitats in conservation planning but highlight the need for the maintenance of forest remnants in the landscape to increase the regional species diversity.

Finally, a complete understanding of the role of *cabrucas* in assisting raptor conservation depends on a better knowledge about raptor assemblages in the forests of this region. More surveys using appropriate sampling methods, as well as ecological and behavioural studies in both forests and *cabruca* sites, are crucial to better understand how raptors are dealing with habitat changes. Such knowledge would clarify the extent to which *cabrucas* can contribute to raptor conservation at a regional scale, and how different species can be specifically affected by *cabruca* intensification. Ultimately, since raptors play a key role as top predators, understanding such issues would allow a better understanding of how stable these communities are, and also of the long-term persistence probability of many species (including endangered species) in *cabrucas* of Southern Bahia.

## Supplementary Material

To view supplementary material for this article, please visit https://doi.org/10.1017/S0959270919000017

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