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Authors: Novaes, Weber G., and Cintra, Renato

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RESEARCH ARTICLE

## Anthropogenic features influencing occurrence of Black Vultures (*Coragyps atratus*) and Turkey Vultures (*Cathartes aura*) in an urban area in central Amazonian Brazil

Weber G. Novaes<sup>1a\*</sup> and Renato Cintra<sup>2</sup>

<sup>1</sup> Graduate Program in Ecology, Instituto Nacional de Pesquisas da Amazônia, Manaus, Amazonas, Brazil

<sup>2</sup> Coordenação de Biodiversidade, Instituto Nacional de Pesquisas da Amazônia, Manaus, Amazonas, Brazil

<sup>a</sup> Current address: WGN Environmental Consulting, Lauro de Freitas, Bahia, Brazil

\* Corresponding author: webernovaes@gmail.com

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### ABSTRACT

Recent increases in Black Vulture (*Coragyps atratus*) and Turkey Vulture (*Cathartes aura*) numbers, particularly in urban–suburban settings, have led to more frequent human–vulture interactions, including vulture–aircraft strikes. This problem highlights the need for vulture management strategies, including determining habitat use by these species in urban settings. We investigated the effects of structures and landscape features on habitat use by Black and Turkey vultures in and around the city of Manaus in central Amazonian Brazil. We repeatedly surveyed 80 sites (3–9 visits per site in 2009–2010) and used detection histories to derive maximum-likelihood estimates of (1) vulture occurrence and detection probabilities and (2) environmental covariate effects on occupancy. Hierarchical logistic models showed that Black Vultures were associated with urban features such as open garbage containers and streams, but Turkey Vultures were associated with forest fragments. These results suggest that Black Vultures select environments where the food supply is abundant, whereas Turkey Vultures may avoid sites that attract Black Vultures in favor of forest remnants, a habitat for which they have specific foraging adaptations. Black Vulture management should focus on reducing the amount of food waste available to the birds in urban open garbage containers and streams, but Turkey Vulture management could be improved through removal of animal carcasses, and perhaps also removal of nests and roosts from forest remnants, especially near airfields.

**Keywords:** Black Vulture, *Coragyps atratus*, Turkey Vulture, *Cathartes aura*, urban habitat use, vulture–aircraft strike.

### Estruturas antropogênicas influenciando a ocorrência de *Coragyps atratus* e *Cathartes aura* em uma área urbana na Amazônia Central, Brasil

### RESUMO

O crescimento populacional de *Coragyps atratus* e *Cathartes aura*, particularmente em área urbanas e suburbanas, tem gerado uma série de conflitos com os seres humanos, incluindo colisões com aeronaves. Este problema evidencia a necessidade de estratégias de manejo de urubus, mas aspectos importantes sobre o uso do habitat dessas espécies permanecem pouco explorados. Nós investigamos o efeito de estruturas urbanas nos padrões de uso do habitat de *Coragyps atratus* e *Cathartes aura* na área urbana e suburbana de Manaus, na Amazônia Central, Brasil. Nós visitamos 80 pontos-fixos (3-9 visitas em 2009-2010) e utilizamos o histórico de detecção para derivar as estimativas de máxima verossimilhança das (i) probabilidades de ocorrência e detecção e (ii) os efeitos de covariáveis ambientais sobre tais probabilidades. Os modelos hierárquicos mostraram que *Coragyps atratus* estava associado a estruturas urbanas como grandes lixeiras e rios poluídos e *Cathartes aura* a fragmentos florestais. Estes resultados sugerem que *Coragyps atratus* buscam ambientes onde a oferta de alimento é abundante, enquanto que *Cathartes aura* está associado a remanescentes florestais, habitat no qual está adaptado a encontrar alimento. Além disso, *Cathartes aura* evitam áreas onde há grandes concentrações de *Coragyps atratus*. O manejo de *Coragyps atratus* deve focar na redução de alimento disponíveis nas áreas urbanas, como em lixeiras e rios poluídos, enquanto o controle de *Cathartes aura* pode envolver a remoção de carcaças e, dependendo da situação, ninhos e dormitórios em fragmentos florestais, especialmente próximo a aeroportos.

**Palavras-chave:** urubu-de-cabeça-preta, *Coragyps atratus*, urubu-de-cabeça-vermelha, *Cathartes aura*, uso do habitat urbano, colisões com aeronaves.

## INTRODUCTION

Factors such as food abundance, vegetation cover, roost site availability, and morphological characteristics regulate the habitat use of birds of prey and scavenger birds (Schnell 1968, Preston 1990, Kirk and Currall 1994). Understanding the relationships between species and their environments is crucial for effective management and conservation (O'Neil and Carey 1986). The urban environment, which tends to support bird communities dominated by a small set of species (Blair 2004), can be high-quality habitat for some raptors (Chace and Walsh 2006). Black Vultures (*Coragyps atratus*) and Turkey Vultures (*Cathartes aura*) have adapted well to landscapes fragmented by human activities, resulting in population growth and range expansion in recent years (Avery 2004, Blackwell et al. 2007, Carrete et al. 2010).

Occurrence of Black and Turkey vultures in urban centers is considered detrimental to humans because of problems such as nuisance related to roosts (Avery et al. 2002), property damage (Hill and Neto 1991, Lowney 1999), interactions with communication towers (Avery et al. 2002), and, particularly, collisions with aircraft (DeVault et al. 2005, Blackwell and Wright 2006, Avery et al. 2011). According to the bird strike database of the United States Air Force (USAF), Turkey and Black vultures ranked as the third and fourth species in losses caused by birds (USAF 2014). Combined, they ranked as the second most hazardous bird group to civil aircraft and first most hazardous to military aircraft in the United States (Zakrajsek and Bissonette 2005, DeVault et al. 2011). In Brazil, according to the bird strike database of the Aeronautical Accidents Investigation and Prevention Center (CENIPA), vultures are responsible for the highest number of wildlife strikes with aircraft, with more than 980 strikes recorded in the 12 years from 2000 to 2011. In Manaus, more than 65 vulture–aircraft strikes occurred between 2000 and 2012. One strike with 2 Turkey Vultures at Manaus International Airport in 2012 cost US\$750,000.00 (data from CENIPA 2012).

Although Black and Turkey vultures share some important features, most notably eating carrion, their behavior differs markedly. Black Vultures find food by sight, whereas Turkey Vultures have a well-developed sense of smell that enables them to find food efficiently in forested environments (Houston 1986, Kirk and Mossman 1998, Buckley 1999). For this reason, Black Vultures prefer foraging in open areas (Coleman and Fraser 1989), where they often congregate in large groups around carcasses (Buckley 1996). Turkey Vultures, however, are less gregarious and, despite their ability to find food first, are often displaced by later-arriving Black Vultures, likely because Turkey Vultures prefer small food items that they can consume quickly before interacting with Black

Vultures (Buckley 1996). Black Vultures will reuse a given feeding site for several days, whereas Turkey Vultures use a large number of feeding sites and return to the same feeding site less often than Black Vultures (Coleman and Fraser 1989).

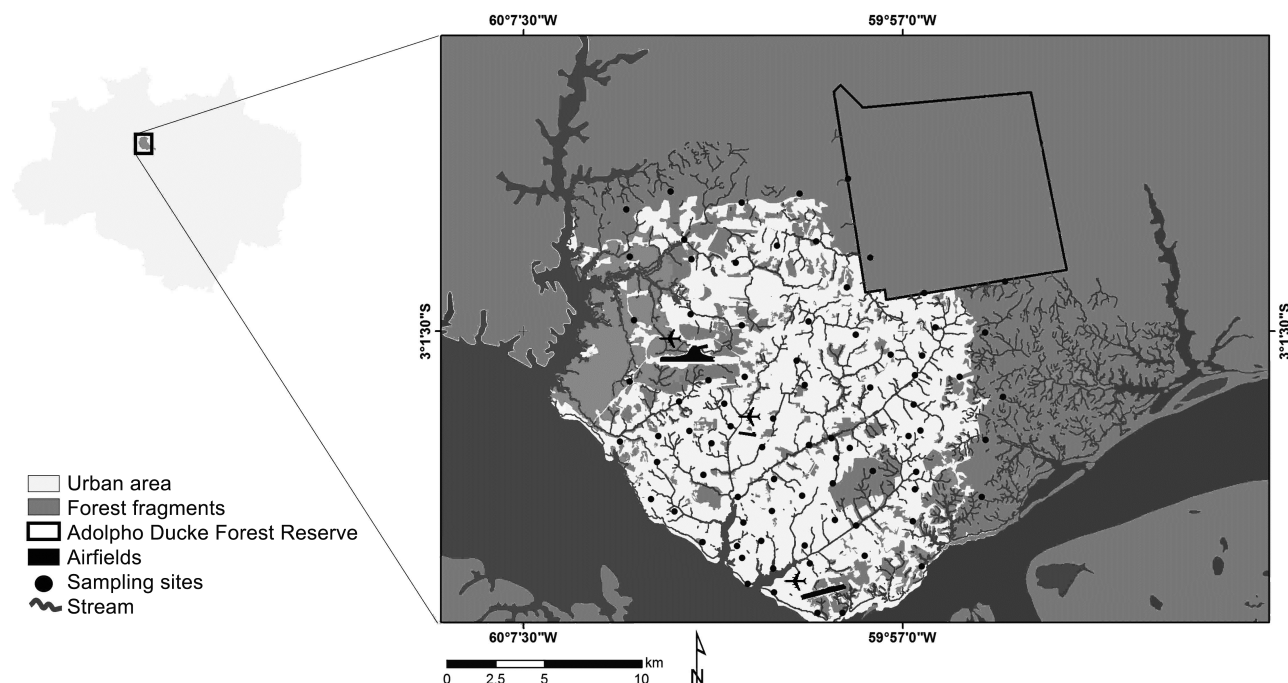
Managing vultures in urban settings, where conflict with humans is most likely, requires understanding how birds use anthropogenic landscapes. Previous ecological studies with these 2 vulture species were conducted mainly in nonurban areas, including agricultural and forested landscapes (Rabenold 1986, Coleman and Fraser 1989, Kirk and Currall 1994, DeVault et al. 2004). In Brazil, including Manaus, Black Vultures are extremely common and gregarious urban birds and use urban habitat to find food and roost, and even use man-made structures (i.e. thermal power plant) to assist their flight (Novaes and Cintra 2013, Novaes and Alvarez 2014, Freire et al. 2015). Turkey Vultures, which are less common in urban settings, may behave differently. Understanding the environmental factors influencing the occurrence of each species will contribute substantially to developing protocols to reduce vulture–human conflicts.

We focused on a typical urban environment, quantifying vulture occurrence and detection probabilities and modeling these probabilities as a function of environmental covariates. We hypothesized that Black Vultures would preferentially use sites where food is available in large amounts. In contrast, we predicted that Turkey Vultures would utilize forest fragments more frequently because their adaptations for finding food in forested areas (Houston 1986, Wallace and Temple 1987, Lemon 1991) might lead to a local competitive advantage over the more common Black Vulture. Thus, we aimed to (1) identify urban features influencing Black and Turkey vulture occurrence and (2) provide information about vulture urban use that could be useful for mitigating human–vulture conflict.

## METHODS

### Study Area

We worked in urban and suburban areas of Manaus (03°08'S, 60°01'W) in central Amazonian Brazil. Mean annual precipitation in Manaus is 2,286 mm with a December–May rainy season and June–November dry season (Ribeiro 1991). The city of Manaus has an area of 377.4 km<sup>2</sup> and is surrounded predominantly by *terra firme* rainforest to the north and the Negro and Amazon rivers to the south (Figure 1). The urban area is covered by a dense hydrographic network (Couceiro et al. 2006) and >50 urban forest fragments that vary in size from 3 to 578 ha (Gontijo 2008). Manaus has grown rapidly in recent decades; between 1991 and 2010 the population grew from 1 to 1.8 million (IBGE 2010). Consequently, there are



**FIGURE 1.** Spatial distribution of the 80 sampling sites in urban and suburban areas of Manaus, Amazonas, Brazil. The airports (from north to south) are International Airport of Manaus, Flores Aerodrome, and Manaus Air Base.

increasing disturbances such as deforestation and water pollution that result in constant changes in the local ecosystem. Furthermore, garbage collection is not adequate in several areas of the city, especially for street markets, where large amounts of food waste are left in the open, providing ample feeding opportunities for vultures.

### Sampling Design

The aim of the sampling design was to estimate vulture occurrence and detection, which is the probability of a species of interest occurring at a site for the duration of the sampling period (MacKenzie et al. 2002). In 2009 we selected 48 sampling sites located  $\sim 3$  km from one another throughout the urban–suburban area of Manaus. To widen our study area and to investigate the influence of features such as streams and street markets on the occurrence of vultures, in 2010 we incorporated an additional 32 sites with these features into our study. To select these additional sites, we identified all street markets and stream reaches present in the urban area and randomly selected 32, keeping a minimum distance of 1 km between sites. Our 80 sites covered an area of 457 km<sup>2</sup> in the urban and suburban areas of Manaus (Figure 1).

Sampling consisted of up to 4 visits to each of the initial 48 sites between July and October 2009 and up to 5 visits to each of the 80 sites between September and November 2010; overall, 38 sites were visited 9 times, 23 sites 8 times, 10 sites 5 times, 8 sites 4 times, and 1 site 3 times, totaling 572 visits. During each visit, an observer recorded the

number of vultures present in a  $\sim 100$  m radius area around the same sampling point. Sampling was concentrated in the dry season because heavy rainfall between December and May in Manaus complicated data collection. At each site and visit, vulture sampling lasted 5 minutes and was conducted by a single observer between 0800 and 1700 hours, a time that corresponds to the most active period for Black and Turkey vultures (Avery et al. 2011); however, the timing of vulture activities (roosting, feeding, and resting) varies throughout the day, and site visits were planned at varying times to incorporate this variation.

Although all vultures detected by the observer were recorded, only vultures that were perching or flying immediately above the site were considered for modeling occurrence and detection probabilities. We used these criteria because vultures could be next to the site (i.e. soaring on a thermal or moving from one place to another) but not using features present in the sample radius.

Based on the behavior of Black and Turkey vultures, 5 site covariates and 2 sampling covariates were chosen to build occurrence and detection models. These covariates included urban features potentially attractive to vultures as feeding and resting sites as well as time variables. Urban features considered were (1) street markets, where large amounts of food waste are often available; (2) urban streams, locally called *igarapés*, most of which are essentially open sewers with large amounts of food waste; (3) garbage containers, which are usually and almost daily



filled to capacity with mostly organic garbage; (4) perches, both natural (such as dead trees) and anthropogenic (e.g., mobile phone, radio, and television communication towers), which are often used by vultures for resting and roosting; and (5) forest fragments, which are suitable for roosting or nesting. We also analyzed the influence of time variables: (1) year of sampling, to investigate variations in vulture occurrence and detection over 2 study years; and (2) time of sampling, divided into morning (0800–1100 hours), midday (1100–1400 hours), and afternoon (1400–1700 hours) to investigate time of day in vulture detection.

### Data Analysis

We first used raw observation data to create abundance maps for each species across sampling sites. Second, we used a likelihood-based method for estimating site occupancy rates and detection probabilities similar to that proposed by MacKenzie et al. (2002), in which investigators repeatedly sample discrete sites and record the detection/nondetection of species of interest for each sampling occasion.

This approach takes into account that the target species will not always be detected within a site that is currently being used. Nondetection may be due to true detection failure (i.e. the species was present at the site, but the observer did not see it) or to temporary absence of the species from the site (i.e. all individuals were in another part of their home range at the time of sampling). In some circumstances it may not be possible to survey all sites for all sampling occasions. These missing observations are also accommodated in the model; if sampling does not take place at site  $i$  at time  $t$ , then on that occasion no information was contributed to the model likelihood for that site (MacKenzie et al. 2002).

We estimated 2 parameters:  $\Psi_i$ , the probability that a species is present at site  $i$ ; and  $p_{it}$ , the probability that a species is detected at site  $i$  at time  $t$ . Following MacKenzie (2006), we interpreted  $\Psi$  as the probability that a site is used by Black or Turkey vultures, and  $p$  as the probability of detecting each species at site  $i$  at time  $t$ , given the site is used. Both parameters may be expressed as a logistic function of site-specific covariates (e.g., habitat type, patch size) and time-varying covariates (e.g., time, temperature, weather; MacKenzie et al. 2002, Bailey et al. 2004). To understand which urban features and time variables contributed to explaining the observed variation in vulture occurrence, we modeled  $p$  as a function of 2 time variables (year and time of day), and  $\Psi$  and  $p$  in relation to the presence/absence of 5 urban features (street markets, garbage containers, streams, forest fragments, and perches) within a 100 m radius of the observation point at each site. Because we were not observing discrete sampling sites with demographically closed populations, our  $p$  values estimate the probability that at least one individual was

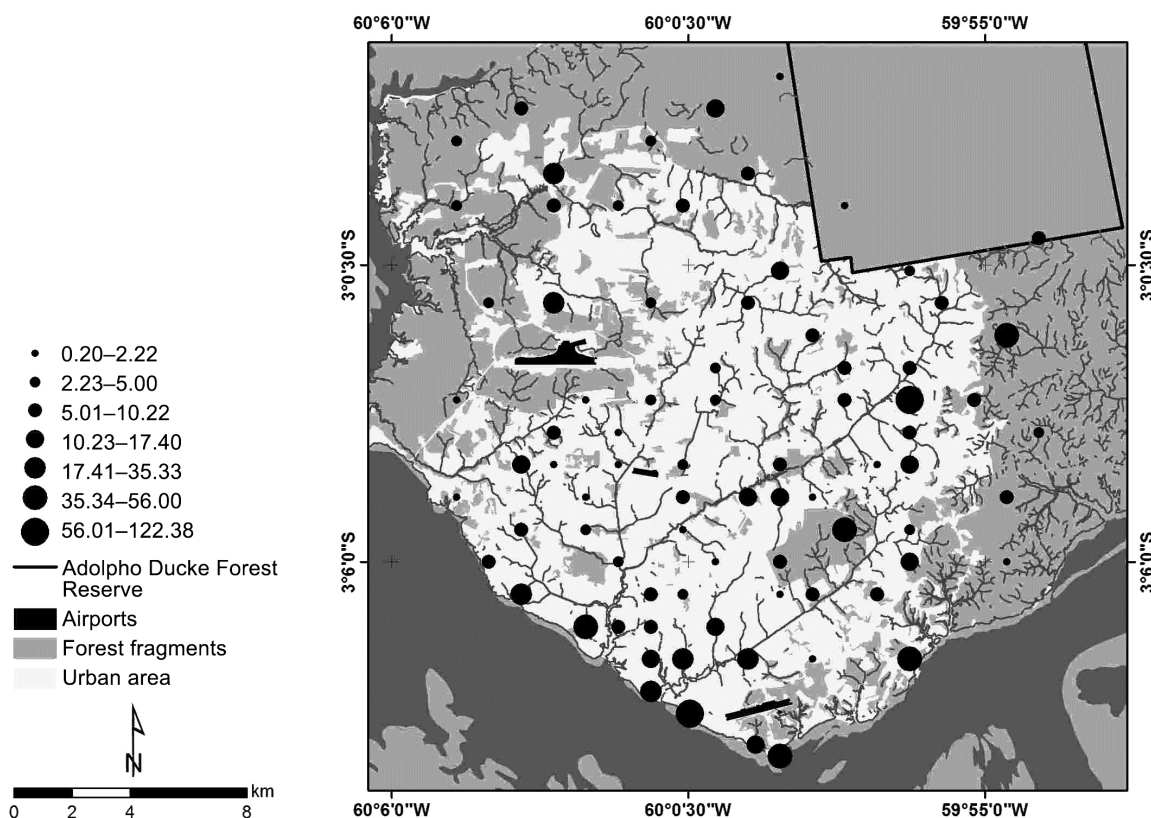
present and detected. Therefore, higher  $p$  values were expected when the sites were used more frequently and individuals were easier to detect. This led us to model  $p$  as a function of the presence of all the site-specific covariates (urban features).

We tested the importance of each covariate separately for Black and Turkey vultures using different model specifications using variations in the basic model parameters,  $\Psi_i$  and  $p_{it}$ . First, we kept the proportion of sites used constant,  $\Psi(\cdot)$ , and allowed species detection to vary with time,  $p(\text{time})$ , and each site-specific covariate,  $p(\text{covariate})$ , separately for a total of 7 models. Next, we kept the species detection probability constant,  $p(\cdot)$ , and varied  $\Psi$  with each covariate (urban features) separately,  $\Psi(\text{covariate})$ , for 5 models. In each set of models we used a constant model,  $\Psi(\cdot)$ ,  $p(\cdot)$ , which represents the hypothesis of no predictable variation. We initially tested 13 models. The best ranked models ( $\Delta\text{AIC}_c \leq 2$ ) of the model sets ( $\Psi(\cdot)$ ,  $p(\text{covariate})$ , and  $\Psi(\text{covariate})$ ,  $p(\cdot)$ ) were combined in a  $\Psi(\text{covariate})$ ,  $p(\text{covariate})$  model to investigate whether including covariates in both parameters ( $\Psi$  and  $p$ ) improved model performance. A total of 16 models were tested for Black and Turkey vultures.

### RESULTS

Total number of visits per point ranged from 3 to 9, with a median of 4 visits per site in 2009 and 5 visits per site in 2010. Black Vultures were detected at 66 sites (82.2%) and Turkey Vultures at 31 sites (38.75%). Black Vultures were widely distributed in the urban area of Manaus, although they were most abundant in the southern and eastern zones (Figure 2). Turkey Vultures were less abundant than Black Vultures and occurred mainly on the outskirts of the city, where there is more primary forest (Figure 3). To estimate the Black and Turkey vultures occurrence and detection probabilities, we used a constant model, no covariates ( $\Psi(\cdot)$ ,  $p(\cdot)$ ). Based on this model, the probability of occurrence of Black Vultures was 0.83 (SE = 0.04) and the probability of detecting them where they occur was 0.57 (SE = 0.02). For Turkey Vultures, the probability of occurrence was 0.50 (SE = 0.07) and detection was 0.20 (SE = 0.03).

The best models from the occurrence and detection model sets showed the best explanation for Black Vulture occurrence was garbage container (Table 1) and for Black Vulture detection was garbage container and streams (Table 1). The best explanation for Turkey Vulture occurrence was forest fragments (Table 2) and for Turkey Vulture detection was forest fragments and street markets (Table 2). The model with time period (year) and time of day (hour) as detection covariates did not rank well, indicating that these time covariates did not influence the detection of vultures as much as other site-specific



**FIGURE 2.** Map showing the average number of Black Vultures (*Coragyps atratus*) observed in each sampling sites within urban and suburban area of Manaus, Amazonas, Brazil.

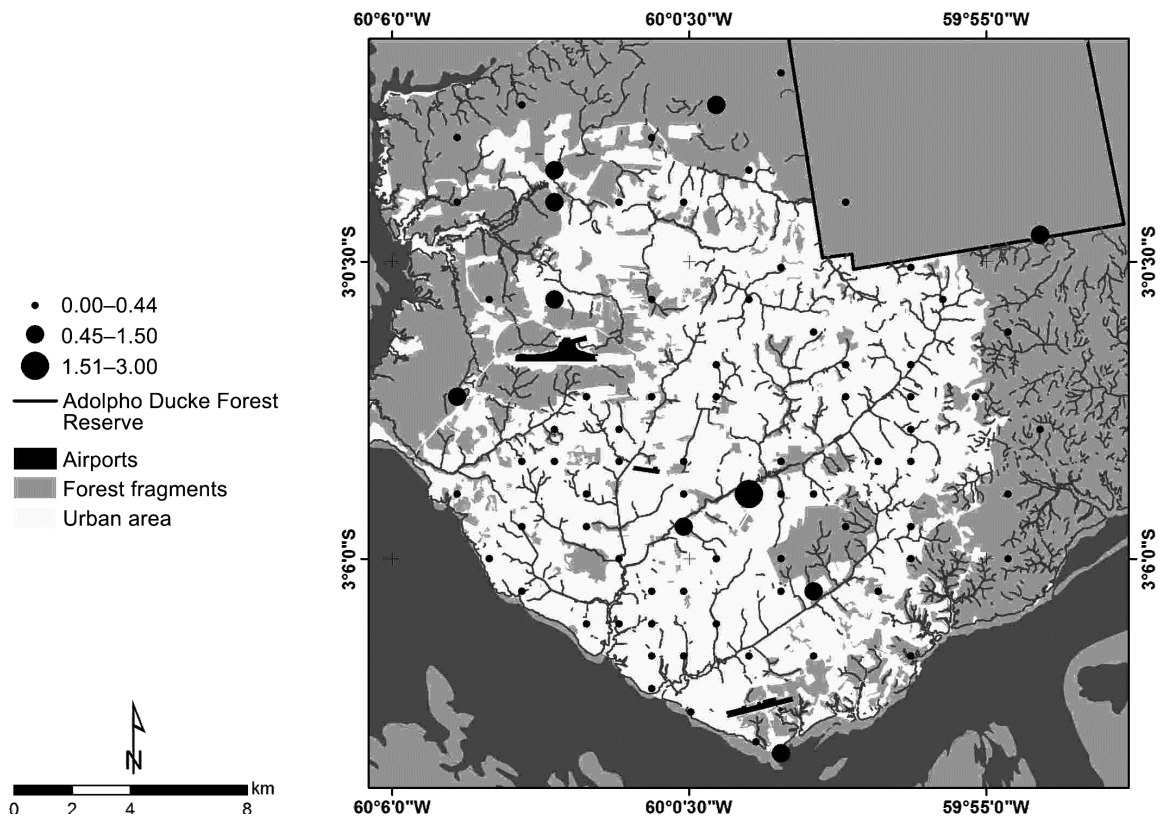
covariates. When the best model was combined in models with covariates in both parameters ( $\Psi(\text{covariate})$ ,  $p(\text{covariate})$ ), model performances were improved for both species (Table 1 and 2).

Black Vultures had a wide distribution throughout the city, and their occurrence was not strongly affected by any particular urban structure (Figure 2). Black Vultures were detected at least once at each site having a garbage container, resulting in quasi-complete data separation; in such cases, the maximum likelihood estimate of the covariate effect does not exist (Allison 2008). We therefore were not able to estimate the effects of garbage containers, even if the data indicated that they are likely important for Black Vultures. Applying the Laplace/DeMorgan correction to the Black Vulture data produced an odds ratio (OR) of 2.96 (~95% confidence interval [CI]: 0.34–25.66) and a conditional maximum likelihood (CML) estimate of the odds ratio (CML-OR) of 2.89 (mid- $P$  exact 95% CI: 0.43–68.42) for garbage container (see Greenland et al. 1999). In other words, there was almost a 3-fold greater chance of finding a Black Vulture in a location with a garbage container than in a place without.

We were able to assess covariate effects (untransformed beta estimates) on Black Vulture detection and on Turkey Vulture occupancy and detection. As expected, the presence of garbage containers and streams had a positive effect on Black Vulture detection (Table 3). Forest fragments had a positive effect on Turkey Vulture occurrence as well as a positive effect on Turkey Vulture detection (Table 3). By contrast, street markets had a negative effect on Turkey Vulture detection (Table 3). Although 95% confidence bounds overlap zero for the forest fragment covariate in the best model for Turkey Vulture, goodness-of-fit suggests a good fit of the model (bootstrap = 1000;  $c\text{-hat}$  = 0.69;  $P$  = 0.52).

## DISCUSSION

Our models demonstrated that the presence of garbage containers increased the probability of occurrence of Black Vultures, whereas forest fragments increased the probability of occurrence of Turkey Vultures. These results corroborate our initial hypothesis that Black Vultures preferentially use sites where food is often available in large amounts, and Turkey Vultures prefer forest frag-



**FIGURE 3.** Map showing the average number of Turkey Vultures (*Cathartes aura*) observed in each sampling sites within urban and suburban area of Manaus, Amazonas, Brazil.

**TABLE 1.** Set of models to estimate occurrence and detection probability of Black Vultures (*Coragyps atratus*) during 2009–2010 in the urban and suburban areas of Manaus, Amazonas, Brazil. Models were ranked based on the difference from the top model in Akaike's Criterion corrected for small sample size ( $\Delta AIC_c$ ). Models include different combinations of covariates of Black Vultures occurrence ( $\Psi$ ) and detection ( $p$ ). The operator '+' indicates additive models.  $w_i$  is Akaike weight;  $k$  is the number of parameters.

Model	$\Delta AIC_c$ <sup>a</sup>	$w_i$	$k$
$\Psi(G), p(G+S)$	0.00	1.0000	5
$\Psi(G), p(G)$	29.08	0.0000	4
$\Psi(G), p(S)$	30.11	0.0000	4
$\Psi(.), p(G)$	31.22	0.0000	3
$\Psi(.), p(S)$	32.34	0.0000	3
$\Psi(.), p(P)$	42.15	0.0000	3
$\Psi(.), p(M)$	44.22	0.0000	3
$\Psi(.), p(Y)$	44.79	0.0000	3
$\Psi(G), p(.)$	55.94	0.0000	3
$\Psi(.), p(.)$	58.22	0.0000	2
$\Psi(P), p(.)$	59.81	0.0000	3
$\Psi(F), p(.)$	59.85	0.0000	3
$\Psi(.), p(F)$	59.88	0.0000	3
$\Psi(M), p(.)$	60.08	0.0000	3
$\Psi(S), p(.)$	60.28	0.0000	3
$\Psi(.), p(H)$	60.29	0.0000	3

<sup>a</sup> Lowest value of  $AIC_c = 658.12$ ; G = garbage container; M = street market; S = stream; P = perch; F = forest fragment; Y = year; = and H = hour.

ments more frequently because of their adaptations for foraging in forest.

Differences in Black and Turkey vulture behavior can help explain their distinct use of urban sites in Manaus. Most of the garbage containers we studied were large, open containers that can accumulate large amounts of waste. These containers are frequently used by Black Vultures as a food source; we often observed large numbers (even approaching hundreds of individuals) fighting over food scraps in containers. In a simple analogy, these garbage containers essentially function as large carcasses, which Black Vultures seem to prefer over smaller ones (Buckley 1996). As with large carcasses, the aggregation of aggressive Black Vultures in sites with garbage containers may have contributed to Turkey Vulture avoidance of garbage containers. In addition, container locations do not change and thus become predictable food sources that Black Vultures can use regularly, as has been reported for other scavenger guilds (e.g., Monsarrat et al. 2013).

Turkey Vultures were more common at sites next to forest fragments. This effect may be attributed to the fact that this species efficiently finds food in forested environments using olfactory cues (Houston 1986, Wallace and Temple 1987, Lemon 1991). In the city of Manaus, there



**TABLE 2.** Set of models to estimate occurrence and detection probability of Turkey Vultures (*Cathartes aura*) during 2009–2010 in the urban and suburban area of Manaus, Amazonas, Brazil. Models include different combinations of covariates of Turkey Vultures occurrence ( $\Psi$ ) and detection ( $p$ ). The operator ‘+’ indicates additive models.  $w_i$  is Akaike weight;  $k$  is the number of parameters.

Model	$\Delta AIC_c^a$	$w_i$	$k$
$\Psi(F), p(F+M)$	0.00	0.4518	5
$\Psi(F), p(M)$	0.62	0.3314	4
$\Psi(.), p(F)$	4.26	0.0537	3
$\Psi(.), p(M)$	4.32	0.0521	3
$\Psi(F), p(.)$	4.39	0.0503	3
$\Psi(F), p(F)$	4.52	0.0471	4
$\Psi(M), p(.)$	7.52	0.0105	3
$\Psi(.), p(G)$	12.35	0.0009	3
$\Psi(.), p(Y)$	13.17	0.0006	3
$\Psi(.), p(.)$	14.73	0.0003	2
$\Psi(G), p(.)$	14.90	0.0003	3
$\Psi(P), p(.)$	14.94	0.0003	3
$\Psi(.), p(H)$	15.01	0.0002	3
$\Psi(.), p(P)$	15.79	0.0002	3
$\Psi(S), p(.)$	16.69	0.0001	3
$\Psi(.), p(S)$	16.69	0.0001	3

<sup>a</sup> Lowest value of  $AIC_c$  = 345.56; G = garbage container; M = street market; S = stream; P = perch; F = forest fragment; Y = year; and H = hour.

are more than 150 forest fragments that range from small tree aggregations (<1 ha) to large forest fragments (>500 ha; Novaes and Cintra 2013). Although we do not have data on food availability in these forest fragments, they possibly represent both foraging areas and roosting or breeding sites for Turkey Vultures.

Even if Black Vulture occurrence did not seem to be affected by the urban features we investigated, detection models with these covariates ranked substantially better. According to Bailey et al. (2004), multiple factors can affect the detection probability of a species. These factors include local population density of the species, seasonal or behavioral patterns, the size of the species, weather and environmental variations, or even sampling effort (i.e. the number of visits to each site). Additionally, MacKenzie (2006) contends that, in many situations, it seems reasonable to expect that individuals will not always be detected within a unit currently being used, or that individuals with large home ranges may be temporarily absent from the site at the time of sampling.

Both Black and Turkey vultures are large black birds, and they are easily detected in a site when they are present; therefore, we believe that nondetection of a vulture in one of our sampling sites is a combination of a few true detection failures and, more frequently, the absence of vultures from a site at the time of sampling (e.g., vultures were in another part of their range). Thus, a detection

**TABLE 3.** Estimates of the effect (untransformed  $\beta$  coefficient) of urban features on the occurrence and detection of Black Vultures (*Coragyps atratus*) and Turkey Vultures (*Cathartes aura*) according best ranked model in the urban/suburban area of Manaus, Amazonas, Brazil.

Covariate	$\beta$ Coefficient	SE	CI <sub>lower</sub>	CI <sub>upper</sub>
<b>Black Vulture</b>				
Model $\Psi(G), p(G+S)$				
$\Psi$				
Garbage <sup>a</sup>	—	—	—	—
$p$				
Garbage	1.78	0.36	1.07	2.48
Stream	1.41	0.27	0.88	1.94
<b>Turkey Vulture</b>				
Model $\Psi(F), p(F+M)$				
$\Psi$				
Forest Fragment	1.00	1.02	−1.00	3.00
$p$				
Forest Fragment	0.91	0.60	−0.26	2.08
Street Market	−1.79	0.78	−3.31	−0.26
Model $\Psi(F), p(M)$				
$\Psi$				
Forest Fragment	1.72	0.73	0.28	3.15
$p$				
Street Market	−1.83	0.81	−3.41	−0.24

<sup>a</sup> Effects of garbage containers on occurrence cannot be estimated due to quasi-complete data separation. See results for more details.

history recorded as {111111010} would be expected at a site frequently by vultures and where detection probability is high, whereas a detection history {000010001} suggests that, although vultures occur at this site, they visit or are detected less frequently, and the detection probability is therefore small.

Our detection models demonstrated that the presence of garbage containers and streams increased the probability of detection of Black Vultures; for Turkey Vultures, forest fragments increased the probability and street markets decreased the probability of detection. We believe that local density and the frequency of use of a site are the factors that influence the detection probability of Black Vultures in sites with garbage containers and streams. The behavioral patterns of Turkey Vultures may increase detection probability near forest fragments because Turkey Vultures primarily find food using olfaction by soaring at low altitudes immediately above the forest canopy to detect carcasses. Turkey Vultures performing this type of flight are easily observed. Finally, the behavioral dominance of Black over Turkey vultures probably explains the negative effect of street markets on Turkey Vulture detection (Wallace and Temple 1987). Most street markets in our study area are in poor hygienic conditions with organic waste scattered throughout surrounding streets. Black Vultures often feed on this waste, and their presence



may drive Turkey Vultures away from these sites, a circumstance that would explain the negative influence of street markets (and, to a lesser extent, garbage containers) on detection of Turkey Vultures.

The occurrence of these 2 large birds near airports in urban areas represents a serious hazard to aircraft. The different habitat use and behavior of Black and Turkey Vultures helps elucidate the problems caused by these vultures to aviation. For example, from January 2011 to May 2013 there were 12 vulture strikes at Manaus International Airport, 6 involving Turkey Vultures, 3 involving Black Vultures, and 3 unidentified (CENIPA 2012). All strikes involving Turkey Vultures occurred below 150 m, when aircraft were in the Airport Operation Area (AOA). Two of the collisions with Black Vultures occurred outside the airport boundary at a height above 450 m. While Black Vultures are associated with environments surrounding the airport, attracted by the food waste accumulated in the city (Figure 2), Turkey Vultures are commonly seen flying or foraging at Manaus International Airport itself (W.G. Novaes personal observation). Turkey Vultures are attracted by the airport environment, likely because it includes 980 ha of forest fragments. Furthermore, airports can harbor large number of small animals, which become carrion after struck by cars or aircraft (DeVault and Washburn 2013). Because small carcasses are the preferred food of Turkey Vultures (Buckley 1996), these birds may have been attracted to the airport area.

Vultures demonstrate plasticity in space use within home ranges, probably driven by food availability (Coleman and Fraser 1989, DeVault et al. 2004, 2005, Novaes and Cintra 2013). Manipulating food resources can potentially reduce influence of wildlife activity pattern at or near airports (DeVault and Washburn 2013). Thus, management programs for Black Vultures should focus on places providing large amounts of organic residue, such as garbage containers, open dumps, and polluted streams, all of which can be improved through increased public sanitation. In contrast, because of their lower flying altitudes, management actions for Turkey Vultures need to be concentrated at AOAs, possibly removing carrion from airport grounds immediately upon discovery (Blackwell and Wright 2006, DeVault and Washburn 2013). Modified aircraft lighting may also be effective for Turkey Vultures and for smaller birds that could become their prey after collisions with aircraft (Doppler et al. 2015).

Additionally, a management approach could include measures such as (1) reducing the availability of perches by removing or blocking access to trees and artificial perches (Cleary and Dicky 2010, Belant and Martin 2011); (2) use of hand-held lasers, vulture carcasses, or taxidermic effigies to keep vultures away from roosts (Avery et al. 2002, Ball 2009); (3) relocating vultures away from airports

(Humphrey et al. 2000) and, lastly; (4) lethal control of adults, the success of which would be dependent upon the initial size of the population. Although nonlethal methods are an important component to reduce many conflicts, it is clear that lethal control is sometimes needed (Runge et al. 2009).

Although Black and Turkey vultures intensely use urban environments, we showed that the habitat features influencing the presence of these birds are different, highlighting the need for different management approaches for the 2 species. Our study provides a valuable contribution to wildlife managers in their efforts to manage vulture populations, particularly in cities in Central and South America that have similar problems with these 2 widespread synanthropic species.

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