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CONSPICUOUS ROADSIDE AVIFAUNA'S SEASONAL VARIATION IN ECOTONE AND WETLAND ENVIRONMENTS WITHIN THE PANTANAL'S AQUIDAUANA REGION

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Abstract · Transport by road is the main mechanism for integrating Brazil, but roads are drivers of land cover conversion, fragmentation, and direct mortality by wildlife-vehicle collisions. In Aquidauana, BR419 and MS170 are important unpaved roads into the rural Pantanal region, and improvement and paving has been planned for BR419, which may increase risks to local avifauna. The aim of this study was to assess the species composition and richness of conspicuous avifauna (defined as being easily quantifiable using roadside surveys), and their spatial and seasonal variation among two important roadways. One of the surveyed roadways accessing rural areas of the Aquidauana region of the Pantanal was scheduled for improvement and paving. Transects of 73 km long were sampled along both highways, six samples along each transect between February and May 2012, for a full sample effort of 103:06 hours. A total of 6888 individuals from 33 families and 93 species were observed in the transects combined, and 83 species were identified in each transect. Jaccard Similarity Index was 0.79, and we found a statistically significant difference ($P < 0.05$) among the bird communities between the highways. Species associated with freshwater environments were more abundant along and indicator species of MS170. That avifauna along MS170 varied temporally and species richness was strongly correlated with river discharge, while the same was not true with BR419. Species particularly vulnerable to wildlife-vehicle collisions, e.g., vultures (*Coragyps atratus*, *C. aura*) and Southern Caracara (*Caracara plancus*), were abundant along BR419. While mitigation measures for mammals, reptiles, and amphibians are common and effective, the vertical movement of most birds into the roadway presents a different challenge for which a technical solution may not currently exist. To protect species observed along the currently unpaved roadways of Pantanal's Aquidauana region, following road improvement, speed limits should be calibrated to facilitate safe transportation for drivers and the continued existence of wild species.

Resumo · Espécies de pássaros conspicuentes variação sazonal em ambientes de ecotone e pântano na região Aquidauana do Pantanal
O transporte rodoviário é o principal mecanismo de integração do Brasil, mas as estradas são propulsoras da conversão, fragmentação e mortalidade direta da cobertura vegetal por colisões de veículos silvestres. Em Aquidauana, a BR419 e a MS170 são importantes estradas não pavimentadas para a região rural do Pantanal, melhorias e pavimentação foram planejadas para a BR419, o que pode aumentar os riscos para a avifauna local. O objetivo deste estudo foi avaliar a composição de espécies e a riqueza da avifauna conspícua (definido como sendo facilmente quantificável usando levantamentos de beira de estrada) e sua variação espacial e sazonal entre duas estradas importantes. Uma das estradas pesquisadas acessando áreas rurais da região de Aquidauana do Pantanal foi programada para melhorias e pavimentação. Transectos de 73 km de extensão foram amostrados ao longo das duas rodovias, seis amostras ao longo de cada transecto entre fevereiro e maio [illegible] 93 espécies foram observados [illegible] ccard foi de 0,79, e encontramos uma diferença estatisticamente significativa ($P < 0,05$) entre as comunidades de aves entre as rodovias. Espécies associadas a ambientes de água doce foram mais abundantes e espécies indicadoras da MS170. Essa avifauna ao longo da MS170 variou temporalmente e a riqueza de espécies foi fortemente correlacionada com a descarga do rio, enquanto o mesmo não ocorreu com a BR419. Espécies particularmente vulneráveis a colisões de veículos silvestres , por exemplo, abutres (*Coragyps atratus*, *C. aura*) e Caracará (*Caracara plancus*), foram abundantes ao longo da BR419. Embora as medidas de mitigação para mamíferos, répteis e anfíbios sejam comuns e eficazes, o movimento vertical da maioria das aves na pista apresenta um desafio diferente para o qual uma solução técnica pode não existir atualmente. Para proteger as espécies observadas ao longo das estradas atualmente não pavimentadas da região de Aquidauana, no Pantanal, seguindo a melhoria das estradas, os limites de velocidade devem ser calibrados para facilitar o transporte seguro dos motoristas e a existência contínua de espécies silvestres.

Key words: Avifauna · Brazil · Conservation · Hydrology · Indicator species · Road improvement · Species richness · Transect counts · Wildlife-vehicle collisions

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INTRODUCTION

The Pantanal is a globally significant freshwater wetland of high conservation priority, and vulnerable to anthropogenic disturbance (Tubelis & Tomas 2003, Harris et al. 2005). Nunes & Tomas (2008) consider the Pantanal biome one of the most diverse for avifauna when compared to other major wetland ecosytems, such as the Everglades (Florida), Inner Niger Delta (Africa), Llanos (Venezuela), and Esteros de Ibera (Argentina). Junk et al. (2006) suggested there are 766 species of birds in the Pantanal based on existing literature, but some of those are restricted to the adjacent upland plateaus, and of the remaining species only 390 had at least one confirmed record in the Pantanal lowlands at the time of publication (Nunes et al. 2008). There remains a great deal of uncertainty concerning the exact avifauna richness in the Pantanal, but estimates include 423, 463, 657, 730, up to 766 species (Brown 1986, Mittermeier et al. 2003, Tubelis & Tomas 2003, Junk et al. 2006, Nunes et al. 2008).

Historically, the Pantanal has been relatively protected due to its remoteness, and rural ranching economy (Souza & Lima 2012). However, the diversity of the region is under constant increasing pressure from deforestation, proposed hydrologic modification, hunting, and the enhanced potential for development following infrastructure improvement (Harris et al. 2005). Transport by road is the main mechanism for integrating Brazil (Silva et al. 2011), and within the Aquidauana region a project to extend 233 km of pavement along BR419 is an infrastructure priority. Laurance et al. (2002) found that paved highways in the Amazon tended to have a considerably larger-scale impact on deforestation than unpaved roads. This process can interfere quantitatively and qualitatively with avifauna, fragmenting habitat, functioning as an ecological barrier, and increasing roadkill mortality (Bandeira & Floriano 2004, Souza et al. 2015).

Accidents with animals can have major impacts on wildlife populations, communities, and ecosystems (Forman et al. 1997, Forman & Alexander 1998, Crooks & Sanjayan 2006, Ament et al. 2008, Carvalho & Mira 2011, Souza et al. 2015). Along the paved highway BR262 in the southern Pantanal many of the birds involved in collisions were likely scavenging, e.g., Southern Caracara (*Caracara plancus*), Black Vulture (*Coragyps atratus*), and Turkey Vulture (*Cathartes aura*) (Souza et al. 2015), which increases the probability of being hit by vehicles while feeding on roadkill. Reductions in the population sizes of avian scavengers, such as vultures in Africa and Asia, provide ample evidence concerning the ecosystem impacts of these declines (Parry-Jones et al. 2003, Ogada et al. 2016). The ecological consequences of vulture declines include changes in community composition of scavengers at carcasses, increased disease transmission rates between mammalian scavengers at carcasses, and increased exposure of livestock and humans to diseases (Parry-Jones et al. 2003, Ogada et al. 2012).

The objective of this research was to assess the species composition and richness of conspicuous avifauna and their spatial and seasonal variation among two important roadways, one of which was scheduled for improvement and paving, that access rural areas of the Aquidauana region of the Pantanal. While MS170 traverses a course parallel to the Aquidauana River into the lowlands, BR419 parallels the escarpment dividing the Pantanal from Cerrado uplands and is slated for eventual improvement and paving. This study provides a baseline prior to further infrastructure improvement, as well as characterizes the composition and diversity of birds across elevational, habitat, and seasonal gradients in one of the world's most diverse wetlands.

METHODS

Study area. Being the largest freshwater wetland on the planet, the Pantanal covers an area of ~140,000 km² in Brazil, Bolivia, and Paraguay, and is split between the states of Mato Grosso and Mato Grosso do Sul in Brazil (Facincani et al. 2006, Pivatto et. al. 2008, Conte et al. 2009, Rezende et al. 2012). The study was conducted in the Aquidauana region of the Pantanal of Mato Grosso do Sul. The Aquidauana region, on the southeastern edge of the Pantanal, is one of 11 subregions, and one of the smallest. Teodoro et al. (2016) conducted a rainfall analysis for Mato Grosso do Sul and determined that months clustered into wet (December–March), dry (June–August), and two transition periods (April–May and September–October). The Aquidauana region is dominated by extensive cattle ranching, and urban development is only found in the transition zones between the wetland and surrounding upland plateau, i.e., the cities of Anastácio/Aquidauana. The study area is adjacent to the Cerrado vegetation dominated upland plateau to the east and south of Anastácio/Aquidauana, and encompasses the alluvial deposits of the transition zone (also historically dominated by Cerrado vegetation) and Pantanal floodplain wetlands dominated by floodplain forests, wetland savannahs, and emergent herbaceous vegetation. There are few regions in the country where roads cross as rich a flora and fauna (MMA 2007, Rodrigues et al. 2002).

Sampling was conducted along two road transects starting on the northern boundary of the City of Aquidauana (Figure 1). One 73 km stretch of BR419 (Taboco Road) was between the coordinates 20°26'49''S, 55°47'01''W and 19°52'50''S, 55°29'41''W. The other transect was a 73 km stretch of MS170 (Retirinho Road) between 20°26'23''S, 55°48'10''W and 19°53'13''S, 56°01'29''W. The BR419 road and transect parallels the escarpment dividing the Pantanal from the uplands, and is at a higher elevation (maximum 267 m and minimum 156 m a.s.l.) compared to MS170 (maximum 169 m and minimum 122 m a.s.l.). BR419 remains in the Pantanal/Cerrado transition zone with 95% of the area within a 100 m buffer of the roadway dominated by cropland and grassland, and the remaining 5% with forest (3%) and shrubland (2%). MS170 leaves the transition zone for the Pantanal lowlands on a path adjacent and parallel to the Aquidauana River, with only 39% of the area within a 100 m buffer of the roadway dominated by cropland and grassland, and 16% with forest and 45% with shrubland, respectively (based on buffer analysis of GlobCover: Global Land Cover Map in ArcMap v.10.2.2; GlobCover, ESA 2010 and UCLouvain; http://due.esrin.esa.int/page_globcover.php, accessed 23 April 2018).

Sampling methods. The study began in February 2012 and ended in May 2012, a period stretching from the wet season into the transition of the wet to dry seasons. Both road transects were sampled the same day only on the first day of sampling, which proved to be a laborious task for accurate observation. Thereafter, each road transect was sampled on

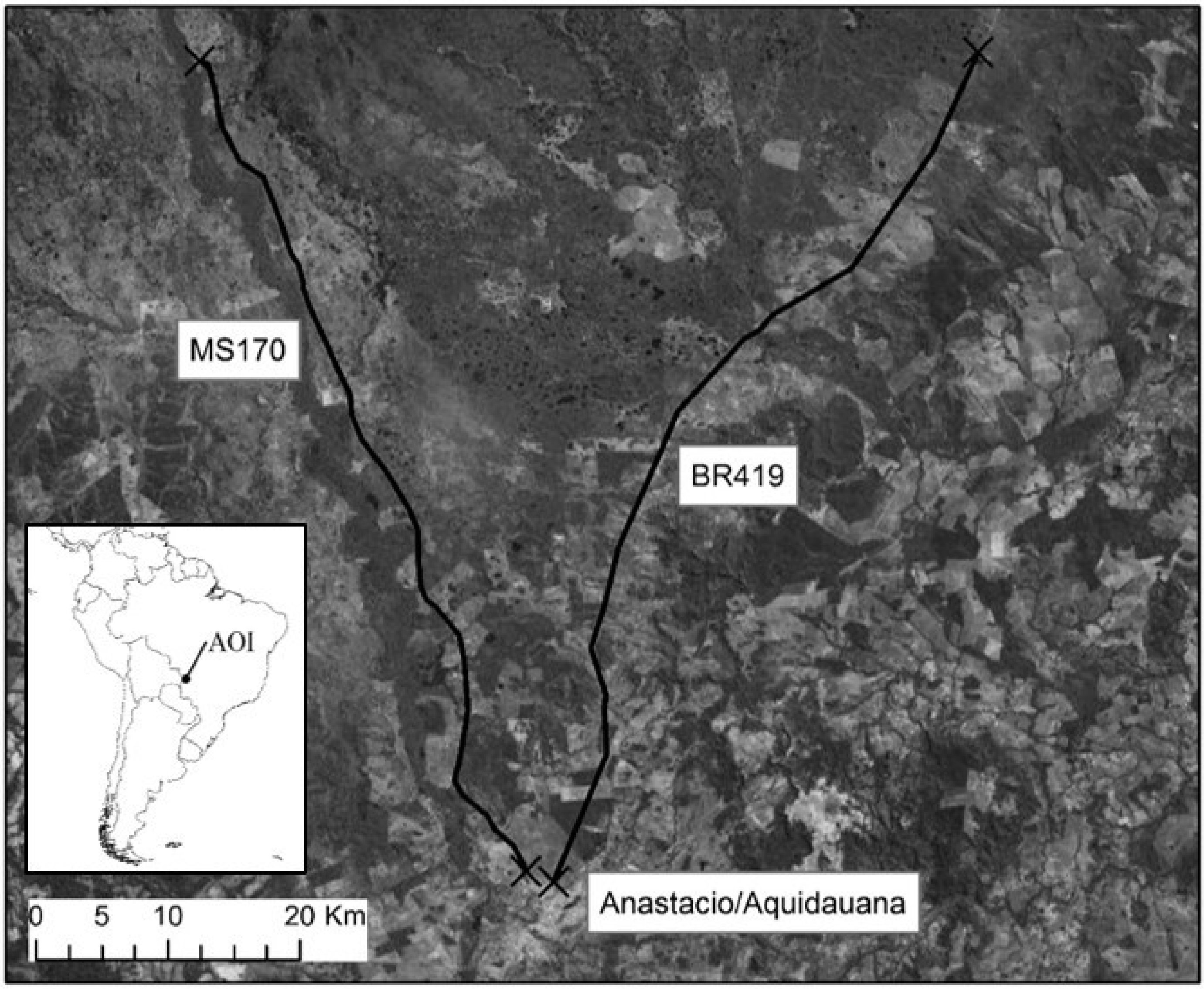

Figure 1. Locations of roads BR419 and MS170 in the Aquidauana region of the Pantanal, Brazil. Inset map of South America shows area of interest (AOI).

different days. BR419 and MS170 were each sampled on six days over the sampling period (a total of 438 km sampled on each road), for ca. 8:30 hours devoted to each sample, and a total of 103:06 hours of observations. We drove an average speed of ca. 20 km/h when sampling the two roads with 1 driver and 2–4 observers. Birds were visually identified and counted within 100 meters of the highway. Stops were made opportunistically for ca. 5 minutes when large congregations of individuals were encountered in order to make accurate counts and identifications. Common and scientific names follow BirdLife Inter-national's taxonomy (http://www.birdlife.org/datazone/species/taxonomy.html).

Hydrologic data were downloaded from Brazil's Agência Nacional de Águas. Daily stream discharge (m^3/s) covering the sampling period was downloaded for an Aquidauana River stream gauge, station code 6695000, from HIDROWEB v.2.0.0.4 (http://www.snirh.gov.br/hidroweb/publico/mapa_hidroweb.jsf, accessed 4 May 2019).

Data analysis. All species observed during sampling are listed in Supplementary Table S1. The analysis is limited to conspicuous species (N = 93, identified in Table S1) that primarily forage in wetlands, on forest edges, in open areas and on the ground, by hawking and diving, and scavenging (Accipitriformes N = 11, Anseriformes N = 5, Cariamiformes N = 1, Charadriiformes N = 2, Ciconiiformes N = 3, Columbiformes N = 7, Coraciiformes N = 2, Cuculiformes N = 2, Falconiformes N = 4, Galliformes N = 1, Gruiformes N = 3, Passeriformes N = 27, Pelecaniformes N = 14, Piciformes N = 1, Psittaciformes N = 5, Rheiformes N = 1, Strigiformes N = 1, Suliformes N = 1, Tinamiformes N = 2). Species that primarily forage in trees were excluded from analysis due to a lower probability of observation with the sampling methods used. Feeding strategies, and locations where resources are obtained, were based on information from del Hoyo et al. (2018).

For the conspicuous species, we calculated the total number of individuals counted (i.e., abundance) and species richness per transect, and for the entire study for each sampling period and across all sampling periods taken together using MS Excel. Species accumulation curves were calculated with 100 random replications using the MS Excel macro AccuCurve 1.0 (Drozd & Novotny 2010) to assess whether the number of periods was sufficient to identify all the species found in each transect. We calculated Jaccard's Similarity Index among the two transects [$J = c/(a+b+c)$, where a is the number of unique species along MS170, b is the number of

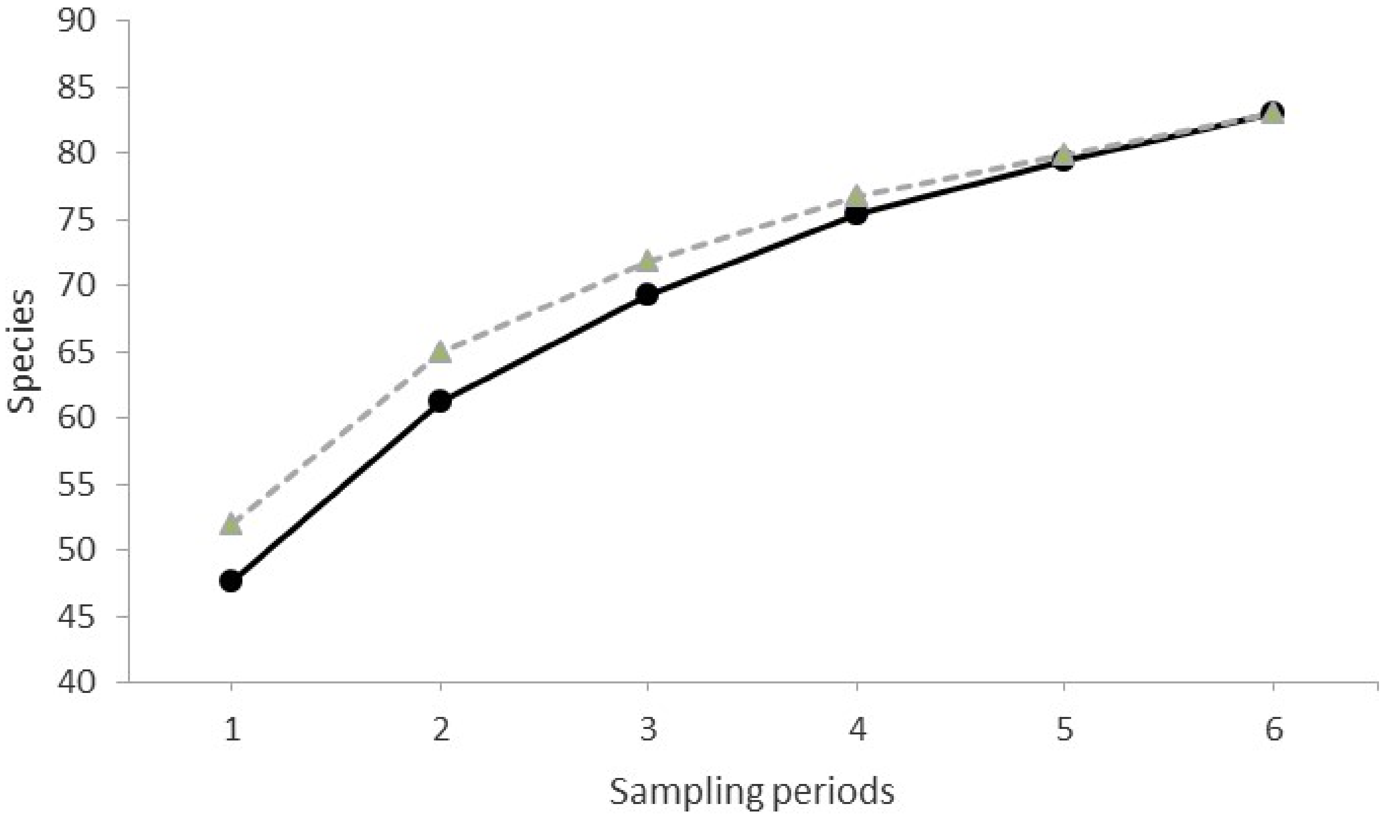

Figure 2. Species accumulation curves over 6 sampling periods for transects along roads MS170 (grey dashed line) and BR419 (solid black line), in the Aquidauana region of the Pantanal, Brazil.

unique species along BR419, and *c* is the number of species common to both road transects]. We also calculated Pearson's correlation coefficient between species richness of each sampling period in each road transect and stream discharge on the Aquidauana River on the day each sample was collected.

Non-metric Multidimensional Scaling (NMS) was conducted to examine the species composition patterns of each transect over the six sampling periods. The NMS analysis was run in PC-Ord v. 7 (McCune & Mefford 2006). Input data consisted of abundances of all observed conspicuous species along each transect during each of the six sampling periods. The following conditions were maintained: a) NMS was first run in autopilot mode to determine the best dimensionality for the analysis, the 3-dimensional solution was best based on the lowest estimated stress of the four dimensions tested and significant improvement over randomized data (P = 0.039), b) maximum number of iterations was 500, c) starting coordinates were random, and d) 250 runs with real data and 250 runs with randomized data. Observations were categorized by transect, i.e., MS170 and BR419, and NMS axis scores were visualized using 2D scatterplots. The NMS scatter plots also include vectors for correlations of sampling period and hydrology with axis scores when r > 0.30, and vectors for directional change connecting observations from sampling period 1 through 6. Differences among transects in community composition were examined using the non-parametric one-way, permutational analysis of variance (PERMANOVA) in PC-Ord v. 7 based on the method of Anderson (2001). Randomization test of significance of pseudo F-values was based on 4,999 randomizations.

Indicator species analysis (ISA) was performed with PC-Ord v. 7 (McCune & Mefford 2006). This analysis assesses the degree to which a species indicates a group, in this case road transects, based on constancy and distribution of abundance. ISA is often used to explore which species are responsible for observed differences following tests for significant group differences (Peck 2016). Input data consisted of abundances of all observed individuals of all conspicuous species along each transect during each of the six sampling periods. Data were grouped by road transect, and significant indicator species were determined by a Monte Carlo test of significance (α = 0.05) of observed maximum indicator values for each species, based on 4999 permutations.

RESULTS

Based solely on conspicuous species, a total of 6888 individuals belonging to 33 families and 93 species of birds were observed in both transects combined (Table S1). Along BR419 3149 (45.7% of total) individuals were observed among 83 species, and along MS170 3739 (54.3%) individuals among 83 species were recorded. Both transects' species accumulation curve approached, but did not reach, asymptote (Figure 2), so additional sampling events may have resulted in the observation of more species. The two transects had 73 species in common and 10 unique species in each road transect, resulting in a Jaccard Similarity Index = 0.79. Species richness of each sampling period along MS170 was strongly correlated with stream discharge in the Aquidauana River on the day of each sampling event (r = 0.78), but there was no correlation of BR419 species richness and discharge (r = -0.01) (Figure 3). The majority of observed species were classified by the IUCN as least concern. However, four conspicuous species were identified by the IUCN as vulnerable (V), near threatened (NT), and Endangered (E) species, including Hyacinth Macaw

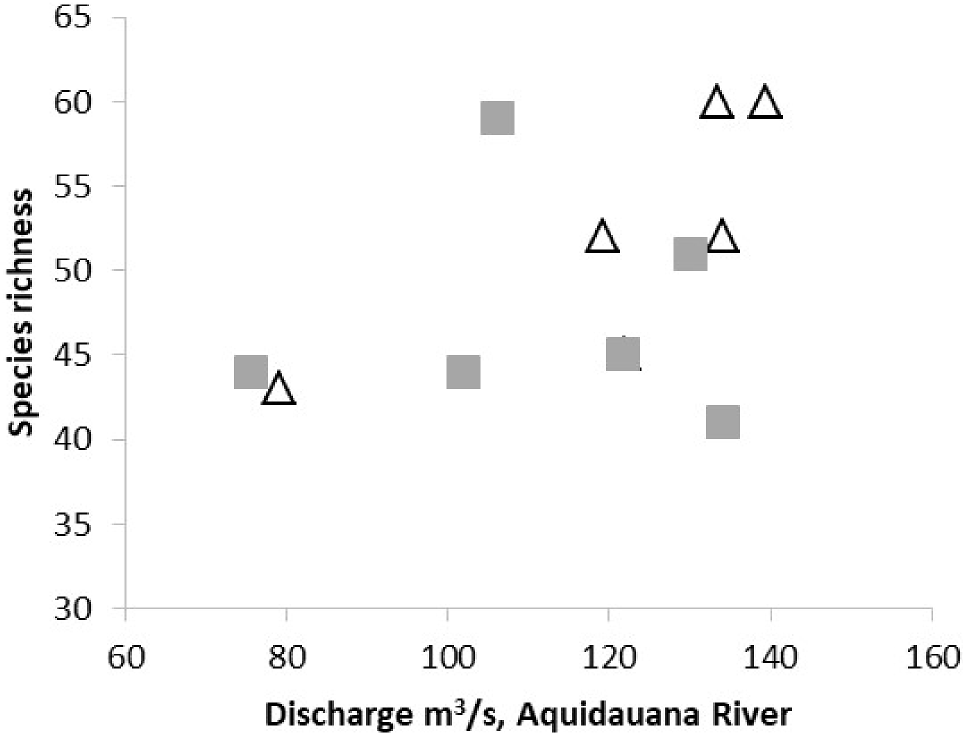

Figure 3. Scatter plot of species richness along MS170 (open triangles) and BR419 (grey boxes) road transects (Pantanal, Brazil) and stream discharge on the Aquidauana River on the day of each sampling event.

(*Anodorhynchus hyacinthinus*) (V), Greater Rhea (*Rhea americana*) (NT), Great-billed Seed-finch (*Sporophila maximiliani*) (E), and Crowned Solitary Eagle (*Buteogallus coronatus*) (E).

The final stress of the three-dimensional solution for the NMS analysis was 6.39, and the cumulative R^2 = 0.843 with incremental R^2 for axis 1 = 0.381, axis 2 = 0.283, and axis 3 = 0.179. The vectors connecting observations for sampling periods 1 to 6 exhibited directional change along MS170, which trended from higher to lower axis 1 scores, although a distinct directional change was not apparent on the other axes or for samples along BR419 (Figure 4). The scatterplots of the three axis scores visually exhibited groupings of observations among the two road transects on axis 1 (observations for MS170 with generally greater axis 1 scores, and BR419 with lesser axis 1 scores), while axes 2 and 3 showed no evidence of grouping of observations by transect (Figure 4). The communities of conspicuous avian species were significantly different among road transects with the PERMANOVA (*P*-value = 0.0242).

Sampling period (Time vector in Figure 4) and hydrology had contrary relationships with NMS axis scores. Sampling period had negative relationships with axes 1 and 3, and a positive relationship with axis 2 (axis 1 r = -0.515, axis 2 r = 0.443, axis 3 r = -0.311). Discharge on the Aquidauana River had positive relationships with axes 1 and 3, and a negative relationship with axis 2 (axis 1 r = 0.120, axis 2 r = -0.449, axis 3 r = 0.256). Table S1 includes the correlations of all conspicuous species used in the NMS with each of the three axis scores, correlations for species with total abundances > 50 and correlation coefficients r ≥ 0.50 are in bold. Abundant species associated with wetlands from multiple families had strong positive correlations with axis 1, many of which are also significant indicator species (see following paragraph and Table 1), e.g., Snail Kite (*Rostrhamus sociabilis*), Black-bellied Whistling Duck (*Dendrocygna autumnalis*), Great Heron (*Ardea alba*), Snowy Egret (*Egretta thula*), Southern Lapwing (*Vanellus chilensis*), Wattled Jacana (*Jacana jacana*), Bare-faced Ibis (*Phimosus infuscatus*), and Plumbeous Ibis (*Theristicus caerulescens*), as did species associated with open grassland habitats, e.g., Red-legged Seriema (*Cariama cristata*) and Greater Rhea. Species strongly correlated with axis 2 were also all positively associated, including two wetland species, Brazilian Teal (*Amazonetta brasiliensis*) and Black-backed Water-tyrant (*Fluvicola albiventer*). Other species positively associated with axis 2 are found in wet and dry savannahs, scrub, and grasslands, and degraded forests, such as Scaled Dove (*Columbina squammata*), Rufous Hornero (*Furnarius rufus*), and Chopi Blackbird (*Gnorimopsar chopi*). The Black Vulture was also strongly positively correlated with axis 2, and like Turkey Vulture had greater than twice the abundance along BR419 compared to the MS170 transect.

A number of species identified as influencing the NMS, with strong correlation coefficients with axis 1, were also indicator species (Table 1). Eight of the nine significant indicator species were more consistently abundant along MS170 and seven of those species along MS170 are generally associated with permanently or seasonally flooded areas, e.g., heron, two ibises, stork, egret, jacana, and lapwing (Table 1). The Greater Rhea was the only terrestrial and flightless significant indicator species, which in the Pantanal is frequently found in open savannah and grassland habitats more common along MS170. The single indicator species along BR419 was the Ringed Kingfisher (*Megaceryle torquata*).

DISCUSSION

Avian involvement in wildlife-vehicle collisions is not insignificant in the Pantanal region of Brazil, with studies in the region reporting birds accounting for 13.5% and 19% of all observed roadkill species (Souza et al. 2015, Sobanski 2016),

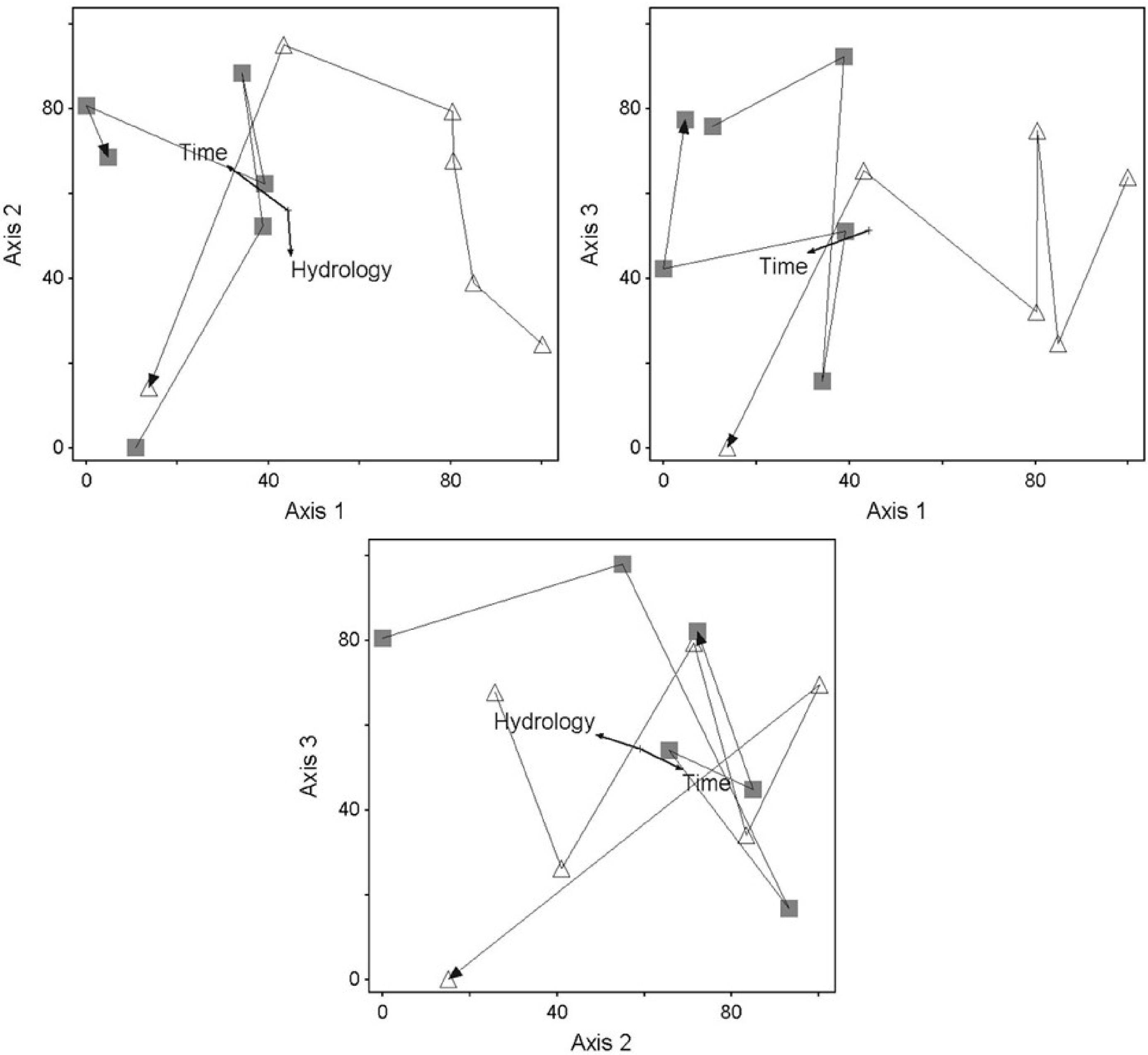

Figure 4. Three-dimensional solution of the nonmetric multi-dimensional scaling analysis of species composition of the 6 sampling periods of both the MS170 (open triangles) and BR419 (grey boxes) road transects (Pantanal, Brazil). Correlations of sampling period (labeled Time) and hydrology with axis scores r > 0.20 are shown as vectors. Vector(s) of directional change among sampling periods is (are) shown as line(s) with an arrow head connecting observations from sampling period 1 through 6.

and 53% of samples counting only birds and reptiles (Fischer et al. 2018). The 73 km segment of BR419 supports a community composed of many conspicuous species that could be at greater risk of wildlife-vehicle collisions caused mortality with road improvement, paving, and subsequent increased highway shipping and vehicle speeds. Souza et al. (2015), Sobanski (2016), and Fischer et al. (2018) all agree that Southern Caracara and Black Vulture are the two most frequent avian victims of wildlife-vehicle collisions in the Pantanal, and relatively substantial populations of both are present along BR419. In fact, Black Vulture observations were exceeded along BR419 by only one other species. Other species present along BR419 commonly involved in wildlife-vehicle collisions included Red-legged Seriema and Turkey Vulture, while other observed species less commonly recorded as roadkill included Chaco Chachalaca (*Ortalis canicollis*), Greater Rhea, Jabiru Stork (*Jabiru mycteria*), and Toco Toucan (*Ramphastos toco*).

Variation among the two road transects in composition and relative abundances were primarily the result of greater observations of species with wetland affinities along MS170. Other than the rare observation, e.g., of Jabiru Stork and Wattled Jacana (*Jacana jacana*) by Fischer et al. (2018), wetland birds are uncommon victims of wildlife-vehicle collisions, perhaps due to feeding preferences and behaviors adapted to aquatic environments that naturally result in road avoidance. With smaller populations along BR419 and low natural probability of collision, wetland species of the Aquidauana region may be lightly impacted due increased traffic and speeds associated with road improvement along BR419. Greater Rhea observations were also substantially greater along MS170, but as a flightless bird commonly present in

Table 1. List of significant indicator species detected during surveys along roads MS170 and BR419 in the Aquidauana region of the Pantanal, Brazil, and NMS axis scores.

Common name	Scientific name	Road transect	Indicator value	*P*	Axis 1	Axis 2	Axis 3
Bare-faced Ibis	*Phimosus infuscatus*	MS170	93.0	0.002	0.696	-0.211	-0.216
Cocoi Heron	*Ardea cocoi*	MS170	77.8	0.034	0.728	0.181	-0.028
Greater Rhea	*Rhea americana*	MS170	92.4	0.011	0.747	0.342	-0.135
Jabiru Stork	*Jabiru mycteria*	MS170	89.2	0.004	0.577	0.111	-0.085
Plumbeous Ibis	*Theristicus caerulescens*	MS170	78.9	0.025	0.747	0.342	-0.135
Ringed Kingfisher	*Megaceryle torquata*	BR419	92.9	0.008	-0.580	0.025	0.208
Snowy Egret	*Egretta thula*	MS170	88.8	0.008	0.728	0.181	-0.028
Southern Lapwing	*Vanellus chilensis*	MS170	65.1	0.015	0.755	0.380	-0.136
Wattled Jacana	*Jacana jacana*	MS170	83.6	0.002	0.935	-0.149	-0.009

wildlife-vehicle collisions samples in the Pantanal, the relatively small population along BR419 could be put at risk.

The accumulation curves of both transects neared, but did not reach, asymptote, indicating that the richness of species in the region was greater than the observed values. Additional sampling, especially across the dry season, would likely increase the richness counts. However, the communities of conspicuous species may have been adequately characterized to address our objectives. Of the 20 species found only in one transect, six species (from the families: *Accipitridae*, *Cathartidae*, *Falconidae*, *Psittacidae*, and *Tyrannidae*) are known to fly over large areas to forage. More sampling days would increase the possibility of observing these species in the transect, in which they were not initially observed, potentially reaching asymptote without changing overall study-wide composition and conclusions. Further characteristics of the methodology likely influenced a full accounting of the community composition of the region, which we factored into our decision to limit analysis to conspicuous species. Data collection was made via automobile, and because of car speed and car noise, the probability of visually observing and hearing birds is lower compared with walking through the buffer area and stopping periodically (point sampling method).

However, sampling along roadways has the advantages of efficiency, and focuses on the effects of anthropogenic impacts facilitated by transportation infrastructure, and the functional diversity and behavioral changes that result. Roads can facilitate hunting and foraging for some species. Large amounts of fruit and grain crops are moved along roadways, and this cargo is constantly dropped on the road, attracting birds (Fischer 1997). While such cargo is currently relatively infrequent, improvement of BR419 may make the road a more attractive shipping route and subsequently affect foraging behavior. Wildlife-vehicle collisions also attract necrophagous species, occasioning further accidents with the feeding scavengers (Scoss et al. 2004). As mentioned previously, a number of studies provide evidence from the paved highway BR262, which crosses the southern Pantanal, of the risk to scavenging avifauna, particularly Southern Caracara, Black Vulture, and Turkey Vulture (Souza et al. 2015, Sobanski 2016, Fischer et al. 2018). Both vulture species were more than twice as abundant along BR419 as along MS170.

Community variation between the MS170 and BR419 transects was apparently correlated with differences in topography and hydrology. The relatively low elevation and presence of the Aquidauana River and floodplain wetlands parallel to and within the MS170 transect sampling area influenced the presence and relative abundance of species with affinities for wetland habitats. All but two of the significant indicator species were associated with flooded or wet habitats. Greater river discharge was strongly associated with greater species richness along MS170, but had no relationship with BR419 species richness. In addition, composition showed a directional trend in the NMS with sampling period. These results suggest that wet season hydrology may push species away from deepening waters along the river and attract them to filling wetlands, ponds, and ditches closer to MS170. As waters recede with the transition to the dry season, species may abandon higher elevations in the floodplain for the riverside wetlands again.

Due to its higher elevation and more limited wetlands, BR419's avian community may vary less by season, and the same species and relatively abundances observed in the sampled buffer zone of the roadway may be consistently present and exposed to the threat of wildlife-vehicle collisions. While mitigation measures for mammals, reptiles, and amphibians are common and effective at barring individuals or transporting them over or under roadways (Aresco 2003, Foster & Humphrey 1995), or warning animals away from the road (Schafer & Penland 1985) or drivers of the presence of animals, the vertical movement of most birds into the roadway presents a different challenge for which a technical solution may not exist. Vehicle speed is apparently an important factor influencing wildlife-vehicle collisions (Jones 2000, Hobday & Minstrell 2008), and paving roads is accompanied by a concomitant increase in speeds. To protect species observed along the currently unpaved roadways of Pantanal's Aquidauana region, speed limits following road improvement should be calibrated to facilitate safe transportation for drivers and the continued existence of wild species.

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REFERENCES

Ament, R, AP Clevenger, O Yu & A Hardy (2008) An assessment of road impacts on wildlife populations in U.S. national parks. *Environmental Management* 42: 480–496.

Anderson, MJ (2001) A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 26: 32–46.

Aresco, MJ (2003) Highway mortality of turtles and other herpetofauna at Lake Jackson, Florida, USA and the efficacy of a temporary fence/culvert system to reduce road kills. Pp 433–449 *in* Irwin, CL, P Garrett & KP McDermott (eds). *2003 Proceedings of the international conference on ecology and transportation*. Center for Transportation and the Environment, North Carolina State Univ., Raleigh, North Carolina, USA.

Bandeira, C & EP Floriano (2004) *Avaliação de impacto ambiental de rodovias.* Caderno Didático n. 8. ANORGS, Santa Rosa, Rio Grande do Sul, Brazil.

Brown Jr, KS (1986) Zoogeografia da região do Pantanal Matogrossense. Pp 137–182 *in* EMBRAPA-CPAP (ed). *Simpósio sobre recursos naturais e sócio-econômicos do Pantanal 1*. Corumbá, Mato Grosso do Sul, Brazil.

Carvalho, F & A Mira (2011) Comparing annual vertebrate road kills over two time periods, 9 years apart: a case study in Mediterranean farmland. *European Journal of Wildlife Research* 57: 157–174.

Conte, CO, PL Sanabria, S Favero & MA Mercante (2009) Mapeamento da avifauna como atrativo turístico na rota turística "Corixão Correntoso", Aquidauana, Pantanal do Negro, Mato Grosso do Sul. Pp 776–783 *in Anais 2° Simpósio de Geotecnologias no Pantanal, 7-11 November 2009.* Embrapa Informática Agropecuária/INPE, Corumbá, Mato Grosso do Sul, Brazil.

Crooks, KR & M Sanjayan (2006) *Connectivity conservation*. Cambridge Univ. Press, Cambridge, UK.

del Hoyo, J, A Elliott, J Sargatal, DA Christie & E de Juana (eds) (2018) *Handbook of the birds of the world alive*. Lynx Edicions, Barcelona, Spain.

Drozd, P & V Novotny (2010) *AccuCurve.* Version 1. Available from: http://prf.osu.cz/kbe/dokumenty/sw/AccuCurve/AccuCurve.xls.

Facincani, EM, ML Assine, A Silva, H Zani, BC Araújo & GM Miranda (2006) Geomorfologia fluvial do leque do rio Aquidauana, borda sudeste do Pantanal, MS. Pp 175–181 *in Simpósio de Geotecnologias no Pantanal*. Embrapa Informática Agropecuária/INPE, Campo Grande, Mato Grosso do Sul, Brazil.

Fischer, WA (1997) *Efeitos da BR-262 na mortalidade de vertebrados silvestres: síntese naturalística para a conservação da região do Pantanal, MS.* Dissertação de Mestrado, Univ. Federal de Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil.

Fischer, WA, RF Godoi & ACP Filho (2018) Roadkill records of reptiles and birds in Cerrado and Pantanal landscapes. *Check List* 14: 845–876.

Forman, RTT & LE Alexander (1998) Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29: 207–231.

Forman, RTT, DS Friedman, D Fitzhenry, JD Martin, AS Chen & LE Alexander (1997) Ecological effects of roads: toward three summary indices and an overview for North America. Pp 40–54 *in* Canters, K (ed) *Habitat fragmentation and Infrastructure – Proceedings*. Ministry of Transport, Public Works & Water Management, Delft, The Netherlands.

Foster ML & SR Humphrey (1995) Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin* 23: 95–100.

Harris, MB, WM Tomas, G Mourão, CJ Silva, E Guimarães, F Sonoda & E Fachim (2005) Challenges to protect the Brazilian Pantanal: threats and conservation initiatives. *Megadiversidade* 1: 156–164.

Hobday AJ & ML Minstrell (2008) Distribution and abundance of roadkill on Tasmanian highways: human management options. *Wildlife Research* 35: 712–726.

International Union for Conservation of Nature (IUCN) (2018) *IUCN Red list of threatened species*. Available at http://www.iucnredlist.org [Accessed 23 April 2018].

Jones, ME (2000) Road upgrade, road mortality and remedial measures: impacts on the population of eastern quolls and Tasmanian devils. *Wildlife Research* 27: 289–296.

Junk, WJ, CN Cunha, KM Wantzen, P Petermann, C Strussmann, MI Marques & J Adis (2006) Biodiversity and its conservation in the Pantanal of Mato Grosso, Brazil. *Aquatics Science* 68: 278–309.

Laurance, WF, AKM Albernaz, G Schroth, PM Fearnside, S Bergen, EM Venticinque & C da Costa (2002) Predictors of deforestation in the Brazilian Amazon. *Journal of Biogeography* 29: 737–748.

MMA (Ministério do Meio Ambiente) (2007). *Cerrado and Pantanal: priority areas and actions for biodiversity conservation.* Biodiversity Series 17. Ministério do Meio Ambiente, Brasília, Brazil.

McCune, B & MJ Mefford (2006) *PC-ORD. Multivariate analysis of ecological data, Version 5.0 for Windows*. MJM Software Design, Gleneden Beach, Oregon, USA.

Mittermeier, RA, CG Mittermeier, TM Brooks, JD Pilgrim, WR Konstant, Da GAB Fonseca, and C Kormos (2003). Wilderness and biodiversity conservation. *Proceedings of the National Academy of Science* 100: 10309–10313.

Nunes, AP, PA Silva & WM Tomas (2008) Novos registros de aves para o Pantanal, Brasil. *Revista Brasileira de Ornitologia* 16: 160–164.

Nunes, AP & WM Tomas (2008) *Aves migratórias e nômades ocorrentes no Pantanal.* Embrapa Pantanal, Corumbá, Mato Grosso do Sul, Brazil.

Ogada, DL, F Keesing & MZ Virani (2012) Dropping dead: causes and consequences of vulture population declines worldwide. *Annals of the New York Academy of Sciences* 1249: 57–71.

Ogada, DL, P Shaw, RL Beyers, R Buij, C Murn, JM Thiollay, CM Beale, RM Holdo, D Pomeroy, N Baker, SC Krüger, A Botha, MZ Virani, A Monadjem & ARE Sinclair (2016) Another continental vulture crisis: Africa's vultures collapsing toward extinction. *Conservation Letters* 9: 89–97.

Parry-Jones, KJ, C Poole, V Prakash, A Round & R Timmins (2003) Causes and effects of temporospatial declines of *Gyps* vultures in Asia. *Conservation Biology* 17: 661–671.

Peck, JE (2016) *Mulitivariate analysis for ecologists: step-by-step.* 2nd ed. MjM Software Design, Gleneden Beach, Oregon, USA.

Pivatto, MAC, RJ Donatelli & DG Manço (2008) Aves da Fazenda Santa Emília, Aquidauana, Mato Grosso do Sul. *Atualidades Ornitológicas On-line* 143: 33–37.

Rezende, MPG, IL Cardoso, BPF Alves, HB Ribeiro & RHG Pereira (2012) Inventário da riqueza de ictiofauna da Lagoa Comprida, Aquidauana/MS. *Revista Pantaneira* 14: 38–43.

Rodrigues, FHG, IM Medri, VM Thomas & GM Mourão (2002) *Revisão do conhecimento sobre ocorrência e distribuição de mamíferos do Pantanal*. Embrapa Pantanal, Corumbá, Mato Grosso do Sul, Brazil.

Sacco, A, F Bergman & A Rui (2013) Assembleia de aves na área urbana do município de Pelotas, Rio Grande do Sul, Brasil. *Biota Neotropica* 13: 153–162.

Schafer JA & ST Penland (1985) Effectiveness of Swareflex reflectors in reducing deer–vehicle accidents. *Journal of Wildlife Management* 49: 774–776.

Scoss, LM, P Marco Junior, E Silva & SV Martins (2004) Uso de parcelas de areia para o monitoramento de impacto de estradas sobre a riqueza de espécies de mamíferos. *Revista Árvore* 28: 121–127.

Silva, TO, CAB Carvalho, DC Lima, ML Calijuri & CC Machado (2011) Influência do tráfego de veículos comerciais em rodovias vicinais não pavimentadas: estudo de caso aplicado à VCS 346, Viçosa, MG. *Revista Árvore* 35: 539–545.

Sobanski, MB (2016) *Avaliação do uso de controladores eletrônicos de velocidade como medida de mitigaçãode atropelamentos de animais silvestres na rodovia BR-262, trecho de Anastácio à Corumbá, Mato Grosso do Sul.* Dissertação de Mestrado, Univ. Federal de Paraná, Curitiba, Brazil.

Souza, JC & JAF Lima (2012) O Pantanal de forma sustentável. Pp 7–18 *in* Souza, JC de (ed). *Pantanal produzindo com sustentabilidade*. Univ. Federal de Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil.

Souza, JC, V Pereira & S Markwith (2015) Spatiotemporal variation in human-wildlife conflicts along highway BR-262 in the Brazilian Pantanal. *Wetland Ecology and Manag*ement 23: 227–239.

Teodoro, PE, JF Oliveira-Júnior, ER da Cunha, CCG Correa, FE Torres, VM Bacani, G Gois & LP Ribeiro (2016) Cluster analysis applied to the spatial and temporal variability of monthly rainfall in Mato Grosso do Sul State, Brazil. *Meteorology and Atmospherics Physics* 128: 197–209.

Tubelis, DP & WM Tomas (2003) Bird species of the Pantanal wetland, Brazil. *Ararajuba* 11: 5–37.