Evaluation of Different Grass Height Management Patterns for Bird Control in a Tropical Airport

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ABSTRACT: Grass height management is an important tool as a wildlife hazard prevention strategy on airports. Different grass heights, mowing regimes, and grass species composition can attract varied groups of species representing different levels of risk for this kind of environment. Therefore, the goal of this study was to characterize the species that make up the grass cover of the *Aeroporto Internacional Presidente Juscelino Kubitschek* and compare potentially hazardous bird activities within three grass management patterns in operation areas of a Brazilian aerodrome. We tested three grass heights and mowing treatments: HF (Tall grass and high frequency mowing), LI (Low grass and infrequent mowing) and LF (low grass and frequent mowing). All analyses were done separately for the species presenting the greatest potential hazard: Southern Lapwing *Vanellus chilensis*, Southern Crested Caracara (*Caracara plancus),* and the collective data of other hazardous bird species. Bird species abundance was compared by GLMM based on two factors: (1) grass height treatment, and (2) mowing/no mowing activities. Our results confirm that grass height at >30 cm is effective to deter the presence of some species of hazardous birds on this airfield. Grass height management strategies should be investigated and conducted at different sites, however, tropical airports can benefit from the results of this study and test whether this height is also appropriate for local species risk management. Nevertheless, for grass management to effectively work in airport settings, this strategy must be fully integrated into airport operations and planning activities.

Key words: Wildlife management. Long grass policy. Birdstrike. *Vanellus chilensis*. C*aracara plancus*.

Avaliação de Diferentes Alturas de Grama para Controle de Aves em um Aeroporto Brasileiro

RESUMO: A gestão da altura de grama é uma ferramenta importante como estratégia de prevenção contra riscos de fauna em aeroportos. Alturas diferentes e a composição de espécies da vegetação podem atrair um grupo variado de espécies, de maior ou menor risco, para este tipo de ambiente. Portanto, o objetivo deste estudo inclui a caracterização das espécies que compõem a cobertura vegetal do Aeroporto Internacional Presidente Juscelino Kubitschek e comparar a atividade de aves potencialmente perigosas em três padrões de gestão de grama na área operacional de um aeródromo brasileiro. Testamos três alturas e tratamentos de roçagem: HF (grama alta e alta frequência de roçagem), LI (grama baixa e roçagem não frequente) e LF (grama baixa e roçagem frequente). Todas as análises foram feitas separadamente para espécies de aves que apresentaram o maior risco em potencial: o Quero-quero *Vanellus chilensis*, o Carcará *Caracara plancus*, e os dados coletivos de outras espécies de risco. A abundância de espécies de aves foi comparada utilizando GLMM na base de dois fatores: (1) tratamento de altura de grama e (2) com a roçagem/ sem roçagem. Nossos resultados confirmaram que a altura de grama acima de 30 cm é eficiente em desencorajar a presença de aves de risco em aeródromos brasileiros. Apesar do fato que as estratégias de manejo de altura de grama devem ser estabelecidas de acordo com as características locais, de forma geral aeroportos tropicais podem se beneficiar deste resultado e testar se essa altura é apropriada para o manejo de suas espécies de risco. Mesmo assim, para o manejo da grama funcionar de maneira eficiente em ambientes de aeroporto esta estratégia deve ser completamente integrada nas operações do aeroporto e nas atividades de planejamento.

Palavras Chave: Manejo de fauna. Altura de grama. Colisão com fauna, *Vanellus chilensis*. *Caracara plancus*.

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1 INTRODUCTION

As civil aviation activity increases worldwide, birdstrikes (i.e., wildlife-aircraft collisions) are safety and financial issues to the aviation industry. Even though birdstrikes occur at a low rate (one in every 2000 flights), the risk of loss of human life is still present (Thorpe 2016). Besides this risk, financial losses both direct (i.e., cost of damage repairs, flight cancellations etc.) and indirect ones (i.e., loss of customer business and passengers re-routing) may result as well. In most cases, indirect costs exceed direct ones (Flight Safety Foundation 2002). It is estimated that birdstrikes cost the global civil aviation industry US$ 1.2 billion per year, but this value is considered conservative because a large proportion of airline birdstrike data is not easily available (Allan 2002).

The increase of certain bird populations in urban areas, as well as the use of faster and quieter jet turbines that are less detectable by birds, have increased birdstrike risk, causing a growing concern amongst aviation authorities (Sodhi 2002). The quality of birdstrike data may have also improved in many countries, particularly where reporting has become mandatory, hence strike numbers have been increasing with time (Mackinnon et al. 2004, FAA 2007, CAA 2013).

To reduce the risk and consequences associated with birdstrikes, airports should implement wildlife monitoring and management programs (IBSC 2006; ICAO 2012). Airport wildlife management should consist of a series of measures that focus on reducing birdstrike risk. These measures include strategies such as bird repellent and direct species control by capture and removal techniques. However, the most effective long-term method of decreasing the number of birds on airfields is modifying the habitat to make it unattractive to animals (Brough & Bridgeman 1980; Buckley & McCarthy 1994, Novaes & Alvarez 2014).

Habitat management provides a nonlethal technique for reducing the presence of wildlife on airports, and generally aims to remove or manage airside attractants associated with food, water, and shelter. Airfield vegetation type has a direct impact on the local fauna composition, providing both food and nesting grounds, especially for birds (Barras & Seamans 2002; Washburn & Seamans 2004; Linnel *et al.* 2009, Blackwell *et al. 2*013). The airfield environment can also be attractive to many animal groups due to the availability of forage and water resources, shelter, and reproductive sites (Washburn & Seamans 2004, DeVault *et al* 2011). In highly urbanized areas, airfields can offer large patches of grassland habitat and thus can be particularly attractive to hazardous birds that use these open areas (DeVault *et al.* 2012, Washburn & Seamans 2013).

Managing vegetation is an efficient method for reducing bird presence in airport habitats, in particular, the management of the vegetation height and associated mowing regime, the modification and selection of plant species composition, and the removal of trees and shrubs (Dekker 2000, Brought & Bridgman 1980; Mead & Carter 1973). Although official aviation safety agencies recognize that vegetation management can be effective to reduce the presence of birds on airports (Mackinnon *et al.* 2004, De Fusco *et al.* 2005 IBSC 2006, FAA 2007, ICAO 2012, CAA 2013), there is no consensus about the specific recommendations for on-field management decisions by the local airport authority (Blackwell *et al.* 1999; Seamans *et al.* 1999, Cleary and Dolbeer 2005, Blackwell *et al.* 2013**,** Washburn & Seamans 2013)**.** In general, taller grass may interfere with predator detection, visibility, feeding capability, and ground movements of some bird species. However, this management strategy may also increase cover and food resources for other potentially hazardous species (Washburn & Seamans 2013). Even after substantial discussions over the past 50 years on the importance of grass management techniques, few studies had evaluated the effectiveness of integrated management techniques on avian abundances (Deacon & Rochard 2000, Seamans *et al.* 2007). It is well documented that ongoing monitoring is crucial to determine the effectiveness of wildlife hazard reduction techniques, and grass management techniques are no exception (Blackwell *et al.* 2013**,** Washburn & Seamans 2013)**.**

Species-specific wildlife management strategies tend to be the most effective (Barras & Seamans 2002), but the lack of management studies for local species in tropical airports is particularly notable (Linnel *et al*. 2009, Novaes & Alvarez 2010). According to the Brazilian wildlife strike database managed by the Aeronautical Accidents Investigation and Prevention Centre (CENIPA), 25.3% of national strikes where the species was identified involved the Southern Lapwing (*Vanellus chilensis*), and 8.4% were classified as collisions with Southern-Crested Caracara (*Caracara plancus*). A similar pattern was observed in the strike records for the *Presidente Juscelino Kubitschek* International Airport (SBBR). From January 2000 to November 2012, 461 collisions were reported in SBBR, where 86 (19.3%) were caused by the Southern Lapwing and 58 (13%) by the Southern-Crested Caracara. These species are known for their high-risk behaviour, especially their territorial, nesting, gregarious and foraging behaviours on short grass (Marateo *et al*. 2015). The Southern Lapwing tends to forage and nest in ground vegetation (Saracura 2003). The Southern-Crested Caracara has adapted well to urban environments, taking of available food such as carrion, garbage, fruits, insects, and small vertebrates (Sick 1997; Montalvo *et al.* 2011).

This paper reports the effects of grass management patterns of an airfield strip on the frequencies of potentially hazardous birds. We evaluated which grass height is least attractive to bird species, in two different scenarios: without any mowing (*no mowing*) and up to 10 days after a mowing event (*mowing*). We tested whether the height and mowing frequency affected bird abundances. The tested prediction was that grass-covered areas mown frequently at low heights are more attractive to hazardous species. We also predicted that the first ten days after mowing should also correspond to greater bird abundances. Our results provide insights which aim to aid other airport authorities in developing their own grass management strategy.

2 METHODS

2.1 <u>**STUDY AREA**</u>

This study was carried out at the *Presidente Juscelino Kubitschek* International Airport (SBBR), 15°52' 09'' S 47°55' 15'' W in Brasília – DF, Brazil. The airport area comprises 11,200 ha, of which 1,716 ha are under military use, and supports two main runways, two passenger terminals, a cargo terminal, several hangars and gas stations. Urban zones and extensive natural areas border the airfield. The airport is situated within an Environmental Protection Area known as *Gama e Cabeça de Veado*. Cerrado vegetation types (as described by Ribeiro and Walter 1998) such as savanna grasslands, wetlands and typical Cerrado (locally known as "cerrado *stricto sensu*") are adjacent to the Airport Operation Area. These areas can provide broad resources for wildlife, encouraging high activity of domestic and wild animals in close proximity to the airport. The Cerrado is a tropical savannah with two well defined seasons, one dry and cold (with 116mm average rainfall) and another hot and dry (with an average of 1383mm of rainfall) (Cardoso, et al, 2015).

2.2 GRASS HEIGHT/MOWING TREATMENT

We conducted a survey in July 2012 to identify the grass species and their abundances in the SBBR airfield. Grass samples were collected during 7 non-consecutive sampling days in adjacent plots to the 11R-29L runway. Small sampling squares measuring 20x20cm were randomly tossed in pre-established quadrants. These quadrants were established according to the runways, whereby each runway was divided into eight equally spaced quadrants. We then walked in a zig-zag pattern inside the quadrant tossing the square at every 10m. All individuals were counted and identified inside the sampling square.

For the height/mowing experiment we determined six experimental plots located on grassed areas adjacent to runway 11R (Figure 1). Each experimental plot was 100 m by 100 m wide, located 20 meters from each other. Overall, the experimental array occupied 6 ha of the32 ha Airport Operation Area. Three grass height treatments were tested with minimum values after mowing and maximum values prior to mowing. Because this study wanted to evaluate the effect of mowing, our experimental design focused on mowing frequency, by different ranges between minimum and maximum heights, not only different height treatments. The experimental treatments were: Low and Frequent (LF) 5cm to 30cm, High and Frequent (HF) 30cm to 50cm and Low and Infrequent (LI) 5cm to 50cm. Each treatment had two replicated plots. Therefore, LF and HF treatments were mowed more frequently as compared to LI. Whereas LF and LI treatments maintained shorter grass height as compared to treatment HF. Grass heights were measured randomly during the bird inspections. The results of these measurements determined when the grass required mowing (i.e., when it exceeded the allocated maximum height for the respective plot) and the grass was mowed to the determined minimum height of each treatment. Observations made up to ten days after plot mowing were classified as "mowing". After this period, they were reclassified to their pre-mowing status – "no mowing".

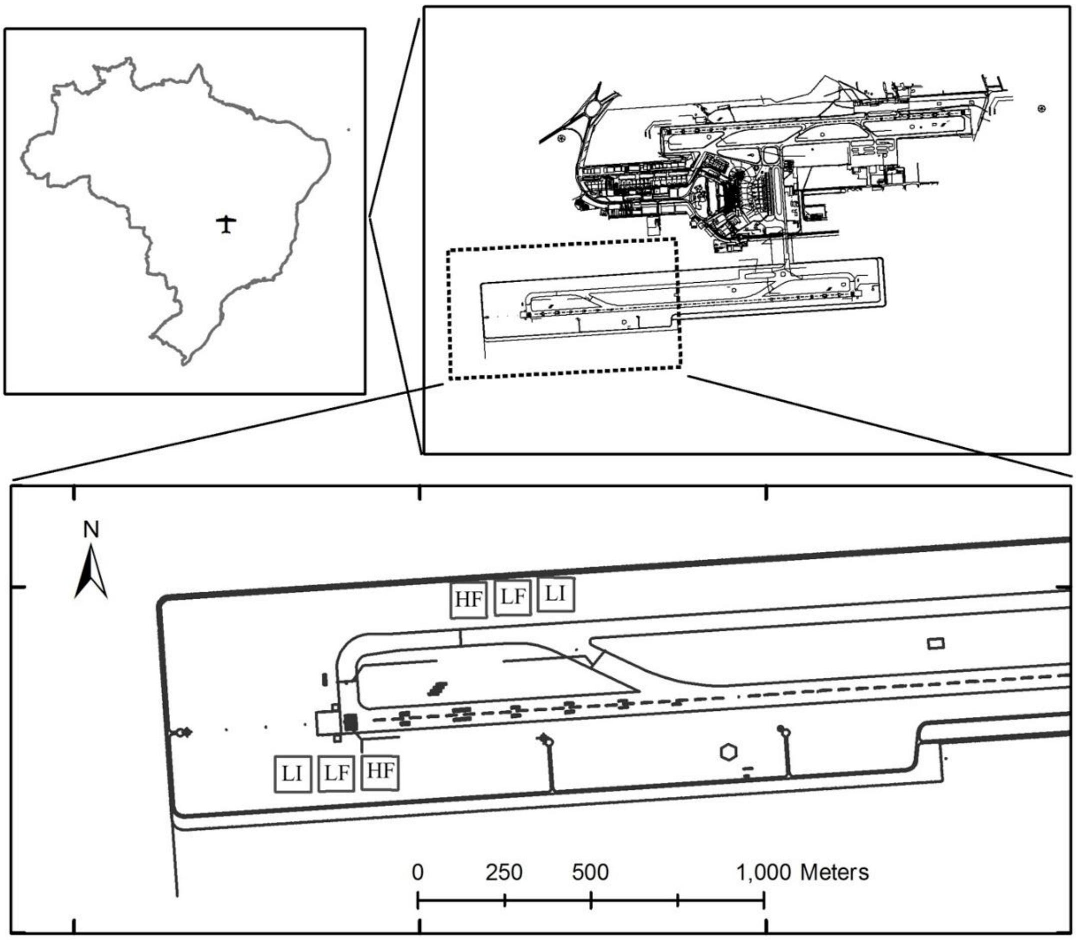

Figura 1: Map of the six experimental plots in the 11R-29L runway at *Presidente Juscelino Kubitschek* International Airport, Brasília, Brazil (15 º 52' 09" S, 47º 55' 15" W).

2.3 BIRD INSPECTIONS

We used the point count method within a 5 min period to estimate bird abundance by species in each plot (Bibby *et al*. 2000). These inspections were conducted once or twice a week, for the duration of the height/mowing treatment study, from 14 October 2011 to 23 May 2012, in all six plots, between 06:00 and 20:00. We attempted to vary the census time in order to avoid seasonal or circadian biases in bird activity. Inspections recorded all bird species using each plot. To determine avian hazard potential, we classified local species according to a heuristic classification (Allan 2006) and also a Brazilian risk matrix (CONAMA 2015), based on the local frequency and severity classifications (De Vault *et al.* 2011). Separate analyses were completed for the two highest risk species, the Southern Lapwing (*Vanellus chilensis*) and the Southern-Crested Caracara (*Caracara plancus*), as well as on the collective data from other local risk species. In accordance with the risk matrix, this group included raptors, such as the Roadside Hawk (*Rupornis magnirostris*) and the Sparrow Hawk (*Falco sparverius*); the Black Vulture (*Coragyps atratus*), the Whistling Heron (*Syrigma sibilatrix*), the Buff-Necked Ibis (*Theristicus caudatus*), the Ruddy Ground Dove (*Columbina talpacoti*), the Picazuro Pigeon (*Patagioenas picazuro*), and the White-Browed Blackbird (*Sturnella superciliaris*).

2.4 STATISTICAL ANALYSES

We used Generalized Linear Mixed Models (GLMM) to analyse the effects of three fixed factors 1) *treatment*, which corresponds to the different grass heights of mowing treatments (HF, LF, LI); and 2) *mowing*, which gathers until ten days post-mowing or "no mowing". We also used *census* (nested within *days*) as a random factor in the analyses to minimize pseudo-replication problems related to effects of repeated measures on the same points or census that occurs at distinct periods during the same day (max = 3). The response variables were tested separately to the three abundances (Southern Lapwing, Southern Crested Caracara, and the collective data of others local hazardous species). Because the abundance measures bird census counts, we used Poisson distribution to create fixed effects models (McDonald *et al*. 2000, Conquest 2000, Manly 2008). The overall model considered both factors and its interaction were compared to an additive model, only *treatment* model and only *mowing* model. The models were determined to each response variable and were tested primarily for the relevance of the random effects and, the fixed effects one by Likelihood Ratio Tests. The best models were selected by variation of Akaike's Information Criterion measures (dAIC < 2) (White & Burnham 1999). The data was evaluated previously for the fit of assumptions underlying statistical tests by a protocol for data errors exploration and graphical residual assessments (Zuur *et al.* 2009).

3 RESULTS

3.1 GRASS SPECIES COMPOSITION

We identified 8 plant species belonging to 4 families on the grass plots adjacent to the 11R-29L runway: Signalgrass or "*brachiaria*" *Urochloa (=Brachiaria) decumbens*, Panicgrass *Panicum maximum,* Rose Natal Grass *Rhynchelytrum (=Melinis) repens* and other unidentified gramineae (Family Gramineae), Arrowleaf Sida *Sida rhombifolia* (Malvaceae), a leguminosae *Bauhinia sp* (Fabaceae-Caesalpinoideae), Horseweed *Conyza bonariensis* and Gallant Soldier (or Potato Weed) *Galinsoga parviflora* (Compositae). The most dominant species was Signalgrass which covers 79,3% of the sampled plots, followed by Arrowleaf Sida and Panicgrass covering 14.9% and 4.8% respectively. For the plots adjacent to the 11L-29R runway, the following species ordered by dominance were identified: Signalgrass *Urochloa decumbens* (74%), Panicgrass *Panicum maximum* (15,3%), Arrowleaf Sida *Sida rhombifolia*, other unidentified gramineae, Rose Natal Grass *Rhynchelytrum repens*, Horseweed *Conyza bonariensis, Bauhinia sp* and Gallant Soldier *Galinsoga parviflora*. The results suggest that the airfield lawns are composed predominantly of a few non-native grasses.

3.2 GRASS HEIGHTS

The HF treatment had the highest average grass height (33.9 ± 15.9 cm) followed by LI (31.2 ± 17,5 cm) and LF (26.3 ± 10,5 cm), indicating the predicted greater variance in treatment LI and greater grass height in treatment HF (Figure 2).

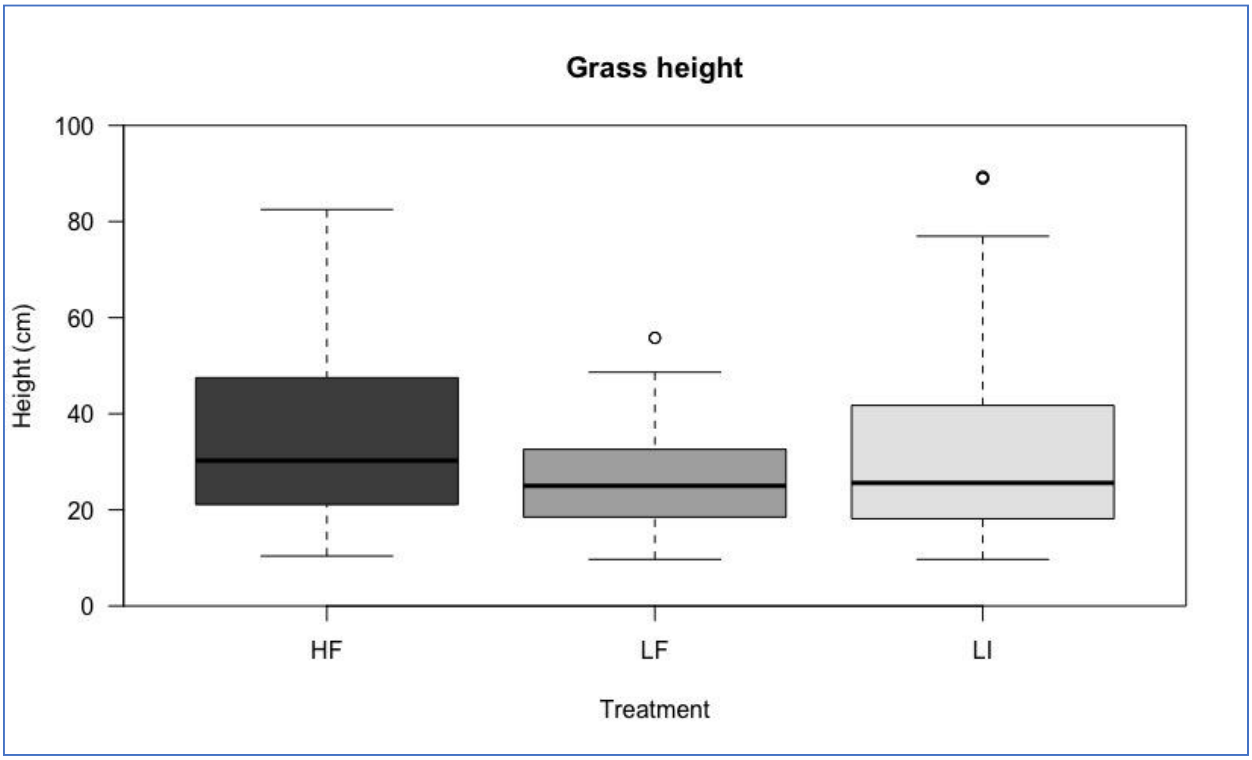

Figure 2: Boxplot of the grass heights per treatment: HF (High-Frequent) = 30-50cm, LF (Low-Frequent) = 5-30cm, LI (Low-Infrequent) = 5- 50cm.

3.3 BIRD ACTIVITY AND GRASS HEIGHTS

We recorded 1,013 bird observations during 313 census inspections over 222 sampling days varying from 36 to 65 inspections in each sampling plot. The observations comprised of 423 Southern Lapwings, 230 Southern-Crested Caracaras, and 215 other hazardous species sightings. We observed 505 birds in treatment LF, 165 in HF and 343 in LI. Among all sampled individuals, 389 were in "mowing" plots (36 inspections), and 624 were in "no mowing" plots (277 inspections). Even though there were fewer mowing observations, the large bird abundances during this activity suggests mowing periods to be more attractive. The results of model selection indicate that both fixed factors (*treatment* and *mowing*) were relevant to the bird abundances. According to the selected model, the abundance of Southern Lapwing and of Southern Caracara differs significantly among the treatments, between the two different mowing occasions and in the interaction of both factors. These results indicate that the maximum grass height, as well as the mowing period influence the abundances of the two most hazardous species. However, this effect is unequal in the different types of treatments. In the case of other hazardous species abundances, only treatment was a meaningful factor, and the presence or absence of the mowing effect was not an important factor to alter the bird count, even among distinct treatment types (Table 1).

Variáveis de Resposta (Y)	Tratamento	Corte	Tratamento*Corte	AIC	ΔAIC
Abundâncias de Quero-Queros *Vanellus chilensis*	***	**	**	*1058.5* +	-
	***	-	-	1070.8	12.3
	-	*	-	1089.5	31.0
	***	***	-	1134.4	75.9
Abundâncias de Carcarás *Caracara plancus*	***	***	***	*303.3* +	-
	***	*ns*	-	355.9	52.6
	***	-	-	375.1	71.8
	-	*ns*	-	403.8	100.5
Abundâncias de Outras espécies de Aves Perigosas	*	*ns*	*ns*	644.5	2.6
	**	*ns*	-	647.2	5.3
	**	-	-	*641.9* +	-
	-	*ns*	-	647.3	5.4

Legendas

*** igual a p<0.001
** igual a p<0.01
* igual a p<0.05
ns - não significativo
"+" – melhores modelos selecionados

Table 1: Selection of Generalized Linear Mixed Models (GLMM) of two fixed factors: *Treatment* - corresponding to different grass heights of mowing treatments, and *Mowing* – corresponding to until ten days after mowing or "no mowing". The overall models (both factors and its interaction) were compared to additive models, only treatment models and only mowing models. The response variables were tested separately for three bird abundances (Southern Lapwing, Southern Crested Caracara, and the collective data of others local hazardous species). The best models were selected by variation of Akaike's Information Criterion measures (ΔAIC < 2,0). Other hazardous bird species included the Roadside Hawk (*Rupornis magnirostris*), the Sparrow Hawk (*Falco sparverius*), the Black Vulture (*Coragyps atratus*), the Whistling Heron (*Syrigma sibilatrix*), the Buff-necked Ibis (*Theristicus caudatus*), doves and pigeons (*Columbina talpacoti*, *Patagioenas picazuro*) and the White-browed Blackbird (*Sturnella superciliaris*).

Southern Lapwing abundance varied among the distinct grass height treatments, and, as it was predicted, the HF treatment had lower Lapwing abundances. The highest number of individuals was recorded in LI treatment, following by LF (Table 2). Likewise, the Lapwing abundance in "mowing" was greater than during "no mowing", indicating that this activity significantly increases the numbers of individuals. Mowing seems to affect abundances on each grass height treatment differently. For the HF treatment, the Lapwing average did not show a large variation before and after the mowing activities. Lapwing abundance showed larger variations in treatments LI and LF, mostly during "mowing" (Figure 3). We also observed differences among the number of individuals of Caracara among the three treatments (Figure 4). The treatment LF was significantly higher than the other treatments, suggesting the former one is more attractive to Caracaras. Equally, Caracara abundance during "mowing" is greater than during "no mowing" periods, but such differences were more pronounced in the LF treatment (Table 2). For other local hazardous species, we also detected differences in bird abundances among the three grass height treatments (Figure 5). Once again, the abundances were highest in LF treatment, compared to LI and HF ones (Table 2). But we did not observe variation in the abundance of other hazardous bird species related to the grass mowing effect. These results suggest that the grass height treatment is an important attractant for other hazardous bird species, irrespective of the presence or absence of the mowing effect. The lack of variation in the abundances of other hazardous bird species compared to the variation observed for Lapwings and Caracaras related to "mowing" indicate that this activity does not affect others hazardous species on the same scale as the afore mentioned species.

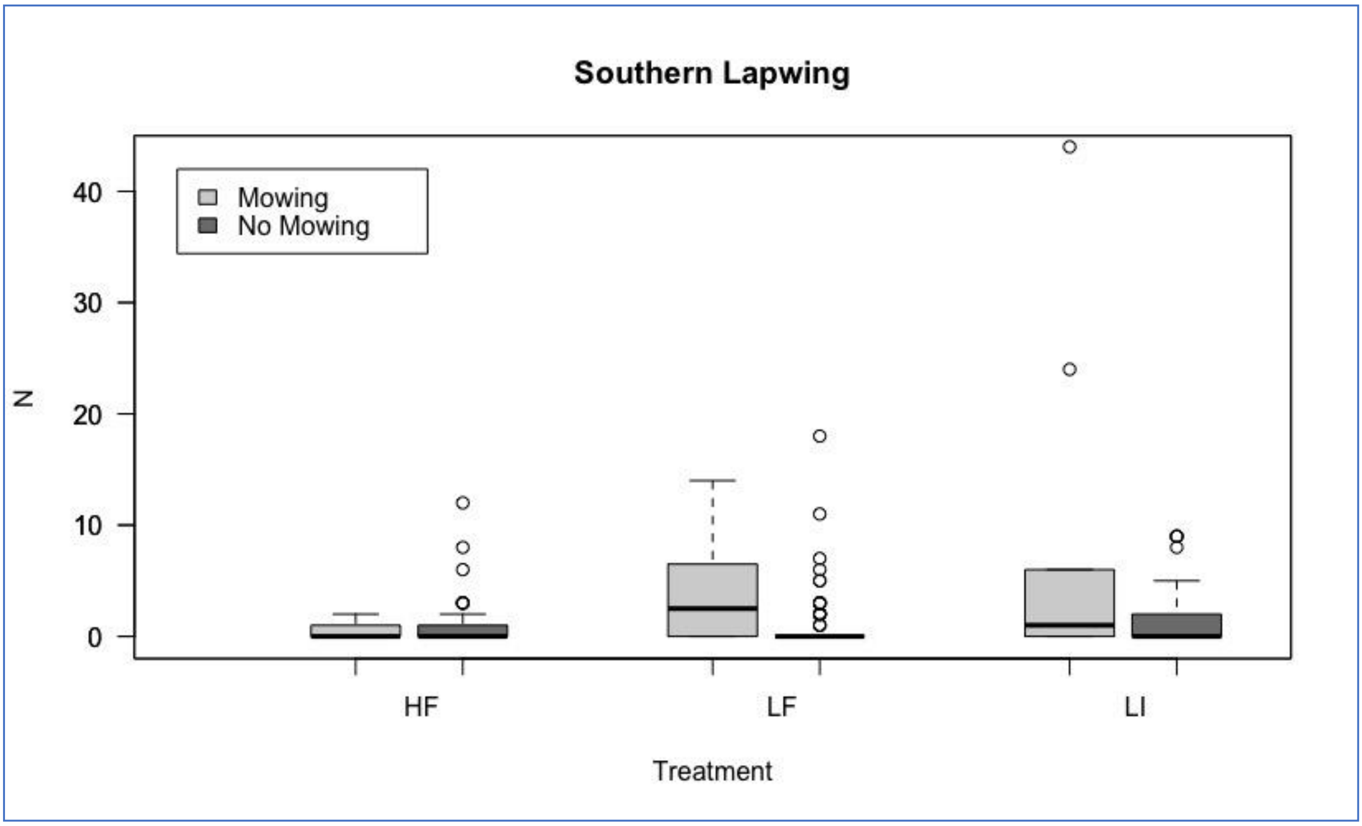

Figure 3: Boxplot of the Southern Lapwing (*Vanellus chilensis*) abundances per treatment: HF (High-Frequent) = 30-50cm, LF (Low-Frequent) = 5-30cm, LI (Low-Infrequent) = 5-50cm. Dark bars indicate "mowing" activities, light grey bars indicate "no mowing" activities.

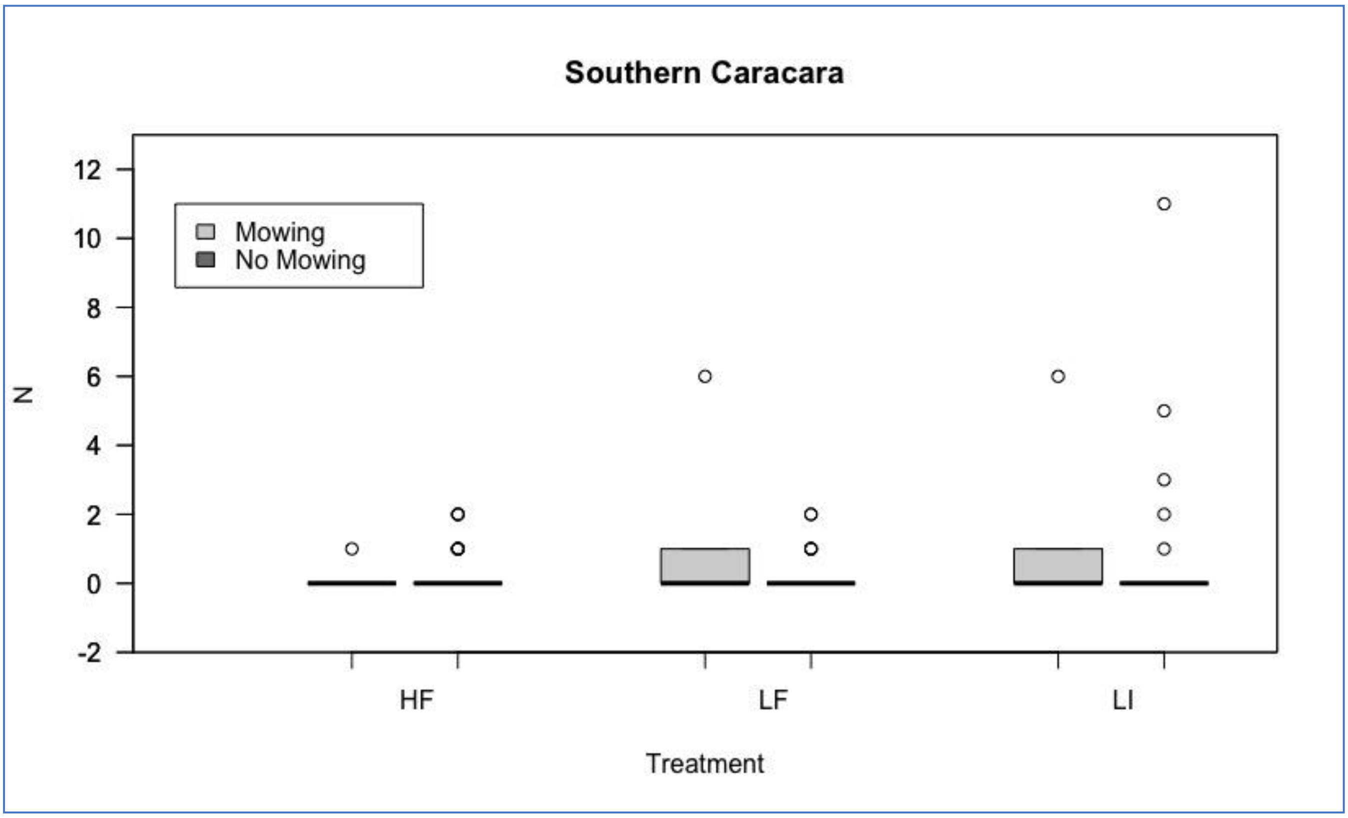

Figure 4: Boxplot of the Southern Crested Caracara (*Caracara plancus*) abundances per treatment: HF (High-Frequent) = 30-50cm, LF (Low-Frequent) = 5-30cm, LI (Low-Infrequent) = 5-50cm. Dark bars indicate "mowing" activities, light grey bars indicate "no mowing" activities.

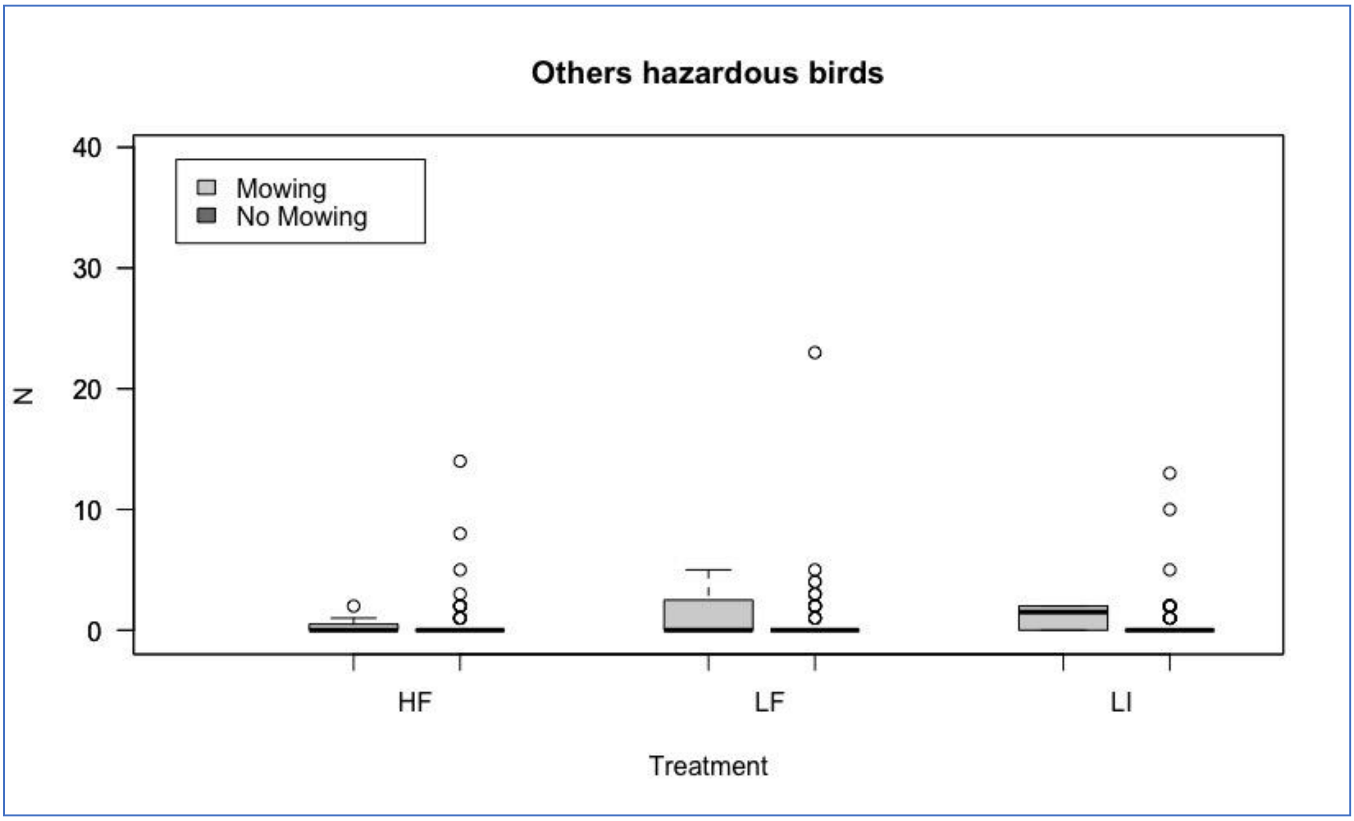

Figure 5: Boxplot of the others hazardous bird species abundances per treatment: HF (High-Frequent) = 30-50cm, LF (Low-Frequent) = 5-30cm, LI (Low-Infrequent) = 5-50cm. Dark bars indicate "mowing" activities, light grey bars indicate "no mowing" activities. Other hazardous bird species (Roadside Hawk (*Rupornis magnirostris*), Sparrow Hawk (*Falco sparverius*), Black Vulture (*Coragyps atratus*), Whistling Heron (*Syrigma sibilatrix*), Buff-necked Ibis (*Theristicus caudatus*), doves and pigeons (*Columbina talpacoti*, *Patagioenas picazuro*) and White-browed Blackbird (*Sturnella superciliaris*)).

Quero-Quero (*Vanellus chilensis*)			
Tratamento \ Corte	**Corte**	**Sem Corte**	**Total**
Tratamento LI - 5cm à 50cm	7.8 ± 14.7	1.3 ± 2.1	**2.0 ± 5.3**
Tratamento LF - 5cm à 30cm	3.8 ± 4.7	1.0 ± 2.6	**1.3 ± 3.0**
Tratamento HF - 30cm à 50cm	0.6 ± 1.0	0.7 ± 1.7	**0.7 ± 1.7**
Total	**4.4 ± 9.3**	**1.0 ± 2.2**	**1.3 ± 3.6**
Carcará (*Caracara plancus*)			
Tratamento \ Corte	**Corte**	**Sem Corte**	**Total**
Tratamento LI - 5cm à 50cm	0.8 ± 1.9	0.2 ± 1.3	**0.3 ± 1.4**
Tratamento LF - 5cm à 30cm	3.7 ± 10.0	0.1 ± 0.4	**0.5 ± 3.5**
Tratamento HF - 30cm à 50cm	0.1 ± 0.4	0.1 ± 0.4	**0.1 ± 0.4**
Total	**1.8 ± 6.6**	**0.2 ± 0.8**	**0.3 ± 2.2**
Outras espécies de aves perigosas			
Tratamento \ Corte	**Corte (SD)**	**Sem Corte (SD)**	**Total (SD)**
Tratamento LI - 5cm à 50cm	1.1 ± 1.0	0.6 ± 1.9	**0.7 ± 1.8**
Tratamento LF - 5cm à 30cm	1.2 ± 1.9	0.7 ± 2.6	**0.8 ± 2.5**
Tratamento HF - 30cm à 50cm	0.4 ± 0.8	0.5 ± 1.8	**0.5 ± 1.7**
Total	**1.0 ± 1.4**	**0.6 ± 2.1**	**0.6 ± 2.0**

Table 2. Estimates of averages and standard deviation of numbers of individuals from the following species: Southern Lapwings (*Vanellus chilensis*), Southern Crested Caracara (*Caracara plancus*) and other hazardous bird species, (Roadside Hawk (*Rupornis magnirostris*), Sparrow Hawk (*Falco sparverius*), Black Vulture (*Coragyps atratus*), Whistling Heron (*Syrigma sibilatrix*), Buff-necked Ibis (*Theristicus caudatus*), doves and pigeons (*Columbina talpacoti*, *Patagioenas picazuro*) and White-browed Blackbird (*Sturnella superciliaris*)).

4 DISCUSSION

Our main results can be concisely summed up in three main conclusions: 1) the maximum grass height directly influences bird abundances at SBBR, and our empiric study demonstrates that; 2) the "mowing" periods pose a greater risk in relation to birdstrike on airfields, and 3) the larger variations of bird abundances observed in the LF treatment indicates that if grass is mowed at a lower height, they can be even more attractive during mowing activities. Therefore, our results partially corroborate our predictions that cutting the grass closer to the ground, or more frequently, should be related to greater bird abundances. But in some cases, the not so frequent mowing regime can be more attractive to hazardous birds, indicating that the grass height had a more pronounced effect than mowing frequency on bird abundances. Consequently, it is better to manage taller grass more often than to manage shorter grass less often.

Our study presents quantitative bird responses to airport grassland management which indicates that the mowing/height regime directly influences bird abundances, especially Lapwings and Caracaras. According to the results for Southern Lapwing, greater abundances were observed in LI and LF treatments compared to HF ones, indicating that taller grass can be a successful management strategy for this species. Lapwings are considered tough to manage since trapping and driving them off is usually very difficult. This species is plentiful and distributed all over Brazil, with grassland management being perhaps the simplest and most efficient way to control these birds. Some studies suggest the preferential use of short grassland areas rather than tall grasslands by different components of the avian community on South American airports (Marateo *et al*. 2015). Fewer Lapwings were registered in tall grass heights (35cm) and there was an inverse, although weak, correlation identified between the number of Lapwings and grass height at *Lauro Carneiro de Loyola* Airport, in the city of Joinville, Santa Catarina, in the southern region of Brazil (Friedrick 2013). Various studies from all over the world have already evaluated the influence of grass height on the abundance of birds (Brough & Bridgeman 1980; Buckley & McCarthy 1994, Devereux et al. 2004, Linnel et al. 2009) but, despite a lack of a linear correlation of bird abundance and grass height, our empiric study demonstrates a cause and effect relationship where different mowing patterns determine the quantities of highest risk bird species on airfield. When the grass is mowed at a height closer to the ground, their attractive potential increases for hazardous birds, especially during the first 10 days after the mowing event.

Birds often follow farm equipment involved in haying or plowing to feed on exposed insects and small vertebrates (Seamans *et al.* 2007). The same behaviour occurs on airfields where it is common to observe high concentrations of bird species exploiting the invertebrate prey items that are exposed during and after the mowing of the grass (Washburn & Seamans 2004). A study conducted on North-American airfields demonstrated that grasshopper detections by crows was significantly higher in short-cut grass than in grass left at intermediate lengths (15 to 30 cm) (Kennedy & Otter 2015). An invertebrate inventory conducted in Brazilian airfields identified a large dominance of ants and grasshoppers in grass strips surrounding the runways in SBBR (Ferreira et al. 2015). It was also demonstrated that Southern Caracara had high feeding preference to grasshoppers (100% presence in seven dissected stomachs).

All this evidence allows us to infer that, in short-cut grass circumstances**,** the mowing period represents the highest risk to aviation safety in airfields. The large abundance variation observed in the lower and infrequent treatment draws our attention because it may be influencing how birds are attracted to airfields. The accumulated biomass from the LF regime could make these areas more attractive. The taller vegetation can provide shelters and harbour rodents, snakes, lizards, insects and small birds, which become exposed during mowing activities, subsequently attracting other hazardous species such as falcons and owls (Barras *et al*. 2000).

According to the grass survey the dominance of Signalgrass in both runways, considered one of the most invasive species in Brazil, was expected due to its reproductive characteristic and it settlement and dispersal capability (Lorenzi 2000). These characteristics also make this species ideal for seed production, and shelter for animals and insects. And so, the mowing activities must be considered when developing a wildlife risk management program aimed at reducing birdstrike. The establishment of a taller grass regime can be useful in reducing the birdstrike risk, but other alternatives can also be employed, e.g. falconry or dog harassment. In addition, nocturnal mowing, the management of insect and other arthropods with the use of pesticides, and rapid thatch removal are other strategies that can be implemented to reduce bird activity after mowing (Deacon & Rochard 2000; ICAO 2012; Ferreira *et al.* 2015).

Tall grass (>30 cm) is effective in dissuading bird presence at SBBR, particularly in relation to two of the most hazardous species, Southern Lapwings and Southern-Crested Caracaras. Other studies in South American airports suggest that maintaining grass height over 30cm might be a cheap and effective strategy to reduce abundances of hazardous species (Friedrick 2013, Marateo *et al*. 2015). Our data showed how effective this strategy is; therefore, we recommend other tropical airports to test the effectiveness of a higher grass height (>30cm) as part of their wildlife management programs.

An airport manager must always consider that there is no universal formula for ideal grass height and there are no consensual recommendations for grass height management for local airport authorities (CAA 2013, ICAO 2012, Washburn & Seamans 2013), due to conflicting results on whether tall grass management regimens reduce bird activity or not (Brough & Bridgman 1980, Buckley & McCarthy 1994, Seamans *et al*. 1999, Barras *et al*. 2000). Therefore, optimum grass management strategies require further research and may be site-specific (Barras & Seamans 2002). The management strategies for specific airports should be congruent with their high-risk species (Mackinnon *et al* 2004), as each site supports a certain suite of bird species that can benefit from different grass height profiles (Luigi 2006). For example, airport operators may need to decide whether small, non-flocking species that are attracted to tall grass can be tolerated in order to improve the management of hazardous high-risk species that prefer short grass. To minimize the effect of possible colonisations of risk species, bird census and inspections of long grass must be continued (Brough & Bridgeman 1980) as well as responsive strategies to harass potential grouping of birds attracted by the tall grass.

When considering vegetation management options on airports, airport managers should focus on plant species, grass height, and plant density to minimize the attractiveness of the airport to most hazardous wildlife species. Specific grass types can reduce foraging success within sites for many bird species (Linnell *et al*. 2009). Therefore, some suggested measures to mitigate this risk may include the use of slow growth grasses, and the use of grasses with low seed production and nutritional value for birds. Soil and land cover characteristics must also be considered since not all fields are appropriate for this sort of ground cover. Recent advances with the use of endophyte-infected grasses in airports, has shown progress in deterring birds species that feed on these plants (Pennell & Rolston 2010); nevertheless, these plant species seem to be only effective in temperate climates, not suitable for most airports in Brazil.

Any management strategy adopted by airports and airfields must be coupled with bird and vegetation monitoring programs, and regular risk assessments to make sure that other problems do not arise with eventual species substitution and habitat modification (Blackwell et al. 2013). Managing vegetation to mitigate the birdstrike risk is just one of the integrated components, and good birdstrike management programs are multi-faceted, requiring the participation of not just the airport operator, but other industry stakeholders such as airlines, regulators, municipalities, and government from federal, state and local levels (Patrick & Shaw 2012).

5 CONCLUSION

Our results confirm that tall grass (>30cm) is effective in reducing abundance of high risk species at SBBR and that the mowing regime can affect bird abundances, but how this regime affects birds varies according to the species. Overall, the mowing effect presents a higher risk to airports since animals are often more attracted to airfield grass strips during and right after this event. The higher the discrepancy between maximum height before mowing and height after mowing can greatly influence bird activity. The predominant grass species also affects bird presence due to its biological and reproductive characteristics. Therefore, according to our results, a more efficient grass management strategy would include the adoption of taller grass, with a more frequent mowing regime in order to reduce the amount of accumulated biomass and prey exposure.

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