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Assessing the risks: An analysis of wildlife-strike data at the three busiest Brazilian airports (2011-2016)

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Introduction

When aircraft and wildlife collide, these strikes have the potential to cause damage to aircraft and injuries to persons aboard the aircraft. In Brazil, wildlife strikes are reported to the Brazilian Aeronautical Accidents Investigation and Prevention Center (CENIPA) that manages the Brazilian National Wildlife Strike Database (NWSD). CENIPA reports that the number of wildlife strikes has increased seven-fold from 311 in 2000 (CENIPA, 2016) to a record 2,173 in 2017 (CENIPA, 2018). From 2011 through 2016, 95.12% of the reported strikes involved birds. Factors that have contributed to the increasing threat of wildlife strikes to aviation in Brazil include increased air traffic, government policies not restricting activities close to airports that attract wildlife, and wildlife adapting to urban areas (Oliveira, 2008; Mendonca, 2008; Santos, Almeida, Farias, Francisco, & Santos, 2017).

CENIPA has initiated several programs to address this important safety hazard, including the collection and analysis of wildlife strikes following the International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs). To feed information to this program, an appropriate and standard form, known as CENIPA 15, was developed and disseminated throughout the Brazilian Aeronautical Accident Investigation and Prevention System (SIPAER) (Santos et al., 2017).

Since 2009, CENIPA has published annual reports summarizing the results of analyses of the wildlife-strike data in a national level, from the Brazilian NWSD. The last report was published in 2016, and covered reported wildlife strikes that occurred in Brazil in 2015 (CENIPA, 2016). The information derived from the analysis of past wildlife strikes is paramount for the development of national and local strategies to mitigate the risk of aircraft accidents (Dolbeer, Weller, Anderson, & Begier, 2016). Such information may also be used to monitor wildlife hazard management programs (WHMP) to see if “they are working effectively and whether they need to be adjusted, extended, or improved” (Cleary & Dickey, 2010, p. 146). Additionally, wildlife strike and hazard information could be used by air operators to develop and/or enhance procedures that could reduce the risk of accidents due to wildlife (DeFusco, Unangst, Cooley, & Landry, 2015).

The CENIPA's reports provide good-quality descriptive data and information for aviation safety enhancement regarding the risk of aircraft accidents due to wildlife strikes in Brazil. However, these reports do not provide information derived from the analysis of wildlife strike data from the three busiest international commercial airports in Brazil: São Paulo international airport (Guarulhos) (SBGR), Brasília international airport (SBBR), and Rio de Janeiro's Tom Jobim international airport (Galeão) (SBGL). The goal of this study is to supplement the CENIPA's annual reports with information derived from the analysis of wildlife strikes to aviation from those three airports from 2011 through 2016. Specifically, the purpose of this study is fourfold:

1. To discover new information based upon the findings of relevant data analyzed, that can be used for the safety management of wildlife.

2. To determine if the rate of wildlife strikes has increased over the years.

3. To investigate wildlife strike data reports between each quarter of year.

4. To determine in which period of the day most strikes occurred.

The collection, analysis, and evaluation of wildlife-strike data is vital for the safety of the aviation industry (Dolbeer & Barnes, 2017; Dolbeer et al., 2016; MacKinnon, 2004). This study analyzed wildlife strike information from the three busiest Brazilian international airports. Information is included that facilitates the integration of Safety Management Systems (SMS) and wildlife hazard management programs (WHMP) by air carriers. The information in this study may inform the development of national policies and standards in Brazil as well as the future integrated research and management efforts to mitigate wildlife strikes.

Literature Review

Brazilian Wildlife Strikes

Globally, aircraft accidents and incidents due to wildlife strikes are an increasingly serious safety concern (DeFusco et al., 2015; Dolbeer & Barnes, 2017;

Dolbeer et al., 2016). In addition, conservative estimates of the monetary costs resulting from wildlife strikes can reach US$ 1.36 billion annually worldwide (Anderson et al., 2015). Wildlife strikes annually cost the Brazilian aviation industry, on average, US$65 million in direct and other monetary losses. According to CENIPA (2017a), only 30% of the strikes are reported to CENIPA. Therefore, those figures could be an underestimate of the total costs.

The risk of wildlife strikes to aircraft in Brazil has increased for many reasons, including the increasing number and capabilities of in-service aircraft, and the growing number of aircraft operations (CENIPA, 2016). According to the Brazilian National Civil Aviation Agency (ANAC), the number of registered of civil aircraft registered in the Brazilian Aeronautical Registry (RAB) increased from 18,710 in 2011 to 21,905 in 2016 (ANAC, 2017a). Moreover, the number of commercial operations increased 31.6 % since 2007. By investigating data from the Brazilian air transport annual report (ANAC, 2017b), the researchers of this paper have found that the number of domestic and international flights departing Brazil increased by 31.6% since 2007. In addition, researchers found that in 2016:

- Approximately 88.7 million passengers were transported in Brazilian domestic flights whereas 20.9 million passengers were transported in international flights departing or arriving in Brazil.
- Brazilian air carriers transported 35.5% of the international passengers to and from Brazil.
- Approximately nine percent of the international commercial flights to and from Brazil were performed by two U.S. air carriers.
- Twenty four percent of the commercial flights connected Brazil and Argentina, and 20.37% of these commercial flights connected Brazil and the U.S.
- 726 tons of cargo were hauled to and from Brazil.

- The United States (147 tons), Germany (133 tons), and Portugal (49 tons) were the most important destinations of cargo flights departing Brazil.
- Only 25.3% of these freights were conducted by Brazilian operators.

Three Busiest Brazilian Airports

According to the Brazilian Air Traffic Control Department (DECEA), São Paulo international airport (Guarulhos) (SBGR), Brasília international airport (SBBR), and Tom Jobim international airport (Galeão) (SBGL) have been the busiest commercial airports in Brazil in terms of aircraft operations since 2014 (DECEA, 2017). One aircraft movement refers to one takeoff, one landing, one touch-and-go, one missed approach, and one itinerant traffic (DECEA, 2016). Guarulhos airport in São Paulo state is a major hub in South America, and the main Brazilian international gateway. Approximately 94% of the aircraft movements in Guarulhos involve commercial operators. Most importantly, 27.1% of the commercial aircraft movements in Guarulhos are to and from international destinations. Brasília is the third busiest commercial airport in Brazil, and second if one considers international commercial operations. Eighty-two percent of the aircraft operations in Brasília involve commercial operators, and three percent of the aircraft movements relates to international commercial operations. Galeão airport, located in Rio de Janeiro city, is the largest Brazilian airport complex which has the largest runway in Brazil. Ninety-one percent of the aircraft movements at Galeão involve commercial air carriers. Additionally, 21.1% of the aircraft movements at Galeão involve international commercial operations.

Wildlife Risks at Airports

Several authors (Cleary & Dickey, 2010; Cleary & Dolbeer, 2005; MacKinnon, 2004; Martin et al., 2013; Rillstone & Dineen, 2013) have emphasized that certain activities on or near the airport can increase the risk of aircraft accidents due to wildlife. Land uses on and especially near the airport properties are important factors for the increased risk of wildlife strikes in Brazil (Carvalho, Figueiredo, Fernandes, Grecco, & Souza, 2016; Novaes & Alvarez, 2014). Brazil is the largest South American country, and its population growth is concentrated in some extremely populated areas, such as São Paulo and Rio de Janeiro (Eekeren, 2014). Due to past federal and state regulations and policies, there are still land-use practices and habitats near some Brazilian airports that could attract hazardous wildlife (Mendonca, 2008; Oliveira, 2008). These concurrent increases in air traffic and wildlife populations have contributed to an increased risk of wildlife strikes in Brazil. Thus, Brazil must face the challenges of reaching a balance between economy, sustainability, and aviation safety (Mendonca & Johnson, 2015).

Airport operators are professionally and legally obligated to mitigate the risk of aircraft mishaps due to wildlife strikes (DeFusco & Unangst, 2013). ICAO Annex 14 provides a standard that requires States to certify all aerodromes used for international operations. As part of the certification process, airport operators are required to develop an airport certification manual which will include pertinent information on the aerodrome site, equipment, operating procedures, and procedures designed to mitigate the risk of wildlife strikes at and around the airport (ICAO, 2013a). ANAC issues airport operating certificates under the Brazilian Federal Aviation Regulation (BFAR) 139 to airports that host domestic, flag, and supplemental operations in accordance with the BFAR 121. Additionally, ANAC issues Part 139 airport certificates to airport operators hosting commercial operations involving international air carriers, in accordance with the BFAR 129 (ANAC, 2016).

Brazilian Part 139 certificated airports are required to conduct a wildlife hazard assessment (WHA), and develop and implement a WHMP (ANAC, 2014). Guarulhos, Brasília, and Galeão airports have been certified by ANAC (ANAC, 2015). Therefore, in agreement with the ICAO Annex 14 (ICAO, 2013a), and also the ANAC regulations and policies (ANAC, 2016), these three airports are expected to have established a WHMP to decrease the risk of aircraft accidents and incidents during flight operations due to wildlife.

Safety Management Systems (SMS)

ICAO (2013b) defines SMS as a "systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures" (p. xii). The implementation of an SMS by certified airport operators has become an ICAO Standard since 2013 when ICAO *Annex 19* (Safety Management) became applicable. An effective SMS provides aviation operators with the capacity to proactively address safety hazards before they contribute to aircraft accidents. The benefits of an SMS include greater regulatory compliance, improved use of the always constrained resources, enhanced productivity, and reduced insurance and liability costs (DeFusco et al., 2015). The most valuable benefit of an SMS is enhanced flight safety (Gnehm, 2013; Mendonca & Carney, 2017). Several authors (DeFusco et al; 2015; Dolbeer et al., 2016; Dolbeer & Wright, 2009; Junior et al., 2009; Mendonca, 2011, 2016, 2017; Mendonca & Carney, 2018; Mendonca, Keller, & Wang, 2017) have demonstrated that the SMS tenets fit with the safety management of wildlife. For example, information obtained from the analysis of safety data is paramount for an effective SMS as well as the safety management of wildlife. It is practically impossible to eliminate the risk of aircraft accidents due to wildlife strikes. However, through the safety risk management process (SRM), which is the heart of an SMS, such risks can be reduced to an acceptable level, and sometime even eliminated. In Brazil, SMS requirements have been imposed to certificated airports (ANAC, 2016).

Implications for Stakeholders

Aviation stakeholders may use information derived from the analysis of previous wildlife strikes to inform the formulation of strategies and associated priorities. For example, this information could be used for aircraft designers and manufacturers to assist in the design of safer airframes and engines and more wildlife-resistant aircraft (MacKinnon, 2004). Airport operators should use the information derived from the analysis of previous strikes to develop or enhance their airport WHMP (Cleary & Dolbeer, 2005; Dolbeer et al., 2016). Civil and criminal liability frequently ensue an aircraft accident due to wildlife strike(s) due to possible negligence of the airport operator, air carrier, other officials, or any combination of those (Dale, 2009; Mateou & Mateou, 2010; Solomon & Relles, 2011). Therefore, it is highly recommended that aviation operators incorporate data and findings from previous strikes in their safety programs to not only enhance safety, but also to demonstrate that they have exercised due diligence in undertaking all strategies available to mitigate the risk of wildlife strikes.

ICAO *Annex 14* provides a Standard that requires ICAO member States to establish a national procedure for reporting and recording wildlife strikes (ICAO, 2012). In Brazil, the Aeronautical Accidents Investigation and Prevention Center (CENIPA) developed a safety reporting system that allows the aviation industry to voluntarily report wildlife strikes, near misses, and sighting of birds that could compromise the safety of flights. Since 2009 CENIPA has issued annual wildlife hazard reports summarizing the results of analyses of the data from the NWSD. Regional conditions and different strategies by airport operators influence the risk of wildlife strikes to aviation (Bellant & Ayres, 2014; Cleary & Dickey, 2010, DeFusco et al., 2015; Rillstone & Dineen, 2013). Therefore, there is a need to analyze regional data in order to develop specific information paramount for accident prevention (Mendonca et al., 2017). Dolbeer et al. (2016) contend that such analyses are vital to understanding the nature and the magnitude of the problem. Most importantly, safety experts assert there is room for improvement with regard to the safety management of wildlife hazard to aviation (Belant & Ayres, 2014; Cleary & Dolbeer, 2005; DeFusco et al., 2015; Dolbeer et al., 2016; DeFusco & Unangst, 2013).

Operators of the three busiest commercial airports serving international flights may not have access to specific analyses regarding the wildlife strikes at or near these airports. The results of analyses of the data from the Brazilian NWSD utilizing wildlife strike data from Guarulhos, Brasília, and Galeão airports could be useful in developing and implementing SMS, and perhaps lay the groundwork for national safety policies

(Dolbeer et al., 2016). Additionally, it could spur the development and/or enhancement of safety programs and strategies by the aviation industry (ICAO, 2012). Data analysis on the number of aircraft accidents and incidents due to wildlife strikes may provide a benchmark for those three Brazilian airports to evaluate and improve their wildlife hazard management programs (Dolbeer & Begier, 2011).

To gain a better understanding of wildlife strike reporting at Guarulhos, Brasília, and Rio de Janeiro international airports (Galeão), four research questions were addressed:

1. What are the descriptive statistics for type of operator, phase of flight, damage to aircraft per time of the day, and damage to aircraft per phase of flight when examining wildlife strike report data from Guarulhos, Brasília, and Galeão airports during 2011-2016?
2. What is the number of wildlife strike reports per 100,000 movements for each year during 2011-2016 at Guarulhos, Brasília, and Galeão airports?
3. What are the differences in wildlife strike reports per 100,000 movements between each quarter of the year during 2011-2016 at Guarulhos, Brasília, and Galeão airports?
4. What are the differences in wildlife strike reports between the four periods of the day at Guarulhos, Brasília, and Galeão airports?

Methodology

Data collection

The researchers in this study answered the research questions by reviewing, sorting, and analyzing existing data. The data collection took place from November 01, 2017 to May 05, 2018 using online databases and official reports. Two data sets were the primary sources of data: the Brazilian national wildlife database (NWSD), managed by CENIPA (CENIPA, 2018), and the Air Traffic Operations Annual Reports, published by the Brazilian Air Traffic Control Department (DECEA, 2013, 2016, 2017). The collection of wildlife strike data and information was supplemented using the

Brazilian Annual Wildlife Strike Summary reports (CENIPA, 2012, 2013, 2014, 2015, 2016).

Researchers used the Brazilian NWSD to obtain the number of reported wildlife strikes that occurred at and within the vicinities of Guarulhos, Brasília, and Galeão airports in Brazil. Only reported strikes were considered during this study. Using the CENIPA 15 Form, aviation professionals are encouraged to report wildlife strikes, near-misses, and sightings (CENIPA, 2017a). Thus, the CENIPA wildlife strike database as well as the CENIPA's annual reports also contain "wildlife near-misses and sightings" data. For the purpose of this paper, researchers used only wildlife-strike data.

The database output was filtered to include: Date Range, Airport, Operator (aviation sector), Phase of Flight, Time of the Day, Reported Damage, Sources of Report, Damage and Phase of Flight, Damage and Time of the Day, and Quarter of the Year. The researchers selected the date range from January 1st, 2011, through December 31st, 2016. We selected this range because we could not find aircraft operation data before 2011 at the studied airports. In addition, CENIPA was still processing wildlife strike data from 2017.

The Air Traffic Operations Annual Reports (DECEA, 2013, 2016, 2017) were used to retrieve the number of aircraft movements at each specific airport. One aircraft movement refers to one takeoff, one landing, one touch-and-go, one missed approach, or one itinerant traffic (DECEA, 2016). Similar to the procedures used with the Brazilian NWSD, a six-year data range from January 1st, 2011 to December 31st, 2016, was selected from Air Traffic Operations Annual Reports. The quarters of the year were defined by the calendar year: January-March, April-June, July-September, and October-December.

Regarding research question 4, it is important to note that the number of aircraft movements by the four periods of the day was not available in the DECEA reports (DECEA, 2013, 2016, 2017). Interestingly, the DECEA (2016, 2017) reports provided data regarding the average, minimum, and maximum number of aircraft movements per hour of the day in 2015 and 2016 at the three studied airports. To facilitate estimating the number of movements by period of the day, researchers defined dawn from 05:00 to 06:00am, day from 06:00am to 5:00pm, dusk from 5:00 to 6:00pm, and night from 6:00pm to 05:00am. Researchers then estimated the number of aircraft movements per time of the day (e.g., dawn), during 2015-2016, based upon the maximum number of aircraft movements per hour in Guarulhos, Brasília, and Galeão airports (DECEA, 2016, 2017). Similarly, researchers investigated, using the Brazilian NWSD (CENIPA, 2018), the number of strikes per period of the day during 2015-2016 (e.g., dawn). Researchers then calculated the number of wildlife strikes per 100,000 aircraft operations per time of the day (e.g., dawn) at Guarulhos, Brasília, and Galeão, during 2015-2016, using data from CENIPA (2018).

Data analysis

Based on the proposed research questions, descriptive data analysis was first adopted to provide an intuitive and overall trend of wildlife strikes at and around Guarulhos, Brasília, and Galeão airports. Initially, research question one was answered by exploring descriptive data such as wildlife strikes and type of operator, damaging wildlife strikes per time of the day, and damaging wildlife strikes per phase of flight. Several factors affect the risk of wildlife strikes (Belant & Ayres, 2014; Cleary & Dolber, 2005), including the number of aircraft movements (Dolbeer et al., 2016; Wang & Herricks, 2012). To take into account the correlation between the number of wildlife strike reports and the number of aircraft movements, researchers used the wildlife-strike index in this study, and defined the wildlife-strike index as the number of wildlife strike reports per 100,000 movements.

To answer research question two, the researchers sorted the data and calculated the wildlife-strike index (2011-2016) in Guarulhos, Brasília, and Galeão airports. In order to answer research question 3, researchers first sorted the data and calculated the number of wildlife-strike index per quarter of the year at the three studied airports. After that, researchers used a one-way analysis of variance test to investigate whether there was a statistically significant difference between the number of wildlife strikes per quarter of the year at each airport. The one-way ANOVA is a technique used to compare the means of more than two groups of sample data based on F distribution (Privitera, 2015). Given the limited sample size and the same group sizes in this study, one-way ANOVA test is generally robust to the assumption of normality and homogeneity of variance.

For research question 4, descriptive analysis was initially conducted to explore the characteristics of wildlife strike reports in the four periods of the day using the available data. As previously noted, the DECEA (2016, 2017) reports provided the minimum, the maximum, and the average number of aircraft movements by hour at the three studied airports during 2015-2016. Using these figures, researchers estimated the number of aircraft movements per period of the day during this time period based upon the maximum number of aircraft movements per hour of the day. Researchers also investigated the number of wildlife strikes at the three studied airports, per period of the day, during 2015-2016 period. Using those figures, researchers calculated an estimated number of wildlife strikes per 100,000 aircraft movements, per period of the day during 2015-2016.

Results

From 2011 through 2016 there were 10,525 wildlife strikes in Brazil that were reported to CENIPA (CENIPA, 2018). There were no fatalities reported resulting from wildlife strikes during this time period in Brazil. Ten accidents resulted in injuries to 13 persons, none of those strikes occurred at or around the studied airports (Oliveira et al., 2017). During this period, the number of occurrences increased from 1,451 to 2,196 when comparing years 2011 and 2016. Of these 10,525 reported strikes, there were 9,989 that involved birds (95% of total), 282 for terrestrial mammals, 105 for reptiles, and 147 for bats. Seventy-two percent (7,606) of the strikes involved commercial aircraft, followed by general aviation aircraft with 768, and military aircraft with 668 incidents. The remaining 1,483 strikes did not indicate the operator. Damage to aircraft was reported for 1,922 strikes and are divided into period of day: 1,321 incidents occurred during the day, 492 at night, 49 at dawn, and 60 at dusk. Most reported wildlife strikes occurred during the landing phase of flight and the majority of the damaging strikes happened during takeoff (see Table 01). Almost twice (6,442) as many wildlife strikes occurred during the day, compared to 3,197 reported strikes at night. Dawn and dusk each accounted for 4% of strikes. Between 2011 and 2016, airport personnel filed 49% (3,246) of the strike reports, aviation safety professionals 24.4% (1,613), flight crews 10.2% (675), air traffic control (ATC) personnel 9.8% (646), and maintenance professionals 6.6% (435). The 3,910 wildlife strike reports that did not indicate the source of report were excluded from the analysis.

Table 1. *Number of wildlife strikes, and damaging wildlife strikes per phase-of-flight in Brazil (2011-2016)*

Phase of Flight	**Number of Strikes**	**Damaging Strikes**
Taxi	136	13
Takeoff	2,631	579
Climb	250	108
Cruise	75	39
Descent	113	41
Approach	1,027	317
Landing	3,314	498
LAN	0	70
Not reported	2,979	270
Total	10,525	1,922

Note. LAN stands for low-altitude navigation flight, a flight mission performed by the armed forces in Brazil in which aircraft fly at low altitudes outside the airport environment for different purposes (e.g., military training) (CENIPA, 2017b).
Note 2. Source: Brazilian NWSD (CENIPA, 2018).

For each of the three airports in the study, the 2011-2016 data was analyzed to develop descriptive statistics. There were 669, 597, and 499 reported wildlife strikes in Guarulhos, Brasília, and Galeão, respectively. Among those, 512 strikes in Guarulhos, 376 in Brasília, and 258 in Galeão involved birds. The number of reported wildlife strikes increased 52.32 %, 65.86%, and 81.52% from 2011 through 2016, in Guarulhos, Brasilia, and Galeão international airports, respectively. During the same period, the number of aircraft operations declined from 274,875 to 272,141 in Guarulhos, from 201,502 to 172,483 in Brasilia, and from 148,711 to 131,168 in Galeão. Table 2 shows the year and the number of wildlife strike reports per 100,000 aircraft movements at Guarulhos, Brasília, and Galeão.

Table 2
Number of wildlife strikes, aircraft movements, and wildlife-strike index at Guarulhos, Brasília, and Galeão airports (2011-2016)

	Guarulhos			**Brasília**			**Galeão**		
Year	**Strikes**	**Aircraft Movements**	**Index**	**Strikes**	**Aircraft Movements**	**Index**	**Strikes**	**Aircraft Movements**	**Index**
2011	79	274,875	28.74	81	201,502	40.19	75	148,711	50.43
2012	117	279,036	41.93	115	203,952	56.38	67	166,053	40.35
2013	125	290,433	43.04	104	195,260	53.26	86	155,126	55.44
2014	80	311,230	25.71	76	200,001	37.99	64	151,282	42.31
2015	117	299,457	39.07	98	199,246	49.18	115	141,549	81.24
2016	151	272,141	55.49	123	172,483	71.31	92	131,168	70.13

Note: Sources: Aircraft movement data from DECEA (2013, 2016, 2017) and wildlife strike data from CENIPA (2018).

Interestingly, researchers could not find a consistent trend regarding wildlife strikes and the number aircraft operations during the period studied. We would expect a positive relationship between the number of aircraft operations and the number of wildlife strikes throughout the period studied. However, findings indicated this trend did not occur at the three studied airports (see Table 2). Researchers further investigated the wildlife strike data in Guarulhos, Brasília, and Galeão airports to obtain information regarding type of operator, damage to aircraft per time of the day, phase-of-flight, and damage to aircraft per phase of flight. The majority of the reported strikes involved commercial operators, followed by GA aircraft. Table 3 depicts the number of reported strikes per type of operator from 2011 through 2016 at the three studied airports. The majority of the reported strikes occurred during the day in Guarulhos (414), in Brasília (440), and in Galeão (334). Similarly, the majority of damaging strikes occurred during the day in the three studied airports (see Tables 4; 5; and 6). Even though 41% of the reported strikes in Guarulhos occurred during the landing phase of flight, most damaging strikes happened during takeoff roll. In Brasília and Galeão airports, the majority of the reported strikes and damaging strikes occurred during takeoff roll. Table 7 shows the number of strikes and the number of damaging strikes per phase of flight in Guarulhos, Brasília, and Galeão airports.

Table 3

Number of reported wildlife strikes per type of operator in Guarulhos, Brasília, and Galeão airports (2011-2016)

Branch	Guarulhos	Brasília	Galeão	Total
Commercial	603	325	457	1,385
GA	10	13	9	32
Military	3	10	7	20
Unknown	53	249	26	328
Total	669	597	499	1,765

Note: Source: CENIPA (2018).

Table 4

Number of reported wildlife strikes and damaging strikes per time of the day in Guarulhos (2011-2016)

GUARULHOS								
	Dawn		**Day**		**Dusk**		**Night**	
	Strikes	Damaging Strikes	Strikes	Damaging Strikes	Strikes	Damaging Strikes	Strikes	Damaging Strikes
2011	6	1	38	12	3	1	32	11
2012	7	1	78	25	5	0	27	10
2013	6	2	79	14	3	0	37	2
2014	3	1	46	9	5	1	26	2
2015	5	0	72	14	5	0	35	3
2016	5	1	101	28	3	0	42	9
Total	32	6	414	102	24	2	199	37

Note: Source: CENIPA (2018).

Table 5

Number of reported wildlife strikes and damaging strikes per time of the day in Brasília (2011-2016).

BRASÍLIA								
	Dawn		**Day**		**Dusk**		**Night**	
	Strikes	Damaging Strikes	Strikes	Damaging Strikes	Strikes	Damaging Strikes	Strikes	Damaging Strikes
2011	3	1	58	9	6	1	14	5
2012	2	0	95	15	5	1	13	0
2013	6	0	77	8	4	0	17	1
2014	6	1	49	3	4	0	17	1
2015	3	0	73	8	2	0	20	3
2016	1	0	88	8	1	0	33	11
Total	21	2	440	51	22	2	114	21

Note: Source: CENIPA (2018).

Table 6

Number of reported wildlife strikes and damaging strikes per time of the day in Galeão (2011-2016)

GALEÃO								
	Dawn		**Day**		**Dusk**		**Night**	
	Strikes	Damaging Strikes	Strikes	Damaging Strikes	Strikes	Damaging Strikes	Strikes	Damaging Strikes
2011	5	2	52	16	4	1	14	6
2012	4	2	43	24	2	1	18	7
2013	4	0	60	24	1	0	21	1
2014	3	0	40	13	4	1	17	1
2015	9	0	70	19	2	1	34	5
2016	4	1	69	26	0	0	19	2
Total	29	5	334	122	13	4	92	22

Note: Source: CENIPA (2018).

Table 7

Number of reported wildlife strikes and damaging strikes per phase of flight in Guarulhos, Brasília, and Galeão airports (2011-2016)

	Guarulhos		**Brasília**		**Galeão**	
Phase of Flight	**Strikes**	**Damaging Strikes**	**Strikes**	**Damaging Strikes**	**Strikes**	**Damaging Strikes**
Taxi	5	1	2	1	3	2
Takeoff	172	48	130	33	177	63
Climb	17	9	14	10	19	21
Cruise	2	1	0	0	1	0
Descent	10	3	4	3	7	2
Approach	60	12	28	7	53	19
Landing	187	32	113	19	150	30
LAN	2	2	1	0	1	1
Not reported	216	39	305	3	88	15
Total	669	147	597	76	499	153

Note. LAN stands for low-altitude navigation flight, a flight mission performed by the armed forces in Brazil in which aircraft fly at low altitudes outside the airport environment for different purposes (CENIPA, 2017b).

Note 2: Source: CENIPA (2018).

Note 3. Researchers considered only the strike reports in which the phase of flight was informed.

During the specified period, airport personnel filed 19.5% of the strike reports in Guarulhos, 71.3% in Brasília, and 56.9% in Galeão. Wildlife strike reports in which the source of report was not informed were excluded from the analysis. See Table 8 for the professional filing the wildlife strike report.

Table 8

Sources of the wildlife strikes reported in Guarulhos, Brasília, and Galeão (2011-2016)

Source of Report	Guarulhos	Brasília	Galeão
Airport Operations	192	258	192
Flight Crews	15	19	15
ATC	35	1	35
Maintenance	30	17	30
Aviation Safety Personnel	65	67	65
Others	162	235	162

Note: Source: CENIPA (2018).

Note 2. Researchers considered only reported strikes in which the identification of the source of report was provided.

In order to investigate the possible impact of seasonal influence on the frequency of reported wildlife strikes, the collected wildlife strike data were categorized by quarters of the year. As previously noted, researchers defined the quarters of the year by the calendar year: January-March, April-June, July-September, and October-December. The summary statistics of wildlife-strike index per quarter of the year is shown in Table 9.

Table 9

Summary statistics of wildlife strike index at three airports in four quarters from 2011 to 2016

SBBR	**Mean**	**Median**	**Stand Deviation**	**Max**	**Min**
Q1	52.33	55.73	17.56	72.97	30.76
Q2	62.08	71.05	22.08	84.51	32.28
Q3	46.08	48.92	13.82	60.67	28.86
Q4	45.87	38.29	26.71	90.92	18.16
SBGL					
Q1	52.35	55.87	14.93	70.07	30.00
Q2	75.31	63.95	33.17	135.72	45.37
Q3	44.88	40.81	15.79	70.53	28.96
Q4	54.64	48.71	28.50	106.78	24.78
SBGR					
Q1	48.27	48.19	19.51	72.49	19.81
Q2	40.67	29.67	23.52	71.84	21.12
Q3	30.46	30.38	3.72	34.26	25.54
Q4	36.75	30.82	12.77	56.17	25.01

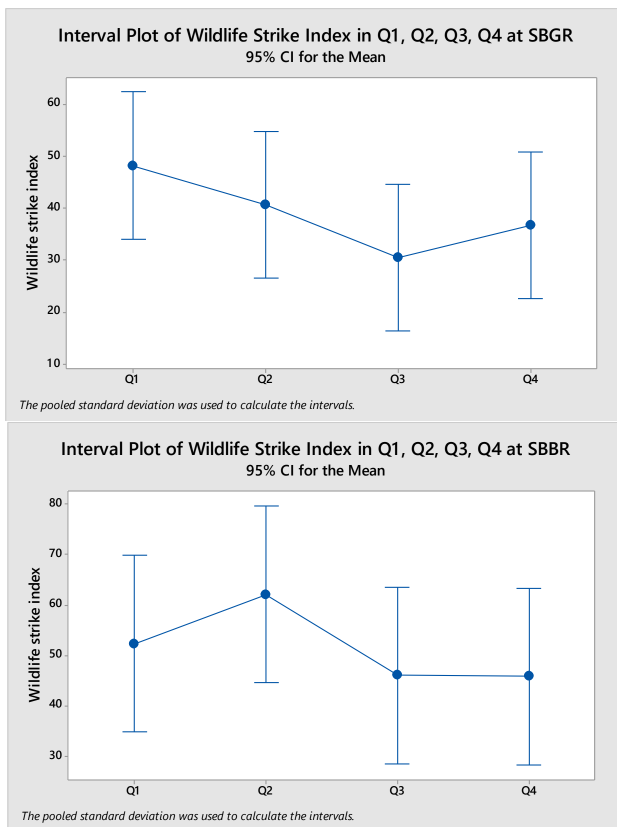
Note: Wildlife-strike index refers to the number of wildlife strike reports per 100,000 movements
Note 2: Source: CENIPA (2018).

The one-way ANOVA was used to investigate whether there was a statistically significant difference in reported wildlife-strikes per 100,000 movements between the four quarters of the year, in each of the studied airports, from 2011 to 2016. Researchers assumed the null hypothesis that all means of wildlife strike index in each quarter were equal. The alternative hypothesis was that at least one mean of wildlife strike index would be different from others. A critical value $\alpha=0.05$ was used in the test. The test results of three airports are summarized in Table 10 and Figure 1.

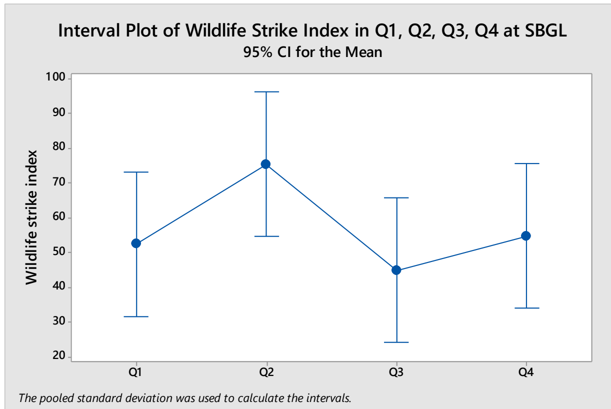
Table 10
Results of one-way ANOVA test of wildlife-strike index of four quarters from 2011-2016

One-way ANOVA test of the wildlife strike index of four quarters (2011-2016)		
Airport	**F-value**	**P-value**
Guarulhos	1.2	0.335
Brasília	0.82	0.5
Galeão	1.71	0.198

Note. Critical value of significance α=0.05



(a) (b)



(c)

Figure 1 Output of one-way ANOVA test of the wildlife-strike index of four quarters (2011-2016), in Guarulhos (a), Brasília (b), and Galeão (c)

Most reported strikes occurred during quarter 1 in Guarulhos, and quarter two in Brasília and Galeão airports. However, there was not a statistically significant difference between the wildlife-strike index per quarter of the year in any of the studied airports (see Table 10). Thus, researchers failed to reject the null hypothesis. In addition to the quarter of the year, the time of a day was another factor investigated regarding reported wildlife strikes at and around the studied airports. These two indicators of time could provide aviation stakeholders invaluable information regarding the probability of wildlife strikes. Therefore, aviation stakeholders could adopt appropriate countermeasures according to the time variables.

The number of reported wildlife strikes during the day is much higher than the other three periods of a day in the studied airports. Similarly, analysis of wildlife data indicates that the number of damaging strikes is also higher during the day. The descriptive statistics of the number of wildlife strike and damaging strike reports by the time of a day is shown in Table 11.

Table 11

Number of wildlife strikes, and damaging wildlife strikes per time of the day in Guarulhos, Brasília, and Galeão airports (2011-2016)

	Guarulhos		**Brasília**		**Galeão**	
Time of the Day	Strikes	Damaging Strikes	Strikes	Damaging Strikes	Strikes	Damaging Strikes
Dawn	32	6	21	2	29	5
Day	414	102	440	51	334	122
Dusk	24	2	22	2	13	4
Night	199	37	114	21	123	22
Total	669	147	597	76	499	153

Note: Source: CENIPA (2018).

It is important to notice that the data shown in Table 11 reflect the absolute number of wildlife strikes, not the wildlife-strike index used in previous analysis due to the lack of recorded aircraft movements in different periods of the day for the entire period studied. Therefore, these results fail to consider the possible influence of the number of aircraft movements in each period. In this case, more aircraft movements during the day time might result in more wildlife strike reports and also more damaging strikes (Wang & Herricks, 2012). Based on the maximum number of aircraft movements per hour (DECEA, 2015, 2016), as explained in the data collection section of this study, researchers estimated the number of aircraft movements per period of the day at each studied airport during 2015-2016. Considering the number of reported wildlife strikes per period of the day at each airport, during 2015-2016, researchers developed a wildlife-hazard index for the four periods of the day in the three studied airports (2015-2016) (see Table 12).

Table 12

Number of aircraft movements per period of the day, number of wildlife strikes per period of the day, and wildlife-strike index per period of the day in Guarulhos, Brasília, and Galeão airports, during 2015-2016

	Guarulhos			**Brasília**			**Galeão**		
Period of day	**Aircraft Movements**	**Total Strikes**	**Index**	**Aircraft Movements**	**Total Strikes**	**Index**	**Aircraft Movements**	**Total Strikes**	**Index**
Dawn	23,098	10	43.29	9,125	4	43.84	8,865	13	146.64
Day	412,502	173	41.94	291,062	161	55.31	249.816	138	55.24
Dusk	37,907	8	21.11	29,930	3	10.02	18,719	2	10.68
Night	355,301	77	21.67	229,741	53	23.07	182,865	54	29.53

Note. Source of average aircraft movements per time of the day: DECEA (2016, 2017).
Note 2. The DECEA (2016, 2017) reports do not provide the exact number of aircraft movements by period of the day, only the average number of movements by hour. Researchers established the number of aircraft movements per time of the day, from 2015 through 2016, based upon the **maximum** number of aircraft movements by time of the day.
Note 3. Sources: Aircraft movement data from DECEA (2016, 2017) and wildlife strike data from CENIPA (2018).

Discussion

The wildlife hazard problem must first be understood before it can be solved. A vital first step toward understanding and solving the multidimensional wildlife hazard problem is “the collection and analysis of data from actual wildlife strike events” (Cleary & Dolbeer, 2005, p. 5). Researchers analyzed wildlife strike data from 2011 through 2016 from the three busiest airports in Brazil: Guarulhos, Brasília, and Galeão international airports. The CENIPA NWSD and the Air Traffic Operations Annual Reports (DECEA, 2013, 2016, 2017) were used as the major data resources. Additionally, researchers used the Brazilian annual wildlife strike summary reports (CENIPA, 2012, 2013, 2014, 2015, 2016) for additional data and information.

Aircraft accidents and incidents due to wildlife strikes is a serious safety and economic problem in Brazil. As previously noted, CENIPA (2017a) estimated wildlife strikes cost the Brazilian aviation industry to average US$65 million per year. Considering that only approximately 30% of the strikes are reported to CENIPA (CENIPA, 2017a), that some reports providing costs estimates are often filed before the aircraft downtime and damage have been fully assessed (M. Maranhão, personal communication, March 30, 2018), and that some costs are frequently delayed and not too obvious (Dolbeer, 2006), it is believed that the current figures underestimate the economic magnitude of the problem.

From 2011 through 2016 the number of reported wildlife strikes in the three studied airports have steadily increased. On the other hand, the number of aircraft movements has slightly varied over that period (see Table 02). The rate of reported strikes per 100,000 aircraft movements increased at the three studied airports, from 28.74 to 55.49 in Guarulhos, from 40.19 to 71.31 in Brasília, and from 50.43 to 70.13 in Galeão. Reasonable explanations for the increasing in reported wildlife strikes could include increased wildlife activity at and around the studied airports. It may also have occurred due to enhanced safety awareness by aviation professionals deriving from safety programs by CENIPA (CENIPA, 2017a; 2018). Moreover, successful wildlife hazard management programs by airport operators could be leading to more strikes being reported.

The majority of the reported strikes involved commercial operators both in Brazil as a whole, as well as at the studied airports. This could occur because the number of commercial aircraft operations is higher than GA and/or military aircraft operations (DECEA, 2013, 2016, 2017). Another plausible explanation could be that commercial aviation professionals are reporting more strikes than the GA and military operators. Previous studies (Dolbeer, Begier, & Wright, 2008; Dolbeer et al., 2016; Schwarz, Belant, Martin, DeVault, & Wang, 2014) have indicated that general aviation pilots are less likely to report wildlife strikes. Airport personnel reported 38% of the strikes in

Guarulhos, 71.27% in Brasília, and 56.98% in Galeão (see Table 08). Flight crews reported only 2.92% of the strikes in Guarulhos, 5.24% in Brasília, and 4.45% in Galeão. It is suggested that CENIPA and other aviation organizations should develop safety efforts targeting pilots in order to increase the reporting of strikes by such an important aviation stakeholder. Flight crews are frequently the last opportunity to mitigate a mishap due to wildlife (Mendonca & Carney, 2018). Most importantly, their reporting of current strikes and near misses, in accordance with the CENIPA (CENIPA, 2017) guidelines, is paramount to the safety of the Brazilian aviation industry (DeFusco et al., 2015; Mendonca, 2008).

Approximately 59% of the 10,525 reported strikes in Brazil occurred during the arrival phases of flight (descent, approach, and landing), compared to 38.17% of the incidents that took place during the departure phases of flight (takeoff roll and initial climb-out). Yet, 51.85% of the 1,922 damaging strikes occurred during the arrival phases, especially during landing (30.14%) (see Table 1). Fifty-six percent of the reported strikes in Guarulhos, 49.65% in Brasília, and 51.09% Galeão, respectively, occurred during the arrival phases of flight (see Table 7). However, most damaging strikes occurred during the departure phases of flight in Guarulhos (52.78%), Brasília (58.91%), and Galeão (60.87%). The faster rotation of the aircraft engines (Dolbeer, 2007; Avrenly & Dempsey, 2014) as well as the increasing aircraft airspeed (Eschenfelder, 2005; Nicholson & Reed, 2011; O'Callaghan, n.d.) during the departure phases of flight could explain these differences.

The risk of accident due to wildlife is affected by different variables, including the number of aircraft movements (Dolbeer et al., 2016; Wang & Herricks, 2012), the effectiveness of safety programs by airport operators (Cleary & Dickey, 2010; Cleary & Dolbeer, 2005), wildlife migratory activities (Drey, Martin, Belant, DeVault, & Blackwell, 2014), actions by pilots (MacKinnon, 2004; Mendonca, 2017; Mendonca & Carney, 2018; Nicholson & Reed, 2011), and weather and seasonal changes (Belant & Ayres, 2014). A one-way Anova statistical test was conducted to determine whether there were significant differences in reported bird strikes per 100,000 movements between the four quarters of the year, at Guarulhos, Brasília, and Galeão airports. The one-way analysis of variance showed that there was no statistically significant difference between the four quarters of the year in Guarulhos. Nonetheless, descriptive data suggest that the highest rate of wildlife strikes per 100,000 aircraft movements occurred during Q2 in Brasília and Galeão, and during Q1 in Guarulhos (see Table 9). Airport operators could scale up safety efforts during these periods in order to improve safety. Moreover, increased safety awareness and communication between pilots and air traffic control during these periods could reduce the risk of accidents due to wildlife strikes (Mendonca et al., 2017). It is important to note that researchers could not conduct a similar investigation in a national level (for comparison) considering the lack of information on aircraft movements in some Brazilian airports.

From 2011 through 2016, 61.20% of the 10,525 reported wildlife strikes in Brazil occurred during the day, and 30.37% at night. Similarly, the majority of the reported strikes in Guarulhos (61.88%), Brasília (73.70%), and Galeão (66.94%) also happened during the day. During the period studied, 68.68% of the 1,922 damaging wildlife strikes in Brazil occurred during the day, followed by night (25.59%). Sixty-eight percent of those damaging strikes occurred during the day, compared to 25.55% at night. Following the same trend, the majority of the damaging strikes in Guarulhos (69.39%), Brasília (67.10%), and Galeão (79.74%) occurred during day time. Yet, 25.17% of the damaging strikes in Guarulhos, 27.63% in Brasília, and 14.38% in Galeão occurred at night (see Tables 11 and 12). The suggested highest number of aircraft movements during day, followed by night (DECEA, 2016, 2017), could be one explanation for this difference (Wang & Herricks, 2012).

In fact, in order to have a better understanding about the risk of strikes during the periods of the day, it would be necessary for the researchers to investigate the number of strikes (and damaging strikes) per 100,000 aircrafts movements during each time of the day. The DECEA reports (DECEA, 2013, 2016, 2017) do not include this type of data. However, the DECEA reports (2016, 2017) provided data about the number of aircraft movements per hour of the day. In fact, these reports provided the minimum, the average, and the maximum number of aircraft operations by hour in 2015 (DECEA, 2016) and 2016 (DECEA, 2017). In order to overcome the limitations in the DECEA datasets, researchers considered the number of aircraft operations per time of the day, during 2015-2016, based upon the maximum number of aircraft operations per hour (DECEA, 2016, 2017) in Guarulhos, Brasília, and Galeão. In addition, researchers used the number of wildlife strikes per time of the day in each studied airport during the 2015-2016 period. In that case, the index, number of strikes per 100,000 aircraft operations, should be more conservative and indicate a smaller figure than the real one. As previously noted, researchers defined dawn from 05:00am to 06:00am, day from 06:00am to 5:00pm, dusk from 5:00pm to 6:00pm, and night from 6:00pm to 05:00am.

The majority of wildlife strikes per 100,000 aircraft movements during 2015-2016 occurred at dawn in Guarulhos and Galeão airports, followed by day. In Brasília, the index was higher during the day, followed by dawn (see Table 12). A finding of concern was the number of reported wildlife strikes per 100,000 movements during dawn at Galeão airport. In theory, the probability of a strike at dawn in Galeão is more than 50% higher than the other three periods of the day. Further studies are recommended in order to identify the factors that could be leading to such increased safety risk during dawn in Galeão. Most importantly, aviation stakeholders could evaluate and implement safety risk management strategies (Cleary & Dolbeer, 2005; Cleary & Dickey, 2010) that could reduce the risk of aircraft accidents due to wildlife strikes during dawn.

Management Implications

Wildlife have long been recognized as a serious threat to the Brazilian aviation industry (CENIPA, 2017a; Mendonca, 2008; Oliveira et al., 2017). Several factors have increased the risk of aircraft accidents due to wildlife, including the growing number of in-service aircraft (ANAC, 2017a) and aircraft operations (DECEA, 2013, 2016, 2017).

In 2016, approximately 109.6 million passengers were transported in national and international commercial flights in Brazil (ANAC, 2017). According to the Brazilian Ministry of Transportation and Civil Aviation (2017), this figure is forecast to increase by 3.35% from 2017 to 2035. Moreover, the number of passengers and aircraft movements is forecast to grow by 4.45 % and 3.69% in Guarulhos, by 3.93% and 3.05% in Brasília, and 4.58% and 3.53% in Galeão, respectively, until 2037. Therefore, the risk of aircraft accidents due to wildlife strikes is also likely to increase.

Previous studies (DeFusco et al., 2015; Dolbeer & Barnes, 2017; Dolbeer et al., 2016; Dolbeer & Wright, 2009; Mendonca et al., 2017) have indicated that safety efforts to reduce the risk of wildlife strikes should be supported by current data and information. “A problem that is not understood and well defined cannot be properly managed” (Dolbeer et al., 2016, p. 15). A vital step in the safety management of wildlife hazards to aviation is the collection and analysis of past aircraft incidents and accidents. CENIPA has successfully implemented several strategies to mitigate this threat to aviation safety, including the collection and analysis of wildlife strikes following the ICAO SARPs. This study addressed a gap in the CENIPA efforts by investigating wildlife strike data from 2011 through 2016, from the three busiest commercial airports in Brazil, Guarulhos, Brasília, and Galeão. Findings indicate that from 2011 through 2016 the majority of the reported strikes involved commercial aviation operators followed by GA aircraft. In addition, results indicate there is a need to improve the quantity and quality of strike reports since a high percentage of important data is missing (e.g., costs; phase of flight). An important finding was that the rate of wildlife strikes per 100,000 aircraft movements has increased from 28.49 to 55.49 in Guarulhos, from 40.20 to 71.31 in Brasília 50.43 to 70.13 in Galeão. Additionally, researchers found that most strikes occurred during the arrival phases of flight. However, most damaging strikes occurred during the departure phases of flight.

Quarter one was identified as the time of year in which wildlife-strike reporting was the highest in Guarulhos, and quarter two the highest strike reporting in Brasilia and Galeão airports. Concentrated efforts by key stakeholders should be emphasized prior and during these periods in order to mitigate the risk of aircraft accidents due to wildlife (Cleary & Dolbeer, 2005). An increase in situational awareness by pilots and ATC could also be mitigating factors (Mendonca et al., 2017). Moreover, flight crews can consider these findings while planning their flights and then use appropriate aircraft operating techniques, as suggested by MacKinnon (2004) and Mendonca and Carney (2018), in order to mitigate the risk of wildlife strikes.

Wildlife strike data and information provide the groundwork for national regulations and policies, for the development or enhancement of WHMP, and "for refinements in the development and implementation of integrated research and management efforts to reduce wildlife strikes" (Dolbeer et al., 2016, p. 4). Moreover, they provide a scientific basis for identifying and assessing safety risks; developing, implementing, justifying, and defending mitigation strategies; and for ensuring continuous improvement of the safety process (Mendonca, 2008). Therefore, when reports are filed, relevant information should be provided whenever possible, and should include phase of flight, direct and indirect costs, species identification, time of the day, amount of damage to aircraft components, and time and height of strike. Findings of this project reinforce the need for increased and more detailed wildlife strike reporting by aviation stakeholders in Brazil.

WHMP and SMS are easily integrated. Both WHMP and SMS are proactive safety programs to manage several operational risks, which could include wildlife at and around the airport environment (DeFusco et al., 2015). Yet, both are data-driven, and involve proactive and reactive processes to ensure all hazards can be managed consistently and comprehensively. As previously noted, SMS requirements have been imposed to Brasilia, Galeão, and Guarulhos airports (ANAC, 2016). Data and information in this study could support SMS processes by those airport operators. For instance, wildlife-strike data could be used as key performance indicators as a means to assess the level of safety performance at the airport (ICAO, 2013b). In addition, wildlife-strike data and information could be used during the safety assurance processes to assess whether the current wildlife risk mitigation strategies are achieving their intended SRM reduction targets and objectives, and to monitor for unintended consequences. If necessary, safety strategies should be modified and additional wildlife-risk mitigation controls developed through SRM processes.

It is of interest to aviation stakeholders operating at those three airports as well as the airport operators to understand and use the findings of this study while developing safety risk management strategies. This will allow a better and more efficient allocation of the aviation stakeholders' finite resources. It is important to note that comparison of the reported wildlife strike data from an airport in relation to other airports is not a valid metric (Dolbeer & Begier, 2011). For example, the risks associated with wildlife may vary in hazard severity level among different species (Dolbeer & Wright, 2009). There might be some bias in reporting damaging wildlife strikes and/or strikes with a negative-effect on flight (e.g., aborted takeoff) compared to all strikes (Dolbeer & Begier, 2011). Airports with successful WHMP are more likely to have higher rates of reported strikes. Airports could be located in an inherent wildlife geographic location where the risk of strikes is higher (Drey et al., 2014). Yet, very often strikes that occur outside the airport jurisdiction are reported (e.g., 3,000 feet AGL) as if they had happened at the airport environment (Dolbeer et al., 2016).

There are limitations to this study. The DECEA (2013,2016, 2017) do not provide information about the number of aircraft movements during the four periods of the day. Such data is vital to establish the rate of strike-incidents per 100,000 aircraft operations. Another limitation to this study is the quantity and quality of the reported wildlife strikes (CENIPA, 2016, 2017). For example, the phase of flight was not informed in approximately 33% of the strikes at and around Guarulhos airport. It is important to incorporate such data in the future if they become available. Yet, further studies are recommended to address the incompleteness of strikes reports. Researchers assumed that the reported wildlife strike data, although incomplete, was accurate. Future research should extend this project to other commercial airports in Brazil.

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