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Safety Management of Wildlife Hazards to Aviation: An Analysis of Wildlife Strikes in Part 139 Airports in Florida 2011–2020

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Abstract

Purpose: The purpose of this study was threefold: (1) to investigate wildlife strike reporting trends in Part 139 airports in the state of Florida (2011–2020); (2) to evaluate the existence of a difference in the rate of reported wildlife strikes between the seasons of the year (2011–2020); and (3) to develop information based upon the data analyzed that can be used for the safety management of wildlife hazards in Florida.
Design/methodology: The researchers in this study answered the research questions through the analyses, revision, and evaluation of existing wildlife strike and aircraft operations data. The data analyzed in this study were collected between May 1 and May 20, 2021. The researchers used the Federal Aviation Administration Air Traffic Activity System and the National Wildlife Strike Database to collect information on aircraft operations and reported wildlife strikes, respectively.
Findings: There were 8,977 and 458 wildlife strikes and damaging strikes, respectively, at and around Part 139 airports in Florida from 2011 through 2020. The majority of strikes (62.6%) and damaging strikes (62%) occurred during the arrival phases of flight. The number of strikes increased almost 37% from 2011 ($N = 614$) to 2020 ($N = 837$). Additionally, the number of strikes per 100,000 aircraft operations (wildlife strike index) increased from 18.6 to 28.62 during the same period. Aggregate data indicated the risk of strikes is higher during the fall and summer seasons of the year.
Originality/value: This study provides valuable information by addressing a gap in published wildlife strike government reports and studies using wildlife strike and aircraft operations data at a regional level. Information obtained from the scientific analyses of wildlife strike data is vital for effective wildlife hazard management programs of aviation stakeholders. Findings of this study can be used by airport operators to improve their wildlife strike mitigation efforts. Also, findings can provide the empirical foundation for integrated research and the development of national and regional standards to enhance aviation safety.

Keywords: aviation safety, wildlife strikes, wildlife hazard management

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Introduction

A vital step toward mitigating the risk of aircraft accidents due to wildlife strikes is the collection, analyses, and understanding of wildlife strike data. According to Dolbeer et al. (2021), wildlife strikes are collisions between aircraft and wildlife. For a complete definition of wildlife strikes to aircraft, the reader is referred to Federal Aviation Administration (FAA) advice (FAA, 2013). Previous studies have focused on gathering and analyzing wildlife encounters over the entire United States (Anderson et al., 2015; DeVault et al., 2018; Dolbeer, 2020; Dolbeer et al., 2021), this way not considering regional and other factors such as bird migration patterns, local wildlife populations, and seasons of the year as they may have a different impact on the risk of strikes in individual regions (Defusco & Unangst, 2013). Dolbeer et al. (2021), Drey et al. (2014), and Mendonca et al. (2020) have advocated for the analyses of wildlife strike data at a regional level. Findings of those studies can provide the foundation for accident prevention efforts. The wildlife species, their population sizes, and their daily and seasonal occurrences at and around airports, for example, vary drastically across the United States. Thus, the effective safety management of wildlife hazards to aviation requires an approach that will look at the specific wildlife patterns as they relate to a specific region (FAA, 2020a).

Analyses of wildlife strike data specifically focused on airports certified under the Title 14 Code of Federal Regulations Part 139[1] (Electronic Code of Federal Regulations, 2021) in the state of Florida will permit a more effective safety approach to these occurrences. The goal of this study is to supplement the FAA wildlife strike annual reports (Dolbeer et al., 2021; FAA, 2022) with information derived from the analysis of wildlife strike reports from Part 139 airports in Florida from 2011 through 2020. Specifically, the purpose of this study is threefold: (1) to investigate wildlife strike reporting trends in Part 139 airports in the state of Florida (2011–2020); (2) to investigate if there is a statistically significant difference in the wildlife strike index[2] for Part 139 airports in the state of Florida from 2011 to 2020 among the four seasons of the year; and (3) to develop information based upon the data analyzed that can be used for the safety management of wildlife hazards in Florida.

Literature Review

The aviation industry plays an important role in the American economy, being responsible for approximately 10% of the total U.S. economic activities (FAA, 2020a). According to the FAA (2020a), the civil aviation industry also generates approximately 10.9 million jobs and contributes to 5.2% of the United States' gross domestic product. As a result of the COVID-19 pandemic, the number of aircraft operations declined by approximately 3.5% in 2020 compared to 2019 (FAA, n.d.-a). Nonetheless, the number of aircraft operations in the United States is forecast to increase from approximately 44 million to over 60 million operations in the next two decades.

Wildlife strikes to aviation are a growing safety and economic concern in the USA. Aircraft accidents and incidents resulting from strikes across the United States from 1990 to 2020 have resulted in $768.9 million in direct repair costs, $101.3 million in other indirect costs, and approximately 1,154,221 hours of aircraft downtime. These values have indicated an average of 96.9 hours of aircraft downtime per wildlife strike and a repair cost of $163,005 per damaging occurrence. According to Dolbeer et al. (2021), a wildlife strike that has resulted in significant damage to an aircraft is more likely to be reported. It is important to note that only approximately 47% and 91% of wildlife strikes involving general aviation (GA) and commercial transport aircraft, respectively, are reported (FAA, 2020b). Yet, reports providing cost estimates are frequently submitted before aircraft downtime, damage, and other associated costs have been fully assessed. Therefore, information on wildlife strikes and associated costs is believed to significantly underestimate "the economic magnitude of the problem" (Dolbeer et al., 2021, p. 32).

From 2011 through 2020 there were 133,275 wildlife strikes reported through the U.S. National Wildlife Strike Database (NWSD) (FAA, 2021b). The majority of these strikes occurred during the day (N = 44,347), while 16.9% (N = 22,582) occurred at night. Among these strikes, 36.0% (N = 47,974) occurred during the arrival phases of flight (descent, approach, and landing roll), while 23,955 (18.0%) occurred during the departure phases of flight (take-off roll, climb, and departure). Almost 43.3% (N = 57,743) of the total strike reports did not contain information on the phase of flight in which the event occurred. During this period there were 11 human fatalities resulting from wildlife strikes.

National wildlife strike data obtained from 2011 to 2020 indicate that 32.7% (N = 43,549) of the reported strikes had an unknown type of operator, 65.3% (N = 87,069) involved commercial aircraft, and 2% (N = 2,657) involved GA operators. Approximately 3% (N = 2,750) of all strikes occurred during dawn or dusk, while 64.4% (N = 58,743) of those strikes occurred during daytime. Between 2011 and 2020, 6,540 (4.5%) of the 142,668 wildlife strikes reported through the NWSD resulted in some level of damage to aircraft. Moreover, information obtained from the analyses of wildlife strike data has indicated a significant increase in the number of wildlife

[1]Part 139—Certification of Airports: includes airports that "serve scheduled and unscheduled air carrier aircraft with more than 30 seats; serve scheduled air carrier operations in aircraft with more than 9 seats but less than 31 seats; and the FAA Administrator requires to have a certificate" (FAA, 2023).

[2]Wildlife strike index is the number of wildlife strikes per 100,000 aircraft operations.

strikes as well as damaging wildlife strikes since 2010. For example, the number of strikes and damaging strikes increased by 75% and 41%, respectively, from 2011 through 2019 in the USA. There was an 84% increase, from 9,241 to 17,050, in the number of wildlife strikes involving commercial aircraft between 2009 and 2019 (Dolbeer et al., 2021). In the same period, the number of aircraft operations rose from 25.45 million to 26.21 million (FAA, n.d.-a). All those factors interact to form the basis of this safety issue that needs effective mitigation by aviation stakeholders.

The reasons for this ever-increasing safety and economic concern are dynamic and complex. Successful environmental programs by government and private organizations have contributed to impressive increases in wildlife populations at and around airports (DeFusco & Unangst, 2013). For example, the population of sandhill cranes, considered the seventh most hazardous wildlife species to aviation operations in the USA (Dolbeer, 2020), "increased over 3-fold from about 200,000 to 700,000 birds from 1990–2020" (Dolbeer et al., 2021, p. 20). Other reasons for the increased risk of wildlife strikes include birds becoming increasingly adapted to urban areas, quieter turbofan engines decreasing animals' ability to detect an incoming aircraft (Cleary & Dolbeer, 2005), and an increase in the number of aircraft operations over the years (Bureau of Transportation Statistics, 2020).

The scientific analysis of wildlife strike data is paramount for aviation safety. Information obtained from methodical analyses of wildlife strikes may provide the foundation for the development and implementation of safety management efforts to mitigate the risk of aircraft accidents resulting from strikes (Altringer et al., 2021). With the large increase in the number of wildlife strikes and aircraft operations over the past decade, the FAA (2020c) has recommended further actions by airport operators to mitigate the risk of wildlife strikes.

The FAA has published annual reports providing information obtained from the scientific analyses of wildlife strikes in the USA (Dolbeer et al., 2021). However, wildlife strike data and information in these reports reflect strikes at a national level. Nonetheless, studies considering a regional scope may provide further insight on the highly variable conditions (e.g., migration patterns, weather, local habitats) that may affect the risk of wildlife strikes across the United States (Drey et al., 2014, Pfeifer et al., 2018). This study will address these regional considerations as this perspective may provide additional information to reported wildlife strike trends, especially as it relates to the seasons of the year.

This study was an attempt to answer the following research questions:

1. What are the wildlife strike descriptive statistics (type of operator, time of day, damage level, part struck, and phase of flight) in Part 139 airports in the state Florida from 2011 to 2020?
2. What is the number of wildlife strike reports per 100,000 operations for each season of the year during 2011–2020 in Part 139 airports in the state of Florida?
3. Is there a difference in the wildlife strike index between each season of the year from 2011 to 2020 in Part 139 airports in the state Florida?

Methodology

Data Collection

The researchers in this study answered the research questions through the analyses, revision, and evaluation of the existing wildlife strike and aircraft operations data. The data analyzed in this study were collected between April 1 and April 20, 2021. We used the FAA Air Traffic Activity System (ATADS) (FAA, 2021a) and the FAA NWSD (FAA, 2021b) to collect information on aircraft operations and reported wildlife strikes, respectively. These data sets are available to the public and can be accessed electronically. To accurately analyze the reported wildlife strikes considering the seasons of the year, data were obtained ranging from December 21, 2010, until December 20, 2020.

The researchers determined all the Part 139 airports in the state of Florida by referring to the Part 139 Airport Certification Status List[3] (FAA, 2021c). After determining the relevant airports to the study (see Table 1), the researchers referred to the ATADS (FAA, 2021a) database to obtain the number of aircraft operations per season of the year from December 21, 2010, to December 20, 2020. Florida Keys Marathon International Airport and Eglin Air Force Base/ Destin-Fort Walton Beach Airport were not included in this research study since aircraft operations data were not available for these airports. We used the NWSD (FAA, 2021b) to obtain the number of reported wildlife strikes that occurred at and within the vicinities of the selected Part 139 airports in Florida during the same period. The data obtained from this database were filtered by season of the year, type of operator, time of day, damage level, part struck, and phase of flight. Wildlife strikes that resulted in at least some damage to the aircraft were considered as damaging strikes. The percentage of strikes obtained for the part struck considered only the strikes with a known part struck. It is important to mention that in order to answer research question 1, we also collected wildlife strike data as well as aircraft operations data from January 1, 2011, through December 31, 2020. Aircraft operations are defined as:

> The number of arrivals and departures from the airport at which the airport traffic control tower is located. There are two types of operations: local and itinerant. 1. Local

[3]Part 139 Airport Certification Status List—the document is electronically published on faa.gov and allows users to filter fully certified airports by state.

Table 1
Part 139 airports in the state of Florida.

Identifier	Airport name	City
APF	Naples Municipal Airport	Naples, FL
DAB	Daytona Beach International Airport	Daytona Beach, FL
ECP	Northwest Florida Beaches International Airport	Panama City, FL
EYW	Key West International Airport	Key West, FL
FLL	Fort Lauderdale/Hollywood International Airport	Fort Lauderdale, FL
GNV	Gainesville Regional Airport	Gainesville, FL
JAX	Jacksonville International Airport	Jacksonville, FL
LAL	Lakeland Linder International Airport	Lakeland, FL
MCO	Orlando International Airport	Orlando, FL
MIA	Miami International Airport	Miami, FL
MLB	Melbourne International Airport	Melbourne, FL
OCF	Ocala International Airport–Jim Taylor Field	Ocala, FL
PBI	Palm Beach International Airport	West Palm Beach, FL
PGD	Punta Gorda Airport	Punta Gorda, FL
PIE	Saint Petersburg–Clearwater International Airport	Saint Petersburg–Clearwater, FL
PNS	Pensacola International Airport	Pensacola, FL
RSW	Southwest Florida International Airport	Fort Myers, FL
SFB	Orlando Sanford International Airport	Orlando, FL
SGJ	Northeast Florida Regional Airport	Saint Augustine, FL
SRQ	Sarasota/Bradenton International Airport	Sarasota–Bradenton, FL
TIX	Space Coast Regional Airport	Titusville, FL
TLH	Tallahassee International Airport	Tallahassee, FL
TPA	Tampa International Airport	Tampa, FL
VRB	Vero Beach Regional Airport	Vero Beach, FL

> operations are those operations performed by aircraft that remain in the local traffic pattern, execute simulated instrument approaches or low passes at the airport, and the operations to or from the airport and a designated practice area within a 20-mile radius of the tower. 2. Itinerant operations are operations performed by an aircraft […] that lands at an airport, arriving from outside the airport area, or departs an airport and leaves the airport area. (FAA, n.d.-b)

Due to the yearly variations in the start of each season of the year, this study assumed that all seasons started and ended at the same day of the year (see Table 2).

The types of aircraft operator obtained from the ATADS (FAA, 2021a) and NWSD (FAA, 2021b) databases were adjusted to fit the following categories: commercial, GA, military, or unknown. Commercial operators included all operators but privately owned aircraft, and government operators. It is noteworthy to mention that this study does not contain wildlife strike data from military aircraft since that information is not available in the NWSD. The ATADS provides information about itinerant and local aircraft operations. Itinerant aircraft operations are subdivided in commercial, GA, and military. For local aircraft operations, the ATADS provides data for military and civil aircraft operations. However, this database does not distinguish between GA and commercial operations regarding local civil aircraft operations. Local aircraft operations are classified as either military or civil. For this reason, the same ratio of GA (38%) and commercial operators (62%) for itinerant operations was assumed to determine the number of local aircraft operations for GA and commercial operators, respectively.

Table 2
Average season start date.

Season	Start date	Average duration (days)
Winter	December 21	89
Spring	March 20	92
Summer	June 20	94
Fall	September 22	90

The times in which dawn, day, dusk, and night start and end vary significantly throughout the year. To account for these variations, the researchers assumed a constant local time for the start and end time of each day. These values were obtained by determining the beginning of civil twilight, sunrise, sunset, and end of civil twilight at the geographic center of the state of Florida using the FAA website (FAA, n.d.-c). The National Oceanic and Atmospheric Administration (NOAA) definitions of dawn, day, dusk, and night were used for the purpose of this study (NOAA, n.d.). Table 3 shows the established start time for each part of the day and their duration in minutes for the purpose of this study.

Data Analysis

Using the parameters established above, the researchers grouped the obtained data in their respective years

Table 3
Time of day—start time.

Phase of day	Start time	Duration (minutes)
Dawn	05:46:00 a.m.	24
Day	06:11:00 a.m.	728
Dusk	06:19:00 p.m.	24
Night	06:43:00 p.m.	664

(2011–2020). We also organized these data considering the seasons of each year using Microsoft Excel. Additionally, we organized the collected data considering the type of operator, time of day, damage level, part struck, and phase of flight for an exploratory analysis. To determine the damage level of an aircraft, the following categories were used: damaging, non-damaging, and unknown. For the purpose of this study, damaging strikes included those reports that indicated the aircraft had sustained minor or substantial damage; or was destroyed as a result of the strike(s). Upon completion of these steps, a wildlife strike index was calculated for each season of the year, representing the number of wildlife strikes per 100,000 aircraft operations. A wildlife strike index was calculated for each calendar year and for each type of operator. A damaging wildlife strike index was also calculated using the number of damaging strikes divided by 100,000 operations.

A Kruskal–Wallis H test was performed using IBM Statistical Package for the Social Sciences® (SPSS) version 27 to determine if there were significant differences in the wildlife strike index in Part 139 airports between the seasons of the year in the state of Florida (2011–2020). To determine the significance of these obtained values, an Alpha (α) 0.05 was used. The researchers hypothesized that there would not be a statistically significant difference in the wildlife strike index through the different seasons of the year.

Results and Discussion

From 2011 through 2020, there were 8,977 wildlife strikes in Part 139 airports in the state of Florida. The number of strikes increased almost 37% from 2011 (N = 614) to 2020 (N = 837). Additionally, the wildlife strike index increased from 18.6 to 28.62 during the same period (see Appendix A). Approximately 5% (N = 458) of the total strikes resulted in some level of damage to the aircraft. One aircraft was damaged beyond repair as a result of a wildlife strike. The data analyzed suggested that 2019 was the year with the highest number of wildlife strikes (N = 1,371) and damaging (N = 64) strikes at Part 139 airports in the state of Florida, while 2011 had the lowest number with only 614 strikes reported. It is important to note that 2012 had the lowest wildlife strike index (18.83). Meanwhile, 2019 had the highest wildlife strike index (34.99), an index 33.1% higher than the 26.29 average index calculated for the 2011–2020 period.

Our findings indicated that two-thirds of all reported wildlife strikes involved commercial aircraft operators, accounting for 5,994 wildlife strikes. The average wildlife strike index also varied significantly when evaluating the different types of operators (see Table 4). Military operators represented 2.7% of the movements within this period. However, the number of wildlife strikes involving military aircraft is not available in the NWSD. Refer also to Appendix B for further information on damaging strikes per type of operator.

Analysis of the relevant data indicated that 48% (N = 4,306) of the reported wildlife strikes from 2011 through 2020 occurred during the daytime, while only 18% (N = 1,616) of the strikes occurred at night (see Table 5). The higher number of reported wildlife strikes occurring within the daytime may be a result of the higher number of aircraft operations during this period (FAA, 2020d). Interestingly, national wildlife strike data obtained from the NWSD from 2011 through 2020 indicated that the day was also the period with the highest number of wildlife strikes, representing 33.3% (N = 44,347) of all reported wildlife strikes.

From 2011 through 2020, 4.7% (N = 6,205) of all wildlife strikes in the USA and 5.1% (N = 458) of all wildlife strikes at Part 139 airports in Florida resulted in some level of damage to aircraft. Interestingly, winter was the season with the highest percentage (8.2%) of damaging wildlife strikes (N = 113). The summer season had the highest number of wildlife strikes (N = 53,769) but the lowest percentage of damaging strikes 3.18% (N = 106). There were 2,495 and 1,748 strikes during the fall and spring seasons, respectively. Yet, 141 and 97 wildlife strikes in the fall and spring seasons, respectively, resulted in some level of damage to aircraft. Further information on the number of wildlife strikes that resulted in damage to aircraft is provided in Appendices B and C. Data included in these appendices indicated that 2019 was the year with the highest wildlife strike index (34.36) and highest damaging wildlife strike index (1.7).

The aircraft part most struck by wildlife within the scope of this study was the nose (N = 948) followed by the windshield (N = 917). Most wildlife strikes to the wing or rotor (N = 722) occurred during the summer season (N = 217) (see Appendix D). There were only 29 reported wildlife strikes to aircraft lights, and only 61 strike reports indicated that animals struck the tail of the aircraft. Nonetheless, the tail of the aircraft had the highest percentage of strikes (79.3%) resulting in damage while the windshield had the lowest (3.1%) (see Appendix E).

Sixty-two percent of the strikes (N = 3,835) with known phases of flight at Part 139 airports in Florida occurred

Table 4
Wildlife strikes per type of operator (2011–2020).

Operator	Wildlife strikes	Aircraft operations	Wildlife strike index	Damaging wildlife strike index
Commercial	5,994	18,818,803	31.85	1.48
General aviation	239	15,322,211	1.6	0.08
Military		942,175		
Unknown	2,859			
Total	8,977	35,083,189	26.3	1.34

Table 5
Number of reported wildlife strikes per time of day (2011–2020).

Time of day	Dawn	Day	Dusk	Night	Unknown	Total
2011	5	271	13	99	226	614
2012	2	295	8	120	201	626
2013	3	312	9	119	250	693
2014	2	441	18	163	279	903
2015	3	309	9	127	374	822
2016	7	489	16	138	291	941
2017	5	454	14	169	398	1,040
2018	1	485	12	217	415	1,130
2019	5	754	15	306	291	1,371
2020	5	496	11	158	167	837
Total	38	4,306	125	1,616	2,892	8,977

during the arrival phases of flight (descent, approach, arrival, and landing roll). Almost 36% of these strikes (N = 2,223) occurred during the departure phases of flight (takeoff run, departure, and initial climb-out) (see Table 6). Forty-one percent (N = 2,523) of the wildlife strikes in which the phase of flight was reported occurred during approach (see Table 6). Additionally, the approach phase of flight had the highest number of damaging strikes (N = 238). None of the five wildlife strikes that occurred while an aircraft was parked resulted in damage to the aircraft. Almost 9% of the total strikes (N = 806) occurred during the fall season and when the aircraft was on the approach phase of flight (see Appendix F).

Regarding the second research question, the majority (N = 3,333) of the reported strikes occurred during the summer season. Findings also indicated that the greatest number of wildlife strikes per 100,000 aircraft operations (wildlife strike index) occurred during the summer season (40.85). Interestingly, the majority of damaging wildlife strikes (N = 75) as well as the greatest damaging wildlife strike index were in the fall season (see Table 7).

All Part 139 airports are required to develop and implement safety measures to mitigate the risk of aircraft accidents resulting from wildlife strikes (Cleary & Dolbeer, 2005). During the safety risk management processes, a risk assessment is conducted to assess the effects of multiple factors on the risk of wildlife strikes, including seasons of the year, and the types of habitats and land-uses around the airport (FAA, 2018). Those factors can affect the size of the population as well as the wildlife behavior at or near airports (Rillstone & Dineen, 2013). Investigating whether there is a significant difference on the wildlife strike index among the four seasons of the year is vital for effective accident prevention efforts by aviation stakeholders. This information can be used, for example, during the development or assessment of the effectiveness of wildlife hazard management programs by Part 139 airport operators. The regional scope used in this study provides further insight into the likelihood of wildlife strikes and damaging wildlife strikes through the seasons of the year at and around Part 139 airports in the state of Florida.

Answering the last research question of this study, a Kruskal–Wallis test was conducted to determine if there were significant differences in reported wildlife strikes per 100,000 operations between the four seasons of the year: fall (N = 10), winter (N = 10), spring (N = 10), and summer (N = 10). The Kruskal–Wallis test was selected over an ANOVA because there was an outlier in the spring season and three outliers in the summer season. Distributions of reported wildlife strikes per 100,000 operations were not similar for all groups, as assessed by visual inspection of a boxplot. The medians in reported wildlife strikes per 100,000 operations were statistically significantly different between the four seasons of the year: $\chi2(3) = 30.297$, $p < 0.001$. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This *post hoc* analysis revealed statistically significant

Table 6
Number of reported wildlife strikes per phase of flight (2011–2020).

Phase of flight	Wildlife strikes	Damaging strikes	Percentage of damaging strikes
Approach	2,523	238	28.1
Arrival	36	1	0.4
Climb	925	123	10.3
Departure	192	5	2.1
Descent	56	12	0.6
Landing roll	1,220	32	13.6
Local	34	2	0.4
Parked	5	0	0.1
Take-off run	1,106	43	12.3
Taxi	31	1	0.3
Unknown	2,849	1	31.7
Total	8,977	458	100.0

differences in reported wildlife strikes per 100,000 operations between the winter (7.70) and fall (26.30) ($p = 0.002$), between the winter (7.70) and summer (33.89) ($p = 0.000$), and between the spring (14.20) and summer (33.89) ($p = 0.001$) seasons of the year. Figure 1 indicates the mean rank and test statistics, with the yellow lines representing significant differences.

Conclusion

The collection and analysis of wildlife strike data are vital steps toward mitigating the risks that wildlife poses to aviation. According to Cleary and Dolbeer (2005), a problem can only be solved when it is well understood. Information obtained from the data analyzed in this study indicated some similarities regarding the number of reported wildlife strikes per type of operator, time of day, damage level, part struck, and phase of flight with national wildlife strike data available through the NWSD. For example, our findings indicated that most wildlife strikes at and around the Part 139 airports in the state of Florida (2011–2020) occurred during the day, the great majority of the total strikes occurred in the arrival phases of flight, and about 5% of all wildlife strikes resulted in some level of damage to aircraft. These results shed some light on the previous research findings by Dolbeer et al. (2021).

Our findings suggested that there was a statistically significant difference in the likelihood of a wildlife strike at Part 139 airports in Florida through the different seasons of the year. Our findings also suggested that there is a higher likelihood of wildlife strikes during the summer and fall seasons of the year. Additionally, results indicated there was a higher incidence of damaging strikes during the winter and fall seasons at Part 139 airports in Florida. These findings could permit aviation safety stakeholders to not only optimize their often limited financial and labor resources but also tailor their safety efforts in order to be more effective.

Commercial aviation and GA have evolved into the safest, most far-reaching, and sustainable transportation mode over the last century. The aviation industry contributes to the health, well-being, and quality of life of millions of people worldwide. The U.S. air transportation industry plays a significant role in the U.S. and global economies. According to the FAA (2020a), the U.S. aviation industry "across both direct and catalytic sectors, amounts to more than five percent of the U.S. gross domestic product, contributes $1.8 trillion in total economic activity and supports nearly 11 million jobs" (p. 3). The number of commercial passengers is expected to grow from 100 million in 2021 to almost 450 million in 2041 (FAA, n.d.-a). Similarly, the GA aircraft fleet is forecast to grow by 0.1% over the same period in the USA. Globally, the passenger and freighter aircraft fleet is set to more than double to 2038 (Airbus, 2019). During the same period, passenger traffic will grow at almost 4.5% worldwide (International Civil Aviation Organization, 2021). Therefore, the number of wildlife strikes to aviation is also expected to grow over the next decades. A better understanding of wildlife strikes affecting aviation can assist in the development of more effective safety strategies to reduce the risk of wildlife strikes to aviation. Most importantly, it may assist in the sustainable growth of the U.S. and global aviation industries.

There are limitations to the current study. The ATADS did not provide information about aircraft operations at Florida Keys Marathon International and Eglin Air Force Base/Destin-Fort Walton Beach airports. Moreover, this database did not specify if local airport operations represent GA or commercial operations. The NWSD only provides information regarding wildlife strikes involving civil operators. Therefore, strikes involving military aircraft were not included in this study. Another limitation of this study was the quantity and especially quality of the reported wildlife strikes. According to Dolbeer (2015), analyses of wildlife strike data suggested that approxi-

Table 7
Wildlife strikes per season of the year.

Year	Season	Strikes	Damaging strikes	Aircraft operations	Wildlife strike index	Damaging wildlife strike index
2011	Winter	86	11	823,488	10.44	1.34
	Spring	145	10	827,748	17.52	1.21
	Summer	194	5	756,716	25.64	0.66
	Fall	186	15	796,707	23.35	1.88
2012	Winter	133	13	835,498	15.92	1.56
	Spring	104	6	879,097	11.83	0.68
	Summer	229	9	802,142	28.55	1.12
	Fall	169	10	808,851	20.89	1.24
2013	Winter	88	10	851,860	10.33	1.17
	Spring	134	6	890,734	15.04	0.67
	Summer	271	8	817,941	33.13	0.98
	Fall	199	12	808,208	24.62	1.48
2014	Winter	134	8	797,711	16.80	1.00
	Spring	188	9	886,109	21.22	1.02
	Summer	321	7	791,929	40.53	0.88
	Fall	251	10	835,941	30.03	1.20
2015	Winter	122	5	839,043	14.54	0.60
	Spring	185	7	931,453	19.86	0.75
	Summer	281	6	803,749	34.96	0.75
	Fall	235	8	836,493	28.09	0.96
2016	Winter	135	2	871,753	15.49	0.23
	Spring	174	3	916,720	18.98	0.33
	Summer	356	7	824,560	43.17	0.85
	Fall	279	14	839,422	33.24	1.67
2017	Winter	131	3	882,762	14.84	0.34
	Spring	188	1	919,552	20.44	0.11
	Summer	410	1	835,992	49.04	0.12
	Fall	309	2	884764	34.92	0.23
2018	Winter	143	4	922,751	15.50	0.43
	Spring	238	1	970,102	24.53	0.10
	Summer	440	1	937,678	46.92	0.11
	Fall	296	0	948,319	31.21	0.00
2019	Winter	228	0	989,162	23.05	0.00
	Spring	289	5	1,028,005	28.11	0.49
	Summer	530	0	917,342	57.78	0.00
	Fall	330	2	987,040	33.43	0.20
2020	Winter	186	1	999,894	18.60	0.10
	Spring	103	1	529,400	19.46	0.19
	Summer	301	0	617,598	48.74	0.00
	Fall	241	2	698,106	34.52	0.29
Total	Winter	1,386	57	8,813,922	15.55	0.68
	Spring	1,748	49	8,778,920	19.70	0.55
	Summer	3,333	44	8,105,647	40.85	0.55
	Fall	2,495	75	8,443,851	29.43	0.91

Note. The wildlife strike index indicates the total number of wildlife strikes per 100,000 aircraft operations. The total number of strikes represents the number of occurrences within the four seasons of the year at Part 139 airports in Florida from 2011 through 2020.

mately 91%, and 50% to 59% of wildlife strikes involving commercial aviation and GA operators, respectively, are reported to the FAA. Yet, previous studies (Anderson et al., 2015; Ball et al., 2021; Dolbeer & Barnes, 2017; Mendonca et al., 2020; Misra et al., 2022) have indicated that missing data and information in the NWSD (e.g., incomplete strike reports) as factors limiting their findings. In the current study, for example, almost 33% (N = 2,901) of the reported strikes did not provide information about the time of the day the strike occurred. It is important to incorporate such data in future studies if they become available. Yet, further studies are recommended to address the incompleteness of strike reports. Researchers assumed that the reported wildlife strike data, although incomplete, were accurate. These limitations could bias the findings of this study. Nonetheless, the authors of this study consider that findings presented here can help with the development (and/or assessment) of safety management strategies to

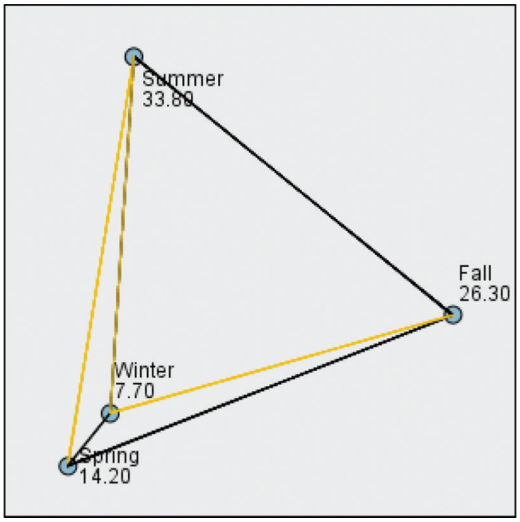

Figure 1. Pairwise comparisons of the wildlife strike index per seasons of the year.

reduce the risk of wildlife strikes to aviation at Part 139 airports in Florida.

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Appendix A: Number of Strikes and Damaging Wildlife Strikes per Year (2011–2020)

Year	Wildlife strikes	Aircraft movements	Damaging strikes reported	Wildlife strike index	Damaging wildlife strike index	Percentage of damaging strikes (%)
2011	614	3,300,392	48	18.60	1.45	7.8
2012	626	3,414,901	44	18.33	1.29	7.0
2013	693	3,458,976	45	20.03	1.30	6.5
2014	903	3,404,096	43	26.53	1.26	4.8
2015	822	3,510,828	36	23.41	1.03	4.4
2016	941	3,567,106	53	26.38	1.49	5.6
2017	1,040	3,615,086	41	28.77	1.13	3.9
2018	1,130	3,882,761	54	29.10	1.39	4.8
2019	1,371	4,004,131	64	34.24	1.60	4.7
2020	837	2,924,912	30	28.62	1.03	3.6
Total	**8,977**	35,083,189	**458**	**26.29**	**1.34**	**5.1**

Note. Part 139 airports in the state of Florida. Wildlife strike index and damaging wildlife strike index values do not include military aircraft movements, since only civilian wildlife strikes are available through NWSD.

Appendix B: Number of Strikes and Damaging Strikes per Type of Operator (2011–2020)

Damage level	Type of operator			Total
	Commercial	General aviation	Unknown	
Damage	279	13	166	458
None	3,119	114	1,426	4,659
Unknown	2,451	86	1,323	3,860
Total	5,849	213	2,915	8,977

Note. Part 139 airports in the state of Florida.

Appendix C: Percentage of Total Reported Wildlife Strikes that Resulted in Damage per Season of the Year (2011–2020)

Year	Winter	Spring	Summer	Fall
2011	15.12	6.90	4.64	9.14
2012	11.28	7.69	5.24	5.92
2013	12.50	6.72	4.06	7.04
2014	6.72	5.85	2.18	4.78
2015	6.56	4.86	3.91	5.11
2016	2.96	5.75	3.37	9.32
2017	6.87	4.26	2.20	5.18
2018	11.19	3.36	4.09	2.70
2019	7.46	7.27	2.64	4.85
2020	5.91	2.91	1.00	4.15
Total	**8.15**	**5.55**	**3.18**	**5.65**

Note. Part 139 airports in the state of Florida.

Appendix D: Aircraft Components Struck per Seasons of the Year (2011–2020)

Part struck	Winter	Spring	Summer	Fall	Total
Radome	108	150	284	213	**755**
Windshield	125	191	334	267	**917**
Nose	139	178	350	281	**948**
Engine	81	108	123	136	**448**
Propeller	0	0	0	0	**0**
Wing or rotor	169	155	217	181	**722**
Fuselage	110	139	237	200	**686**
Landing gear	45	75	94	86	**300**
Tail	9	13	15	24	**61**
Lights	8	6	7	8	**29**
Other	336	346	769	553	**2,004**
Unknown	401	542	1140	769	**2,107**
Total	**1,531**	**1,903**	**3,570**	**2,718**	8,977

Note. Part 139 airports in the state of Florida.

Appendix E: Aircraft Components Struck (Damaging and Non Damaging)

Part struck	Damage	Non-damaging	Total	Percentage of damaging (%)	Percent of non-damaging (%)
Radome	50	692	752	6.6	92.0
Windshield	29	882	924	3.1	95.5
Nose	60	874	950	6.3	92.0
Engine	103	344	458	22.5	75.1
Wing or rotor	20	97	120	16.7	80.8
Propeller	42	628	685	6.1	91.7
Fuselage	183	524	722	25.3	72.6
Landing gear	33	257	301	11.0	85.4
Lights	26	35	62	41.9	56.5
Tail	23	5	29	79.3	17.2
Other	54	1,020	2,007	2.7	50.8

Note. Part 139 airports in the state of Florida, 2011–2020. The percentage of strikes does not include those with an unknown selection.

Appendix F: Wildlife Strikes per Phase of Flight—Seasons of the Year

Phase of flight	Winter	Spring	Summer	Fall	Total
Approach	447	549	721	806	**2,523**
Arrival	4	3	19	10	**36**
Climb	167	197	288	274	**926**
Departure	27	21	89	54	**191**
Descent	5	3	8	40	**56**
Landing roll	189	219	525	286	**1,219**
Local	10	6	8	10	**34**
Parked	3	1	1	0	**5**
Take-off run	133	200	533	241	**1,107**
Taxi	3	7	8	12	**30**
Unknown	398	542	1,133	762	**2,858**
Total	1,386	1,748	3,325	2,495	**8,977**

Note. Part 139 airports in the state of Florida: 2011–2020.