Beyond: Undergraduate Research Journal

Volume 6 Article 7

July 2022

High-Risk Wildlife Strike Regions: An In-depth Visual Representation of Wildlife Strikes at and Around Part 139 Airports in Florida.

Luke P. Ochs
Embry Riddle Aeronautical University, ochsl@my.erau.edu

Flavio A. C. Mendonca Ph.D.
Embry-Riddle Aeronautical University, coimbraf@erau.edu

High-Risk Wildlife Strike Regions: An In-depth Visual Representation of Wildlife Strikes at and Around Part 139 Airports in Florida.

Cover Page Footnote

This project was funded by the Embry Riddle Aeronautical University Summer Undergraduate Research Fellows (SURF). Special thanks to Daniel Burrow who assisted the researcher with ArcGIS.

UNDERGRADUATE RESEARCH JOURNAL
Beyond

High-Risk Wildlife Strike Regions: An In-depth Visual Representation of Wildlife Strikes at and Around Part 139 Airports in Florida

Luke P. Ochs, Flavio A. C. Mendonca Ph.D

Abstract

Wildlife strikes with aircraft have been and continue to be a problem in the aviation industry costing millions of dollars in both damage and delays. This study used the geoprocessing information system ArcGIS to depict wildlife strikes at Florida's 26 Part 139 Airports from 2012 to 2021. Importing reports from the National Wildlife Strike Database into ArcGIS, this study used symbology and geoprocessing tools to create a color/ size gradient that depicts the risk (number of damaging strikes out of known strikes) at each airport. Using an interactive map with ArcGIS Online viewers can observe then select each airports vector point and view a table containing the important information on that airports strike data. Data like number of strikes during time of the day, strikes per weather conditions, and whether the strikes were damaging or not, are contained in the online resource. Attempts to study and depict wildlife strikes are limited, the industry and researchers need to continue research on a localized scale to help mitigate wildlife strikes.

Introduction

Wildlife strikes to aircraft are a serious safety and economic concern. In the United States, wildlife strikes to aviation have resulted in, on an annual average, 139,469 hours of aircraft downtime and $328 million in monetary losses (Dolbeer et al., 2022). Aircraft accidents resulting from strikes have killed 41 people and destroyed 77 aircraft in the U.S. since 1990. While not all wildlife strike events are preventable, scientific studies, safety programs by airport operators, and the effective training and education of pilots about the factors contributing to strikes are essential while developing strategies to reduce the risk of collisions. Most research studies have focused on the analysis of wildlife strikes at a national level (Altringer et al., 2021; Avrenli & Dempsey, 2014; Dolbeer et al., 2022). Yet, these studies do not give a comprehensive understanding of wildlife strikes considering the highly dynamic regional conditions that influence wildlife presence and behavior (e.g., natural habitats; seasons of the year) at and around airports. Therefore, there is a need to analyze regional data in order to develop empirical information that is vital for more effective accident prevention (Drey et al., 2014; Mendonca et al., 2017). The identification of "High-Risk" areas for strikes at a regional level is critical to determining the magnitude of safety issues, and most importantly, the nature of the problem. For example, this information can be used to alert pilots to areas in which the risk of accidents resulting from wildlife strikes is high.

The goal of this study was to develop an online visual and table that showcases the risk of wildlife strikes at Part 139 airports in Florida using Geographic Information Systems (GIS) (ArcGIS, 2022) and wildlife strike data from the Federal Aviation Administration (FAA) National Wildlife Strike Database (NWSD) (FAA, 2022a). Users will be able to gauge the risk level of these airports based on the map's colored features. They will also be able to receive supplemental information on local strikes through attributes tables that accompany each airport.

Literature Review

ArcGIS can serve as a useful tool for many occupations to help analyze and predict outcomes.

Not many examples of GIS occur in the aviation industry. Yet it could prove to be a beneficial tool for qualified airport wildlife biologists while developing or assessing the effectiveness of Wildlife Hazards Management Plans (WHMP) (Cleary & Dolbeer, 2005). Similar specialists like zoologists use GIS software extensively to create visuals that help them analyze factors in their studies. Prasad et al. (2011) performed a study using ArcGIS on human elephant conflict factors in Western Ghats, India. The team found several influencing factors that encouraged elephants to be in human occupied zones such as distance from hamlets, slope of the ground, and presence of agricultural land. This information was used to develop preventive measures by altering these attractants to detour elephants and thus reduce conflict between people and elephants. Another study by Ng et al. (2008) looked at deer-vehicle collisions in Edmonton, Alberta, Canada. Their study used ArcGIS in combination with statistical analysis in an attempt to find factors that lead to collisions. They found the main factor contributing to collisions was the speed of cars, justifying the quantitative data with the logic that drivers going at slower speeds were better able to see and avoid deer. They were able to recommend the lowcost solution of reducing speed limits to prevent deer-vehicle collisions. Both of these studies used ArcGIS to help researchers visualize multiple factors at the same time, allowing them to cross reference what their data was describing and what they were seeing.

With GIS and geoprocessing tools researchers are able to view and understand data faster and better (ArcGIS, 2022; Chybicki et al., 2008). Chybicki and their team explored tools/devices that would be useful to study marine pollution. Using a plethora of abilities available in GIS software such as 2D and 3D thematic layering, storing and managing vector data, they came up with many different maps that helped track the movement of pollution. The researchers described ArcGIS as a tool to efficiently handle/display data from many different inputs resulting in an easily interpretable visual.

Wildlife strikes to aircraft are on the rise at Part 139 airports as well as at general aviation airports. The number of strikes has increased annually since 1990 with the exception of 2020 due to less flights because of SARS-CoV-2 (Dolbeer et al., 2022). However, despite an increase of total wildlife strikes, the number of damaging strikes has not increased at Part 139 Airports proportionally. For example, during 2010 there were 9,889 wildlife strikes, 6% (N=595) being damaging strikes. In 2021 there were 15,556 strikes with only 4.2% (N=657) of those causing damage to the aircraft (Dolbeer et al., 2022). General aviation (GA) airports, on the other hand, have had an increasing number of total and damaging strikes.

Devault et al. (2009) studied GA airports in Indiana, finding that as they are located in less developed areas with abundant habitat for hazardous species they are at greater risk of strikes. They accounted that limited financial and technological resources as well as the lack of personnel are factors affecting the development of wildlife hazard management plans for GA airports. Dolbeer et al. (2000) ranked some of the most hazardous species using multiple factors from reported strikes. They used criteria such as number of strikes, cost of the strike resulting damage to the aircraft, and cost of flights delayed/canceled due to presence of wildlife to determine the most hazardous species. Their findings suggested that larger species such as the deer (Cervidae), vultures (Cathartidae), and geese (Anserina) pose the highest threat. From 1991 through 1998, wildlife strikes involving these species resulted in $28.5 million dollars in direct and other monetary losses (Dolbeer et al., 2000). Studies like these are important as different solutions are needed to control and repel different wildlife species. Negative impacts on flight resulting from wildlife strikes such as precautionary/emergency landings, dumping fuel, and aborting take-off have declined in the past 20 years. However, the aviation industry still loses millions of dollars a year and thousands of hours of aircraft downtime due to wildlife strikes (Dolbeer et al. 2022).

Current preventative wildlife hazard management plans have helped reduce the number of safety events between wildlife and aircraft. However, studies like those performed by Prasad et al. (2011) and Ng et al. (2008) have indicated that ArcGIS could help the aviation industry better understand the driving factors behind wildlife strikes. ArcGIS, when used in combination with wildlife strike data could prove another key strategy in reducing the risk of wildlife strikes to aircraft saving millions of dollars and preventing human injuries/fatalities.

Methodology

Wildlife strike data were collected from the FAA NWSD (FAA, 2022a). The researcher utilized wildlife-strike data from strikes that occurred within the vicinities of the 26 Part 139 airports in Florida. The researcher selected the date range from 2012 January 1st through 2021 December 31st for the study. Part 139 airports are classified by the FAA (2022b) as "airports that serve scheduled and unscheduled carries with more than 30 seats, and/or airports that serve scheduled carries with between 9-31 seats" (p. 1). These airports were sourced from the Airport Certification Status List (FAA, 2022c) (see Table 1). Part 139 airports were used for two reasons. First, the majority of wildlife strikes occur at and around those Part 139 airports if compared to GA airports (Dolbeer et al., 2022). Secondly, they generally have more traffic and more passengers being transported than GA airports. The main data required for the map was the airports' location and whether the strike was damaging or non-damaging. Additional information on the wildlife-strike such as aircraft altitude, weather conditions, and phase of flight were added to the supporting table that will also be available for users of this tool.

Airport Name	Damaging	Non-Damaging	Unknown Damaging	Damaging/ Total Strikes
Orlando International Airport	92	807	742	5.6%
Orlando-Sanford International Airport	43	352	170	7.6%
Miami International Airport	38	556	57	5.8%
Tampa International Airport	32	389	593	3.2%
Southwest Florida International Airport	31	447	46	3.3%
Fort Lauderdale/ Hollywood International Airport	30	495	448	3.1%
Daytona Beach International Airport	25	170	228	5.9%
Naples Municipal Airport	23	44	34	22.8%
Palm Beach International Airport	20	176	105	6.6%
St. Pete/Clearwater International Airport	20	182	139	5.9%
Jacksonville International Airport	14	394	207	2.3%
Melbourne/Orlando International Airport	14	76	102	7.3%
Punta Gorda	12	93	140	4.9%
Sarasota/Bradenton International Airport	12	123	213	3.4%
Vero Beach Regional Airport	12	20	40	16.7%
Gainesville Regional Airport	8	43	266	2.5%
Northeast Florida Regional Airport	6	41	12	10.2%
Key West International Airport	5	121	122	2.0%
Lakeland Linder International Airport	5	26	90	4.1%
Pensacola International Airport	5	112	31	3.4%
Tallahassee International Airport	5	59	18	6.1%
Eglin Afb/Destin-Ft Walton Beach	4	48	3	7.3%
Space Coast Regional Airport	3	14	2	15.8%
Northwest Florida Beach's International Airport	2	65	8	2.7%
Ocala International Airport	2	8	20	6.7%
The Florida Keys Marathon International Airport	1	5	30	2.8%
Total	**464**	**4,866**	**4,288**	**On average 6.46% were damaging**

Table 1: Wildlife Strikes at Part 139 Airports in Florida

ArcGIS[1] is the software that the researcher used to display the information obtained from the analysis of wildlife strike data from the NWSD. ArcGIS is a Geographical Information System (GIS) used by many occupations that need to do spatial analysis and map-making (ArcGIS, 2022). To get wildlife strike data into ArcGIS, the researcher first sorted the NWSD to contain only data needed for the project into an Excel file. Then exported the excel file as a .txt file for ArcGIS.

The .txt file was exported into the ArcGIS project folder (which contains the map base and all the added layers). From there, the project folder could be opened and the .txt file accessed as "Data" and imported into the map. The same was done with ACSL data (location of airports). With both .txt files imported into the map the files were then merged into a joined table. The table created points based on where the airports are located and gave

[1] ArcGIS: A professional map-making software.

each airport its own strike history. This resulted in each airport having its own attribute table containing information only relative to it. Wildlife-strike information available for each airport includes phase of flight, aircraft altitude, time of day, weather conditions, and if the strike resulted in damage. The researcher then created specific vector data for each airport.

Vector data are points, lines, and polygons that represent features one desires to showcase to the viewer. In this map the main vector type are colored points used to indicate the location of airports. The location of these points was created using the latitude and longitude coordinates (FAA, 2022a) of the airports and a geoprocessing tool in ArcGIS called "XY Table to Point" (ArcGIS, 2022). To achieve a more realistic scope of risk, the researcher used the difference between damaging strikes and damaging plus non-damaging strikes to create percentages. The percentages were then used to create the following symbology[2] to indicate the level of risk per airport. A large red point means that 27-38% of the total strikes at that airport were damaging strikes; a medium orange point means that 16-26% of the total strikes at that airport were damaging strikes; and a small yellow point means that 3-15% of the total strikes caused damage to the aircraft (see Figure 1).

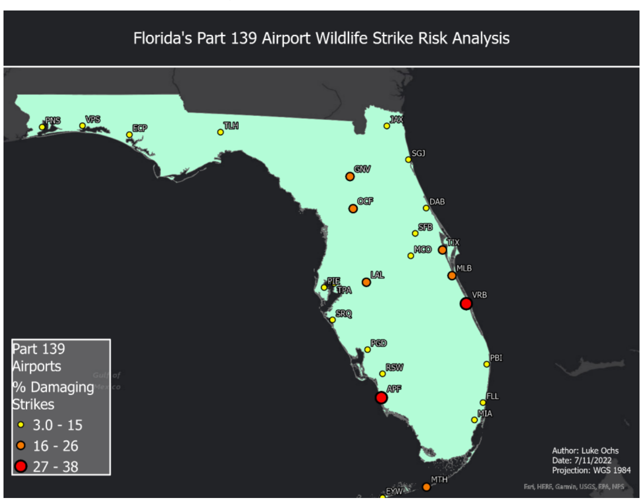

Figure 1: Florida's Part 139 Airport Wildlife Strike Risk Analysis
Note: The above map was made using ArcGIS's geoprocessing tools and symbology to display the percentage damaging strikes out of known strikes for each airport. Use this link to access the map. An ArcGIS online account is needed.

High, medium, and low risk parameters were created using a natural break setting in the graduated color symbology tool in ArcGIS. This tool works by viewing each airports' percentage of damaging strikes and looks for substantial gaps to differentiate which airport belongs in which category. For more information on an airport strikes, a table and pie chart were created. The refined table only includes wildlife strikes that have been reported to one of the Part 139 airports in Florida from 2012 January 1st through 2021 December 31st. Moreover, it only includes the following categories: damaging and non-damaging strikes, altitude of impact, weather conditions, time of day, phase of flight of aircraft, and the airport's name/airport ID. This vector data was placed on top of a "Dark Gray Canvas" base map known as the raster data to add good contrast. The pie chart shows a different percentile breakdown of damaging, non-damaging, and unknown damaging strikes. Unknown damaging strikes were left out of the map as they would pose a challenging factor to symbolize and would add little value. However, they were included in the pie chart to remain transparent as they were still reported as strikes. It is plausible to assume that strikes that were reported as "unknown damage" were non-damaging, as larger more damaging impacts would be obvious and thus more likely reported.

Results

From 2012 January 1st through 2021 December 31st there were 9,618 wildlife strikes at and around the 26 Florida's Part 139 Airports. Approximately 4.82% (N=464) of the total strikes caused damage to the aircraft. Most strikes were either non damaging (N=4,866) or unknown damaging (N=4,288) compared to damaging. The amount of unknown data in this study shows the challenges with community reported data. However, it could be interpreted that unknown damage most likely belongs in the non-damaging category as that information would be much more apparent if the strike was damaging to the aircraft. The majority of strikes occurred during the day (N=4,002) with night being the second most numerous (N=1,380). Dawn and dusk were both under 250 strikes, and there were 3,868 strikes occurring at an unknown

[2] Symbology: The use of symbols to indicate a meaning to a viewer.

time of day. The weather condition when the most strikes occurred on flights was with "some cloud cover" (N=2,261) closely followed by "no cloud cover" (N=1,881). "Overcast" flights had the least number of strikes at 529, and unknown weather conditions accounted for the remaining 4,947 strikes.

The greatest number of strikes occurred during the approach phase of flight (N=2,594). Reports indicated that 1,323 wildlife strikes occurred during the landing roll, 1,169 happened during the takeoff run, and 937 occurred during the climb phases of flight. During the departure phase, there were 212 strikes. The following phases of flight were all under 100 strikes, "arrival", "descent", "local", "parked" and "taxi". The remaining 3,205 strikes occurred during an unknown phase of flight. Expectedly, the majority of strikes occurred at or below 500 ft above ground level (AGL) (N=4,004). There were 407 strikes between 500 and 1,000 ft AGL, 401 strikes from 1,000 to 2000 ft AGL, 317 strikes from 2,001 to 5,000 ft AGL, and 126 strikes above 5,000 ft AGL. There were 4,363 strikes at unknown altitudes.

The top three airports with the most wildlife strikes from 2012 through 2021 were Orlando (N=1,641), Tampa (N=1,014), and Fort Lauderdale (N=973) (see Table 1). Orlando and Fort Lauderdale airport also had the majority of strikes occurring on their approach phase of flight. While most airports did have more strikes occurring on the approach phase of flight, St. Pete–Clearwater International Airport (PIE), Key West International Airport (EYW), Northeast Florida Regional Airport (SGJ), Space Coast Regional Airport (TIX), and the Florida Keys Marathon International Airport (MTH) had a majority of their strikes occur in a different phase of flight. The map assigned the highest risk of a damaging strike to Vero Beach (37%), Naples (34%), and Ocala (20%) due to the larger proportion of damaging strikes (see Figure 1).

The following Figures and Tables are the products of this study, created with data from the NWSD and ACSL databases. Table 1 shows a breakdown of all types of strikes (damaging, nondamaging, unknown damaging) for each airport as well as the percentage of damaging strikes compared to the total number of strikes at each airport. Using the method that contains unknown damaging strikes instead of the method used by the map, the researcher identified Naples Municipal airport (AFP) as having the highest percentage of damaging strikes out of total strikes. Readers should refer to Table 1 and Figure 1 to compare the two different methods. The map made with ArcGIS lets viewers observe the ratio of damaging vs non-damaging strikes (excludes unknown damaging strikes) at each of Florida's Part 139 airports. This shows that the highest ratio of damaging strikes occurred at Vero Beach Regional then Naples Municipal airports. In total, there were two high risk, five moderate risk, and 19 low risk Part 139 airports in Florida. This study shows airports with percentages between 3.0%-38% because there were no values below or above those percentages. Future studies using a similar methodology may have to alter these parameters in order to keep up with new reports from NWSD (see Figure 1). Figure 2 shows a pie chart that each airport has when selected. The pie chart shows the ratio between damaging, non-damaging and unknown damaging strikes, it also allows users to see the actual number of each of those strikes. Tables 2 and 3 contain the attributes tables for Vero Beach Regional and Naples Municipal, and Orlando International and Fort Lauderdale, respectively. They also contain additional information on wildlife strikes that the map does not directly project such as the aircraft phase of flight and altitude as well as weather and other information associated with the strike (see Tables 2 and 3.)

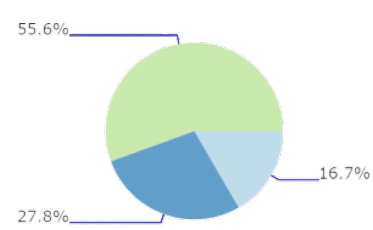

Figure 2: Proportion of Damaging, Non-damaging and Unknown Damaging Wildlife Strikes. At VERO BEACH RGNL, there was 12 damaging strikes, 20 non-damaging strikes, and 40 strikes with unknown damage status.
Note: This is part of Vero Beach (VRB) airport's supplemental information.

A VRB

Part 139 Airports - VERO BEACH RGNL

OBJECTID	26
State	FLORIDA
FAA Region	ASO
Airport Id	VRB
Airport Name	VERO BEACH RGNL
Associated City	VERO BEACH
Hub Size	N/A
NPIAS Role	Regional
Class	I
ARFF Index	A
Lat	27.6539
Lon	-80.4173
Strikes	72
Day	37
Night	0
Dawn	0
Dusk	0
Unknown_Time	35
Damaged	12
NonDamaged	20
Unknown_Damage	40
Some_Cloud	7
Overcast	1
No_Cloud	6
Unknown_Condition	58
Approach	15
Arrival	0
Climb	7
Depature	6
Descent	0
Landing_Roll	6
Local	1
Parked	0
Take-off_Run	6
Taxi	1
Unknown_PF	30
<=500	18
Alt>500-<=1000	4
Alt>1000-<=2000	4
Alt>2000-<=5000	2
Alt>5000	0
Unknown_Alt	44

B APF

Part 139 Airports - NAPLES MUNI

OBJECTID	1
State	FLORIDA
FAA Region	ASO
Airport Id	APF
Airport Name	NAPLES MUNI
Associated City	NAPLES
Hub Size	N/A
NPIAS Role	National
Class	I
ARFF Index	A
Lat	26.1521
Lon	-81.7749
Strikes	101
Day	54
Night	10
Dawn	3
Dusk	5
Unknown Time	29
Damaged	23
NonDamaged	44
Unknown Damage	34
Some Cloud	22
Overcast	3
No Cloud	37
Unknown Condition	39
Approach	34
Arrival	0
Climb	10
Depature	2
Descent	0
Landing Roll	12
Local	0
Parked	0
Take-off Run	14
Taxi	1
Unknown PF	28
<=500	48
Alt>500-<=1000	3
Alt>1000-<=2000	7
Alt>2000-<=5000	5
Alt>5000	1
Unknown Alt	37

Table 2: Support Tables for Vero Beach & Naples Airports (ArcGIS)

A MCO

Part 139 Airports - ORLANDO INTL

OBJECTID	9
State	FLORIDA
FAA Region	ASO
Airport Id	MCO
Airport Name	ORLANDO INTL
Associated City	ORLANDO
Hub Size	Large
NPIAS Role	<Null>
Class	I
ARFF Index	E
Lat	28.4179
Lon	-81.3041
Strikes	1641
Day	649
Night	256
Dawn	14
Dusk	33
Unknown Time	689
Damaged	92
NonDamaged	807
Unknown Damage	742
Some Cloud	228
Overcast	53
No Cloud	320
Unknown Condition	1040
Approach	490
Arrival	8
Climb	168
Depature	50
Descent	12
Landing Roll	321
Local	8
Parked	1
Take-off Run	258
Taxi	2
Unknown PF	323
<=500	818
Alt>500-<=1000	54
Alt>1000-<=2000	73
Alt>2000-<=5000	55
Alt>5000	28
Unknown Alt	613

B FLL

Part 139 Airports - FORT LAUDERDALE

OBJECTID	5
State	FLORIDA
FAA Region	ASO
Airport Id	FLL
Airport Name	FORT LAUDERDALE/HOLLYWOOD INTL
Associated City	FORT LAUDERDALE
Hub Size	Large
NPIAS Role	<Null>
Class	I
ARFF Index	E
Lat	26.0742
Lon	-80.1506
Strikes	973
Day	436
Night	132
Dawn	22
Dusk	12
Unknown Time	371
Damaged	30
NonDamaged	495
Unknown Damage	448
Some Cloud	333
Overcast	61
No Cloud	150
Unknown Condition	429
Approach	278
Arrival	5
Climb	88
Depature	13
Descent	6
Landing Roll	112
Local	3
Parked	0
Take-off Run	110
Taxi	3
Unknown PF	355
<=500	386
Alt>500-<=1000	46
Alt>1000-<=2000	44
Alt>2000-<=5000	35
Alt>5000	15
Unknown Alt	447

Table 3: Support Tables for Orlando & Fort Lauderdale Airports (ArcGIS)

Conclusion

Wildlife strikes to aircraft cost hundreds of millions of dollars annually to the U.S. aviation industry. These strikes have directly impacted the industry by causing damage to airplanes, flight cancellations, and fatalities (Allan, 2000; Dolbeer et al., 2022). More research is needed to investigate, track, and display empirical information obtained from the analyses of wildlife strikes on a regional scale. Thus, empirical information obtained from smaller scale scientific studies considering strikes in specific regions of the U.S. is crucial while developing safety strategies to prevent strikes (DeVault et al., 2009).

This study addressed a gap in literature by identifying "High-Risk" areas for wildlife strikes to aircraft at a regional level. The goal of this study was to develop an online visual and table that showcases risk of wildlife strikes at Part 139 airports in Florida using ArcGIS (ArcGIS, 2022) and wildlife strike data from the NWSD (FAA, 2022a). Using ArcGIS to create maps of areas with a higher percentage of damaging strikes relative to non-damaging could provide valuable information associated with higher populations of hazardous wildlife. These maps could be compared to those that show the presence of natural and man-made habitats around airports that could attract hazardous wildlife species to airports.

Findings suggested that the majority of wildlife strikes generally occur with diurnal species due to the number of strikes occurring during the day. Additionally, findings indicated that the risk of a strike is higher during the arrival phases of flight (approach and landing roll). The risk of wildlife strikes is associated with the number of aircraft operations (Dolbeer et al., 2021). A finding of concern was that the majority of strikes (2012-2021) occurred at Orlando International Airport even though Miami International Airport is the busiest airport in Florida (FAA, 2023). Possible explanations include a more effective WHMP at Miami International Airport and/or a more robust and mature safety reporting system by Orlando International Airport.

These data and information are crucial for determining where airport operators should effectively allocate their usually constrained budget and resources for preventing wildlife strikes. Yet, by using ArcGIS maps to identify low to high risk areas of strikes, aviation stakeholders can develop and implement effective safety management protocols to mitigate the risk of aircraft accidents resulting from wildlife strikes.

Only data from Florida was utilized in this study. Thus, findings are not generalizable. Nonetheless, future studies could apply a similar methodology in different regions of the U.S. Additionally, future studies could incorporate aircraft-operations data from each airport so as to facilitate comparisons of findings among airports. As previously mentioned, the number of aircraft operations correlates with the risk of strikes (Dolbeer et al., 2021).

Gaps in the NWSD data were accounted for by excluding unknown data from the map (see Table 1). Nonetheless, this data was shown within a pie chart/table found within each airport point to remain transparent (see Figure 2). The researcher assumed the reported wildlife-strike data, although incomplete, was accurate.

References

Allan. R. J. (2000, August 1-3). The cost of bird strikes and bird strike prevention [Paper presentation]. Human Conflicts with Wildlife: Economic Considerations. Fort Collins, CO. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1017&context=nwrchumanconflicts

Altringer, L., Navin, J., Begier, M. J., Shwiff, S. & Anderson, A. (2021). Estimating wildlife strike costs at US airports: A machine learning approach. Transportation Research Part D: Transport and Environment, 27, 1-16.. https://doi.org/10.1016/j.trd.2021.102907

ArcGIS. (2022). ArcGIS Online. Esri. https://www.esri.com/en-us/arcgis/products/arcgisonline/overview

Avrenli, K. A., & Dempsey, B. J. (2014). Statistical analysis of aircraft–bird strikes resulting in engine failure. Journal of Transportation Research Board, 2449. 14-23. . https://journals.sagepub.com/doi/epdf/10.3141/2449-02

Chybicki, A., Kulawiak, M., Lubniewski, Z., Dabrowski, J., Luba, M., Moszynski, M., & Stepnowski, A. (2008, May 19-21). GIS for remote sensing, analysis and visualisation of marine pollution and other marine ecosystem components [Paper presentation]. International Conference on Information Technology, Gdansk, Poland. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4621628

Cleary, E. C., & Dolbeer, R. A. (2005). Wildlife hazard management at airports: A manual for airport personnel. Federal Aviation Administration. http://www.faa.gov/airports/airport_safety/wildlife/resources/media/2005_faa_manual_complete.pdf

Devault, T. L., Kubel, J. E., Rhodes, O. E., & Dolbeer, R. A. (2009) Habitat and bird communities at small airports in the Midwestern USA. Digital Commons-University of Nebraska – Lincoln. https://core.ac.uk/download/pdf/188130774.pdf

Dolbeer, R. A., Begier, M. J., Miller, P. R., Weller, J. R., & Anderson, A. L. (2022). Wildlife Strikes to Civil Aircraft in the United States, 1990–2021. Federal Aviation Administration. https://www.faa.gov/airports/airport_safety/wildlife/media/Wildlife-Strike-Report-1990- 2021.pdf

Dolbeer, R. A., Wright, S. E., & Cleary, E. C. (2000). Ranking the hazard level of wildlife species to aviation. Wildlife Society Bulletin, 28(2), 372-278. https:/www.jstor.org/stable/3783694#metadata_info_tab_contents

Drey, K. M., Martin, J. A., Belant, J. L., DeVault, T. L., & Blackwell, B. F. (2014). Interactions between wildlife and civil aircraft in Mississippi. Southeastern Naturalist, 13(1), 156-165. https://doi.org/10.1656/058.013.0115

Federal Aviation Administration (FAA) (2022a). FAA wildlife strike database. https://wildlife.faa.gov/homehttps://wildlife.faa.gov/home

Federal Aviation Administration (FAA) (2022b). Part 139 airport certification. https://www.faa.gov/airports/airport_safety/part139_cert/

Federal Aviation Administration FAA (2022c). Airport Certification Status List (ACSL). Part 139 airport certification – airports.

Federal Aviation Administration (FAA). (2023b, January 4). Air traffic activity system (ATADS): Airport operations. FAA. https://aspm.faa.gov/opsnet/sys/airport.asp

Mendonca, F. A. C., Keller, J. C., & Wang, Y. (2017). Managing the risk: An analysis of bird strike reporting at Part 139 airports in Indiana (2001-2014). Journal of Airline and Airport Management, 7(1), 43-64. http://dx.doi.org/10.3926/jairm.82

Ng, J. W., Nielsen, C., & St. Clair, C. C. (2008). Landscape and traffic factors influencing deer– vehicle collisions in an urban environment. Human-Wildlife Conflicts, 2(1), 34-47. http://www.jstor.org/stable/24875104

Prasad, G., Shiny, R., Reghunath, R., & Prasannakumar, V. A. (2011). GIS based spatial prediction model for human – elephant conflicts (HEC). Wildlife Biology in Practice, 7(2), 30-40. 10.2461/wbp.2011.7.14.