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An Analysis of Department of the Air Force Bird Strikes and Precipitation

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Bird strikes have the potential for catastrophic consequences (Metz et al., 2020). Annually, wildlife strikes in the United States cost an estimated $196 million and nearly $1.2 billion worldwide (Allan & Orosz, 2001; Dolbeer et al., 2021). With this type of risk, the United States Department of Defense (DoD) airfields and 14 CFR § 139 require airfields to establish a wildlife hazard program to reduce the risk caused by wildlife strikes (Certification of Airport, 2022). There are significant efforts to predict and mitigate aircraft damage caused by bird and wildlife strikes; however, the mitigation efforts are complicated and not always well understood (Beiger et al., 2021).

DeVault et al. (2016) highlight the significant research that habitat management is one of the best long-term methods for reducing bird/wildlife strike risk. However, Swaddle et al. (2016) found that reducing or mitigating bird strikes over a long period is complex and, many times, ineffective. Swaddle et al. (2016) theorized that focusing on specific mitigations applied at the proper time may be a better use of resources. Dolbeer et al. (2015) found that many of the tactics outside of habitat management are commonly untested and only temporarily effective. A better understanding of the variables associated with bird strike risk may assist in the proper application of specific mitigations to improve habitat management and other mitigation techniques. Analysis of different variables that may increase strike risk is paramount to help reduce the risk of a catastrophic mishap (Metz et al., 2020).

Background/Overview of the Study

The annual cycle of the seasons directly relates to the increased probability of a bird strike (Metz et al., 2020). The airfield's migratory pattern and environmental conditions, driven by food, water, and shelter, directly influence the probability of bird strikes (Metz et al., 2020). Dietary changes in birds occur due to the availability of food sources (Stanton et al., 2018). The environmental conditions alter the food sources available, which can affect bird movements and behaviors that can increase the probability of impacting a bird. For example, insectivorous bird concentrations increase when environmental conditions support food source development (Blackwell et al., 2019).

Insectivorous birds prey on various insects depending on environmental factors such as insecticide use, fertilizer, precipitation, and vegetation (Stanton et al., 2018). Insect population growth correlates with weather patterns, even with removing time from consideration (Kahilainen et al., 2018). For example, Kahilainen et al. (2018) found the strongest association between insect population and May precipitation. They postulated that the slow growth of habitat in the Spring caused by a lack of precipitation drives higher competition and lower food availability. An increase in airfield food resources may attract smaller birds that, in turn, attract larger, more hazardous predatory species with a higher risk of damaging an aircraft. This study focused on the relationship between reported bird strikes and precipitation in distinct United States Department of Agriculture (USDA) climate zones to understand better the relationship between environmental conditions and bird strike risk.

Statement of the Problem

The severity of damage related to bird strikes is not only the aircraft part struck but also associated with the environmental conditions of the airfield that attract wildlife (Metz et al., 2020). Smaller mass birds have a relatively low damage potential (Metz et al., 2020); however, they can attract larger, more hazardous predatory birds that prey on smaller birds. Smaller flocking birds also increase the risk of aircraft damage due to increased total biomass. Smaller bird species, such as insectivorous birds, are more likely to strike aircraft due to their inability to see and avoid, which is still poorly understood within the scientific community (Blackwell et al., 2019).

There are substantial databases of weather and bird strikes. With the weather's many variables, evaluating one aspect can help focus future research into bird strike risk and mitigation. One variable might result in a difference in results due to the synergistic effects caused by multiple variables. This study helped fill the knowledge gap relative to weather and bird behavior related to bird and aircraft strikes.

Research Question and Hypotheses

RQ_1 What is the relationship, if any, exists between precipitation and bird strike species?

H_{01} There is no relationship between precipitation and bird strike species.

H_{A1} There is a relationship between precipitation and bird strike species.

RQ_2 What is the relationship, if any, exists between agricultural zone and bird strike species?

H_{02} There is no relationship between agricultural zone and bird strikes.

H_{A2} There is a relationship between agricultural zone and bird strike species.

RQ_3 What is the interaction, if any, exists between agricultural zone, precipitation, and bird strike species?

H_{03} There is no interaction between agricultural zone, precipitation, and bird species.

H_{A3} There is a relationship between agricultural zone, precipitation, and bird strike species.

Literature Review

The relevant literature for this study covers bird migration, behavior, insect density, and BASH mitigation efforts. Higher bird concentrations around the aircraft flight path directly relate to increased bird strike risk (Metz et al., 2021). Weather affects the migration and growth patterns of both birds and insects. Haest et al. (2018) indicated an increase in bird migration due to precipitation, with some exceptions of birds that prefer to migrate in the winter. This concept drives many theories about temperature being the more prominent indicator for migration. However, Haest et al. (2018) acknowledge that an ecosystem driven by rain production is most likely the driver. Increased food availability allows birds to move selectively, and food availability is most likely caused by precipitation (Haest et al., 2018).

Theoretical Framework

McNamara et al. (2011) proposed a method to predict organisms' best survival chances utilizing characteristics and cues from the environmental conditions. They found that the environmental cues and timing are paramount to maintaining predictability in their model (McNamara et al., 2011). Insect populations thrive in certain regional areas that match their ecological needs (Courson et al., 2022). When evaluating insect populations within a region, the temperature is not as much a factor as humidity and soil moisture (Courson et al., 2022), driving the discussion on how weather affects food sources. Knoblauch et al. (2021) found that temperature and cloud cover are the most significant contributors to insect prevalence. Insect movement increases with temperature and decreases with cloud cover. For example, arthropod species require specific vegetation and environmental factors to develop, creating a rich food source for bird species (Stanton et al., 2018).

Paxton et al. (2014) postulate that precipitation affects food sources such as vegetation and arthropod development. The density of the insect population varies widely between dense and sparsely populated vegetation (Andersson et al., 2013). Insect population also varies depending on the resources available for foraging and reproduction (Andersson et al., 2013). The most significant contributor to ecological patterns is the level of precipitation (Knapp et al., 2016).

Migration Patterns

Biologists have limited knowledge of the link between bird species and migration patterns (Drake et al., 2014). Food availability may drive birds through the migration route (King et al., 2017). No matter the time of year, weather patterns affect the migratory pattern of birds (Drake et al., 2014). Paxton et al. (2014) postulate that temperature and precipitation directly affect the migration patterns of birds. However, the impact of precipitation is limited by region and species (Paxton et al., 2014). McKellar et al. (2013) found a potential spatiotemporal relationship between bird migration and climate, specifically temperature and precipitation.

King et al. (2017) did not find a relationship between precipitation and migration patterns; however, they did find a positive correlation between the greening of the vegetation, no matter the season, and migration patterns. They postulate that insectivorous birds may require a habitat with greater precipitation than the carnivorous birds their study tracked (King et al., 2017). There is a need to develop better bird behavior models based on conditions other than temperature and vegetation index (Kelly et al., 2016). The temperature may be a cue for longrange migrations; however, short-range migrations do not necessarily correlate strongly to temperature (Kelly et al., 2016).

Wildlife Habitat Management and Deterrence

Land management has changed significantly since the 1960s, driving a change in wildlife dependent on various habitats (Stanton et al., 2018). Organisms of all types require certain environmental conditions to reproduce, hibernate, or survive (McNamara et al., 2011). Wildlife management plans rely heavily on habitat management to reduce the risk of wildlife strikes (Washburn et al., 2011). Warmer and wetter weather, particularly in the winter, may alter prey behavior, affecting predatory species migration due to food source availability (King et al., 2017). Environmental conditions, such as temperature and moisture, significantly affect the development of arthropods (Quinn, 2019), a food source for insectivorous birds, as is the vegetation the seed-eating birds use for subsistence.

The type of ground cover can drastically alter the food availability on an airfield and change the bird strike risk (Conover et al., 2009). Seed-producing cover attracts high levels of seed-eating birds, while insectivorous birds tend to frequent all vegetation that can support insects (Conover et al., 2009). Techniques for controlling wildlife strikes, particularly bird strikes, reduce the risk and do not eliminate the risk of a strike (Conover et al., 2009). More effective management plans identify wildlife resources, such as food, shelter, and water, and implement proper control practices (Washburn et al., 2011). Non-lethal and lethal techniques for bird control do not necessarily prevent birds from utilizing the airfield for roosting, drinking, and foraging (Conover et al., 2009).

Food availability is tied more to vegetation dynamics than temperature (Kelly et al., 2016). Airfields present the perfect location for birds and insects to forage (Washburn et al., 2011). Grasslands provide a nutritional resource for arthropods (Hussain et al., 2022). Arthropod occurrence in non-established grasslands is low and takes years to recover, except for certain carabids that adapt quickly to new environments (Hussain et al., 2022).

Gaps in Literature

Models of precipitation and how it affects the ecological area are commonly expressed either spatially or temporally (Knapp et al., 2016). Spatial models show steeper slopes and are better for linear analysis, while temporal models are highly sensitive and are typically non-linear (Knapp et al., 2016). Knapp et al. (2016) postulate that the difference is that once the vegetation reaches a constraint, it will not change appreciably over time, but the change may be spatially measured.

Insect cues that drive vegetation selection vary by species, but there is a lack of scientific research addressing the differences (Andersson et al., 2013). Environmental conditions, such as temperature and moisture, significantly affect the development of arthropods (Quinn, 2019). There is an inconsistency in research on land phenology and temperature as the driving factors for bird behavior (Kelly et al., 2016).

Methodology

This study analyzed precipitation and agricultural zone variables to identify if any relationship exists between aircraft and bird/wildlife strikes. The methodology and design utilized in this study was a quantitative, non-experimental analysis of empirical data gathered from weather sources and airfields that track bird strike data. The precipitation (measured in inches) was compared against the order of the bird species struck, total birds struck, and types of food sources available for birds at four military airports in different USDA agricultural zones. The Poisson regression and a binary logistic regression were utilized to analyze the data.

Population and Sample

Although the target population was all military and civilian airfields, the delimitation of the military airfields did not allow for this generalization. The four Department of the Air Force (DAF) airfields were selected due to their similar mission, aircraft, and data-gathering equipment. This deliminiation further limits the generalization to military training aircraft in the central and southern United States. Each airfield resides in a different USDA agricultural zone. The study could only demonstrate whether a relationship exists, which can be retested at airfields in other locations to increase generalizability.

Data Collection Process

The scope of this study focused on bird strikes at four of the Department of the Air Force (DAF) flight training bases over five years, from 2015 to 2019. The time frame allowed for varied weather patterns whereby the flight operations are relatively stable and will not include operational changes caused by the COVID-19 pandemic. Delimiting the study to only birds struck by aircraft types in generally southern-tier, central United States airfields limited the generalizability; however, the study intended to demonstrate whether a relationship exists between precipitation and bird strike species in various USDA agricultural zones.

The DAF Safety Center maintains an extensive database of all reported historical wildlife strikes. The assumption is that all strikes are reported; however, some non-damaging strikes may go unreported. This data was requested through the DAF Safety Center and reviewed by their legal team before release. The NOAA website (https://www.ncdc.noaa.gov/cdo-web/datatools/lcd) allowed for the download of weather information from each weather station. Each selected military installation has a weather station, allowing 24-hour weather monitoring. The weather sampling and reporting have different intervals, with missing data from periods of maintenance or malfunctions, but were assumed to be representative of the precipitation for that location's time period.

Design and Procedures

The NOAA data was a CSV file coded by installation (Table 1). The weather data was transformed from hourly to a five-day total to allow for sufficient precipitation events to demonstrate an effect on the bird strike data, standardize missing data from each weather station, and test for a temporal relationship suggested by Knapp et al. (2016). The purpose of the five-day breakdown allowed for evaluating the data at the zero-day, 5-day, 10-day, and 15-day intervals to test for any differences in relationships over the temporal variables (Appendix 1), as suggested by McKellar et al. (2013). The last iteration of data in December 2016 was six days due to the leap year. An additional categorical variable was created for the precipitation quantity to test beyond covariance in the Poisson regression (Table 2).

The bird strike data was an XLS file coded by installation (Table 1). The file contained each aircraft strike, date, order of the bird struck, and species struck, as provided by the DAF Safety Center. The aircraft struck were limited to the T-38 and T-6 aircraft, and any airfields or airports not located within the same city of the installation were removed. As their flight duration and average sortie requirements dictate, the T-38 and T-6 aircraft typically remain close to the installation. The order of the bird species was selected because many of the species' scientific names were annotated as the order of the bird species struck (Table 3). Utilizing the species' order reduced the dependent variable's levels but eliminated missing data. Any order listed as other, Rodentia, or Insecta was removed from the data. Due to the limited data available on most bird orders, only Cathartiformes, Passeriformes, and the bird strike totals were evaluated. The bird strike totals were transformed into a binary logistic of either a strike (1) or no strike (0). For further analysis driven by wildlife deterrence efforts that target food sources, the species struck were divided into insectivores, carnivores, seed-eating (including fruit-eating), and omnivores. The strike counts were summed and added to the five-day weekly column for analysis.

The data was manually entered into the International Business Machines Statistical Package for the Social Sciences (IBM® SPSS®). SPSS was utilized to test the assumptions of the Poisson regression and binary logistic regression. The data was manually adjusted by moving the bird strike data down one interval for the five-day, 10-day, and 15-day analyses, then removing the extraneous data at the end of each airfield's data set.

Results

Hair et al. (2018) discussed the challenges of the sample size in binary logistic regression. Although a larger sample size is recommended, binary logistic regression can handle smaller sizes (Hair et al., 2018). However, the binary logistic regression in this study resulted in 1,104 no-strike data points and 356 strike data points. The amount of data was sufficient to establish the impact of the independent

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variables on the dependent variables. The remaining variables and data reduction are listed in Table 4.

A binary logistic regression was performed to ascertain the effects of precipitation and the USDA agricultural zone on the likelihood of a bird strike occurring on DAF training aircraft on a zero-day, 5-day, 10-day, and 15-day post-precipitation data set. The linearity of the continuous variables with respect to the logit of the dependent variable for each time delay was assessed via the Box-Tidwell (1962) procedure. A Bonferroni correction was applied to using all three terms in the model, resulting in the acceptance of statistical significance ($p < .017$; Tabachnick & Fidell, 2014). Based on this assessment, all continuous independent variables were found to be linearly related to the logit of the dependent variable. There were no standardized residuals or outliers. The Hosmer and Lemeshow Test was not significant ($p > .05$) when using precipitation as a categorical variable, indicating a good fit for the test. However, the Hosmer and Lemeshow Test was significant when using precipitation as a continuous variable, indicating a poor model fit. Thus, all interpretations were limited to the categorical representation of the precipitation. There were no significant findings using the binary logistic regression in all data sets, indicating no relationship between total bird strikes and precipitation or agricultural zone. The potential cause of the significance is the distribution of the Passeriformes within the total bird strike count. An increase in strike locations would be necessary to increase the total bird strike count within acceptable analysis parameters without Passeriformes. Another option would be to further break up the Passeriformes into identifiable species, which may also demonstrate the same limitations of the current sample.

The Poisson regression was run to predict the number of bird strikes that occur based on the USDA agricultural zone, bird order, type of food, and the amount of precipitation each week at the zero-day, 5-day, 10-day, and 15-day post-precipitation data sets. A second Poisson regression was run to predict the same dependent variable utilizing precipitation as a categorical variable. The Poisson regression required at least three airfields; otherwise, the data was under-dispersed. The fourth airfield provided more data than required to ensure proper distribution; however, more airfields increased the total count and decreased the occurrence of a zero count. The data set has a higher-than-normal zero count than expected for a Poisson regression (Hilbe, 2014). The data fit the Poisson distribution and met all other assumptions. The likelihood ratio x^2 test indicated that the model significantly improved fit over the null model (Table 5 and Table 6) in all cases, except for omnivore as the dependent variable where the data was under distributed, and no relationship could be discerned. Hilbe (2014) described high sample size limitations for the likelihood ratio x^2 as less than the normally acceptable 1.25. In the case of this data set, the highest distribution was 1.17, with most being a nearly perfect 1.0.

Only on the 10-day offset of precipitation, where precipitation was a covariate, the Total Birds struck variable demonstrated a significant relationship ($p < .05$). In addition, all of the cases, except for Carnivore and Omnivore, demonstrated a significant relationship. In all cases where precipitation was a covariate (zero, 5-, 10, and 15-day offset), Cathartiformes had a significant value based on the USDA agricultural zone ($p < .05$). In the zero-day and 5-day data set, Columbus AFB (USDA zone 8a), Vance AFB (USDA zone 6b), and Laughlin AFB (USDA zone 9a) had a significantly higher mean difference of .03 over Sheppard ($p < .01$) (USDA zone 7b). However, the overall evaluation did not demonstrate a statistical significance ($p > .05$), resulting in the difference not being considered a valid comparison. When utilizing precipitation as a covariate on the 10-day data set, there were significant relationships due to precipitation in Total Birds struck for every expected bird struck (6% increase, $p = .01$), Cathartiformes struck (20% increase, $p = .01$), Passeriformes struck (9% increase, $p < .01$), and Insectivore struck (8% increase, $p = .02$). For Passeriformes and Insectivore, the model fit was not sufficient to warrant consideration as a valid predictor ($p > .05$). The 10-day data set had similar seed-eating bird differences between Columbus AFB and the other locations. Seed-eating birds were struck on a significantly different basis based on the USDA agricultural zone ($p < .00$). Columbus AFB demonstrated a 69% less chance of striking seed-eating birds in all data sets, including precipitation as a covariate and as a categorical variable ($p < .00$).

The 15-day data set with precipitation as a covariate, as well as all the delay cases with precipitation as a categorical variable, demonstrated a significance for Cathartiformes, whereby Sheppard AFB had a mean that was .03 below Columbus ($p < .00$), .02 below Laughlin (p < .01), but not statistically different from the mean of Vance AFB ($p > .05$). Overall, for every one Cathartiformes expected to be struck, Columbus AFB struck 343% more Cathartiformes ($p = .03$) on the 15-day post precipitation data set with precipitation as a covariate. With precipitation as a categorical variable for the zero, 5-, and 15-day data, Columbus AFB struck 313%, 317%, and 318% ($p < .05$), respectively. The 10-day data set demonstrated no significant predicted increase ($p > .05$) for Cathartiformes with precipitation as a categorical variable. With these results, the null hypothesis can be rejected for RQ_1, RQ_2, and RQ_3. The results indicated a statistically significant predictive relationship between bird species, precipitation, and agricultural zone in at least one of each condition.

Discussion and Conclusions

With the significant results occurring primarily ten days following a precipitation event and on certain species no matter the precipitation, this would follow the logic of the environmental conditions requiring time for food to develop and attracting wildlife that can become a hazard. Evidence supports the theory that food availability is a more significant determinant of arthropods' successful growth

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and development than temperature (Quinn, 2019); however, food sources for insect and seed-eating birds require proper environmental conditions to develop. There are arguments as to whether extreme weather decreases precipitation's effects on environmental conditions or has no effect. The effects of La Niña drive wind and rain conditions that negatively alter bird migration and breeding (Drake et al., 2014). Extreme weather conditions can also negatively affect arthropods', a potential food source, early development (Quinn, 2019). However, Quinn (2019) states that there is a lack of academic research on the impact of temperature on all arthropod development, as current research focuses on copepod and crustacean development. The resources birds need to thrive on airfields are insects and the vegetation that support them.

Drenovsky et al. (2016) found more significant interaction with nutrient availability over water; however, both significantly contributed to the germination and development of plant life. The overall results of Drenovsky et al. (2016) were that plant development was plastic and not necessarily tied to resources as much as temperature and water availability. Seed production was linked to nutrient and water availability (Drenovsky et al., 2016). The similarity between USDA agricultural zones of Vance, Sheppard, and Laughlin AFB versus the nutrient availability at Columbus AFB located east of these airfields may contribute to why Columbus AFB has lower predicted strikes from seed-eating birds. One possible consideration is that Columbus AFB has more seed-eating resources outside of the airfield that attracts the seed-eating birds. The more centralized airfields may not have the vegetation support for seed-eating birds except on the airfield.

Although Gellesch et al. (2015) found that the most critical aspect of plant growth is meeting the basic precipitation levels, the temperature may be a factor. An extreme increase in precipitation increased germination and development. However, the minimum duration for germination required at least three days at the minimum moisture level (Gellesch et al., 2015; Moreno-de las Heras et al., 2016), which may be why the larger offset from precipitation demonstrated the most significant predictor due to precipitation. Moreno-de las Heras et al. (2016) found the best germination temperatures for the seeds in their study was 20-25 degrees centigrade with a soil moisture content of 9.7%, which is plant specific. The environmental contributions toward the germination of seeds may also describe why USDA agricultural zones may have different wildlife present. Although the plants in their study responded to lower moisture and temperatures, the time to develop plants increased, and the germination rate decreased.

The production of mature arthropods differs even from within the species (Minelli et al., 2006). When environmental conditions are ideal, the mating insects' feeding may drive the mature gamete's successful development and molting schedule (Minelli et al., 2006). The development of insects such as arthropods varies, and the causes of the variance are poorly understood (Minelli et al., 2006).

Molting still occurs when there is insufficient food. However, the time between molts increased significantly (Minelli et al., 2006). The concept of molting and development are essential for wildlife deterrence due to the application and effectiveness of both herbicide and insecticide. Arthropods, which take time to grow and mature, are a food source for many members of the Passeriformes order but also attract the animals and reptiles that Cathartiformes feed on (Smithsonian, n.d.b.).

Cathartiformes is an order of birds with 38 species, including Vultures and Condors (Smithsonian, n.d.a). These large birds feed on meat such as carrion, small birds, rodents, and lizards (Smithsonian, n.d.a). They are also present in all migration patterns; however, they may be more present near Columbus AFB, the only airfield not located in the same migration pattern as the other three airfields (Cornell University, 2022). After a precipitation event, it would take time for the environmental conditions to attract Cathartiformes as the resources for their food sources must develop, then attract predators or cause an event whereby the food source becomes carrion. With the availability of food sources, the already present Passeriformes, which account for nearly half of all birds (Smithsonian, n.d.a), could become active, as would other potential Cathartiformes prey. However, more research may be required into why Cathartiformes were more prevalent in each category.

The great variety of bird species in the Passeriformes order combined with the order accounting for more than 50% of all of the strikes at the DAF airfields may drive the lack of statistical significance in the Total Birds struck and insectivore categories. However, the precipitation may still be a driver for overall environmental conditions. A better model with a three-day over-lap for each of the 5-day intervals may demonstrate a better effect of the time between precipitation. However, adding the addition of temperature, humidity, and other factors may improve the logistic regression and the Poisson regression results. Also, by not delimiting the aircraft, the number of potential strikes may increase, allowing the borderline evaluations to become more robust and decrease the occurrence of a zero count. Another possible method to improve the Poisson regression would be to utilize a traditional seven-day week.

With the ability to better predict when aircraft are at risk of a bird strike, wildlife hazard professionals could better allocate resources to decrease risk. The selection and application of pesticides, herbicides, or other control methods must target the resources utilized appropriately (Washburn et al., 2011). Species-specific mitigation applied at the proper time significantly decreased the likelihood of a strike (Swaddle et al., 2016). With the dietary plasticity among birds found near or around airports, the airfield manager can better address wildlife deterrents between five and ten days following a precipitation event. The interaction effect from the

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Poisson regression suggested that the agricultural zone may be a more vital determinant for bird strikes, which would follow the availability of food theory.

The theoretical foundation of weather and bird strike data is not well developed. Lee (2022) and Baugh (2020) utilized data mining and machine learning to analyze aircraft mishaps at airfields. Lee (2022) focused on bird strikes and improving models for one US airfield but could not accurately analyze the impact of weather due to the types of weather data acquired. Andrews et al. (2022) modeled bird strike likelihood at Brisbane Airport, Australia, but did not include weather or a spatiotemporal aspect. Further research should develop the theory from a data mining or machine learning algorithm, which will require more data and be confirmed through a structural equation modeling process. The benefit of this process will be a better analysis without the requirement for structured statistics with strict assumptions that natural research does not always provide. The increased understanding gained through the deliberate process will help focus future research and mitigation efforts.

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Tables

Table 1

Installation Coding and USDA Agricultural Zone (USDA, 2022)

Installation	Code	Agricultural Zone
Columbus AFB	1	8a
Laughlin AFB	2	9a
Sheppard AFB	4	7b
Vance AFB	5	6b

Note. USDA agricultural zones are based on a 30-year period of environmental conditions (USDA, 2022). These zones take into account soil type, moisture, humidity, pollution, snow, and average sunshine that influence plant growth. Similar zones will have the same characteristics and support plant life that may influence the entire ecosystem, including insect and bird movement.

Table 2

Precipitation Coding

Precipitation	Code
0 Inches	0
0 but less than 1 Inches	1
1 but less than 2 Inches	2
2 Inches or more	3

Note. The Food and Agriculture Organization (FAO) of the United Nations (2022) recommends a minimum amount of precipitation to ensure the germination and sustainment of vegetation. The soil moisture requirements established by Moreno-de las Heras et al. (2016) and Gellesch et al. (2015), combined with the FAO (2022) recommendation, support a one-inch weekly categorical differential in precipitation.

Table 3

Bird species' order and quantity struck at each location

Order	Columbus	Laughlin	Vance	Sheppard
Accipitriformes	4	5	7	9
Anseriformes	2	0	2	0
Apodiformes	17	3	0	2
Caprimulgiformes	1	7	2	1
Cathartiformes[a]	12	12	4	1
Charadriiformes	3	8	8	2
Chiroptera	4	2	1	0
Columbiformes	1	9	14	22
Falconiformes	0	4	2	4
[a]Passeriformes[a]	61	62	66	77
Gruiformes	0	1	1	0
[a]Insectivore[a]	53	60	59	56
Seed and Fruit[a]	9	20	41	29
Carnivorous[a]	17	21	11	16

Omnivore[a]	2	0	0	2
Total[a]	105	113	109	118

a. Utilized for statistical analysis

Note. Each strike from the different orders was manually entered into the appropriate five-day week for analysis.

Table 4

Weather and Bird Strike Reduction

Location	Original Reading	Weather Count	Weather Reduction	Original Bird Strike Count	Bird Strike Reduction
Columbus AFB	84,818	365	292	105	81
Laughlin AFB	66,201	365	246	113	101
Sheppard AFB	62,422	365	246	118	111
Vance AFB	60,234	365	172	109	103

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Table 5

Poisson Regression Results (Precipitation as a continuous covariate)

Dependent Variable	Time	x^2	USDA Zone P-Value	Precipitation P-Value	(EXP) B-Value	CI
Total Birds Struck	0	1.17	.85	.42		
Cathartiformes	0	0.91	.02*	.59	c	0.94 – 9.08
Passeriformes	0	1.17	.53	.77		
Insectivore	0	1.11	.89	.19		
Seed Eating	0	0.95	.00*	.81	0.31	0.15 - 0.66
Carnivore	0	0.99	.33	.42		
Omnivore[b]	0	0.47	----	----		
Total Birds Struck	5	1.17	.83	.89		
Cathartiformes	5	0.99	.03*	.75	c	
Passeriformes	5	1.17	.48	.76		
Insectivore	5	1.12	.91	.91		
Seed Eating	5	0.95	.00*	.66	0.31	0.15 - 0.67
Carnivore	5	0.99	.36	.68		
Omnivore[b]	5	0.45	----	----		
Total Birds Struck	10	1.15	.88	.01*	1.07	1.07 - 1.12
Cathartiformes	10	1.09	.02*	.01*	1.20[c]	1.04 - 1.39
Passeriformes[a]	10	1.15	.76	.00*	1.09	1.03 - 1.15
Insectivore[a]	10	1.10	.85	.02*	1.08	1.01 - 1.15
Seed Eating	10	0.95	.00*	.71	0.31	0.15 - 0.66
Carnivore	10	0.99	.33	.38		
Omnivore[b]	10	0.45	----	----		
Total Birds Struck	15	1.17	.87	.42		
Cathartiforms	15	0.97	.02*	.16	3.43	1.10 - 10.72
Passeriformes	15	1.16	.69	.12		
Insectivore	15	1.12	.90	.31		
Seed Eating	15	0.95	.00*	.46	0.31[c]	0.94 - 1.15

Carnivore	15	0.97	.54	.12
Omnivore[b]	15	0.47	----	----

**Significant result based on p < .05*
a. Significant result without model fit (Omnibus test, p > .05)
b. Insufficient data for a Poisson distribution
c. See text for detailed results

Table 6
Poisson Regression Results (Precipitation as a categorical dependent variable and food source)

Dependent Variable	Time	x^2	USDA Zone P-Value	Precipitation P-Value	(EXP) B-Value	CI
Total Birds Struck	0	1.16	.94	.08		
Cathartiformes	0	1.07	.02*	.85	3.13	1.00 - 9.80
Passeriformes	0	1.17	.56	.18		
Insectivore[a]	0	1.10	.98	.04*	c	
Seed Eating	0	0.95	.00*	.84	0.31	0.14 - 0.65
Carnivore	0	0.98	.38	.99		
Omnivore[b]	0	0.39	----	----		
Total Birds Struck	5	1.17	.84	.99		
Cathartiformes	5	0.95	.02*	.66	3.17	1.01 - 9.92
Passeriformes	5	1.17	.44	.63		
Insectivore	5	1.12	.93	.98		
Seed Eating	5	0.95	.00*	.10	c	0.14 - 0.64; 0.18 – 0.96
Carnivore	5	0.98	.35	.58		
Omnivore[b]	5	0.38	----	----		
Total Birds Struck	10	1.16	.83	.12		
Cathartiformes	10	1.04	.02*	.59	c	
Passeriformes	10	1.16	.63	.20		
Insectivore	10	1.11	.89	.53		
Seed Eating	10	0.95	.00*	.88	0.31	0.15 - 0.66

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Carnivore	10	0.99	.33	.50		
Omnivore[b]	10	0.38	----	----		
Total Birds Struck	15	1.16	.90	.52		
Cathartiformes	15	0.92	.03*	.36	3.18	1.01-9.91
Passeriformes	15	1.16	.69	.24		
Insectivore	15	1.12	.90	.59		
Seed Eating	15	0.95	.00*	.23	0.31	0.14 - 0.64
Carnivore	15	0.98	.49	.35		
Omnivore[b]	15	0.40	----	----		

**Significant result based on p < .05.*

a. Significant result without model fit (Omnibus test, p > .05)

b. Insufficient data for a Poisson distribution

c. See text

Appendix 1: Weather Calendar

Week	Month	Day	Year
1	Jan	01-05	2015
2	Jan	06-10	2015
3	Jan	11-15	2015
4	Jan	16-20	2015
5	Jan	20-25	2015
6	Jan	26-30	2015
7	Jan-Feb	31-04	2015
8	Feb	05-09	2015
9	Feb	10-14	2015
10	Feb	15-19	2015
11	Feb	20-24	2015
12	Feb-Mar	25-01	2015
13	Mar	02-06	2015
14	Mar	07-11	2015
15	Mar	12-16	2015
16	Mar	17-21	2015
17	Mar	22-26	2015
18	Mar	27-31	2015
19	Apr	01-05	2015
20	Apr	06-10	2015
21	Apr	11-15	2015
22	Apr	16-20	2015
23	Apr	21-25	2015
24	Apr	26-30	2015
25	May	01-05	2015
26	May	06-10	2015
27	May	11-15	2015
28	May	16-20	2015
29	May	21-25	2015
30	May	26-30	2015
31	May-Jun	31-04	2015
32	Jun	05-09	2015
33	Jun	10-14	2015
34	Jun	15-19	2015
35	Jun	20-24	2015
36	Jun	25-29	2015
37	Jun-Jul	30-04	2015
38	Jul	05-09	2015
39	Jul	10-14	2015
40	Jul	15-19	2015
41	Jul	20-24	2015
42	Jul	25-29	2015
43	Jul-Aug	30-03	2015
44	Aug	04-08	2015
45	Aug	09-13	2015
46	Aug	14-18	2015
47	Aug	19-23	2015
48	Aug	24-28	2015
49	Aug-Sep	29-02	2015
50	Sep	03-07	2015
51	Sep	08-12	2015
52	Sep	13-17	2015
53	Sep	18-22	2015
54	Sep	23-27	2015
55	Sep-Oct	28-02	2015
56	Oct	03-07	2015
57	Oct	08-12	2015
58	Oct	13-17	2015
59	Oct	18-22	2015
60	Oct	23-27	2015
61	Oct-Nov	28-01	2015
62	Nov	02-06	2015
63	Nov	07-11	2015
64	Nov	12-16	2015
65	Nov	17-21	2015
66	Nov	22-26	2015
67	Nov-Dec	27-01	2015
68	Dec	02-06	2015
69	Dec	07-11	2015
70	Dec	12-16	2015
71	Dec	17-21	2015
72	Dec	22-26	2015
73	Dec	27-31	2015

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74	Jan	01-05	2016
75	Jan	06-10	2016
76	Jan	11-15	2016
77	Jan	16-20	2016
78	Jan	20-25	2016
79	Jan	26-30	2016
80	Jan-Feb	31-04	2016
81	Feb	05-09	2016
82	Feb	10-14	2016
83	Feb	15-19	2016
84	Feb	20-24	2016
85	Feb	25-29	2016
86	Mar	01-05	2016
87	Mar	06-10	2016
88	Mar	11-15	2016
89	Mar	16-20	2016
90	Mar	20-25	2016
91	Mar	26-30	2016
92	Mar-Apr	31-04	2016
93	Apr	05-09	2016
94	Apr	10-14	2016
95	Apr	15-19	2016
96	Apr	20-24	2016
97	Apr	25-29	2016
98	Apr-May	30-04	2016
99	May	05-09	2016
100	May	10-14	2016
101	May	15-19	2016
102	May	20-24	2016
103	May	25-29	2016
104	May-Jun	30-03	2016
105	Jun	04-08	2016
106	Jun	09-13	2016
107	Jun	14-18	2016
108	Jun	19-23	2016
109	Jun	24-28	2016
110	Jun-Jul	29-03	2016
111	Jul	04-08	2016

112	Jul	09-13	2016
113	Jul	14-18	2016
114	Jul	19-23	2016
115	Jul	24-28	2016
116	Jul-Aug	29-02	2016
117	Aug	03-07	2016
118	Aug	08-12	2016
119	Aug	13-17	2016
120	Aug	18-22	2016
121	Aug	23-27	2016
122	Aug-Sep	28-01	2016
123	Sep	02-06	2016
124	Sep	07-11	2016
125	Sep	12-16	2016
126	Sep	17-21	2016
127	Sep	22-26	2016
128	Sep-Oct	27-01	2016
129	Oct	02-06	2016
130	Oct	07-11	2016
131	Oct	12-16	2016
132	Oct	17-21	2016
133	Oct	22-26	2016
134	Oct	27-31	2016
135	Nov	01-05	2016
136	Nov	06-10	2016
137	Nov	11-15	2016
138	Nov	16-20	2016
139	Nov	20-25	2016
140	Nov	26-30	2016
141	Dec	01-05	2016
142	Dec	06-10	2016
143	Dec	11-15	2016
144	Dec	16-20	2016
145	Dec	20-25	2016
146	Dec*	26-31	2016
147	Jan	01-05	2017
148	Jan	06-10	2017
149	Jan	11-15	2017

150	Jan	16-20	2017
151	Jan	20-25	2017
152	Jan	26-30	2017
153	Jan-Feb	31-04	2017
154	Feb	05-09	2017
155	Feb	10-14	2017
156	Feb	15-19	2017
157	Feb	20-24	2017
158	Feb-Mar	25-01	2017
159	Mar	02-06	2017
160	Mar	07-11	2017
161	Mar	12-16	2017
162	Mar	17-21	2017
163	Mar	22-26	2017
164	Mar	27-31	2017
165	Apr	01-05	2017
166	Apr	06-10	2017
167	Apr	11-15	2017
168	Apr	16-20	2017
169	Apr	21-25	2017
170	Apr-May	26-30	2017
171	May	01-05	2017
172	May	06-10	2017
173	May	11-15	2017
174	May	16-20	2017
175	May	21-25	2017
176	May	26-30	2017
177	May-Jun	31-04	2017
178	Jun	05-09	2017
179	Jun	10-14	2017
180	Jun	15-19	2017
181	Jun	20-24	2017
182	Jun	25-29	2017
183	Jun-Jul	30-04	2017
184	Jul	05-09	2017
185	Jul	10-14	2017
186	Jul	15-19	2017
187	Jul	20-24	2017
188	Jul	25-29	2017
189	Jul-Aug	30-03	2017
190	Aug	04-08	2017
191	Aug	09-13	2017
192	Aug	14-18	2017
193	Aug	19-23	2017
194	Aug	24-28	2017
195	Aug-Sep	29-02	2017
196	Sep	03-07	2017
197	Sep	08-12	2017
198	Sep	13-17	2017
199	Sep	18-22	2017
200	Sep	23-27	2017
201	Sep-Oct	28-02	2017
202	Oct	03-07	2017
203	Oct	08-12	2017
204	Oct	13-17	2017
205	Oct	18-22	2017
206	Oct	23-27	2017
207	Oct-Nov	28-01	2017
208	Nov	02-06	2017
209	Nov	07-11	2017
210	Nov	12-16	2017
211	Nov	17-21	2017
212	Nov	22-26	2017
213	Nov-Dec	27-01	2017
214	Dec	02-06	2017
215	Dec	07-11	2017
216	Dec	12-16	2017
217	Dec	17-21	2017
218	Dec	22-26	2017
219	Dec	27-31	2017
220	Jan	01-05	2018
221	Jan	06-10	2018
222	Jan	11-15	2018
223	Jan	16-20	2018
224	Jan	20-25	2018
225	Jan	26-30	2018

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226	Jan-Feb	31-04	2018
227	Feb	05-09	2018
228	Feb	10-14	2018
229	Feb	15-19	2018
230	Feb	20-24	2018
231	Feb-Mar	25-01	2018
232	Mar	02-06	2018
233	Mar	07-11	2018
234	Mar	12-16	2018
235	Mar	17-21	2018
236	Mar	22-26	2018
237	Mar	27-31	2018
238	Apr	01-05	2018
239	Apr	06-10	2018
240	Apr	11-15	2018
241	Apr	16-20	2018
242	Apr	21-25	2018
243	Apr-May	26-30	2018
244	May	01-05	2018
245	May	06-10	2018
246	May	11-15	2018
247	May	16-20	2018
248	May	21-25	2018
249	May	26-30	2018
250	May-Jun	31-04	2018
251	Jun	05-09	2018
252	Jun	10-14	2018
253	Jun	15-19	2018
254	Jun	20-24	2018
255	Jun	25-29	2018
256	Jun-Jul	30-04	2018
257	Jul	05-09	2018
258	Jul	10-14	2018
259	Jul	15-19	2018
260	Jul	20-24	2018
261	Jul	25-29	2018
262	Jul-Aug	30-03	2018
263	Aug	04-08	2018

264	Aug	09-13	2018
265	Aug	14-18	2018
266	Aug	19-23	2018
267	Aug	24-28	2018
268	Aug-Sep	29-02	2018
269	Sep	03-07	2018
270	Sep	08-12	2018
271	Sep	13-17	2018
272	Sep	18-22	2018
273	Sep	23-27	2018
274	Sep-Oct	28-02	2018
275	Oct	03-07	2018
276	Oct	08-12	2018
277	Oct	13-17	2018
278	Oct	18-22	2018
279	Oct	23-27	2018
280	Oct-Nov	28-01	2018
281	Nov	02-06	2018
282	Nov	07-11	2018
283	Nov	12-16	2018
284	Nov	17-21	2018
285	Nov	22-26	2018
286	Nov-Dec	27-01	2018
287	Dec	02-06	2018
288	Dec	07-11	2018
289	Dec	12-16	2018
290	Dec	17-21	2018
291	Dec	22-26	2018
292	Dec	27-31	2018
293	Jan	01-05	2019
294	Jan	06-10	2019
295	Jan	11-15	2019
296	Jan	16-20	2019
297	Jan	20-25	2019
298	Jan	26-30	2019
299	Jan-Feb	31-04	2019
300	Feb	05-09	2019
301	Feb	10-14	2019

302	Feb	15-19	2019
303	Feb	20-24	2019
304	Feb-Mar	25-01	2019
305	Mar	02-06	2019
306	Mar	07-11	2019
307	Mar	12-16	2019
308	Mar	17-21	2019
309	Mar	22-26	2019
310	Mar	27-31	2019
311	Apr	01-05	2019
312	Apr	06-10	2019
313	Apr	11-15	2019
314	Apr	16-20	2019
315	Apr	21-25	2019
316	Apr-May	26-30	2019
317	May	01-05	2019
318	May	06-10	2019
319	May	11-15	2019
320	May	16-20	2019
321	May	21-25	2019
322	May	26-30	2019
323	May-Jun	31-04	2019
324	Jun	05-09	2019
325	Jun	10-14	2019
326	Jun	15-19	2019
327	Jun	20-24	2019
328	Jun	25-29	2019
329	Jun-Jul	30-04	2019
330	Jul	05-09	2019
331	Jul	10-14	2019
332	Jul	15-19	2019
333	Jul	20-24	2019
334	Jul	25-29	2019
335	Jul-Aug	30-03	2019
336	Aug	04-08	2019
337	Aug	09-13	2019
338	Aug	14-18	2019
339	Aug	19-23	2019
340	Aug	24-28	2019
341	Aug-Sep	29-02	2019
342	Sep	03-07	2019
343	Sep	08-12	2019
344	Sep	13-17	2019
345	Sep	18-22	2019
346	Sep	23-27	2019
347	Sep-Oct	28-02	2019
348	Oct	03-07	2019
349	Oct	08-12	2019
350	Oct	13-17	2019
351	Oct	18-22	2019
352	Oct	23-27	2019
353	Oct-Nov	28-01	2019
354	Nov	02-06	2019
355	Nov	07-11	2019
356	Nov	12-16	2019
357	Nov	17-21	2019
358	Nov	22-26	2019
359	Nov-Dec	27-01	2019
360	Dec	02-06	2019
361	Dec	07-11	2019
362	Dec	12-16	2019
363	Dec	17-21	2019
364	Dec	22-26	2019
365	Dec	27-31	2019
* Contains 6 Days			

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