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Spatiotemporal Dynamics in Identification of Aircraft–Bird Strikes

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A primary concern for human–wildlife interactions is the potential impacts resulting from wildlife (primarily birds) collisions with aircraft. The identification of species responsible for collisions with aircraft is necessary so that airport management can develop effective strategies to reduce strikes with those species. Of particular importance in developing such strategies is the identification of regional, seasonal, and temporal patterns in collisions with unidentified bird species that may limit the effectiveness of regional habitat management to reduce bird strikes. The authors analyzed 105,529 U.S. civil aviation strike records from 1990 to 2012 in the FAA's National Wildlife Strike Database to examine patterns of collisions involving unidentified birds. Factors that affected identification were airport certification class, FAA region, mass of struck species, state species richness (if damage was reported), and interactive effects between the last four factors. Identification varied by region and declined with increasing species richness; this identification was greater for general aviation (GA) airports and the mass of struck species, especially when damage was reported. Species identification might be improved by increasing reporting efforts relative to species richness, especially by GA airport managers and operations staff, who may have a higher propensity of reporting bird strikes, and by collecting more field-based data on avian populations. The results can provide guidance for the development of airport management and personnel training.

The ecological implications of climate change, urbanization, and other factors influencing bird populations and migration patterns can affect species interactions with humans (*1–5*). One primary concern for these interactions is the potential impacts from bird strikes with aircraft. Airports and surrounding landscapes are often grasslands that are perceived by wildlife as habitat (*6, 7*). In addition, factors influencing damage sustained to aircraft include aircraft speed and the mass and number of struck individuals, the latter of which is dependent on flocking behaviors of each avian species (*8–12*). Bird abundances and flocking and flight behaviors in airport vicinities may be related to seasonal changes in migration patterns, weather, food availability, and predation risk (*13–17*). As a result, development of models that incorporate ecological data is important for increasing the understanding of spatiotemporal factors that hinder aviation safety.

The richness of avian species demonstrates spatial variation, with decreasing richness at greater latitudes (*18, 19*); this richness may also be affected by elevation, climate dynamics, existing habitat and geographic features, and potential food resources (*2, 14, 20–22*). Furthermore, site-specific richness of species varies seasonally because of (*a*) the presence of breeding or wintering avian species and (*b*) temporal pulses during spring and autumn migrations. Distributions of migrating birds may also be influenced by geographic features (e.g., mountain ranges or coastlines) that may concentrate migrating populations (*23*), and all of these factors can adversely affect aviation safety (*24, 25*). Many species known to be detrimental to aircraft [e.g., Canada geese (*Branta canadensis*), gulls, etc.] are also increasing in numbers and easily adapting to urbanized environments where they may be more likely to occur at airports (*26, 27*). By incorporating measurements of the richness of avian species into training and reporting procedures, researchers could improve identification proficiency by accounting for spatiotemporal variation in avian populations and the relative influence on aviation strike risk.

The objectives of this study were to (*a*) examine incidents involving unknown bird species relative to the total incidents (unidentified bird ratio) and (*b*) model nonidentification of bird strikes to identify potential regions and factors adversely influencing species identification, including spatial, temporal, and management variables. This study examined specific hypotheses that could potentially influence nonidentification rates related to species richness, location, airport classifications, estimated mass of struck species, and the occurrence of damage.

Species richness may negatively influence correct classification of struck species if the ease of identification for observers is dependent on the number of similar candidate species. Therefore, the authors predicted species nonidentification to be greater in FAA regions with higher overall species richness and also expected nonidentification to increase during peak migration periods in spring and autumn, when species richness is greater. Airportcentric management practices may also influence identification. Certificated–classified airports often have a trained airport biologist, whereas general aviation (GA) airports generally do not, and therefore, personnel at GA airports may be less likely to identify species because they lack specialized training (*28*). If any of the above factors is important to species identification, modifications in training relative to influential factors may improve identification, strike reporting, and the effectiveness of hazardous species management.

METHODS

Databases

The authors analyzed U.S. civil aviation strike records from 1990 to 2012 in the FAA's National Wildlife Strike Database to determine patterns of collisions involving unidentified birds and factors

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influencing nonidentification. Since 1990, the FAA has compiled voluntary reports of strikes involving civil aircraft and wildlife (*29*); this information determines economic costs of strikes and provides important data regarding the wildlife species involved, the type of damage, and aircraft and location details. The analyses were restricted to civil aviation operations involving avian species within the contiguous United States. Each record was classified in the database as identified or unidentified, and all bird strikes were considered identified if they were at least classified to family level (e.g., Anatidae).

Each incident was categorized in the data set by month, airport, FAA region, state, Part 139 airport classification type (certificated or GA), estimated mass of the struck species, and reported damage, if any. The richness of avian species was determined for each state on a mean weekly basis by using data collected through citizen science and submitted to the eBird website (www.ebird.org) from 1990 to 2010 (*30*). eBird is a citizen science website that allows users to submit data on numbers of observed avian species. The numbers of registered observers and submitted lists vary widely by location, so the observations were pooled at the state level for subsequent analyses. Observation data queried from eBird presented species observations as the proportion of checklists containing that species divided by all checklists submitted for a given week (e.g., first week of January) for all years combined. For example, Canada geese occurred on 16% ($n = 5{,}737$) of California checklists for the first week of January. The authors determined the species richness for each state and month by calculating the total species present on more than 1% of reported checklists during each weekly interval to exclude single records of vagrant species. In addition, weekly species records were pooled to estimate the total species observed in a state by month.

Statistical Analyses

The authors modeled the relationships between bird identifications (response variable) by using logistic regression within generalized linear mixed models in R 3.03 (R Development Core Team, Vienna, Austria) with the lme4 package (*31*) and ranked models by using a sequential modeling approach using Akaike's information criterion (AIC) and weights (*32*). Models with a ΔAIC <4 were considered competitive, as this value reduces the potential for errors involving interpretation of models with ΔAIC <2 (*33*). Coefficients and 85% confidence intervals for biologically significant effects were also examined. The fixed effects included main effects and additive combinations of location characteristics (FAA region, airport type), species richness, estimated mass for struck species, and reported damage, if any. Then the best model from the previous step was used to determine whether interactive effects between species richness and region or mass and damage reported improved model fit. State, airport, and year were classified as random effects in the model, and random effects structure was determined by fitting the full model with multiple combinations of the specified random effects. Next pseudo-R^2 was calculated to examine the proportion of variance explained by the best-fit models and to assess model fit (*34*).

RESULTS

The authors reviewed 105,529 bird strikes associated with 1,363 airports in the database, with 47% of strikes not identified to species or group (e.g., family or genus classification). The proportion of identified bird strikes, damaging strikes, and mass and species richness varied by FAA region (Table 1). Bird strikes associated with certificated airports accounted for 94.7% of the records. Approximately 8.4% of strikes reported damage to the aircraft, and the mean mass standard deviation (±SD) of struck species involved in damaging incidents (1,317.5 ± 1,271.2 g) was 2.3 times as large as when no damage was reported (456.5 ± 616.8 g). The number of bird strikes increased annually; however, the proportion of reports with unidentified birds relative to identified species declined (Figure 1).

The richness of avian species varied by month and location, with the highest species richness within the Southern, Northwest, Southwest, and Western Pacific FAA regions (Table 1). In addition, two peaks, corresponding to spring and autumn migration periods, occurred from March to June and August to November. Identification of species in strike incidents was best explained by certification class, damage reported, species mass, and an interactive effect between FAA region and species richness and an interaction between damage reported and species mass (Table 2); no other models were within 531 ΔAIC. Identification was highest in New England; other FAA regions were 50% (Northwest) to 79% (Southern) less likely to identify strikes by species group (Table 2). Bird strikes declined

TABLE 1 Summary Statistics for Total Bird Strikes, Percentage of Unidentified Strikes, Percentage of Strikes with Damage, Estimated Mass of Struck Species, and Annual Species Richness, by FAA Region for Incidents Reported in FAA National Wildlife Strike Database, 1990–2012

FAA Region	Total Bird Strikes (*n*)	Unidentified Strikes (%)	Damage Reported (%)	Species Mass (g) Mean	Species Mass (g) SD	Species Richness Mean	Species Richness SD
New England	4,559	31.9	7.8	602.0	885.5	331.6	69.4
Central	5,548	44.1	8.2	441.9	715.0	294.5	47.3
Eastern	20,261	39.7	8.7	597.1	832.4	354.8	80.8
Great Lakes	17,131	41.7	8.1	540.3	795.3	333.0	48.5
Northwest	11,031	42.0	7.9	490.9	699.2	377.1	54.5
Southern	20,499	58.5	8.8	544.0	728.6	355.5	88.8
Southwest	13,670	52.7	6.9	392.9	500.1	516.4	123.2
Western Pacific	12,830	51.0	10.1	571.0	666.8	563.4	84.4

NOTE: SD = standard deviation.

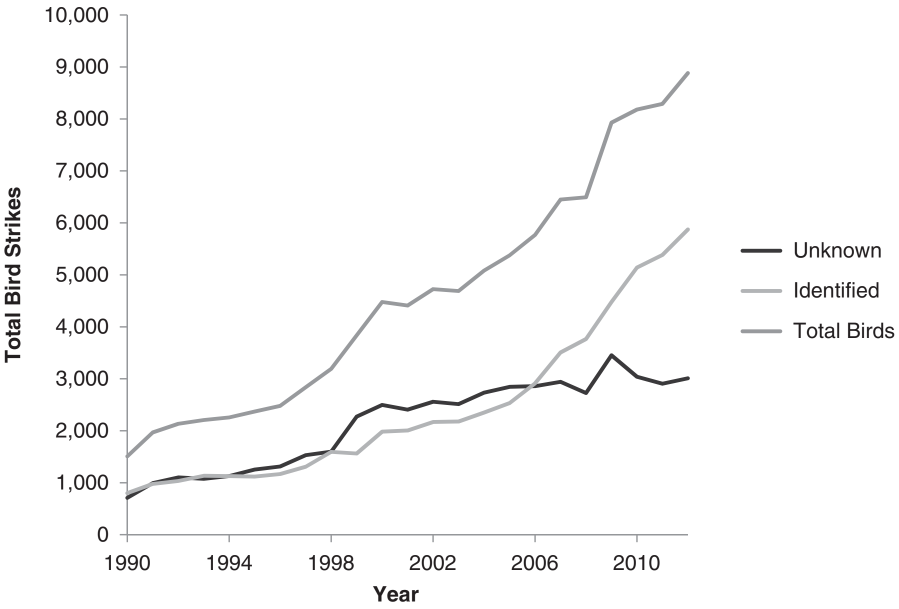


FIGURE 1 Number of bird strikes and number of bird strikes involving unidentified and identified species reported in FAA National Wildlife Strike Database for contiguous United States, 1990–2012.

with increasing species richness, and strikes at GA airports were 1.27 times as likely to be identified as those at certificated airports (Table 2). Identification was 15% lower when damage was reported, but damage had a significant interaction with species mass: larger species responsible for damaging strikes were 1.56 times as likely to be identified. For R^2, fixed effects in the best-fit model accounted for 9.4% of total variance, and the full model explained 34.9% of variance in the data set.

DISCUSSION OF RESULTS

Recent research has focused on the importance of managing strike risk through ecological assessments of hazardous species (*6, 9, 35–37*). The results in the current research provide further support that inclusion of basic spatial and temporal ecological data improves researchers' ability to interpret patterns of strike risk and nonidentification. Species richness significantly influenced strike identification efforts, although this effect varied by location and season. The greatest frequency of strikes involving unknown species occurred during periods of avian migration (especially autumn), when species richness was the greatest (Table 3) and large populations of new juveniles from the recent breeding season attempted their first migration (*38*). Observers who account for the influence of species richness by placing more emphasis on identification effort, especially during peak migration periods, will not only increase identification rates but also provide more data on species posing collision risks to aircraft. Future research incorporating migration data within spatial models to identify hot spots for risk may also reduce risk to both aircraft and migrating birds (*39*).

TABLE 2 Model Selection Results for Generalized Linear Mixed Models to Analyze Factors Influencing Bird Identification for Incidents in FAA National Wildlife Strike Database, 1990–2012

Model	Log Likelihood	AIC	ΔAIC	Weight
Certification class + FAA region × species richness + damage × mass	–63,189.81	126,425.60	0.00	1.00
Certification class + FAA region + species richness + damage × mass	–63,456.78	126,957.60	531.94	0.00
Certification class + FAA region × species richness + damage	–63,551.79	127,145.60	719.97	0.00
Certification class + FAA region × species richness	–63,595.50	127,231.00	805.39	0.00
Certification class + FAA region + species richness	–63,658.86	127,343.70	918.12	0.00
Species richness	–63,681.28	127,372.60	946.95	0.00
Damage reported	–63,988.39	127,986.80	1,561.16	0.00
Certification class + FAA region	–64,004.27	128,032.50	1,606.93	0.00
FAA region	–64,016.49	128,055.00	1,629.37	0.00
Certification class	–64,029.42	128,068.80	1,643.22	0.00
Null	–64,040.70	128,089.40	1,663.78	0.00

TABLE 3 Model Coefficients, 95% Confidence Intervals, and Odds Ratios for Parameters in Best-Fit Generalized Linear Mixed Models to Analyze Factors Influencing Bird Identification for Incidents in FAA National Wildlife Strike Database, 1990–2012

	Confidence Intervals				
Parameter[a]	Estimate	SE	Lower 95%	Upper 95%	Odds Ratio
(Intercept)	0.77	0.25	0.29	1.27	—
Central	–1.28	0.37	–2.02	–0.58	0.28
Eastern	–0.76	0.32	–1.38	–0.14	0.47
Great Lakes	–0.79	0.31	–1.40	–0.20	0.46
Northwest	–0.69	0.32	–1.33	–0.07	0.50
Southern	–1.55	0.31	–2.17	–0.96	0.21
Southwest	–1.11	0.34	–1.79	–0.46	0.33
Western Pacific	–0.75	0.39	–1.53	–0.01	0.47
Species richness	–0.34	0.10	–0.53	–0.15	0.71
Certification class[b] (general aviation)	0.23	0.07	0.09	0.37	1.27
Damage reported[c]	–0.16	0.03	–0.22	–0.10	0.85
Mass	–0.002	0.01	–0.02	0.02	1.00
Central: species richness	–0.14	0.13	–0.40	0.11	0.87
Eastern: species richness	–0.55	0.11	–0.76	–0.33	0.58
Great Lakes: species richness	–0.27	0.11	–0.49	–0.05	0.77
Northwest: species richness	0.24	0.11	0.02	0.46	1.27
Southern: species richness	–0.28	0.11	–0.50	–0.07	0.76
Southwest: species richness	–0.15	0.11	–0.38	0.07	0.86
Western Pacific: species richness	–0.04	0.12	–0.28	0.19	0.96
Damage[c]: mass	0.45	0.02	0.41	0.49	1.56

NOTE: SE = standard error; — = not applicable.

[a] Reference FAA region = New England.

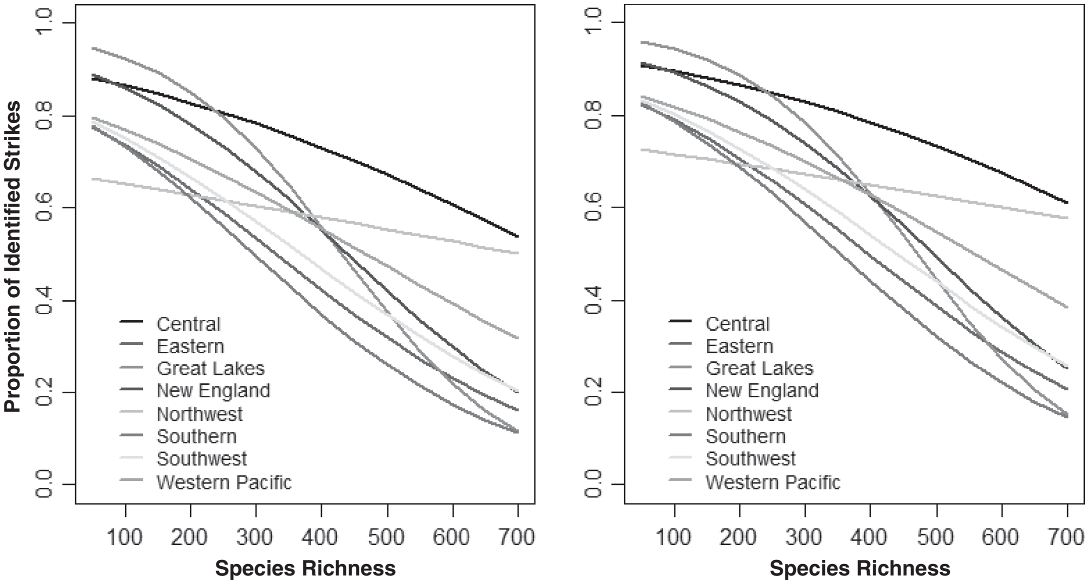
[b] Reference certification class = certificated.

[c] Reference condition = no damage reported.

The models in this research considered the influence of species richness on proper identification, but other population metrics, such as abundance, could be a better predictor of struck-species identification. An area could have relatively low species richness but still have high populations of a few common species; if these common species (e.g., geese) are also hazardous to aircraft, local abundances could have a substantial impact on strike risk. Although widely available citizen science data on bird populations such as eBird provide information on the number of species detected in a given state, the availability of site-specific data varies. The North American Breeding Bird Survey provides annual roadside monitoring data for breeding birds in the United States and Canada; however, survey data are restricted to May and June (*40*). Year-round abundance data for avian assemblages do not exist for most locations within the United States. Airports could benefit from employees or volunteers conducting regular surveys that include point counts or line transects to determine species richness and abundance of avian species to supplement the existing data set (*41–43*).

The current results also demonstrated regional variation in identification, even when species richness and management-specific factors such as airport classification are taken into account (Figure 2). Although the number of flight operations in a given region can affect the number of bird strikes reported, this potentiality does not explain the difference in the proportion of strikes identified by species group. The three regions with the lowest species richness (Central, Great Lakes, and New England) were also most likely to identify struck species (Figure 2). The Western Pacific region had the greatest mean species richness, but the model predicted species identification to be higher there than in other regions located along major flyways, especially in locations where convergence of northern-based migrants and funneling land features may concentrate bird populations (Eastern, Southern, and Southwest). Tailoring training to emphasize both identification efforts (even at the level of the species group) and submission of samples of unidentified remains to the Smithsonian Feather Identification Lab (*44, 45*), especially during periods of increased species richness (i.e., migration), will help improve the overall data set.

Also important is continuing to obtain baseline data on strike frequencies, locations, and the species involved through strike reporting to the FAA National Wildlife Strike Database; however, many of these data are still sparse partly because of the voluntary reporting standards. The number of reported incidents in the database increased annually over the past two decades (*29*), and high-profile incidents, such as US Airways Flight 1549 crash landing in the Hudson River in 2009 after colliding with a flock of Canada geese (*46*), may have encouraged pilots and airports to report bird strikes. However, because reports are voluntary, the accuracy of these numbers in reflecting total incidents and the cause of this increase—whether from more strikes or simply increased reporting effort—are unknown (*35*).



(a) (b)

FIGURE 2 Predicted probability of bird strikes, identified by avian species or species group, by FAA region, relative to species richness, for best-fit model explaining the nonidentification for damage reported by *(a)* certificated airports and *(b)* GA airports from civil aviation bird strikes in the continental United States, from FAA National Wildlife Strike Database, 1990–2012.

The FAA has expanded outreach programs to increase reporting efforts through poster distributions at more than 4,000 airports, aviation flight schools, and industry and even developed a strike report mobile application for smartphones. Continued development of the reporting website and social media could further enhance reporting of strike incidents (*29*).

While mandatory reporting would be the most effective method for obtaining information on wildlife strikes, enforcement of this requirement at more than 500 FAA and contract tower airports would be difficult. Future analyses comparing strike data from the FAA's voluntary data set with those from other countries that require mandatory reporting would be beneficial in determining whether mandatory reporting improves the quality of the data set (*47*). Regardless of causes for the overall increase in bird strikes, identification rates have improved substantially, especially since 2006, because of the increasing involvement of the Smithsonian Institution Feather Identification Lab in using biological samples and DNA to classify unknown birds (*44, 45*). Identification and classification of strike remains can also provide insight into ecological factors, including avian flight behaviors and predator avoidance tactics, that may reduce future aviation risk (*48*).

One surprising result from the analyses described here was that species identification was higher at GA airports than at certificated airports. Many certificated airports employ a biologist who is responsible for on-site wildlife management, and the authors had expected bird strike identification there to be greater as a result. Possibly, strike reports at certificated airports may be filed by pilots or other airport personnel independent of the biologist, and this factor could contribute to lower identification rates. Submission of all strike reports at an airport, with approval from the staff biologist, or increased training for all personnel and pilots could improve identification. At GA airports where such a step may not be feasible, the prudent practice may be to continue outreach and training efforts to encourage strike reporting (*49*). Another explanation for the species identification difference is that GA operators and airports may be vastly underreporting wildlife strikes, which may skew results. GA airports account for at least 25% of aircraft operations annually but report less than 5% of total strike incidents (*50*). Efforts by the FAA to increase reporting led to an 11% increase in strike reports at GA airports between 2011 and 2012 (*29*); such an increase suggests that underreporting may be prevalent.

Improving identification of species in bird strikes also has benefits beyond aviation flight risk and airport wildlife management, including for aviation engine manufacturers. Turbine engines in modern aircraft attempt to strike a balance between designs that are sufficiently robust to avoid engine failure when struck by a bird and those that minimize weight to reduce aircraft fuel costs (*51,* p. 1007). Engineers can more effectively design engines both to be cost-effective to airlines and to withstand bird strikes when the relative mass of hazardous species is known (*52*).

By identifying factors influencing species nonidentification and by determining potential clusters of low identification rates, the authors hope that this research helps foster sound management and personnel training. Understanding the limitations of the current data set and increasing reporting efforts through training, improving reporting standards, and collecting more field-based data on avian populations will help to increase the industry's knowledge of avian species and to reduce the aviation risk for both humans and wildlife.

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Opinions expressed in this study do not necessarily reflect current FAA policy decisions regarding the control of wildlife on or near airports.

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