Received: 21 April 2024 | Accepted: 23 August 2024
DOI: 10.1002/2688-8319.12384

Ecological Solutions and Evidence | BRITISH ECOLOGICAL SOCIETY

RESEARCH ARTICLE

Biogeographical patterns in the seasonality of bird collisions with aircraft

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Handling Editor: Christos Mammides

Abstract

1. Bird collisions with aircraft pose a serious threat to human safety. However, broad-scale patterns in how bird strikes might vary through space and time have yet to be fully understood.
2. Here, we conducted a biogeographical study of bird strikes to answer two questions: (1) Are bird strikes higher at certain times of the year in the Northern and Southern Hemispheres? and (2) Is seasonality in bird strikes more prominent in the Northern Hemisphere than in the Southern Hemisphere?
3. To answer these questions, we collated data on monthly bird strikes from 122 airports across the globe and used circular statistics to test for hemispherical asymmetries in the circular mean and variance in bird strikes.
4. Results showed that annual peaks in bird strikes occurred between late summer to autumn seasons, and as a result, they occurred at opposite times of year in the northern and southern hemispheres. Results also showed that bird strikes were more seasonal in the Northern Hemisphere than in the Southern Hemisphere, where strikes tended to occur more consistently throughout the year.
5. Practical implication: Overall results indicate that avian collisions with aircraft show strong biogeographical patterning, concomitant with global patterns in bird breeding seasons and migration tendencies.

KEYWORDS
aviation, bird strikes, breeding phenology, flight safety, hemispherical asymmetry, migration, seasonality, wildlife strikes

1 | INTRODUCTION

Collisions of wildlife with aircraft are a serious threat to human safety (Dolbeer et al., 2021; Marra et al., 2009; Thorpe, 2010). While all strikes with non-volant animals occur at the ground level, birds usually move within 3000 feet above ground level, which is the altitude block at which most civil aircraft movements also occur during approach and departure in the vicinity of aerodromes (McKee et al., 2016). Hence bird strikes are more frequent than strikes with other animal groups. The first bird strike was recorded by the Wright Brothers in 1905 and the first bird strike-related fatality occurred in 1912 (Solman, 1973). In the decades that followed, bird strikes increased in frequency and intensity as aircraft became larger, faster, quieter, and more numerous (McKee et al., 2016). Up until 25th January 2024, 804 human lives have been lost to wildlife strikes worldwide, of which 784 have been due to collisions with birds (Avisure, 2024). In addition to jeopardizing human health and safety, conservative estimates indicate that bird strikes cost airlines between US$1.21 billion to US$1.36 billion per annum globally due to repairs, maintenance, and compensations (Allan & Orosz, 2001).

Mitigation research thus far has included development of risk assessment models (e.g. Hu et al., 2020; Ning & Chen, 2014), assessment of land-use management near airports (Allan, 2005; Blackwell et al., 2009; Schmidt et al., 2013; Shao et al., 2020), and assessment of the effects of bird body size, flocking behaviour, and resource availability around airports on bird strikes (Flores et al., 2022; Leshem et al., 1998; Sarkheil et al., 2021; Soldatini et al., 2010). Industrial research has included aircraft design optimizations to avoid or withstand bird strikes (e.g. Fernández-Juricic et al., 2011; Hasilci & Boğoçlu, 2021; Qui et al., 2021). Much of this work has been conducted at the local level of individual airports. Most flying bird species, however, operate at larger geographic scales, thus bird strike management policies must account for factors beyond the aerodrome and involve multiple stakeholders (McKee et al., 2016).

Biogeographical patterns in bird strikes have not been fully understood. Avian migration and reproduction are important drivers of spatiotemporal variation in bird distributions and abundances across the globe (Ng et al., 2022; Somveille et al., 2015). Approximately one-fifth of bird species migrate in response to seasonal changes in resource availability, resulting in cyclical patterns of movement and behaviour with predictability in timing, migratory routes, and overwintering destinations (Kirby et al., 2008). Newton and Dale (1996a, 1996b) found that in eastern United States and western Europe, going northward, the proportion of breeding species moving south for the winter increases with latitude, while the proportion of wintering species moving north for the summer decreases with latitude. Importantly, migratory behaviour in birds is generally stronger in the Northern Hemisphere than in the Southern Hemisphere (La Sorte & Fink, 2017; Somveille et al., 2013). Bird abundances also fluctuate through time according to annual variation in reproductive phenology (Kelly et al., 2001). Although previous work has shown that strikes can increase during fledging periods at certain airports (Burger, 1985; Metz et al., 2020; Solman, 1978), whether this might influence global patterns in bird strikes is unknown.

Latitudinal gradients in diversity are a hallmark of life on earth. However, they are not always symmetrical on both sides of the equator (see Gaston, 1996). Hemispherical asymmetry in biodiversity has been documented previously in a variety of organisms (see Currie et al., 2004; Gaston, 1996), including trees (Burns, 2007), epiphytic plants (Burns, 2010), ground-feeding ants (Dunn et al., 2009), and other insects (Archibald et al., 2010). This phenomenon may also apply to Anthropocene ecological issues such as bird strikes. Hemispherical differences in the seasonality of bird strikes have only been discussed thus far using whole-country data instead of local, site-specific data (Burger, 1985; Metz et al., 2020).

Understanding macroecological patterns in bird strikes would have major policy implications beyond the aerodrome at the higher level of air traffic and wildlife hazard management, such as predicting seasonal surges in bird strikes at various destinations, and making long-term projections of bird strikes in response to factors such as climate change. Here, we assess these seasonal patterns of bird strikes by answering two related questions:

1. Are bird strikes higher at certain times of the year in the Northern and Southern Hemispheres? and
2. Is seasonality in bird strikes more prominent in Northern Hemisphere than in the Southern Hemisphere?

2 | MATERIALS AND METHODS

We focused on bird strikes instead of all wildlife strikes, since bird strikes pose a greater threat to human safety, having resulted in considerably more incidents and fatalities (Avisure, 2024). We searched the Google Web, Google Scholar, and Web of Science search engines for data on monthly bird strikes at airports using the keywords 'bird strike' with 'airport', 'seasonal', 'monthly' and 'annual'. The language settings allowed for search results in any language. We included sources that reported bird strikes in each calendar month over a minimum of 12 months at individual airports. The data availability ranged from 1 year to 20 years (Table S1). Monthly data from studies conducted over multiple years were averaged for each calendar month among years prior to analyses. Apart from online sources, data for Wellington Airport were obtained via personal communication with airport personnel. Studies that reported either yearly bird strikes for individual airports, or monthly bird strikes for entire countries did not match the spatial and/or temporal resolution of this study and hence were not included. Data on strikes with non-avian species (bats, non-volant mammals, reptiles) were also not included. We restricted our data sources to those available via web search for logistical reasons (except for the Wellington data, to which we had access prior to commencing the study).

Given that time is a 'non-linear' variable, we used circular statistics to analyse the data (Berens, 2009). In this instance, the circle is used to represent one cycle (i.e. one calendar year), and we analyse the timing of an event within this cycle (i.e. occurrences of high bird strikes, see Jammalamadaka & Sengupta, 2001). Seasonality in bird strikes was assessed using the temporal scale of months of the year. Each month occupied 30° on the circular plot starting with January by convention and going clockwise. The monthly strike frequency data were visualized using circular plots called rose diagrams (circular frequency distributions). Seasons were classified generally as December–January–February being boreal winter and austral summer, March–April–May being boreal spring and austral autumn, June–July–August being boreal summer and austral winter, and September–October–November being boreal autumn and austral spring.

For some airports, bird strikes were reported as number of strikes in each month, while others used 'strike rates' (typically strikes/10,000 flight movements) accounting for aircraft movements. We converted the strike frequencies to angles (in degrees)

Ecological Solutions and Evidence BRITISH ECOLOGICAL SOCIETY

prior to analyses using the *circular* package in R to make them comparable across airports (Agostinelli & Lund, 2022; R Core Team, 2022). For each airport, we calculated two metrics to characterize the annual distribution of bird strikes: (1) angle of mean vector (in degrees, 0°–360°), a measure of central tendency, to identify the time of year with overall high bird strikes (referred to in this study as timing of 'peak strikes') and (2) circular standard deviation, a measure of dispersion of the bird strikes around the mean (as per Ting et al., 2008). These values were then used to calculate the overall angles of mean vector and circular standard deviations for the Northern and Southern Hemispheres to identify the time of year with the highest bird strikes in each hemisphere. The angle of the mean vector represents the timing of peak strikes for each airport and corresponds to the direction of the vector arrow on the circular plot. Circular standard deviation represents the spread of the strikes around the mean, and is inversely related to the length of the vector (see Ting et al., 2008; Wright & Calderon, 1995). A high circular standard deviation would indicate that the strikes are more dispersed around the mean, while a low circular standard deviation would indicate that strikes are less dispersed around the mean, and thus, more seasonal.

To answer the first question of whether bird strikes were higher at certain times of the year, we used the angles of mean vector for each airport to calculate the overall angles of mean vector and circular standard deviations for the Northern and Southern Hemispheres. The month of peak bird strikes for each hemisphere was determined by back-calculating the angle of the mean vector to the corresponding month (January for values between 0° and 30°, February between 30° and 60°, and so on). To test for differences in timings of peak strikes in both hemispheres, the mean directions of the distributions were compared using Watson-William's Test of Homogeneity of Means. Rayleigh's Test of Uniformity was conducted to assess the overall extent of seasonality in each hemisphere, that is, if the strikes were uniformly distributed throughout the year (see Pewsey et al., 2013).

To answer the second question of whether the annual spread of bird strikes differed between hemispheres, we conducted linear regression analyses to assess the relationship of circular standard deviations at individual airports with latitude in both hemispheres. Additionally, we conducted Welch's *t*-test on the circular standard deviations between hemispheres to test for overall hemispherical differences in annual dispersions of strikes (Sakai, 2016). Analyses and visualizations were conducted in the R environment using *circular* and *ggplot2* packages, respectively (Agostinelli & Lund, 2022; R Core Team, 2022; Wickham, 2016).

3 | RESULTS

Data sources that met our inclusion criteria consisted of journal and conference publications ($n=11$), aviation databases ($n=2$) and university thesis ($n=1$). The final dataset consisted of monthly bird strike data from 122 airports in 16 countries on 5 continents (Northern Hemisphere $n=88$, Southern Hemisphere $n=34$) ranging latitudinally from 61° N to 43° S (see Figure S1).

Angles of mean vector from individual airports in the Northern and Southern hemispheres (Table S1) were used to calculate the overall angle of mean vector and circular standard deviation for both hemispheres (Figure 1). Peaks occurred at different times

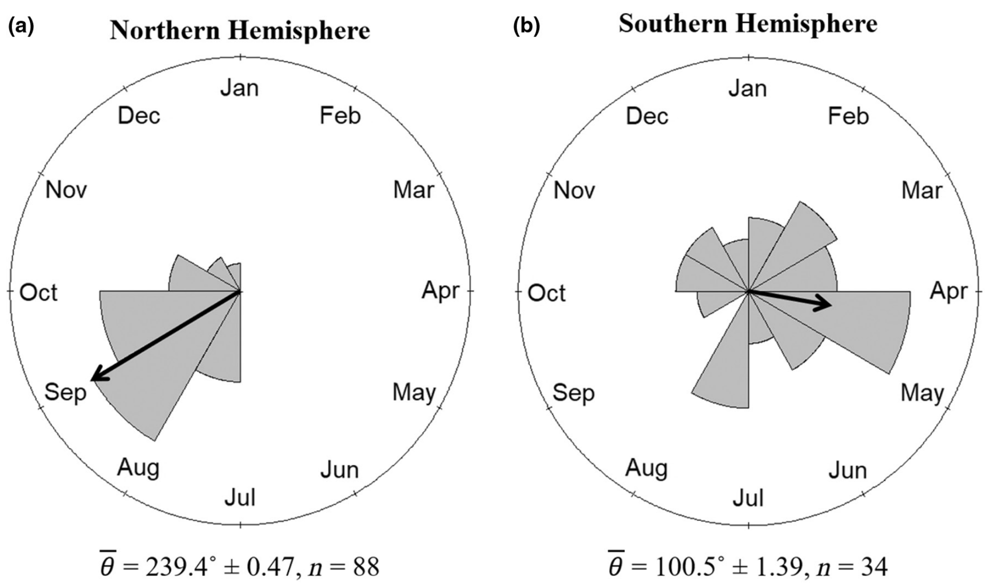

FIGURE 1 Rose diagrams illustrating monthly frequencies of bird strikes for airports in the Northern Hemisphere (a) and airports in the Southern Hemisphere (b). Each bin represents 1 month and occupies 30° of the circle in a clockwise manner. Angle of mean vector (black arrow) indicates the time of year with higher strikes on average. Length of vector is inversely proportional to circular standard deviation. Bird strikes in the Northern Hemisphere airports peaked distinctly in August–September and had a lower circular standard deviation than the airports in the Southern Hemisphere, indicating that strikes are more frequent in that period compared to other months. Bird strikes in the Southern Hemisphere peaked in April and had a higher circular standard deviation, meaning that the strikes are more spread out annually.

of the year in both hemispheres ($F=111.74$, $p<0.001$, Watson-William's Test of Homogeneity of Means). Bird strikes were highest in August–September in the Northern Hemisphere (Figure 1a, angle of mean vector = 239.4° ± 0.47) and in April in the Southern Hemisphere (Figure 1b, angle of mean vector = 100.5° ± 1.39). For the Northern Hemisphere, peak bird strikes at all airports occurred between July and December, with no peaks observed in the first half of the year (i.e. the angles of mean vector for all Northern Hemisphere airports were higher than 180°). For most airports in the Southern Hemisphere, bird strikes peaked between February and July; however, peaks were not limited to that time of year and were observed in other months as well. Peaks were not distributed uniformly throughout the year in both hemispheres, indicating seasonality in bird strikes. However, they were relatively more temporally concentrated in the Northern Hemisphere ($Z=0.896$, $p<0.001$, Rayleigh's Test of Uniformity) than in the Southern Hemisphere ($Z=0.381$, $p<0.05$, Rayleigh's Test of Uniformity). Correspondingly, peaks in bird strikes coincide with late summer to autumn seasons in both hemispheres, with outliers observed during other seasons only in the Southern Hemisphere.

Latitudinal trends in the extent of seasonality in bird strikes differed between hemispheres. Linear regression analyses (Figure 2) of circular standard deviations at each airport ($n=122$) versus latitude for airports in the Northern Hemisphere indicated that circular standard deviations decreased significantly from the equator to the north pole ($R^2=0.189$, $\beta=-0.010$, $F=20.02$, $p<0.001$). Circular standard deviations were unrelated to latitude in the Southern Hemisphere ($R^2=0.005$, $\beta=0.002$, $F=0.165$, $p=0.687$). Circular standard deviations between the two hemispheres differed significantly ($t=-8.875$, df = 53.16, $p<0.001$, Welch's t-test), with the average circular standard deviation in Southern Hemisphere (1.97 ± 0.09) being statistically higher than in the Northern Hemisphere (1.46 ± 0.067). Thus, strikes in the Southern Hemisphere had higher dispersion around the mean than those in the Northern Hemisphere.

4 | DISCUSSION

The timing and intensity of bird strikes at airports across the globe showed strong patterning in space and time. We characterized the timing of peak bird strikes within the calendar year using the angle of mean vector as a measure of central tendency rather than the mode, or the month with the highest strikes, and circular standard deviation as the spread of strikes around the mean, following Ting et al. (2008). Annual peaks in bird strikes occurred at roughly opposite times of the year in each hemisphere, corresponding to the respective autumn months. Monthly dispersion of bird strikes also differed between hemispheres, with strikes becoming more seasonally concentrated away from the equator towards the North Pole, and occurring more evenly throughout the year in the Southern Hemisphere.

The mechanisms underpinning global patterns in the seasonality of bird strikes have yet to be determined. However, there are several plausible explanations for increased bird strikes in the observed seasons. Breeding seasons in temperate zones usually occur

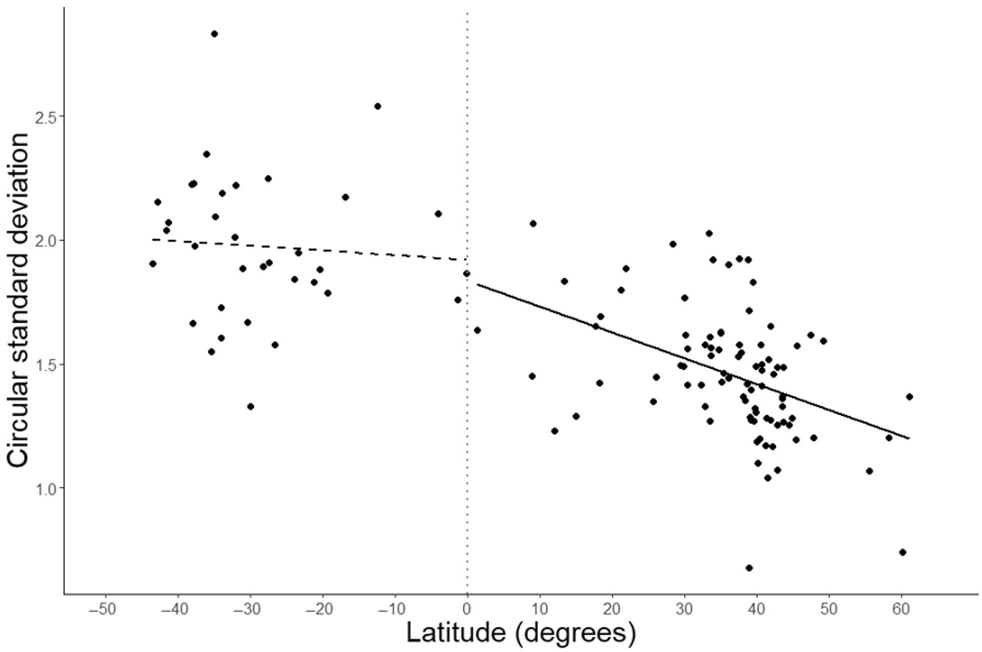

FIGURE 2 Linear regression analyses of circular standard deviations (annual spread of bird strikes) versus latitude of each airport. Circular standard deviations remain relatively constant in the Southern Hemisphere (black dashed line; $R^2=0.005$, $p=0.687$, $n=34$) but decrease significantly from the equator (grey dotted line) towards the northern latitudes (black solid line; $R^2=0.189$, $p<0.001$, $n=88$). Southern Hemisphere latitudes are shown as negative values.

during spring in response to seasonal spikes in resource availability due to increased photoperiod, while reproduction at lower latitudes occurs in response to other environmental variables such as rainfall (Berman et al., 2022; Cockrem, 1995; Wyndham, 1986). Previous bird strike studies have reported a higher proportion of strikes with juvenile birds at certain airports (see Burger, 1985; Metz et al., 2020; Solman, 1978). Our results indicate that annual periods of increased bird strikes generally coincide with the annual peaks in the fledging of young birds. Therefore, local bird densities are likely to be highest at this time of year (Kelly et al., 2001). If birds collide with aircraft stochastically, periods of greater bird abundance will coincide with peak periods of greater bird strikes.

Avian aircraft collisions may also be influenced by a bird's prior experience with aircraft (Shamoun-Baranes et al., 2017). Newly fledged birds have no prior experience with the dangers associated with aircraft, and thus may be less capable of avoiding collisions while flying. The fledging period is generally characterized by strong selection on fledglings to avoid danger, including learning to avoid aircraft (Chilvers et al., 1997; Evans et al., 2020). Thus, as birds mature, they may learn to avoid aircraft through near misses, causing fewer strikes as adults (Kelly et al., 2001). For a better understanding of seasonal increases in bird strikes, future studies can test the two possible hypotheses—higher bird strikes due to higher local bird abundance or inexperienced fledglings being struck more often.

As with peak dates in bird strikes, the mechanisms underpinning monthly dispersion of bird strikes have yet to be pinpointed. However, this pattern may be related to hemispherical asymmetry in avian migration. Around 80% of the surface of the Southern Hemisphere is covered by water (Rasool & Prabhakara, 1966). Because the latent heat, or the energy involved in the conversion from one state to another, is high for water, the oceans absorb and store large amounts of solar energy (Burns, 2019). Therefore, the Southern Hemisphere has a more stable temperature regime and thus lower fluctuation in annual productivity compared to the Northern Hemisphere. This may result in differences in species richness, absolute number of migratory species, and the proportion of migratory species between the Northern and Southern Hemispheres, as shown by Somveille et al. (2013). Bird strikes were more seasonal in the Northern Hemisphere. This is consistent with annual migration schedules, which tend to be stronger at more northerly latitudes (Somveille et al., 2013). Conversely, local bird abundances tend to be more stable seasonally in the Southern Hemisphere due to weaker geographic fluxes of annual migrants (Somveille, 2016). Bird strikes in Anchorage or Oslo in the Northern Hemisphere were considerably higher in August compared to other times of the year, while in Wellington or Hobart in the Southern Hemisphere, bird strikes occurred more consistently throughout the year. Results reported here provide a novel example of hemispherical asymmetry in human-wildlife interactions leading to substantial conflict.

Current bird strike prevention policies at airports include active management such as culling, reproductive control, dispersal via light, sound, and predators; and passive management through fencing and landscape modifications around the aerodromes to make the vicinity less attractive to wildlife (McKee et al., 2016). Newer airports proactively include wildlife management policies since the planning phase (Fu et al., 2016). According to the Wildlife Officer at Wellington International Airport, management plans at airports typically focus on local problem species, such as the kelp gull *Larus dominicanus dominicanus* (Jack Howarth, personal communication, 5th May 2024). These strategies are often adapted from existing ones for similar species at other airports. Understanding global differences in the timing and duration of strikes would enable managers to customize their policies based on local avian phenology even when dealing with similar species as other airports. Seasonal strike patterns can be incorporated into the dispersal, relocation and, if needed, lethal control measures of birds at airports. Targeting juveniles, especially in fledging seasons, would increase the efficiency of the management techniques.

Previous studies have analysed seasonality in bird strikes at broader, country-level spatial scales. Burger (1985) compared country-wide data between the United States and Canada and found that peak bird strikes in Canada occurred earlier during autumn migration, likely because migration begins earlier in more northern latitudes. Metz et al. (2020) compared region-wide data from Australia, Canada, the United States and Europe, and found that strikes were higher in late summer to autumn seasons, with strikes in Australia peaking around April and those in the Northern Hemisphere regions peaking between July and August. Oruç et al. (2022) also reported similar results for certain European and Middle Eastern regions and proposed that increased tourism-related air travel during warmer months may contribute to higher bird strikes.

The airports included in this study spanned a large proportion of the Earth's surface, although lack of freely available monthly bird strikes data prohibited us from including many important aviation spaces in the analyses (e.g. South America and Asia). Majority of the data is from the United States and Australia, which are located on opposite ends of the latitudinal and seasonal spectrum. While this does not change the interpretation of our results, data from other continents would provide more evidence for the observed patterns. Better standardization in data collection and communication would greatly help future investigations of global bird strikes. We recommend the use of strike rate (strikes/10,000 aircraft movements) as the preferred unit to report bird strikes to account for variation in flight movements. Implementing a standardized approach to wildlife hazard management, such as the Safety Management System (SMS) approach (DeFusco et al., 2015), would also make the data more universally accessible.

Broad-scale bird strike reviews have recognized variability in data communication and availability as the chief reasons for the lack of a global perspective (Metz et al., 2020; Oruç et al., 2022). Along with greater methodological standardization, novel techniques that yield high-resolution spatiotemporal data with minimal human effort would improve the predictive power of the studies. For example, Nilsson et al. (2021) used publicly available data from weather radar and citizen science platforms to map local migratory bird movements around three New York airports. Use of Doppler radar under suitable operation modes has also proven effective in detecting bird movement in airport areas (Gazovova et al., 2020). Future research would benefit from incorporating such techniques to study global bird abundance and ecology, and by extension, bird strikes (Nilsson et al., 2021).

Migration and breeding phenology are being affected by global climate change, for instance the increasing frequency of mid-latitude climate extremes (Clairbaux et al., 2019; La Sorte et al., 2016; Lawrence et al., 2022; Romano et al., 2023). This study highlights the importance of bird strikes in the context of avian phenology and bridges a gap between aviation safety and macroecology. Our findings suggest that autumn is a priority season for bird management measures worldwide, particularly in boreal regions. The spatiotemporal trends demonstrated here can assist aviation authorities in predicting the likelihood of bird strikes at various travel destinations, optimizing resource allocation, establishing early-warning systems, and understanding possible changes in the timing of peak bird strikes due to factors like climate change.

AUTHOR CONTRIBUTIONS

All authors contributed to writing the paper. Tirth Vaishnav and Kevin C. Burns conceived the ideas and designed methodology; Tirth Vaishnav collected the data; Tirth Vaishnav and John Haywood analysed the data; Tirth Vaishnav and Kevin C. Burns led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

ACKNOWLEDGEMENTS

The authors would like to thank Ayolt Wiertsema, Matthew Palliser and Jack Howarth at the Wellington International Airport for providing the bird strikes data that inspired this global study. Open access publishing facilitated by Victoria University of Wellington, as part of the Wiley - Victoria University of Wellington agreement via the Council of Australian University Librarians.

FUNDING INFORMATION

No funding was received for this study.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/2688-8319.12384.

DATA AVAILABILITY STATEMENT

Data available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.h9w0vt4s4 (Vaishnav et al., 2024).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Table S1. Locations included in the analysis of seasonal variation in global bird strikes sorted by latitude (degree decimal) from north to south ($n=122$, Southern Hemisphere latitudes are negative) along with duration of the studies, angles of mean vector (mean angle), circular standard deviations (CSD) and citations.

Figure S1. Locations of the airports included in the study ($n=122$) denoted by red diamonds. Refer to serial numbers in Table S1 to identify locations.

How to cite this article: Vaishnav, T., Haywood, J., & Burns, K. C. (2024). Biogeographical patterns in the seasonality of bird collisions with aircraft. *Ecological Solutions and Evidence*, *5*, e12384. https://doi.org/10.1002/2688-8319.12384