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RESEARCH ARTICLE

The wildlife strikes back: determining the secondary strike risk associated with a mammal–aircraft collision

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Abstract

Wildlife–aircraft collisions are becoming increasingly common and pose a serious threat to the global aviation industry. While wildlife strike mitigation is a well-researched area, often focusing on a specific species or taxonomic group, secondary strike risk with scavenger or predatory species is rarely considered within the literature. Dublin Airport is the largest civil airport in the Republic of Ireland, reporting an average of 23.9 (±12.8 SD) strikes with native Irish hares (*Lepus timidus hibernicus*) annually. We employed motion-activated camera traps to identify the species attracted to simulated hare-strike events and to record the time to initial carcass detection. We used commercially available rat carcasses as a proxy for hare carcasses to assess the secondary strike risk associated with such events. We recorded 542 detections within 24 hours of carcass deployment from 82 trials. Hooded crows (*Corvus cornix*) were the most frequently detected species, involved in 86% of interactions. Initial carcass detection took an average of 4 hours and 54 minutes for avian species, with birds spending an average of 5 minutes and 29 seconds with a carcass. In comparison, it took mammal species an average of 9 hours and 32 minutes to detect the carcass in the first instance. Mammals remained with the carcass for an average of 2 minutes and 35 seconds. These data indicate that current clean-up practices at Dublin Airport

(i.e., immediate clean-up and closing of the runway to facilitate clean-up operations) are adequate for reducing the likelihood of a secondary strike event.

KEYWORDS
airfield ecology, bird strike, human–wildlife conflict, wildlife hazard, wildlife strike

Collision between wildlife and the cohort of vehicles involved in the transportation sector represents one of the most recurrent and ubiquitous human–wildlife conflicts worldwide (Conover 2002, Pfeiffer et al. 2018). The aviation industry is no exception, with wildlife–aircraft collisions (strikes) resulting in wildlife mortality and aircraft damage (DeVault et al. 2018, Ball et al. 2021*b*) in addition to compromising passenger safety (Metz et al. 2020). It is estimated that wildlife strikes cost the aviation industry $54–$155 million USD annually in the United States alone (Dolbeer 2013, Anderson et al. 2015, Altringer et al. 2021), which is of particular concern to airport authorities and airline operators, as the number of reports of wildlife strikes is generally increasing per annum across the globe (Strauss 2020, Dolbeer et al. 2021, Ball et al. 2021*b*). However, given the heightened awareness of the importance of reporting strike events in recent years, these increases could merely reflect an increase in recording effort rather than an increase in incidents or risk (Metz et al. 2020, Ball et al. 2021*b*).

Wildlife strike mitigation research often focuses on a target species or taxonomic group (Carswell et al. 2021, Ball et al. 2021*a*, Washburn et al. 2025) with little consideration for the secondary strike risk posed by other species utilizing an airfield. For example, the presence of small mammals (e.g., mice, rabbits) can attract scavenger and predator species to an airfield, with these species themselves becoming wildlife hazards (Finch et al. 2015, Pennell et al. 2016, Shiels et al. 2025). Similarly, a carcass from a strike event could likely attract scavenger species (Dale 2009), as is seen with roadkill on road networks (Slater et al. 2022). Hence, airfield managers need to understand the relative risks associated with the entirety of the faunal community both within the airfield and in the wider landscape (Ball et al. 2023).

A high-density population of the Irish hare (*Lepus timidus hibernicus*), an endemic subspecies of the mountain hare (*L. timidus*), resides in the grasslands at Dublin Airport in the Republic of Ireland, with an estimated population size of 118 (95% CI = 84–166; S. Ball, University College Cork, unpublished data). Since 1997, >320 strike events between hares and aircraft have been reported, with strikes increasing by an average of 14% annually (Ball et al. 2021*a*). Organic debris from a single hare strike has been reported to cover an area >20 m^2 (Bolger and Kelly 2008). A carcass, or organic debris, could therefore attract a predator or scavenger species to the active runway area, increasing secondary strike risk, particularly as there is a scavenger guild consisting of mammalian and avian taxa present at the airfield with the potential to inflict damage to an aircraft. Such species include common buzzard (*Buteo buteo*), herring gull (*Larus argentatus*), lesser black-backed gull (*L. fuscus*), greater black-backed gull (*L. marinus*), rook (*Corvus frugilegus*), magpie (*Pica pica*), hooded crow (*Corvus cornix*), raven (*Corvus corax*), and red fox (*Vulpes vulpes*).

Baited camera traps represent an established ecological survey method, having been used to identify scavenger guild composition (Walker et al. 2021), estimate wildlife mortality on roads (Schwartz et al. 2018) and with man-made structures (Smallwood et al. 2010), monitor protected areas (Schlacher et al. 2015) and species (Joubert et al. 2020), and investigate the role of scavengers in urban environments (Inger et al. 2016). In the current study, we demonstrate a novel application of baited camera traps to explore the potential role of a mammal–aircraft strike event in promoting secondary-strike risk at an international airport. We investigate temporal variation in carcass detection and removal times and quantify effective post-strike clean-up windows for airfield operators. We also explore the length of time scavengers typically remain with a carcass. We hypothesized that carcass detection time would be influenced by the time of day in which a strike event occurs, and that avian species would pose the greatest secondary strike risk.

STUDY AREA

Dublin International Airport (53.4264° N, 6.2499° W) is the largest civil airport in Ireland. In 2024, 234,570 aircraft movements were recorded (Central Statistics Office 2025), making it one of the busiest airports in Europe. The airfield is located approximately 7 km north of Dublin and approximately 8 km from Ireland's eastern coastline and experiences a temperate climate. Surrounding the 3 runways (Figure 1) is a collection of grass islands, collectively 370 ha in size. These grasslands consist of a blend of Italian ryegrass (*Lolium multiflorum*) and tall fescue (*Festuca arundinacea*), maintained according to long grass management policy (United Kingdom Civil Aviation Authority 2008; ≥15 cm) to deter hazardous bird species such as starling (*Sturnus vulgaris*) from settling.

METHODS

Field trial set-up

We conducted field trials between August 2020 and March 2022. Owing to the confirmation of rabbit hemorrhagic disease (RHD2) in Irish hares in July 2019 (Byrne et al. 2022), we did not use hare strike carcasses in field trials to prevent any possible transmission of the virus. Therefore, we used commercially purchased rat carcasses (250–395 g) as proxies for hares. However, there is the potential for differences in carcass detection between the 2 taxonomic groups (Lagomorpha vs. Rodentia; Gerke et al. 2022). We conducted the majority of trials (n = 68) in a

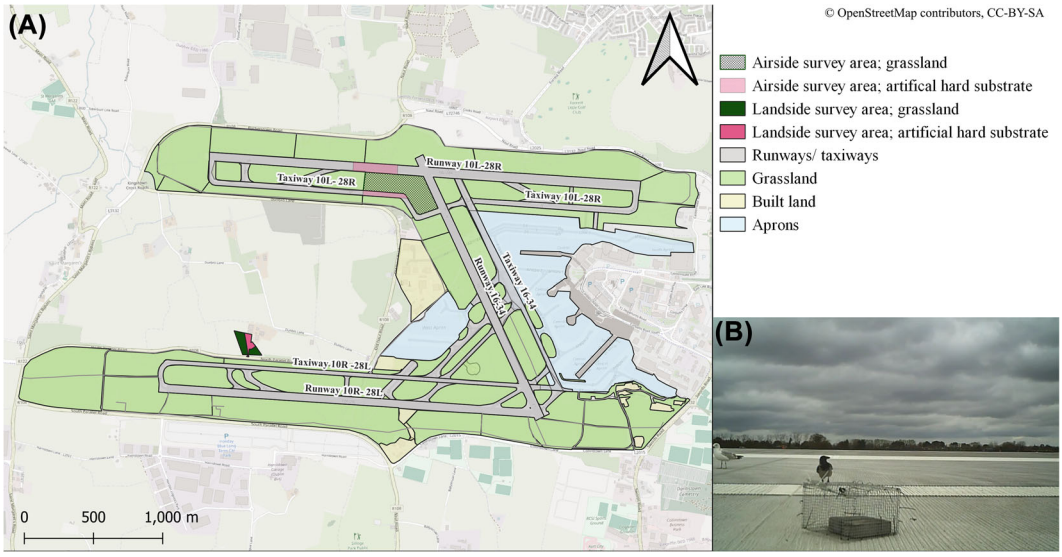

FIGURE 1 Location of scavenger trials landside and airside in relation to Dublin Airport, Ireland (August 2020–March 2022). (A) Map of Dublin Airport indicating the layout of the area. Landside trials were conducted in a disused compound about 200 m from the main runway. Grass areas where trials were conducted are indicated in solid dark green. Artificial hard substrate areas are indicated in pink. Artificial hard substrate trials were conducted airside on a section of runway and taxiway 10L-28R (shaded pink) and in adjoining grassland (GA41) highlighted in thatched green. All grasslands, runways, taxiways, aprons (paved areas used for the parking, loading, and fueling of aircraft), and miscellaneous built land (any artificial surfaces present for the purpose of facilitating airside services (e.g., fire station, sub- stations) are also indicated. (B) Image showing the metal cage deployed for airside trials with the 2-kg brick to mimic the weight of a hare. Note that the rat carcass is on the other side of the brick in this instance.

TABLE 1 Definitions of study set up terms where we deployed carcass trials at Dublin Airport, Ireland (August 2020–March 2022).

Term	Definition
Airside	The part of an airport beyond passport and customs control
Landside	Area accessible to members of the public. Prior to passport and customs control
Runway	A rectangular area for the landing and take-off run of aircraft
Taxiway	The main routes running parallel to runways to allow aircraft to taxi to and from a runway
Apron	Concrete or paved areas used for the parking, loading, and fuelling of aircraft
Built land	Artificial surfaces present for the purpose of facilitating airside services (e.g., substations)
Artificial hard surface[a]	Relatively flat, open area of man-made surface
Grassland	Relatively flat, open areas of vegetation predominantly consisting of grasses

[a]In the landside study area, the hard surface consisted of concrete. In the airside study area, the hard surface consisted of tarmac.

disused landside compound (Table 1), 250 m away from the active runway (runway 28R-10L; Figure 1). The compound featured an artificial hard-surfaced road (concrete) with grassland on either side, mimicking the airfield environment. Owing to ongoing construction work at the airfield for the development of an additional runway, some sections of the airfield were closed to air traffic, allowing for 16 trials to be conducted airside, between March 2021 and February 2022. We placed carcasses in a metal wire cage for airside trials to prevent carcasses from becoming foreign object debris (FOD) and hazardous to aircraft (Figure 1).

We defrosted all rat carcasses for 12 hours at room temperature. We secured carcasses to a brick approximately 2 kg in weight to match the body mass of an Irish hare ($\bar{x}$ = 2.2 kg; Ball et al. 2021) and prevent easy removal of the carcass. We opened the abdominal and thoracic cavities of the rat carcasses to provide an olfactory cue similar to that which might result from a strike event. We positioned carcasses 2 m in front of a motion-sensitive camera (Bushnell Trophy Cam HD, model 119476; Bushnell, Overland Park, KS, USA) that was positioned 50 cm above ground level with a ~ 15° downwards tilt, with one carcass deployed per camera. Cameras were programmed to record a 10-second timestamped video when triggered by movement at medium sensitivity, with a 5-second interval between videos. As all interaction events with a carcass could be considered as an opportunity for a secondary strike event with the scavenger, there was no applied threshold for independence between detections.

Trial periods lasted for 24 hours to assess short-term scavenger attraction (Huijbers et al. 2013) to a strike event. Current practices at the airfield dictate that clean-up following a strike event should be completed as rapidly as possible; the largest parts of a carcass are typically removed from the active runway within minutes. However, debris from a hare strike event has been recorded to cover an area of up to 20 m^2 (Bolger and Kelly 2008), and a more comprehensive clean-up of the runway can be prolonged by a high volume of air traffic, restricting access to clean-up operations. In some circumstances, a FOD control unit must be deployed to sweep the runway, or the area must be hosed down. In such instances, vehicles are only permitted to enter the active area when Air Traffic Control (ATC) directs air traffic with the intention of facilitating clean-up, following the Dublin Airport Wildlife and Habitat Management Plan (WHMP). Therefore, while the majority of carcasses are removed promptly, some organic debris may take substantially longer to remove. Similar practices are likely implemented at other airfields, depending on the extent of the debris created from a strike event. At Dublin Airport, there are also procedures in place to ensure that any unreported carcasses are removed from the active runway, in the form of routine (every 30-60 minutes) runway inspections and the deployment of a wildlife patrol vehicle at active runways during hours of daylight.

Hare strikes are most frequently reported close to sunrise and after hours of darkness (Ball et al. 2022). Therefore, we deployed trials as close to, and within 1 hour of, either sunrise or sunset, the time of which varied

seasonally, on 1 of 2 substrate types: 1) artificial hard surface, to replicate a strike directly on the runway; or 2) grassland, to replicate areas of grass surrounding a runway where a carcass (or part thereof) may be deflected in the event of a strike (Table 1). We deployed 41 carcasses at sunrise, 39 at sunset, and 4 at midday (November 2021) because of logistical constraints. We grouped these 4 deployments with deployments from sunrise for analysis, as these deployments also occurred during hours of daylight. To mitigate the artificial inflation of scavenger densities during trials due to an abundance of food (i.e., predator swamping; Smallwood et al. 2010), we separated deployment dates by an average of 29 days. We carried out deployments seasonally, defined as spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). Despite the Irish hare not being a scavenger, we included them in analysis, as they were observed interacting with carcasses on 19 occasions. We predicted that scavenger species would detect carcasses on artificial hard surfaces (i.e., runways) substantially faster than those positioned on grasslands, as carcasses on artificial hard substrates were not obstructed from view or camouflaged via vegetation (Riding and Loss 2018).

Relative abundance of species present at sites

Throughout the study period (August 2020–March 2022), we conducted species surveys during daylight hours at the landside compound ($n = 23$), in addition to the main (runway 10R-28L; $n = 19$) and new (inactive) runways (runway 10L-28R; $n = 15$) to gain an understanding of the fauna present in the area and their relative abundance. We recorded the number of each avian species recorded flying over each location for a 30-minute period, representing a reasonable amount of time required to manage air traffic and deploy a FOD unit in the event of a strike. As mammals are more likely to be crepuscular or nocturnal and typically avoid humans, direct observation was not possible. Therefore, we used pre-existing motion-activated camera trap data from the airfield (360 recording days between July 2019 and May 2021; Ball et al. 2022) to determine the composition and relative abundance of mammal species airside. We deployed 3 additional camera traps for 29 recording days between March and April 2022 using the same setup as described for scavenger trials, to determine the relative abundance of mammals in the landside compound. We assumed camera trap triggers for both airside and landside deployments were independent of each other if they were separated by a minimum of 30 minutes or by a clearly different animal (e.g., distinguishable markings; Viviano et al. 2021).

Analysis

We investigated carcass persistence by examining the length of time (hours) each carcass remained for the duration of the 24-hour study period. We assigned a value of 24 hours to carcass deployments that yielded no interactions or any trials in which interaction events were recorded but where the carcass was still present at the end of the trial. We used the survival package (Therneau 2022) to create a Kaplan-Meier curve and to estimate the probability of a carcass still being present at the end of the 24 hours. As carcasses deployed airside were placed into cages, preventing removal from the trial, we excluded these from survival analyses. We used log-rank tests to assess differences between survival curves given different lighting conditions, substrates, and seasons.

We calculated the length of time between a carcass being deployed and the first detection by an animal (henceforth referred to as time to initial detection), which we identified as the first 10-second camera trigger by a scavenger after deployment. We examined effects of substrate type, light condition, season, and taxonomic group using non-parametric Wilcoxon tests to determine differences in the length of time it took for a carcass to initially be detected. We used a Fisher's exact test to explore the distribution (i.e., even or uneven) of species interacting with carcasses across the 2 substrate types (Schwartz et al. 2018) to investigate if scavenger pressure differed between them. We also examined the length of time taxa spent with a carcass, as risk is likely to increase with

increasing duration with a carcass. We obtained weather data (maximum temperature [°C], minimum temperature [°C], precipitation [mm], and mean wind speed [knots]) from the weather station permanently located at Dublin Airport by Ireland's national Meteorological Service (Met Eireann) for the date of each initial detection (MET Eireann 2025). We used a correlation function to examine the relationship between time to initial detection and climatic conditions.

To identify whether scavenger species had the potential to engage with hare carcasses at the time that a strike event occurred, we obtained historical hare strike data with aircraft detailing the date and time of a confirmed strike event at Dublin Airport from 2012-2021 from the daa (Dublin Airport's managing body). This database detailed 238 hare strike events and indicated that a high proportion of historical strikes (34%) occurred within the first 2 hours following sunset and preceding sunrise (Ball et al. 2022). To identify the extent of temporal overlap (24-hour scale) between historical strike events and scavenging events in the current study, we used the overlap package (Meredith and Ridout 2021) to determine the temporal overlap between hare strikes and scavenger-carcass interactions from trials with mammals and birds by estimating the overlap coefficient (Δ), with the Δ_4 estimator. A coefficient of $\Delta = 0$ indicated no overlap and $\Delta = 1$ indicated complete temporal overlap. We bootstrapped data 1,000 times to generate 95% confidence intervals (CI) of the overlap coefficient (Zanni et al. 2021). We ranked overlap estimates as either high ($\Delta > 0.75$), moderate ($0.50 < \Delta < 0.75$), or low ($\Delta < 0.50$) for each season (Monterroso et al. 2014).

RESULTS

Trial detections

Camera traps recorded 542 scavenger detections at carcasses within 24 hours of deployment across 82 trials ($\bar{x}$ = 6.9 ± 8.4 SD detections per carcass). Of these, 64 detections were recorded airside ($\bar{x}$ = 5.3 ± 4.3 SD detections per carcass) and 478 ($\bar{x}$ = 9.4 ± 9.5 SD detections per carcass) were recorded landside. Nineteen trials (23%) did not elicit a single interaction event. Birds comprised 86% and mammals 14% of all detections. Nine species were recorded interacting with carcasses, including hooded crow (84.1%), jackdaw (*Corvus monedula*; 1.5%), rook (0.2%), herring gull (0.2%), common buzzard (0.2%), red fox (7.7%), Irish hare (3.5%), domestic cat (*Felis catus*; 2%), and brown rat (*Rattus norvegicus*; 0.6%). While both airside (n = 43, 67%) and landside (n = 413, 86%) detections were dominated by hooded crow, faunal composition differed between the 2 study sites (Figure 2). Buzzard (n = 1) and herring gull (n = 1) were exclusively recorded interacting with a carcass airside, while domestic cats (n = 11), brown rats (n = 3), rooks (n = 1), and jackdaws (n = 8) were recorded at the landside compound only.

More detections occurred on artificial hard surface substrates (57%, n = 324) than grassland (43%, n = 237). Between the 2 substrate types, there were no notable differences in time to initial detection, demonstrating that substrate type did not influence how rapidly a carcass was detected. Likewise, we did not record notable differences for the duration of time spent with a carcass between the 2 substrate types. Scavenger pressure was uniform between artificial hard surface substrates and grassland, with no differences in the relative frequencies of taxa scavenging carcasses between the 2 substrate types (P = 0.11). When considering the light condition (i.e., day vs. night) at the time of a trigger event, 88% (n = 476; $\bar{x}$ = 9.6 ± 9.1 SD per deployment) of all events occurred during hours of daylight with 12% (n = 66; $\bar{x}$ = 7.0 ± 8.5 SD per deployment) occurring during hours of darkness. The highest number of detections per carcass was recorded for the spring sampling period ($\bar{x}$ = 10 ± 11.7 SD), followed by summer ($\bar{x}$ = 6.9 ± 6.5 SD), autumn ($\bar{x}$ = 5.25 ± 5.3 SD), and winter ($\bar{x}$ = 4.9 ± 7.8 SD).

Avian species composition and abundance were similar across sites (Table S1), albeit with some differences. Hooded crow and rook dominated the avifauna at the main runway (10R-28L; 36% and 16%, respectively) and new runway (10L-28R; 32% and 28%, respectively) sites. At the landside survey site, avifauna were dominated by hooded crow (35%) and pigeon species (19%; *Columba* spp.), followed by rook (13%). Lagomorphs were the most

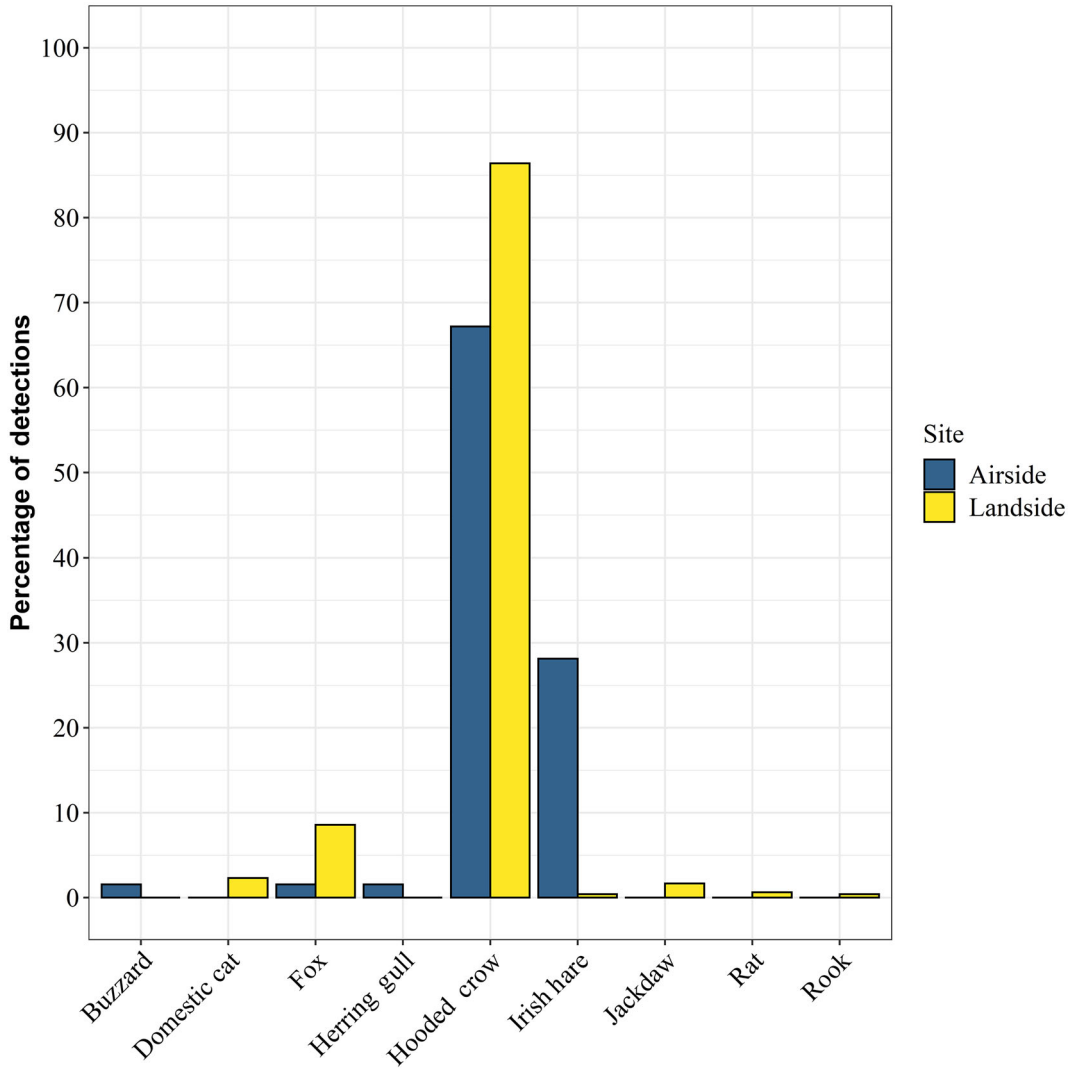

FIGURE 2 Relative frequency of species detections to commercial rat carcasses (*Rattus norvegicus*) for both airside and landside at Dublin International Airport, Ireland (August 2020–March 2022).

common mammal, both airside and landside, with the Irish hare making up 90% of mammal detections airside and the European rabbit (*Oryctolagus cuniculus*) making up 77% of detections landside. The red fox was the largest scavenger species detected in these trials and was the second most frequently detected mammal species airside (15% airside vs. 10% landside). The brown rat was the most frequently encountered scavenger mammal species landside (11%; Table S2).

Time to carcass detection

Scavengers removed 31 carcasses (of $n = 68$) from the study set up within 24 hours, all of which were removed by red fox (58%), hooded crow (35.5%), and domestic cat (6.5%). Only foxes removed carcasses under both diurnal and nocturnal conditions (52% vs. 48%, respectively), with mammals being responsible for 65% of carcass removals.

TABLE 2 Average time to initial detection by taxonomic group to commercial rat carcasses (*Rattus norvegicus*) for each lighting condition (i.e., deployed at either sunrise or sunset), to the closest minute. The range of detection values is displayed in parentheses under each value. All trials were conducted in Dublin, Ireland (August 2020–March 2022).

	All species	Birds	Mammals
All light conditions	6 hr 21 min (8 min–20 hr 40 min) *n* = 64	4 hr 54 min (8 min–20 hr 40 min) *n* = 44	9 hr 32 min (3 hr 38 min–17 hr 18 min) *n* = 20
Sunrise deployment	3 hr 21 min (8 min–17 hr 18 min) *n* = 35	2 hr 28 min (8 min–11 hr 2 min) *n* = 31	10 hr 13 min (5 hr 27 min–17 hr 18 min) *n* = 4
Sunset deployment	9 hr 57 min (17 min[a]–20 hr 40 min) *n* = 29	10 hr 41 min (17 min[a]–20 hr 40 min) *n* = 13	9 hr 21 min (3 hr 38 min–14 hr 13 min) *n* = 16

[a]= Carcass deployed <1 hour prior to sunset. This detection occurred during daylight.

The mean time to initial detection of a deployed carcass across all species and light conditions was 6 hours and 21 minutes (Table 2). We observed significant differences in the duration of time to first detection, depending on whether a carcass was deployed at sunrise or sunset ($Z = 175.5$, $P < 0.001$; Table 2). Likewise, we observed differences in duration to the first detection according to taxonomic group ($Z = 190.5$, $P < 0.001$), with initial time to detection for birds at 4 hours and 54 minutes and 9 hours 32 minutes for mammals (Table 2). We did not detect strong evidence for correlations between the time to initial detection and any of the examined weather variables. Between the 2 substrate types, there were no notable differences in time to initial detection, demonstrating that substrate type did not influence how rapidly a carcass was detected ($P = 0.32$).

Timing of carcass interactions and carcass persistence

Birds almost exclusively detected carcasses during daylight hours (Figure 3), with the exception of 10 events (2% of bird detections), which took place within 33 minutes of sunrise or sunset. Detections by avian fauna were concentrated in mid-morning, with 41% of detections occurring during the hours of 0900–1100 (2 hours). While mammals detected carcasses under all lighting conditions over the 24-hour survey periods, the majority of detections occurred during hours of darkness. These detections were concentrated in the early hours of the morning, with 44% of detections occurring between the hours of 0000–0400 (4 hours). There was little seasonal variation in activity patterns for detection times for both mammal and bird species, with peaks in activity moving in relation to seasonal changes in sunrise and sunset times.

Birds spent an average of 5 minutes and 29 seconds with a carcass (range = 2 seconds to 52 minutes and 51 seconds), whereas mammals spent an average of 2 minutes and 35 seconds with a carcass (range = 4 seconds to 27 minutes and 39 seconds). All carcass interactions with mammals involved only 1 individual, except 2 airside interactions with Irish hares, where we observed 2 groups of 2 hares. Comparatively, 28% of bird detections were of >1 individual bird, with a mean group size of 1.35 (±0.82 SD).

A mean of 23.9 (±12.8 SD) hare strikes per year were recorded between 2012–2021. To gain an understanding of how scavengers could potentially interact with a carcass from a hare strike event at the airfield, we investigated the temporal overlap in scavenger-carcass interactions and historical strike events. Overlap times for mammal interactions with a deployed carcass and recorded strike events at the airfield with Irish hares ($n = 239$, 2012–2021) was high (81%; 95% CI = 74–92%), with low overlap recorded during the afternoon hours (Figure 4). In comparison,

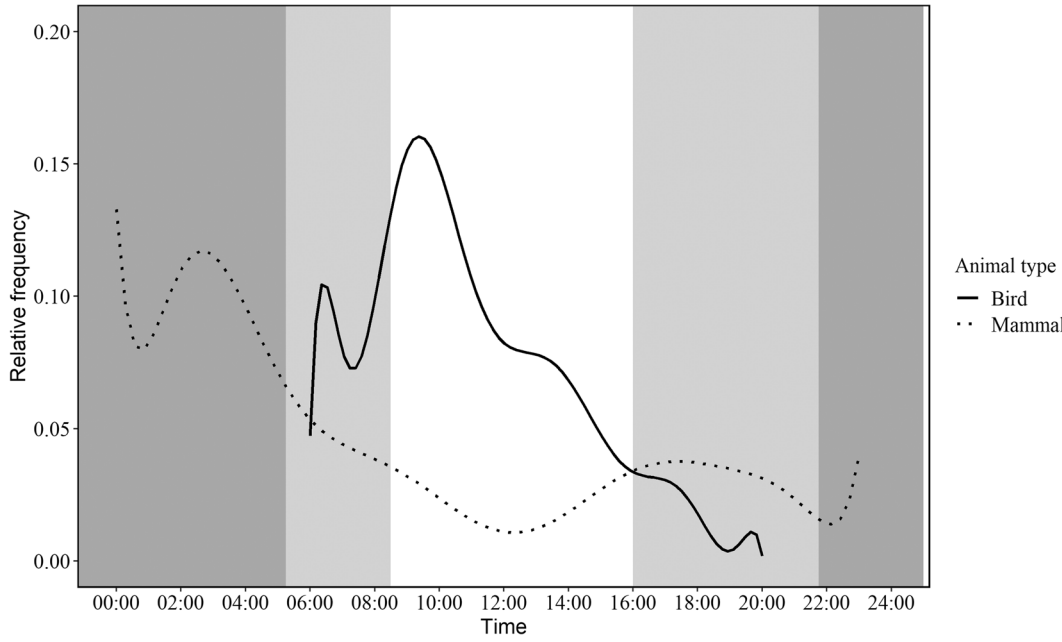

FIGURE 3 Density curves derived from cumulative hourly interactions between bird and mammal species and commercial rat carcasses (*Rattus norvegicus*), across all surveys, in Dublin, Ireland (August 2020–March 2022). Light grey shaded areas demonstrate the range of sunrise and sunset times through the study period, using the longest and shortest days of the year where a detection occurred (i.e., 15 July vs. 20 December). Dark grey shaded areas demonstrate hours of darkness across the whole study.

overlap times for bird interactions with a carcass and reported hare strike events was low (32%; 25–36%). There were 2 clearly defined periods of activity overlap during the morning and evening (Figure 4), indicating the times of day that avian species are more likely to interact with a carcass resulting from a strike.

The probability of a carcass remaining at the end of each deployment period was 0.54 (95% CI = 0.41–0.69; Figure 5). We did not detect a difference in carcass persistence depending on whether the carcass was deployed at sunrise or sunset ($P = 0.99$), or for the substrate type (i.e., artificial hard surface vs. grass; $P = 0.80$). We observed differences in carcass persistence between seasons ($\chi^2_3 = 10.3$, $P = 0.01$). Carcasses were the least likely to persist in the autumn (0.20; 95% CI = 0.07–0.52) and most likely to persist in the summer (0.76; 95% CI = 0.55–0.99; Figure 6).

DISCUSSION

Understanding the faunal composition and scavenger guild utilising an airfield environment is vital for the implementation of targeted secondary strike mitigation measures. We recorded 9 species interacting with carcasses, 8 of which engage in scavenging behavior and are widespread throughout Ireland (Lysaght and Marnell 2016, Cummins et al. 2019, Lewis et al. 2019) and 3 of which are ranked in the top 10 most hazardous species at Dublin Airport (buzzard, rook, and herring gull) as identified by the Dublin Airport WHMP. Corvids constitute a major component of the diurnal scavenger guild (Slater 2002), and this is reflected in our results, where hooded crows were the most frequently encountered species. Likewise, hooded crows made up the highest proportion of avifauna, potentially influenced by the heterogeneous landscape surrounding Dublin Airport and the species' generalist nature (Lewis et al. 2019). Although data are generally lacking for Ireland on scavenger guild and

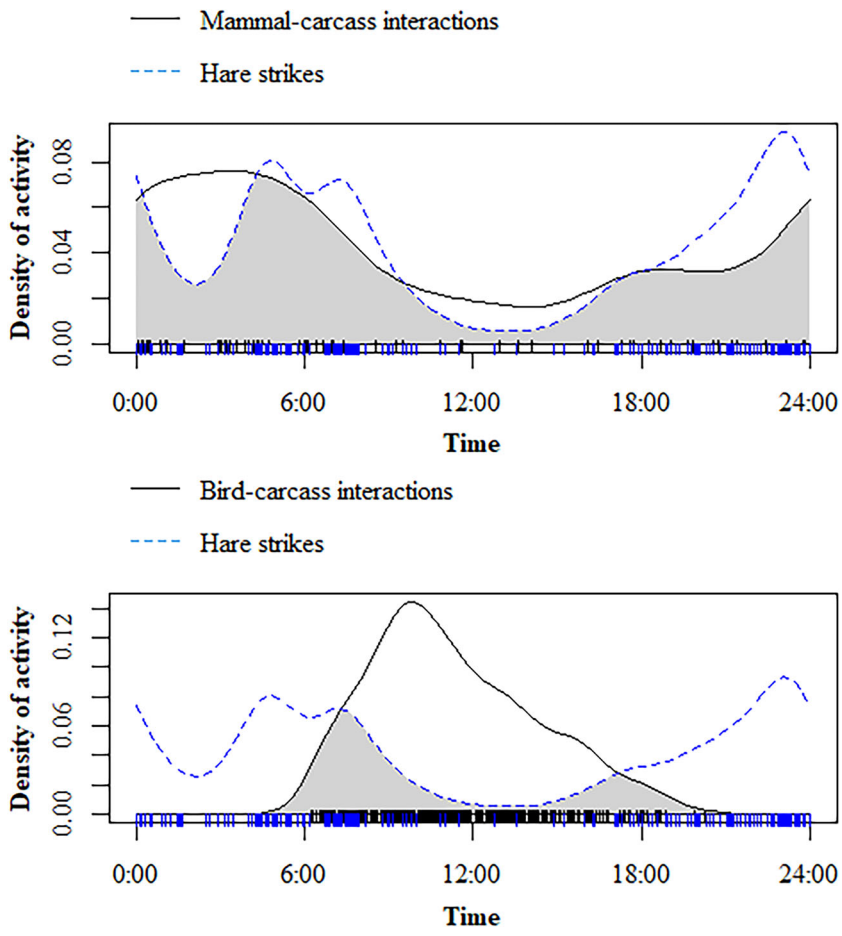

FIGURE 4 Activity overlap for mammal (top) and bird (bottom) interactions with commercial rat carcasses (*Rattus norvegicus*; August 2020–March 2022) and recorded Irish hare (*Lepus timidus hibernicus*) strike events at Dublin Airport, Ireland (2012–2021), as indicated by shaded grey areas. The x-axis displays the density of points recorded according to time, with blue showing the density of recorded hare strike times and black showing the density of interactions for mammals (top) and birds (bottom).

carcass interactions, studies from the United Kingdom demonstrate that carrion crow (*Corvus corone*), which fill a similar ecological niche to hooded crow in Ireland, are often the species most commonly recorded interacting with carcasses (Inger et al. 2016, Schwartz et al. 2018). However, secondary strike hazard is likely to be country- or even airfield-specific, and historical strike records should be consulted when determining high-risk species on a local level.

In the current study, the average duration of time to initial carcass detection by animals was 6 hours and 21 minutes across all trials, with a small number of detections (<2%) made within 30 minutes of deployment, suggesting that current clean-up procedures are adequate in reducing secondary strike risk in the majority of cases. However, secondary strike risk is likely to increase in circumstances where clean-up operations are prolonged or delayed. In this study, we highlighted that the probability of a carcass persisting past 24 hours was high, at 54%, indicating that a missed carcass (e.g., deflected into nearby grassland) could potentially attract scavenger species long after airfield inspection. As pilots often report strike events to air traffic control where no carcass is recovered during the resulting runway inspection, the possibility remains that carcasses could be pushed into the surrounding grasslands and remain undetected by airfield management but nonetheless could be attractive to scavenger species.

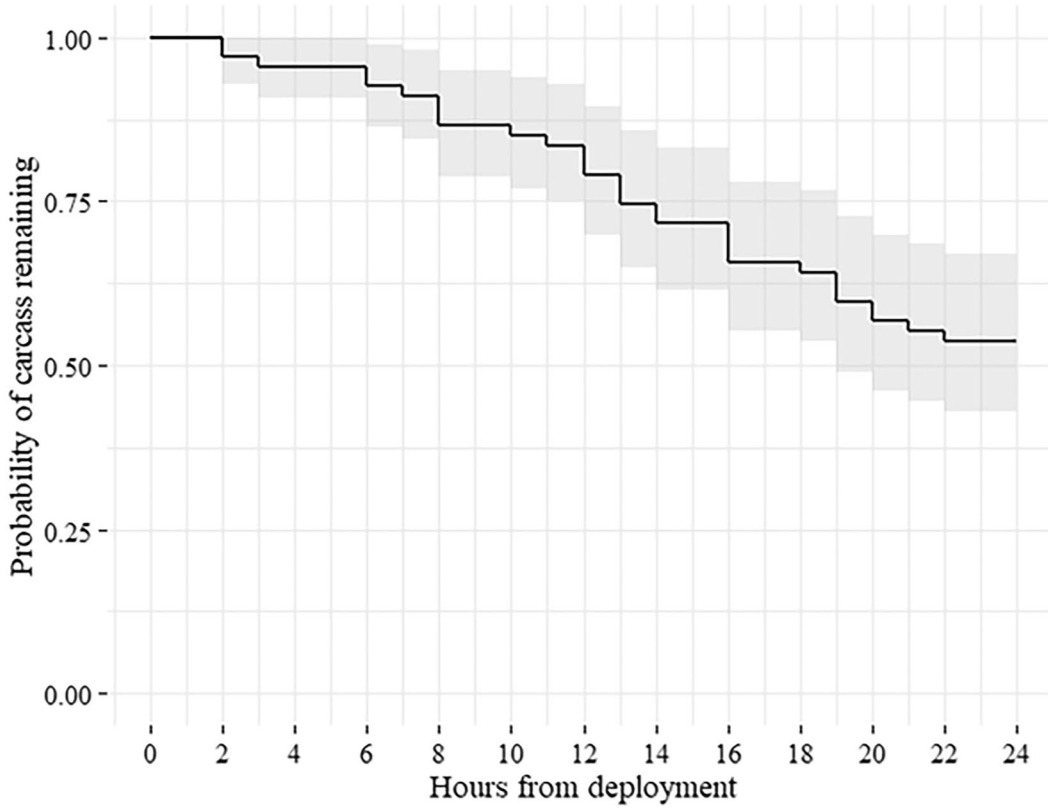

FIGURE 5 Kaplan Meier survival curve for rat carcass (*Rattus norvegicus*) persistence probability within the 24-hour study period in Dublin, Ireland (August 2020–March 2022). We included only landside trials (n = 68), with all deployment times, seasons, and substrate types included. We included trials that did not yield a single interaction event (n = 15), with survival time set as 24 hours. Shaded grey areas represent 95% confidence intervals.

While a higher proportion of detections were made on artificial hard surfaces than the grass (57% vs. 43%), the duration of time to initial detection and time spent with a carcass were similar for both substrate types. Likewise, we found scavenger pressure to be uniform across substrate types (similar to Ponce et al. 2010), with no differences in the relative frequencies of taxa interacting with carcasses. In contrast, Schwartz et al. (2018) found that land cover type (urban or parkland) strongly influenced the species engaging with a carcass. In our study, the short distance between carcasses for both substrate types (~50 m) could have resulted in similar scavenger guilds but highlights the issue that any carcass subsequently pushed into the grasslands during a strike event is likely to attract hazardous species to the site of a strike, potentially within minutes.

Birds generally detected carcasses more rapidly than mammals, likely owing to a combination of greater population densities of avian species in the area, locomotive differences (i.e., flying allows birds to forage across a large area in a short amount of time), and mammals' reliance on olfaction for carcass detection (Turner et al. 2017, Bernardino et al. 2020) compared to birds' capacity to detect carrion via more visual cues (Harrimanab and Berger 1986, Potier et al. 2019). However, despite the possibility that olfaction can be less important in lower temperatures owing to slower decomposition rates (Shean et al. 1993, DeVault et al. 2003), the highest proportion of carcass detections by mammals was made in the winter sampling periods (25% of detections). This reflects longer periods of activity of nocturnally active generalist mammalian predators such as foxes, during the prolonged hours of darkness in winter months (Needham et al. 2014). However, it cannot be ruled out that the observed differences in carcass

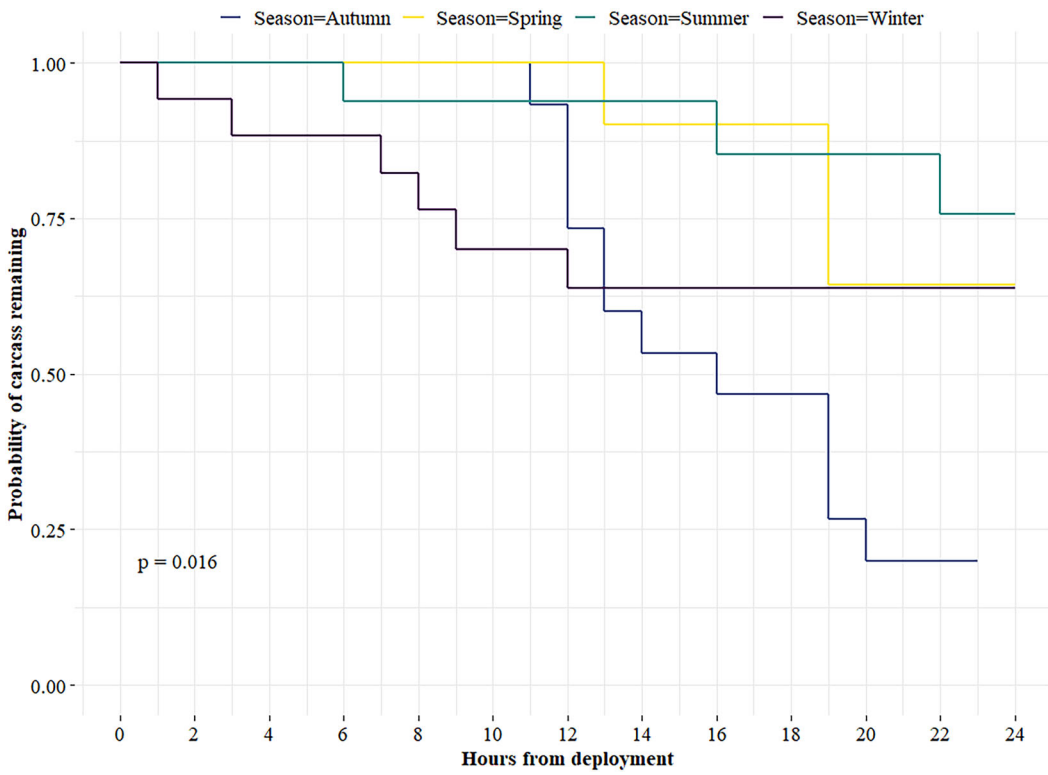

FIGURE 6 Kaplan Meier survival curve for commercial rat carcass (*Rattus norvegicus*) persistence for each season, from landside trials only, in Dublin, Ireland (August 2020–March 2022). The log-rank test shows a significant difference between seasonal survival curves (P = 0.016). We excluded 95% confidence intervals for ease of interpretation.

detection times between taxonomic groups may be influenced by variations in seasonal behavioral patterns or food availability specific to each taxonomic group. While there is evidence that corvids can deter mammals from feeding on carrion (e.g., wolves [*Canis lupus*]; Vucetich et al. 2004, but see Hill et al. 2018), it is likely that mammals at Dublin Airport and other airfields are deterred by increased anthropogenic activity during daylight hours. Indeed, several studies have found anthropogenic activity to have a deterring effect on wildlife (Parsons et al. 2016, Oberosler et al. 2017), although this may vary species to species (Procko et al. 2022). We used commercially available rat carcasses in the current study to act as a surrogate for a hare strike event because of logistical constraints, but the possibility that detection times could vary for a hare carcass cannot be ignored. Indeed, Gerke et al. (2022) found significant differences in carcass detection times between rodent and lagomorph carcasses. Therefore, trials utilizing lagomorph carcasses, confirmed to be RHD2 free, could be beneficial for further informing secondary strike risk.

Climatic conditions are known to influence carcass detection by scavenger species, with specific weather patterns favoring detection by different taxonomic groups (Enari and Enari 2021). In the present study, we did not observe strong evidence of a correlation between general daily weather variables (wind speed, minimum and maximum temperature, and precipitation) and the time taken for carcasses to be detected. However, these weather metrics were averaged across the day, and precise conditions at the exact time of detection were not recorded. Consequently, it remains plausible that intra-day variations in climatic factors (e.g., wind speed and direction) may influence both the likelihood and timing of carcass detection. Additionally, the proximity of carcass placement to known animal resting or activity sites (e.g., rookeries, fox dens, badger setts) was not accounted for in this study, but may represent an important variable affecting scavenger detection efficiency (Inagaki et al. 2022).

While the data presented offer valuable insights into secondary strike events following a primary wildlife strike, it is important to acknowledge certain limitations that may influence the interpretation of the results. It was not feasible to conduct experimental trials on an active runway because of health and safety constraints. This limitation may introduce bias, as the absence of continuous air traffic could affect the behavior and detection times of scavenger species, for both avian and mammalian taxa. In operational environments, persistent aircraft activity is likely to deter such species from approaching strike sites, potentially altering the dynamics observed in this study. Moreover, the trials were conducted between August 2020 and March 2022, coinciding with the COVID-19 pandemic. This period, often referred to as the anthropause, was characterized by a significant reduction in human activity, which has been shown to influence the movement patterns and behaviors of various wildlife taxa (Łopucki et al. 2021, Schrimpf et al. 2021, Procko et al. 2022). These atypical conditions may have further influenced the outcomes and should be considered when interpreting the findings. Owing to logistical constraints, it was not possible to replicate the trials under post-pandemic conditions reflective of typical human activity levels. Despite these limitations, the findings presented here represent the first documented assessment of secondary strike risk following a mammal strike event at an international airport, providing a foundational basis for future research in this area.

Identifying increased periods of strike risk and the factors driving these events is crucial in the development of targeted mitigation measures for both primary and secondary strikes. We used historical hare strike data to determine when carrion was likely to be available for scavenger attraction at the airfield and identified that hare strikes occurred largely in a bimodal pattern. Although overlap between mammal–carcass interactions and hare strikes was high (81%), the relative abundance of these species' airside, alongside longer carcass detection time, short interaction time, and a small number of interactions, is likely to reduce the likelihood of a strike event being detected by a mammal. Conversely, while temporal overlap between hare strikes and bird–carcass interactions was low (32%), the high relative abundance of avian species, shorter detection time, high number of interactions, longer carcass interaction time, and a high proportion of detection events involving multiple birds (28%), means that birds present as a higher secondary strike risk. Indeed, one carcass interaction event recorded the presence of 13 jackdaws looking at a carcass. The temporal overlap between birds and strike events demonstrated a bimodal pattern, with peaks around 0800 and 1700 across the year. While there is likely to be some seasonal and local variation (Engel and Young 1992, Taufique et al. 2016), understanding these patterns provides an insight into when problematic species are likely to engage with a carcass and can help to inform airfield managers as to what times of day additional precautions need to be taken (i.e., increased runway patrols, noise harassment), to reduce secondary strike risk following a strike event. Methods aimed at predicting wildlife–aircraft interactions (e.g., camera traps, Ball et al. 2022; radar, Lopez-Lago et al. 2017) for both primary and secondary strikes could be beneficial to airport managers in attempting to mitigate against strike risk and to minimize costs associated with wildlife strikes (Carswell et al. 2021) and should therefore be incorporated into wildlife hazard management plans.

MANAGEMENT IMPLICATIONS

We have explored secondary strike risk, which has the potential to occur when carcasses that result from bird or mammal strikes by aircraft attract scavenger species (Bernardino et al. 2020). We demonstrated that both avian and mammalian scavengers are attracted to the site of a mammal strike event and spend on average 2.5-5.5 minutes at a carcass. Yet initial carcass detection times for birds and mammals averaged 5 hours and 9.5 hours, respectively. Thus, with an immediate response in place to remove primary strikes, current clean-up procedures at Dublin Airport are likely adequate in reducing secondary strike risk. By their very nature, airfields are inherently physically protected environments with wildlife exclusion measures (e.g., fencing) in place. Despite this, many mammal species can still gain access to airfield environments (Biondi et al. 2011, Scheideman et al. 2017, Ball et al. 2023) or establish populations within the boundary fence, as is the case with the Irish hare at Dublin Airport. Certainly, the most

effective way to mitigate against the hazards of secondary strike risk is adequate primary strike mitigation. Hence, understanding the faunal composition of an airfield is of the upmost importance for implementing relevant and effective mitigation measures to exclude and disperse wildlife.

In 2005, Air France was awarded €4 million for engine damage as a result of a strike event with a gull that that had been feeding on an undetected hedgehog (*Erinaceus europaeus*) carcass (Dale 2009). Therefore, while here we report on a specific airport, our data are relevant for other airfields worldwide and are relevant in understanding secondary strike risk, which has important safety and economic implications for airport authorities, airline operators, passengers, and personnel.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

All surveys conducted as part of this work were observational and required no handling of any live animals. All bait used was commercially available pet food. The project received ethical approval from University College Cork's Animal Experimentation Ethics Committee (AEEC; 2019-003).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Figshare at https://figshare.com/articles/dataset/Secondary_strike_risk_associated_with_a_mammal-aircraft_collision/28524464, reference number 10.6084/m9.figshare.28524464.

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