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RESEARCH ARTICLE

Hareport hazard: Identifying hare activity patterns and increased mammal–aircraft strike risk at an International Airport

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Abstract

Reported strike events between wildlife and aircraft are hazardous to aircraft and airfield operations and are increasing globally. To develop effective mitigation strategies, the relative hazard a species poses to aircraft, as well as information relating to its life history, are key to the development of effective mitigation strategies in Wildlife Hazard Management Plans. However, given the complex nature of airfield environments with access restrictions and the presence of sensitive equipment, the collection of high-quality ecological data can be difficult. Here we use motion-activated camera traps to collect activity data on a population of Irish hares (*Lepus timidus hibernicus*) inhabiting the airfield at Dublin International Airport, to investigate the link between hare activity and aircraft activity in relation to hare strikes. Camera traps revealed that the hare population at the airfield largely displayed a bimodal crepuscular activity pattern, with activity peaking at sunrise and at sunset. Recorded hare strike times at the airfield were closely associated with hare activity times with a high temporal overlap between these datasets. In comparison, hare activity and aircraft movement activity had a moderate overlap across all seasons, with strikes peaking at times with low aircraft movements. We demonstrate the importance of understanding the circadian and seasonal activity patterns of hazardous species at airfields for targeted strike mitigation.

Introduction

Wildlife collisions or 'strikes' with transport vehicles can have serious consequences for passenger safety, industry economics (*e.g.* Dolbeer & Begier, 2021), the local economy (*e.g.* Jaren et al., 1991) and wildlife conservation efforts (*e.g.* Clair et al., 2019). While the majority of strike-related research has focused on road traffic networks (*e.g.* Popp & Boyle, 2017; Wright et al., 2020), similar consequences are also reported for other modes of transport including rail (Dorsey et al., 2017), shipping networks (Laist et al., 2001) and air transportation (Altringer et al., 2021). Mammals are well represented within the literature regarding strikes for most modes of transport (*e.g.* Pokorny et al., 2022), yet relatively little research has focussed on mammals in the context of the air transportation sector, despite mammalian strikes composing 3–10% of reported strikes in the aviation industry (Ball, Caravaggi, & Butler, 2021b). Terrestrial mammals are hazardous to aircraft only when they move on to the active runway, therefore, understanding the circadian (over 24 hours) and seasonal activities of animals inhabiting or using the airfield could help to identify periods of increased risk when animals are likely to come into contact with aircraft. Identifying these periods of risk can then allow for the targeted development and application of strike mitigation measures.

Animal behaviours and activity patterns are greatly influenced by a variety of pressures within their environment, including- but not limited to- food availability (Pereira, 2010), predation risk (Ross et al., 2013), disturbance and anthropogenic activities (Lendrum et al., 2017). Circadian and seasonal activity patterns are photoresponsive cycles regulated by the suprachiasmatic nucleus of the hypothalamus in mammals (Meijer et al., 2010), allowing for species to fulfil daily requirements (*e.g.* feeding) while adapting to seasonal day length. This plasticity (Phillips et al., 2013) allows for mammals to exploit the ecological environment they inhabit and alter activities relative to changing sunrise and sunset times. Hence, in the context of wildlife management, wildlife hazards are likely to exhibit temporal variability, particularly with increasing distances from the equator where seasonality becomes increasingly pronounced. This highlights the importance of understanding species composition and associated life histories of potentially hazardous fauna on an airfield-specific basis.

Given the sensitive nature of airfield environments, the collection of high-quality ecological data can often be complicated, requiring the use of remote field methods due to limited accessibility, such as camera traps (Carswell et al., 2021; Scheideman et al., 2017), radio telemetry (York et al., 2000), GPS tracking (Askren et al., 2019) and predictive modelling based on pre-existing movement data (Arrondo et al., 2021). Lagomorphs (particularly rabbits and hares) are frequently reported in airfield environments and are reportedly involved in strike events near globally (Ball, Caravaggi, & Butler, 2021b; Dolbeer & Begier, 2021; Kitowski, 2016). A population of the Irish hare (*Lepus timidus hibernicus*, Bell 1837), an endemic subspecies of the Mountain hare (*L. timidus*, Linnaeus 1758), resides at Dublin Airport in the Republic of Ireland where strike events between hares and aircraft have been increasing by an average of 14% annually since 1997 (Ball, Butler, et al., 2021a). The damage potential of a hare strike (10,576 J; Ball, Butler, et al., 2021a), in tandem with the conservation status (Caravaggi et al., 2017; Reid et al., 2010) of this endemic subspecies, require that effective management strategies be developed to mitigate against strike events. Here, we investigate whether motion-activated camera traps – an easily accessible and relatively inexpensive method of monitoring – can be successfully used to identify periods of increased strike risk between aircraft and hares.

Understanding the relationship between animal activity patterns and temporal distributions of air traffic can help to comprehend and mitigate strike risk (Arrondo et al., 2021; Carswell et al., 2021; Schwarz et al., 2014). Here, we apply an approach more frequently used in inter-specific competition and predator–prey modelling (*e.g.* Caravaggi et al., 2018; Ross et al., 2013) to an industry setting. We hypothesize that aircraft-hare activity overlap will fluctuate seasonally, and that hare activity represents a better indicator of strike patterns than aircraft activity. We focus on the Irish hare as a model species and propose that this approach could be used to identify periods of risk associated with other ground dwelling species at airfields worldwide and for use on public road networks.

Methods

Study area

Dublin International Airport (53.4264°N, 6.2499°W) is Ireland's largest civil airport and one of the busiest in Europe, with almost 250,000 aircraft movements recorded in 2019 alone. The airfield was composed of approximately 275 hectares (680 acres) of grassland throughout the study period, which increased to approximately 370 hectares (914 acres) in August 2021 due to the expansion of the airfield to incorporate an additional runway. The grasslands are maintained according to a long grass management policy (UKCAA Safety Regulation Group CAP, 2008) comprising of a blend of Italian ryegrass (*Lolium multiflorum*) and tall fescue (*Festuca arundinacea*). The airfield is located on the east coast of Ireland and experiences a temperate climate. A mean temperature of 9.4°C and mean rainfall of 62.8 mm was recorded throughout the study period (July 2019–May 2021; MET Eireann, 2021).

Strike data

A database of all strike events at the airfield has been maintained since 1990, encompassing all confirmed strike events with avian and mammal species. The first strike event with a hare was reported at the airfield in 1997. These data were provided by the daa (Dublin Airport's managing body). Carcasses were recovered from active areas (*i.e.* runways, taxiways) following a reported strike event or during mandatory routine inspections with the location and environmental conditions surrounding an event recorded (*e.g.* weather; see Ball, Butler, et al., 2021a). From 2012 onwards, temporal data detailing the date and time of a strike were also recorded, resulting in n = 238 hare strike events with an associated strike time from 2012 until December 2021. Despite the presence of other mammal species occasionally reported at the airfield including foxes (*Vulpes vulpes*), hedgehogs (*Erinaceus europaeus*), rabbits (*Oryctolagus cuniculus*), rats (*Rattus norvegicus*), domestic cats (*Felis catus*) and bats (Kelly et al., 2017), strike events with these species are rare (Bolger & Kelly, 2008). With an increasing number of hare strike events reported annually and a sufficient kinetic energy to cause damage to an aircraft (Ball, Butler, et al., 2021a), the Irish hare is the most hazardous mammal species at the airfield. Therefore, here we focus on the Irish hare due to a high incidence of strike events.

Camera trapping

Seven Bushnell Trophy Cam HD (model 119476) camera traps were deployed into the grasslands surrounding the main runway at Dublin Airport (RW28-10 L), at seven fixed locations, identified *a priori* by airfield safety authorities and dependant on the location of appropriate permanent structures (*e.g.*, gate posts). Camera positions were not changed due to ongoing construction work throughout the study period. Cameras were positioned 50 cm above ground level with a ~ 15° downwards tilt with cameras pointing away from areas of high aircraft and vehicle traffic, to prevent false triggers and operated 24/7 with the use of infrared for nocturnal image capture (Appendix 1 and Appendix 2). The shortest distance between the two closest camera traps was 520 m (0.5 km, range 520 m–920 m), to minimize spatial replication. This was well beyond the typical hare home range (0.14km^2 ± 0.02 m Caravaggi et al., 2016) and slightly over the median home range size of male hares reported by Wolfe and Hayden (1996) of 0.5 km^2. Cameras were left *in situ* for 32–69 days (dependant on logistics, camera performance and accessibility), for each season between July 2019–May 2021 (Appendix 3), for a total of 360 calendar days. Seasons were defined as spring (March–May), summer (June–August), autumn (September–November) and winter (December–February). Interannual survey data were pooled for each season. Cameras were programmed to record two-time stamped images when triggered by movement at medium sensitivity, with a 60-second interval between images.

Circadian activity- data analysis

Camera trap images were assumed 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) and therefore defined as an independent mammal detection. As camera traps were only triggered by movement (*i.e.*, activity), we also assumed that detections of hares were a true reflection of the circadian activity of the species. For trigger events where the image contained more than one individual (n = 39 events), only a single event was recorded (Caravaggi et al., 2018). Aircraft movement data for the runway (RW28-10 L) were obtained from the daa, whereby a movement is defined as a take-off or landing manoeuvre. All aircraft manoeuvres were considered to be independent events. These data were truncated to include only those dates where camera traps were deployed on the airfield. All statistical analysis was carried out in programme R v 4.0.4. (R Core Team, 2021).

A cross-correlation function (CCF) was used to determine negative ($h-$) or positive ($h+$) lags in time series data between aircraft and hares. CCFs show correlations between events in time series data (X_a, Y_a; a = time), where a positive lag ($h+$) shows a correlation between X_{a+i} and Y_a (*i.e.*, X succeeds Y). Likewise, a negative lag ($h-$) shows a correlation between X_{a-i} and Y_a (*i.e.*, X precedes Y). The significance of the correlation coefficient was established by calculating the t value, where the critical t value ($P = 0.05$, 22 degrees of freedom, one-tailed) = 1.72. The '*Overlap*' package (Meredith & Ridout, 2021) was used to determine the temporal overlap between hares and aircraft, by estimating the overlap coefficient (Δ), where Δ = 0 indicated no overlap and Δ = 1 indicated complete temporal overlap. Data were bootstrapped 1,000 times to generate 95% confidence intervals (CI) of the overlap coefficient (Zanni et al., 2021). The Δ_4 estimator was used for all pairwise comparisons between aircraft movements and hare activity and was also used to compare aircraft movements and hare strike events across the whole year. The Δ_1 estimator was used for seasonal aircraft strike pairwise combinations due to seasonal strike records ranging from 54–69 events (Meredith & Ridout, 2021) and for seasonal hare activity *vs.* seasonal hare strike comparisons. Temporal overlaps between hares and aircraft were ranked as either high ($\Delta > 0.75$), moderate ($0.50 < \Delta < 0.75$) or low ($\Delta < 0.50$), for each season (Monterroso et al., 2014).

Given Irelands northern latitude, day length varies substantially with seasons with the longest days in the summer experiencing ~17 hours of daylight, and the shortest days in the winter experiencing ~7 hours of daylight. Therefore, to investigate how activity patterns changed in relation to the rising of a setting sun seasonally, trigger events were offset to either sunrise or sunset (*i.e.* 00:00–11:59 offset relative to sunrise, 12:00–23:59 offset relative to sunset; Caravaggi et al., 2018). All daytime offsets (*i.e.*, events which occurred between sunrise and sunset) were converted to positive integers and night-time offsets (*i.e.*, events which occurred between sunset and sunrise) to negative integers. As an example, a detection at 10:15 on a day where sunrise was at 08:00 would have an offset value of +2 hrs 15mins, which would indicate diurnal activity. Similarly, a detection at 20:30 on a day where sunset was at 19:00 would have an offset value of -1 hr. 30 mins, indicating nocturnal activity. Finally, a detection which occurred at 03:55 (after midnight) would be offset to sunrise and on a day where this was at 07:15, an offset value of -3 hrs 20mins would be allocated, indicating nocturnal activity closer to sunrise than sunset. These offset values were used as the dependant variable in a one-way analysis of variance with *post hoc* Tukey tests, to test differences in activity patterns across seasons. Likewise, as the Covid-19 pandemic substantially impacted on the number of aircraft movements at Dublin Airport, the same method was used to compare hare activity between seasons (*i.e.*, Summer 2019 *vs*. Summer 2020) to test whether hares exhibited altered activity patterns with the relief in aircraft movements.

Camera trap data and aircraft movement data were from the same sampling periods with aircraft movement data having been truncated to match camera trap deployment dates (between July 2019–May 2021). As hare strike data were available from 2012–2021 (n = 238), the entire data set was used to investigate the overlap patterns with aircraft movements and hare activity to ensure a sufficient sample size for robust estimates (Lashley et al., 2018; Meredith & Ridout, 2021). Truncating hare strike data to the sampling period dates (July 2019–May 2021) would result in an insufficient sample size (n = 17) to reliably estimate activity overlap.

Results

Camera trap detections

Of the potential 2,520 recording days (*i.e.*, 7 cameras recording for 360 calendar days), 2,144 were successful (85%). Camera failings were a result of removal by personnel, hares chewing through camera straps as well as battery and mechanical failure. A total of 684 independent mammalian detections were recorded on the airfield at Dublin Airport, from 5 species, across 360 calendar days (*i.e.*, full 24-hour periods; Table 1). The Irish hare was the most frequently detected species, making up 84.9% (n = 574) of detections, followed by the red fox (*Vulpes vulpes*) with 14.6% (n = 100) of detections. The European hedgehog (*Erinaceus europaeus*, n = 5), European rabbit (*Oryctolagus cuniculus*, n = 3) and domestic cat (*Felis catus,* n = 2) were rarely recorded. Over the course of the study period (360 days), a total of 114,559 aircraft movements were recorded at the airfield (Table 2).

Activity patterns

Hares demonstrated a largely crepuscular activity pattern, with peaks in activity recorded at, or close to, sunrise and sunset (Fig. 1). This pattern was less defined during the winter months, when hares were active over a longer period, likely due to the prolonged hours of darkness typical of the season in Ireland (*e.g.*, day length on winter solstice in Dublin is approximately 7 hours and 30 minutes, compared with approximately 17 hours on the summer solstice). In contrast, while aircraft movements were recorded continuously throughout the year, the majority of movements occurred according to a diurnal pattern (Fig. 1). Movements rapidly increased around 06:00 across all seasons and remained high for the duration of the day, decreasing in volume approaching midnight (00:00). Overlap between hares and aircraft was moderate across the year (58%; CI 53–60%) and across all seasons (Table 3), with spring having the highest activity overlap (63%; CI 55–65%). Activity overlap estimates for the sampling periods prior to the Covid-19 pandemic were slightly lower than those when both years were considered together (41–51%; Appendix 4).

Hare activity generally preceded aircraft activity, with a significant peak of activity at zero indicating contemporaneous activity patterns recorded only for the winter sampling period (peak = 0, r = −0.576, t = 3.30; Table 4), when hare activity was less confined to a strictly crepuscular pattern. Significant correlations between aircraft and hares were observed across all seasons, with activity patterns crossing zero throughout the year (peak = −3, r = −0.628, t = 3.79) as well as for the summer (peak = −1, r = −0.592, t = 3.45), autumn (peak = −2, r = −0.608, t = 3.59) and winter sampling periods (Table 4).

Table 1. Total number of seasonal detections of Irish hare and red fox using camera traps at Dublin Airport 2019–2021. Sampling commenced in the Summer of 2019 until Spring 2021.

Species	Year	Summer	Autumn	Winter	Spring	No. of independent triggers	No. days *in-situ*	No. of animal detections	No. of triggers per 50 days
Irish hare	*1*	40	30	45	59*,†	174	152	175	57.2
Lepus timidus hibernicus	*2*	82*	46*	114*	158*	400	208	444	94.7
Red fox	*1*	18	9	10	12*	49	152	49	16.1
Vulpes vulpes	*2*	7*	13*	10*	21*	51	208	51	12.1

Year 1 = Summer 2019- Spring 2020.
Year 2 = Summer 2020- Spring 2021.
†Denotes the onset of the Covid-19 pandemic in Ireland.
*Denotes sampling periods during the Covid-19 pandemic in Ireland.

Table 2. Total number of Aircraft Movements (ACM) 2019–2021 recorded by the (daa) for the time frame during which the cameras were deployed on the airfield to record wildlife activity. Sampling commenced in the Summer of 2019 until Spring 2021.

Year	Summer	Autumn	Winter	Spring	Total	No. days	No. of ACM per 50 days	No. of ACM per 50 days prior to Covid-19
1	24,219	36,363*	17,287	2,363*,†	80,232	152	26,392	32,445
2	16,035*	5,697*	8,022*	4,613*	34,367	211	8,144	NA

Year 1 = Summer 2019- Spring 2020.
Year 2 = Summer 2020- Spring 2021.
†Denotes the onset of the Covid-19 pandemic in Ireland.
*Denotes sampling periods during the Covid-19 pandemic in Ireland.

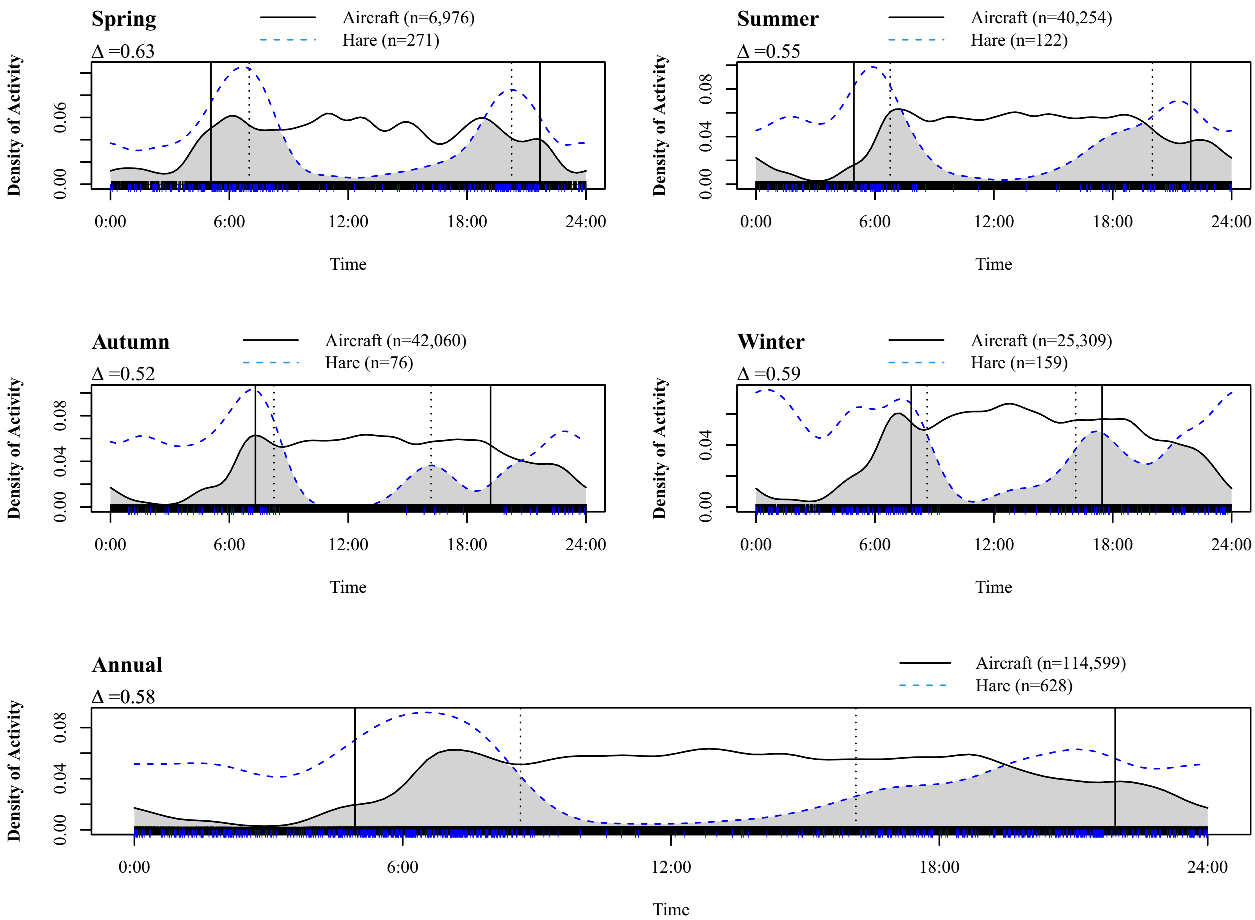

Figure 1. Overlap estimates of hare activity and aircraft movements at Dublin Airport. Shaded grey areas indicate times when activity overlapped. Dotted and solid black lines indicate sunrise/sunset times on the shortest day and longest day of the sample period respectively. Events are indicated along the x-axis for hares (blue) and aircraft movements (black).

Significant differences ($P < 0.001$) in hare activity relative to sunrise/sunset were recorded across all seasons at Dublin Airport ($F_{3,570} = 81.89$, $P < 0.0001$), with the exception of autumn–winter and spring–summer (Fig. 2). Due to disruptions caused by the Covid-19 pandemic to standard airfield activity patterns, interannual hare activity for each season was compared ($F_{3,566} = 37.46$, $P < 0.0001$) to ensure that activity patterns were a true reflection of circadian activity with no significant differences observed between the same season for each year. Using Tukey's HSD test, small differences (diff) in mean activity offsets were observed for spring (diff: -0.87, 95% CI = −2.13, 0.39, $P = 0.42$), summer (diff:1.32, 95% CI = −0.28, 2.92, $P = 0.19$), autumn (diff: -0.33, 95% CI = −2.27, 1.61, $P = 0.99$) and winter (diff:-0.62, 95% CI = −2.07, 0.84, $P = 0.90$).

Table 3. Annual and seasonal temporal overlap estimates for hare activity (2019–2021), aircraft movement activity (2019–2021) and reported strikes between hares and aircraft (2012–2021) at Dublin Airport with bootstrapped confidence intervals (95%).

Season	Overlap estimate (%)	Upper CI	Lower CI
i. Hare activity and aircraft activity temporal overlap (Fig. 1)			
Annual	58.3	53.3	59.9
Spring	62.7	54.8	64.7
Summer	55.0	45.5	59.7
Autumn	52.0	41.9	58.3
Winter	59.2	51.6	64.8
ii. Aircraft activity and recorded hare strike events (2012–2021) temporal overlap (Appendix 5)			
Annual	57.6	51.3	61.4
Spring	61.3	53.1	70.8
Summer	38.4	29.0	46.0
Autumn	62.6	52.9	73.0
Winter	61.7	52.3	68.0
iii. Hare activity and recorded hare strike events (2012–2021) temporal overlap (Fig. 3)			
Annual	85.8	79.5	90.3
Spring	66.1	54.2	74.0
Summer	74.5	64.2	84.5
Autumn	78.2	69.5	91.1
Winter	79.5	72.0	91.9

Table 4. Annual and seasonal associations and dissociations in temporal activity between hares and aircraft at Dublin Airport, estimated using Cross-Correlation Functions (CCF). *r* = Pearson's correlation coefficient.

	Hours				
Season	Lag (from)	Lag (to)	Peak lag	*t-value*	*r*
Annual	−12	−8	−9	3.14	0.557*
Annual	−5	0	−3	3.79	−0.628*
Spring	−5	−3	−4	2.42	−0.603*
Spring	−9	−9	−9	1.62	−0.327
Summer	−12	−8	−9	2.64	0.491*
Summer	−4	0	−1	3.45	−0.592*
Autumn	−11	−8	−9	2.28	0.438*
Autumn	−5	1	−2	3.59	−0.608*
Winter	−11	−8	−10	2.76	0.507*
Winter	−4	2	0	3.30	−0.576*
Winter	10	12	12	1.55	0.315

Negative lags indicate that hare activity preceded aircraft movements and positive lags indicate that hare activity followed aircraft movements. Zero indicates that activity was contemporaneous.
*Denotes significant lag.

Strike patterns

Strike events across the year followed a crepuscular pattern. The highest number of strikes was recorded simultaneously to peak hare activity in the morning (04:00–07:59; 33% of strike events) and following the peak in the evening (21:00–23:59; 27% of strike events). Strike event times had a high ($\Delta > 0.75$) level of overlap with hare activity patterns across the year (86%; CI 80–90%, Fig. 3), as well as throughout the summer, autumn and winter seasons. Spring was the only season where a moderate overlap was recorded (66%; CI 54–74%).

Strike event times had a moderate overlap with aircraft activity times across the year (58%; CI 51–61%), with varying degrees of overlap across seasons. Highest overlap was recorded during the autumn period (62%; CI 53–73%) with the least amount of overlap recorded during the summer (39%; CI 29–46%; Table 3). Significant differences ($P < 0.001$) in strike events relative to sunrise/sunset were recorded ($F_{3,234} = 6.14$, $P < 0.0001$) for winter compared with all other seasons (Fig. 2). Aircraft movements generally picked up from approximately 06:00, with a high proportion of strike events recorded until 08:00 across the year. A second peak in strike events was recorded at night (21:00-23:59) when hourly aircraft movements were declining (Fig. 4, Appendix 5). Overall, 12% of strikes occurred between 07:00–07:59 and a further 12% between 23:00–23:59.

Discussion

Here we show that camera trap data can be used to identify the circadian and seasonal periods of increased strike risk in the air transportation sector (see Carswell et al., 2021). Prior research has investigated the suitability of camera traps for use on airfields for understanding species composition (Scheideman et al., 2017) and here we demonstrate their suitability in determining the activity patterns of a terrestrial mammal species in relation to aircraft movements. This study, using camera traps in a transportation management setting, represents a valuable addition to the growing literature on camera trap applications for wildlife conservation and management (*e.g.* Caravaggi et al., 2018; Garrote et al., 2019; Hofmeester et al., 2020; Jachowski et al., 2015; Schwartz et al., 2018). More importantly, it demonstrates the suitability of this survey method for quantifying ecological phenomena of management concern in busy, dynamic and heavily regulated environments.

Previous studies have demonstrated that lagomorphs alter activity patterns with increasing human influence on the landscape (Wong & Candolin, 2015; Ziege et al., 2016). However, the activity patterns of the Irish hare recorded during this study did not appear to be influenced by ongoing operations at Dublin Airport and were similar to previously recorded seasonal and circadian activity patterns for this sub-species (Caravaggi et al., 2018). The hare population at Dublin Airport

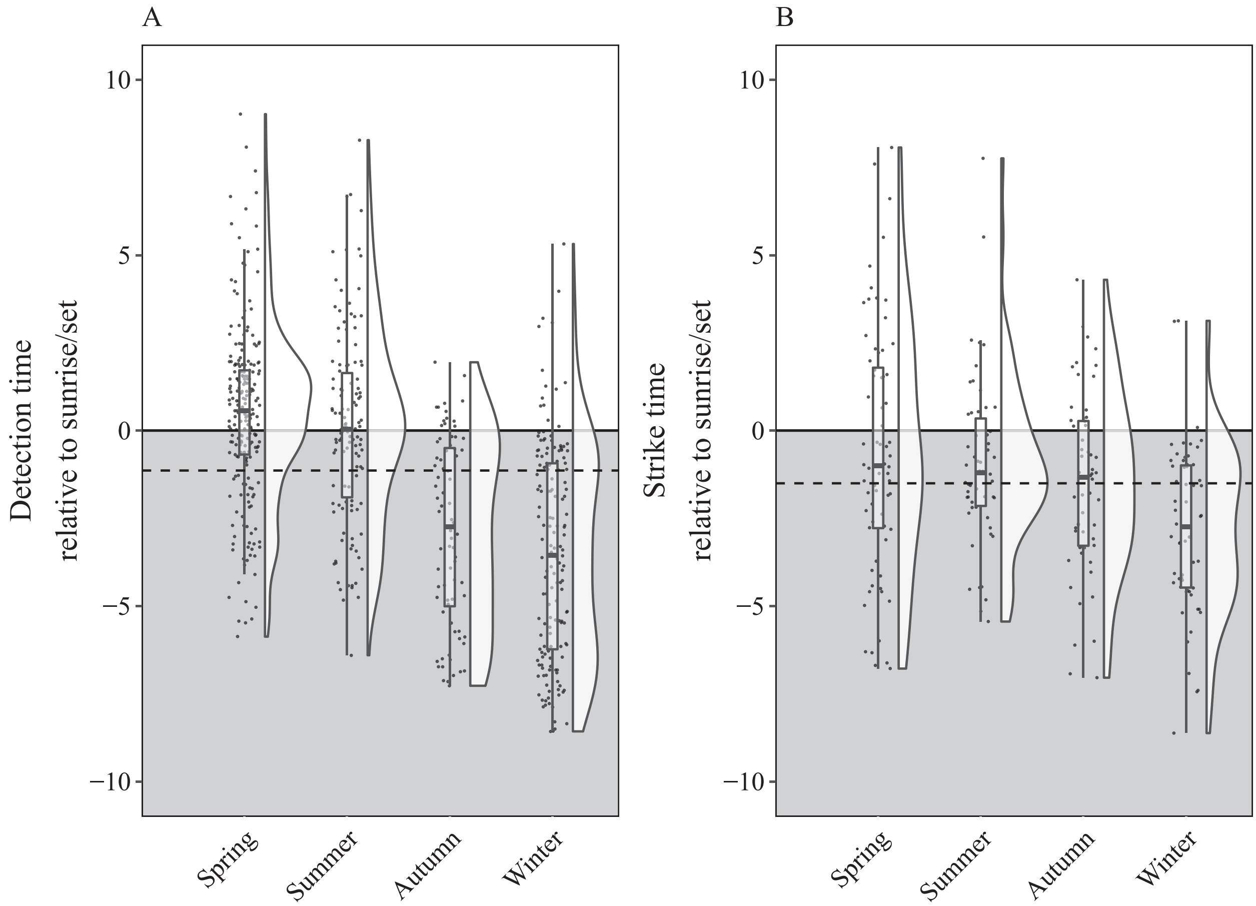

Figure 2. (A) Detection time of hare activity (2019–2021) on the airfield using motion-activated camera traps and (B) time of reported hare strike events (2012–2021) relative to sunrise and sunset for each season. Shaded areas indicate hours after sunset and lighter areas indicate hours after sunrise. Mean ± SD are represented by boxplots (left) and the density and spread of the data are represented by raincloud plots (right; Allen et al., 2021). The mean annual offset of events relative to sunrise and sunset across all seasons is represented by the dashed line.

exhibited a bimodal, crepuscular activity pattern, with clear peaks in activity at sunrise and sunset for the spring and summer seasons when days are longer. A higher rate of diurnal activity was also recorded during these seasons, likely due to energetic requirements and the need to continue foraging beyond the hours of (semi-) darkness. During the autumn and winter seasons, hares exhibited a trimodal activity pattern, with peaks at sunrise, sunset and at approximately midnight, as seen in some other mammal species (Brivio et al., 2016; Ikeda et al., 2019). Generally, activity times of the Irish hare at Dublin Airport preceded peak aircraft activity times, with winter being the only season when a significant peak in hare activity was contemporaneous with aircraft movements. Given that the majority of aircraft movements occurred in the daytime, this is to be expected as hares were predominantly active prior to the start of daily airfield operations.

The development of effective strike mitigation measures requires an understanding of strike events and factors driving these events. Overlap between hare activity and aircraft movements was moderate (58%) but was high between hare activity times and hare strike times at the airfield (85%), with strikes typically occurring according to a bimodal pattern with a peak at 04:00–07:59 and another at 21:00–23:59. Identifying times of higher risk is useful from a management execution and implementation perspective. These, for instance, are the times during which scaring and patrol efforts may be increased or aircraft may receive additional alerts about possible hare activity. Indeed, concentrating efforts for only 2 hours a day (07:00–07:59 and 23:00–23:59) could be greatly beneficial. However, as animals adjust activity seasonally with changing sunrise and sunset times, actual intraspecies activity peaks may change week to week based on natural and artificial light levels (Hoffmann et al., 2018). Indeed,

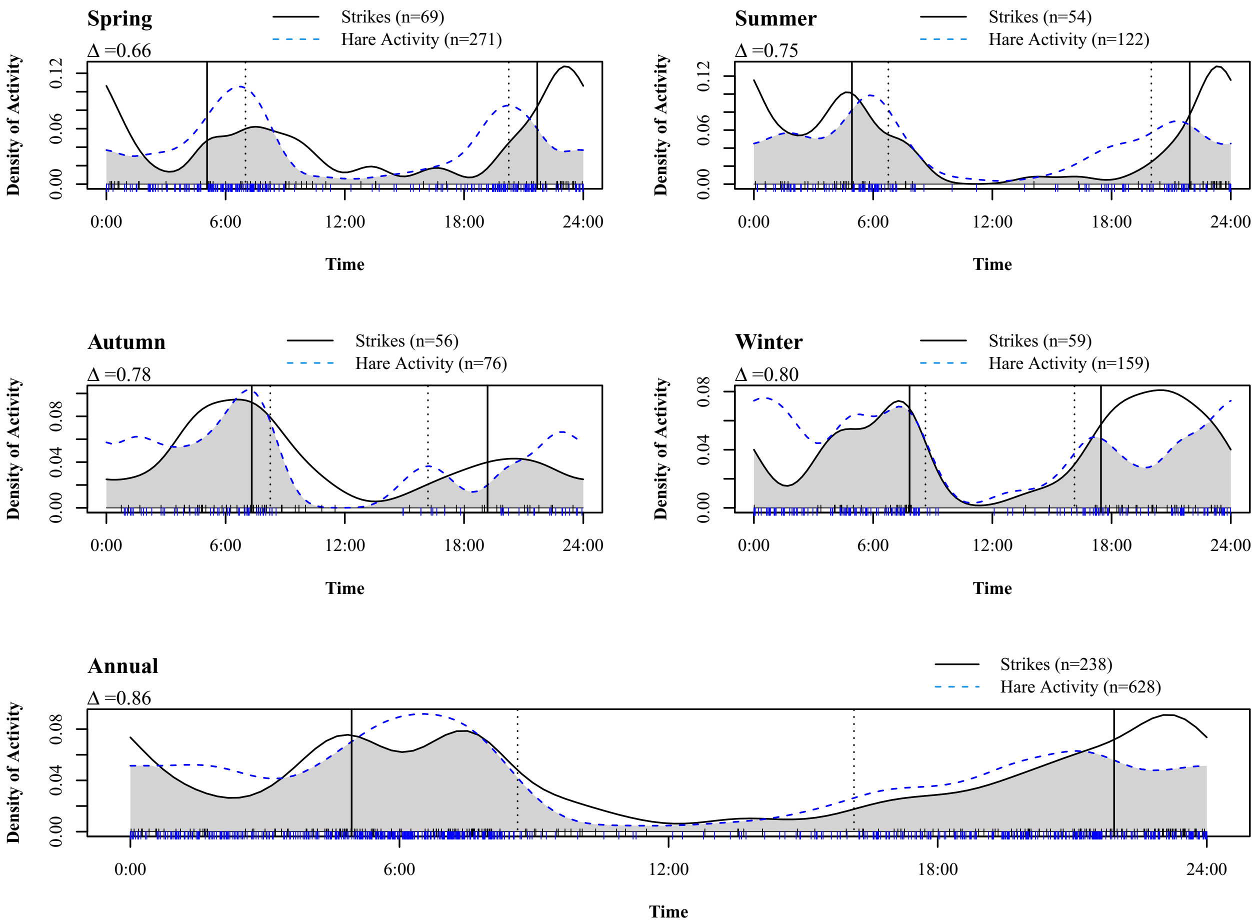

Figure 3. Overlap estimates of hare activity and hare strikes at Dublin Airport. Shaded grey areas indicate times when activity overlapped. Dotted and solid black lines indicate sunrise/sunset times on the shortest day and longest day of the sample period respectively. Events are indicated along the x-axis for hares (blue) and strikes (black).

we have demonstrated that hare activity at Dublin changes according to sunrise and sunset times and on a seasonal basis. Consequently, airfield managers need to operate a suite of mitigation measures that are flexible in their response to changing animal activity patterns.

Despite several road ecology studies demonstrating that increased volumes of road traffic are associated with increased roadkill rates (*e.g.* Haigh, 2012), strikes occurred at Dublin when aircraft movement numbers were relatively low, indicating that hare activity is a better indicator of strike risk than the volume of aircraft movements. This has important considerations should aircraft activity patterns be altered and suggests that strike risk may remain high at specific times of the day (periods of high hare activity) even during periods when aircraft activity patterns are altered (*e.g.* such as during the Covid-19 pandemic and economic crashes (Franke & John, 2011)). This furthermore demonstrates the importance of maintaining high-quality strike data on a local and national scale (*e.g.* FAA, 2021).

With the onset of the Covid-19 pandemic, national lockdowns were implemented in Ireland at the end of March 2020 with aircraft movement numbers being severely impacted during the remainder of the year. As with road-traffic data on collisions with mammals (*e.g.* Łopucki et al., 2021), this reduction in air traffic coincided with a reduction in the number of hare strikes recorded at Dublin Airport. An average of 77% of recorded hare strikes at Dublin Airport occurred during April–December from 2012–2019. However, only 38% of strike events were recorded during this time frame in 2020. Although there was a small decrease (~8%) estimated in the size of the population once surveys resumed (June 2020–July 2021) from pre-lockdown data (*SB, unpublished data*), this is unlikely to explain the reduction in strike numbers. Despite this, annual strike rates (per

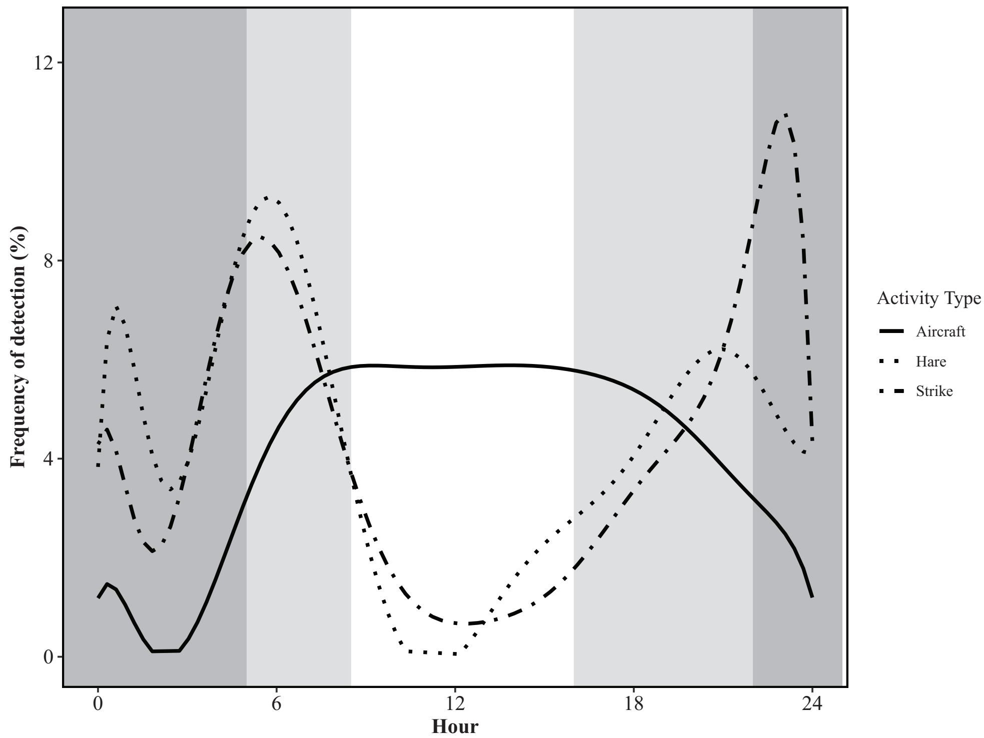

Figure 4. Activity times for the Irish hare (circadian), aircraft movements and recorded strike events (2012–2021) between hares and aircraft at Dublin Airport, across the year. Hare and aircraft activity data were collected between 2019–2021. Light grey shaded areas demonstrate the range of sunrise and sunset times through the study period (*i.e*., 21st June *vs*. 21st December). Dark grey shaded areas demonstrate hours of darkness across the whole study.

10,000 aircraft movements) with the Irish hare did not decrease, notwithstanding a 65% reduction in aircraft movements for 2020 compared with 2019 (daa, *unpublished data*). Indeed, strikes increased from 0.54 strikes per 10,000 aircraft movements in 2019 (Ball, Butler, et al., 2021a), to 0.92 strikes per 10,000 aircraft movements in 2020, indicating that the number of aircraft movements are at least partially responsible for the number of strike events. However, strike rates in 2019 were unusually low, potentially attributed to population management practices in 2018 (1.89 strikes per 10,000 aircraft movements; Ball, Butler, et al., 2021a) and habitat disturbance in 2019 due to ongoing construction works for a new runway. These observed changes in strike rate at the airfield could potentially be attributed to the consequential changes in aircraft movement patterns, land use changes by the hares or potentially due to increased naivety of the population (Mumme et al., 2000; Schwartz et al., 2020). Despite the conservation status of the Irish hare, strike events are unlikely to have population level impacts (Ball, Butler, et al., 2021a). Dublin Airport was not the only airfield to report an increased strike rate with hares, with Italian airports reporting an 81% increase in hare strike rate during the 2020 lockdown periods (Montemaggiori, 2021).

Despite changes to air traffic volume at Dublin post the implementation of Covid-19 lockdown measures, the circadian activity of the hares at the airfield did not change between seasonal sampling periods (*i.e*., summer 2019 *vs*. summer 2020). While hare activity data for the spring prior to pandemic-related disruptions to aircraft traffic were not available, we do not believe that reduced aircraft movements impacted on hare activity at Dublin Airport. Circadian activity patterns for spring followed the same bimodal pattern as the summer sampling period and were consistent with previously published activities of the Irish hare (Caravaggi et al., 2018). While circadian activity of the hares was unchanged by the reduction of air traffic, camera traps documented a change in hare grouping behaviour at the airfield. Prior to the pandemic, more than one hare was recorded in a frame only 0.89% of the time and group size did not exceed two. Multiple hares were recorded 11% of the time during the same seasons in 2020, with up to four hares recorded within a single frame. Other mountain hare populations have been recorded to spend long periods of time under canopy cover to avoid predation (Rehnus, 2014). However, by design, Dublin Airport is devoid of diverse habitat which could offer shelter to wildlife. With reports of increased and altered bird and wildlife activity at airfields with reduced air traffic (Schrimpf et al., 2021), the forming of these groups could be a social response to perceived increase in predation pressure at the airfield, with reduced aircraft movements to deter predators. Alternatively, reduced aircraft movements and consequential reduced disturbance could have allowed for the formation of leisurely social groups.

Daily and seasonal activities are thought to be two behavioural factors influencing mammal strike incidents with aircraft (Schwarz et al., 2014). As mammal strike events are becoming an increasing concern to the airline industry, understanding these patterns could help to mitigate strike risk at airfields by allowing for the targeted implementation of strike mitigation measures. Such measures could include increased runway patrols (*e.g.* Crain et al., 2015), species-specific noise and light harassment (Biondi et al., 2011), or giving prior warning to pilots operating during periods of increased risk. While aircraft movement temporal activity and volume are likely to play a role in strike patterns, we found wildlife activity itself to be more closely associated with strike patterns, highlighting the importance of understanding the ecology and life histories of the fauna using the airfield environment. Hence, while we use data for the Irish hare, these methods would be suitable for a cohort of terrestrial mammals associated with airfields (*e.g.* canids, Crain et al., 2015; ungulates, Biondi et al., 2011), assuming that an adequate number of detections (~100; Lashley et al., 2018) are obtained. High-quality data are vital to aid wildlife strike prevention research on airfields and for other modes of transportation within the sector (Steiner et al., 2014). An added benefit of data collection through the use of camera traps is the ability to capture the activities of sympatric species using one piece of equipment which can help inform risk and management decisions regarding multiple species (Appendix 6).

Conclusion

Using predator–prey data analytical methods and relatively inexpensive remote sensing equipment, we determined the activity patterns of a mammal species inhabiting the airfield in a large, international airport and identified periods of increased risk. Strike events were more closely associated with hare activity at the airfield rather than aircraft activity. This demonstrates the importance of identifying and understanding the wildlife populations utilising the airfield environment. These data can be used to inform the development of suitable mitigation strategies focussed on the species of concern (as opposed to the near-impossible task of altering aircraft activity) and to identify periods of increased risk with other mammalian species at other airfields.

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Supporting Information

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

Appendix 1. Images demonstrating that camera traps were effective at capturing activity during hours of daylight (*top*) and darkness (*bottom*).

Appendix 2. Minimum Metadata Standards for camera trap deployment. This is in in Excel format attached separately.

Appendix 3. camera trap deployment log.

Appendix 4. Overlap estimates of hare and aircraft activity for sampling periods prior to the Covid-19 pandemic.

Appendix 5. Overlap estimates of aircraft activity and recorded hare strike events (2012–2021) temporal overlap.

Appendix 6. An example of how the methodology is applicable to other terrestrial mammal species.

