Human–Wildlife Interactions 16(3):442–459, Winter 2022 • digitalcommons.usu.edu/hwi

Impact of COVID-19 on aviation–wildlife strikes across Europe

Isabel C. Metz, Institute of Flight Guidance, German Aerospace Center (DLR), Lilienthalplatz 7, 38108 Braunschweig, Germany *isabel.metz@dlr.de*
Marta Giordano, French Civil Aviation Technical Center (STAC), 9 Av. du Dr Maurice Grynfogel – BP 53735 – 31037 Toulouse Cedex 1, France
Dionysios Ntampakis, Fraport Greece, 10 Germanikis Scholis, 15123 Maroussi, Attica, Greece
Marianna Moira, Fraport Greece, 10 Germanikis Scholis, 15123 Maroussi, Attica, Greece
Anneke Hamann, Institute of Flight Guidance, German Aerospace Center (DLR), Lilienthalplatz 7, 38108 Braunschweig, Germany
Rosanne Blijleven, Amsterdam Airport Schiphol, Evert van der Beekstraat 202, 1118 CP Schiphol, The Netherlands
Jurgen J. Ebert, Fraport AG, Frankfurt Airport, 60547 Frankfurt/Main, Germany
Alessandro Montemaggiori, Bird Strike Committee Italy, c/o Ente Nazionale Aviazione Civile (ENAC), Viale Castro Pretorio 118, 00185 Roma, Italy

Abstract: Collisions between aircraft and wildlife (i.e., wildlife strikes) pose a serious threat toward the safety of aircraft, its crew, and passengers. The effects of COVID-19 related travel restrictions on wildlife strikes are unknown. With this study, we aim to address this information gap by assessing the changes of wildlife hazard management performance across European airports during the lockdown period (e.g., period of reduced operations and borders closure in spring 2020). We also sought to raise awareness of the importance of wildlife strike prevention in times of reduced operations. The objective of our study was to compare wildlife strike data before and during the lockdown based on the following criteria: (1) the number of wildlife strikes per 10,000 flights, (2) the groups of wildlife species involved, and (3) the lighting conditions. To conduct our research, we analyzed a dataset of 12,528 wildlife strikes, gathered from 157 civil airports across Europe for the period from March 2017 to February 2021. Our analysis revealed a wide variation in the wildlife strike rates during the lockdown (period of time from March 1, 2020 to February 28, 2021). Our study uncovered an increasing trend of the relative strike rates for almost all wildlife species categories and a slight trend toward more strikes occurring during daytime compared to nighttime. Our findings highlighted the need for continuous wildlife hazard management despite fluctuation in flights and provide potential for airports, airline operators, and other aviation stakeholders to reduce wildlife strike risk.

***Key words*:** airport, aviation, bird strike, COVID-19, Europe, flight safety, hazard mitigation, lockdown, pandemic, wildlife strike

The impact of the COVID-19 pandemic on the aviation industry was unprecedented (Rahman et al. 2020, Suau-Sanchez et al. 2020). The aviation sector continues to recover from the economic and organizational impacts. Concerns over costs have resulted in the reduction of operating expenses and capital expenditures postponement (Parveen 2020, Malka 2021). Airlines experienced a reduction of about 70% in the number of passengers during 2020, according to the International Civil Aviation Organization (ICAO; ICAO 2021). The decline of global air traffic due to the COVID-19 pandemic restrictions peaked at 90% in March and April 2020 (ICAO 2021). In contrast to the reduction in passenger traffic, cargo traffic increased since passenger aircraft were used for cargo only operations (ICAO 2021). The COVID-19 pandemic has also impacted wildlife hazard management activities on airports, with reduced employment costs, altered maintenance, and habitat management services as well as reduced monitoring of wildlife activity in the vicinity of the airports (Malka 2021).

Concomitantly, reduced human mobility due to COVID-19 related restrictions led to a documented increase of wildlife presence in many urban areas (Manenti et al. 2020, Rutz et al. 2020, Zellmer et al. 2020). Similarly, reduced flights and airport personnel activity as well as the availability of new shelters and reproductive sites (i.e., parked aircraft) may have favored the presence of wildlife on airports during the period of reduced operations from March 1, 2020 to February 28, 2021 (hereafter termed the "lockdown period"). The increased wildlife activity on and around airports has been identified by the European Union (EU) Aviation Safety Agency (EASA) as a major flight safety hazard during the air traffic restart phase (EASA 2020*a, b*; Mountain and Giordano 2020).

Airports can be attractive areas for wildlife since they provide suitable habitats for feeding, roosting, and breeding (Barras and Seamans 2002, Gleizer et al. 2005). Most impacts occur up to 914 m (3,000 feet), and as such within or close to the airport boundaries, during the take-off and landing phases (ICAO 1989, Dolbeer 2006, McKee et al. 2016). Modifications of the environment and repelling techniques are commonly used to limit the attractiveness of an airport to wildlife and mitigate the wildlife strike risk (Washburn et al. 2007, Blackwell et al. 2009). Around 4,000 wildlife strikes per year are reported to the ICAO Bird Strike Information System by the National Aviation Authorities of Europe and the North Atlantic Region. Over 60% of these strikes occur during the day, and 7% at dawn or dusk (ICAO 2017).

Although wildlife strikes occur throughout the year, the highest number of wildlife strikes takes place during the spring-summer months (ICAO 2017). Bird species are the most involved in strikes, causing >90% of reported collisions (ICAO 2017, Australian Transport Safety Bureau 2019, Dolbeer et al. 2021, Samson and Giordano 2021). The severity of a strike strongly depends on mass and social behavior of the involved wildlife (Dolbeer et al. 2000, DeVault et al. 2011). In fact, the probability of engine damages increases proportionally with the mass of the bird struck (Hovey et al. 1991, Dolbeer 2008). In western and south-central Europe, wildlife strikes are mainly caused by yellow-legged gulls (*Larus michaehellis*), black-headed gulls (*Chroicocephalus ridibundus*), Eurasian kestrels (*Falco tinnunculus*), common buzzards (*Buteo buteo*), rock pigeons (*Columba livia*), common wood-pigeons (*Columba palumbus*), barn swallows (*Hirundo rustica*), common swifts (*Apus apus)*, hooded crows (*Corvus cornix)*, and European starlings (*Sturnus vulgaris*; Kitowski 2011, Montemaggiori 2021*a*).

The number of wildlife strikes reported has increased over the last decade, in parallel with air traffic increase (Thorpe 2010, Dolbeer et al. 2014), engine technology evolutions (Kelly et al. 1999), and the introduction of mandatory reporting (Allan et al. 2016). By the provisions in European regulations, wildlife strikes are required to be reported at the national level by airports and airlines operators as well as by air traffic control services and maintenance staff (European Parliament and the Council 2014, 2015). Each EU member state shall establish an organization to manage the collection, the processing, the analysis, and the storage of wildlife strike data. Furthermore, strike occurrences shall be stored in the European Central Repository for occurrences (ECR-ECCAIRS).

The effects of reduced human vehicular mobility on terrestrial wildlife have been extensively investigated during the COVID-19 pandemic (Abraham and Mumma 2021, Bíl et al. 2021, Driessen 2021, Shilling et al. 2021). However, at the best of the authors' knowledge, only few studies analyzed the potential effects of reduced air traffic on wildlife–aircraft strikes (Parsons et al. 2022). A reduction of wildlife strikes has been observed in several European countries alongside the decline in air traffic (Giordano 2021, Montemaggiori 2021*b*, Ntampakis 2021) during the post-COVID-19 restart phase beginning in June 2020 (ICAO 2021). However, for some wildlife species, there was an increase in the number of strikes during the restart phase (Fraport Greece 2021, Giordano 2021, Montemaggiori 2021*b*).

The likelihood of wildlife strikes depends on various factors such as the abundance and behavior of different wildlife species, the frequency of flights, the season, and the time of the day (MacKinnon 2004, Metz et al. 2020). Restrictions on air traffic imposed by the COVID-19 pandemic reduced the frequency of ground and air operations on airports. The consequent softening of the wildlife management procedures and change of flights planning as well as a larger availability of shelters and nesting sites and a reduced disturbance due to the limited aircraft and ground vehicles activity led to an increased presence of birds on airports (Ebert 2021, Budd et al. 2022) and consequently to a higher wildlife hazard.

The objective of our study was to assess the effects of the reduction in air traffic due to the

Figure 1. Map showing in red the European countries (Denmark, France, Greece, Italy, The Netherlands, and Switzerland), which provided wildlife strike data from March 1, 2017 to February 28, 2021.

COVID-19 pandemic on wildlife strike occurrences on European airports. For this purpose, we compared the number and rate of wildlife strikes, the species involved, and the daily phase during which the collisions occurred between the COVID-19 period and a 3-year pre-COVID-19 control period.

We hypothesized that the smaller number of flights and reduced wildlife management programs during the pandemic (EASA 2020*a*, *b*) resulted in an increase in wildlife strike rates (number of strikes per 10,000 flights) compared to before the pandemic.

Further, we expected changes in the species-specific strike rates during the pandemic as compared to before, due to behavioral modifications of wildlife in response to the suddenly quieter airport areas. Lastly, the national lockdowns and travel restrictions mostly affected passenger flights. In the course of the pandemic, a large number of those flights was cancelled throughout Europe (EUROCONTROL 2022). The number of cargo flights remained similar or even increased (ICAO 2021). According to observations at different airports, these changes as well as reductions in opening hours led to shifts in operation times. Flights that previously took place during night were rescheduled to daytime. We hypothesized that this shift would influence the daytime distribution of wildlife strikes.

Study area

We analyzed the wildlife strike data of 157 airports in 6 European countries: Denmark, France, Greece, Italy, The Netherlands, and Switzerland (Figure 1). Our analysis provides a multi-country evaluation of the effects of COVID-19 related constrains on wildlife hazard on airports.

Methods

We analyzed the wildlife strike reports of 157 European airports from March 1, 2017 to February 28, 2021 to determine the consequences of COVID-19 lockdown on wildlife strikes at these airports. We chose this period based on data availability and to compare full 12-month periods. Air traffic restrictions ("lockdown") due to the COVID-19 pandemic started in March 2020 and were still in place across Europe in February 2021 (EUROCONTROL 2022). In accordance, we chose 3 12-month periods prior to the pandemic ("pre-lockdown") for comparison, from March 1, 2017 to February 29, 2020. The precise dates and terminology used throughout the paper can be found in Table 1.

Data source

Following a call for data to assess the impact of the COVID-19 pandemic on wildlife strikes on a European level, airport operators and national civil aviation authorities of the 6 countries Denmark, France, Greece, Italy, The Netherlands, and Switzerland provided their wildlife strike numbers for 160 airports for the period considered. From this dataset, 157 airports reported strikes for at least 1 of the years considered. Airport ICAO codes were available for 50 airports, while the identity of 107 airports was anonymized to accommodate data privacy requirements.

In this study, we only considered confirmed strikes (e.g., any reported collision between a bird or other wildlife and an aircraft) as they were defined by the individual airports to ensure consistency with the data provider.

To verify similar reporting quality between the 2 periods of interest, we compared the ratios of damaging to non-damaging strikes. As suggested by the literature (United Kingdom Civil Aviation Authority 2006, Dolbeer 2015, Allan et al. 2016), damaging strikes can be considered to always be reported while non-damaging strikes might not. Hence, a change in that ratio may in-

Table 1. Overview of the periods considered in this paper, with precise terminology and timespans. "Year" corresponds to the terminology used in the paper to refer to each timespan.

Period	Dates	Year
Pre-lockdown	Mar 1, 2017 to Feb 28, 2018	2018
	Mar 1, 2018 to Feb 28, 2019	2019
	Mar 1, 2019 to Feb 29, 2020	2020
Lockdown	Mar 1, 2020 to Feb 28, 2021	2021

dicate different reporting quality. With an offset of 6% between the pre-lockdown (difference in ratio: 0.103, n = 10,580 strikes) and the lockdown period (difference in ratio: 0.096, n = 1,794), the reporting quality was judged to be similar and therefore the data to be comparable.

Flight numbers, which were required to calculate wildlife strike rates, were obtained from EUROCONTROL (2021) and the Italian Civil Aviation Authority Ente Nazionale per l'Aviazione Civile (2021). For the analysis of lighting conditions, numbers of flights per hour were obtained from EUROCONTROL (S. Méson-Mancha and T. de Lange, personal communication).

Data analysis

We analyzed the wildlife strike data from 3 specific aspects: (1) flights, (2) groups of species, and (3) lighting conditions. For each aspect, the data considered and analysis strategy are detailed in the subsections below. Note that the data used in this study showed strong deviations from a normal distribution. Therefore, mainly non-parametric tests were carried out and descriptive data are provided where necessary. Data processing and analyses were carried out using Python 2.7 including the packages Ephem, Numpy and Pandas, SPSS 26 (IBM Corp. 2020), and JASP 0.16.2 (JASP Team 2022).

Flights and wildlife strikes

To evaluate potential effects of COVID-19 on wildlife strike occurrences with respect to flights, we calculated wildlife strike rates, expressed in number of strikes per 10,000 flights. To reveal significant changes in wildlife strikes over time, we computed the annual strike rates for each of the 4 years of interest, 2018 to 2021. As the most frequently used statistical tests rely on the assumption of normally distributed data, we performed an initial Kolmogorov-Smirnov test for normality. This analysis revealed a violation of the normality assumption, all P-values <0.001. Thus, we carried out a nonparametric Friedman test with Bonferroni-Holm corrected post-hoc Conover tests to identify changes over time. In case of a significant test result that would indicate a substantial difference between the observed years, the post-hoc Conover tests were added to investigate which of the 4 years differed significantly. To account for multiple testing, we report and interpret Bonferroni-Holm adjusted P-values.

For further analysis, we applied monthly averages of wildlife strike rates and made comparisons between the pre-lockdown and the lockdown period. By merging the data of the pre-lockdown years, a sufficient sample size per month and group of species was ensured. The monthly aggregation enabled the detailed analysis of effects both of the changes in flights and of the wildlife behavior due to seasonality.

Groups of species and wildlife strikes

To obtain insight into potential effects of the COVID-19 pandemic on wildlife strike occurrences, we separated the recorded wildlife strikes into 13 groups of species: (1) mammals (including bats), (2) reptiles, (3) crows, (4) gulls (including terns), (5) birds of prey (diurnal), (6) owls, (7) pigeons, (8) passerines (excluding crows, martins, and swallows), (9) swifts and swallows (including martins), (10) unknown, (11) shorebirds (excluding gulls and terns), (12) waterfowl (including cormorants, herons, flamingos, and storks), (13) other birds (<55 bird strikes/group; coracids: 52, pheasants: 51, bustards: 24, nightjars: 5, parrots: 1, rails: 1, woodpeckers: 1).

For these 13 groups of species, we compared the total wildlife strike rate of the 3 years before lockdown and during it. Reptiles were excluded because only 15 strikes were recorded during the entire study period.

We compared the monthly number of strikes of each of the 13 groups of species before and during the lockdown for all airports. To obtain the pre-lockdown strike rate, the average of the sums of flights and strikes per group from 2018 to 2020 was taken. Since monthly strike values were normally distributed in the pre-lockdown period, we used averages instead of medians. For the lockdown year, we directly used the sums of flights and groups of species.

Table 2. Descriptive statistics of the annual wildlife strike rates (strikes/10,000 flights; pct = percentile). Strikes with 182 wildlife taxa at 157 European airports from March 1, 2017 to February 28, 2021 (N = 157).

Year	Minimum	Maximum	25th pct	50th pct (median)	75th pct	Skew	Kurtosis
2018	0.00	1,666.67	0.00	6.19	14.43	7.43	59.87
2019	0.00	5,000.00	0.27	6.75	18.84	11.06	130.37
2020	0.00	1,666.67	0.50	8.64	18.37	6.72	48.96
2021	0.00	6,666.67	0.45	11.42	21.32	11.67	141.69

Table 3. Results of the post-hoc Conover tests for the comparison of wildlife strike rates (strikes/10,000 flights) between years. Strikes with 182 wildlife taxa at 157 European airports from March 1, 2017 to February 28, 2021.

Comparison[a]	t	P_{corr}
2018 vs. 2019	0.325	0.834
2018 vs. 2020	0.812	0.834
2018 vs. 2021	2.390	0.086
2019 vs. 2020	1.137	0.769
2019 vs. 2021	2.714	0.041*
2020 vs. 2021	1.578	0.461

[a]N = 157, df = 468, P_{corr} = Bonferroni-Holm corrected P-values for multiple comparisons. Significance threshold marked $P < 0.05$*.

Lighting conditions and wildlife strikes

The number of flights dropped strongly during the lockdown at airports worldwide (ICAO 2021). In addition, some airports reduced their opening hours. Reports from different airports indicated that this led to a shift from flights that previously took place during nighttime to daytime. In this part of the analysis, we evaluated whether there were also timely shifts in wildlife strike occurrences. For this purpose, we considered all reports containing information in the field "lighting conditions." Strikes classified as "day" or "night" were directly transferred. Strikes classified as "dawn" or "dusk" were grouped into a single category ("twilight") to obtain a representative sample size for the analysis.

To assign flights to lighting conditions, we applied the following definition: daytime is the time between the end of nautical twilight in the morning and onset of nautical twilight in the evening. The time between civil and nautical twilight in the morning, respective nautical and civil twilight in the evening, is ascribed as twilight. Between civil twilight in the evening and the morning, nighttime takes place (EASA 2022). We calculated the civil and nautical twilight times for all airports and all days of the 4 years with the Python package Ephem (Anaconda 2022). We applied a uniform distribution to the number of flights per hour and sorted them into the lighting condition categories based on their time and date of occurrence. Eventually, we descriptively compared the changes of number of flights per category between the pre-lockdown and lockdown period.

We performed the analysis of 156 airports because the reports of 1 of the considered airports did not contain information about lighting conditions.

We conducted chi-square tests to investigate significant differences between the numbers of observed wildlife strikes per lighting condition and year, and the expected numbers. Because a single chi-square test only shows if there is a significant difference, but not which factors are responsible for it, we used a 3-level approach. On level 1, a 3 (lighting condition) x 4 (year) analysis was conducted to evaluate if there was an overall effect. In case the test revealed a significant result, separate chi-square tests were conducted on level 2 to investigate which years differed. Therefore, pairs of years were compared (i.e., 3 [lighting condition] x 2 [year]), resulting in 6 pair comparisons. To prevent alpha error inflation, we applied a Bonferroni correction. Finally, on level 3, the lighting conditions were compared for each pair of years with a significant level 2 result (i.e., 3 [lighting condition] x 2 [year]) analyses per pair of years, with the lighting condition pairs "night vs. twilight," "night vs. day," and "twilight vs. day." Again, we applied a Bonferroni correction.

Results

Flights and wildlife strikes

Across all airports, the median annual wildlife strike rates were <12 (Table 2), but high outliers led to strongly skewed distributions. These outliers are caused by airports with very few movements, where due to the definition of the strike rate itself, already 1 single strike could cause a very high strike rate. We decided against excluding such outliers to not bias the dataset by systematically removing small airports. There were changes in wildlife strike rates across time, χ^2 (3) = 8.82, P = 0.032. Post-hoc tests revealed an increase between the pre-lockdown year 2019 and the lockdown year 2021, P = 0.041 (Table 3). The median of wildlife strike rates increased over all observed years (Table 2).

Monthly strike rates differed between the analyzed periods (Figure 2). During the lockdown year, strike rate increased from May to July, when it reached the maximum value before decreasing again from August to November. In the pre-lockdown period, strike rates ranged between 5 and 12, with a slight increase from March to July and an equivalently slight decrease from August to February.

The wildlife strike rate is a function of number of flights and number of strikes. Hence, the above described changes in strike rate can be caused by changes in 1 or both parameters. To investigate the respective influence, numbers of flights and numbers of strikes were analyzed individually (Figure 3).

Flight numbers were approximately 3 times lower in March 2020 than in the pre-lockdown years. In June, we observed a strong drop, which was followed by a recovery peaking in October before numbers decreased again. In the pre-lockdown period, on the contrary, the flight numbers constantly rose in March with a slight gradient to July before slowly decreasing again until they reached a relatively constant level from November to February (Figure 3).

The absolute number of wildlife strikes of the lockdown period always remained lower than the one in the pre-lockdown period during all months. However, in March and from July to January, the values almost reached identical levels (Figure 3).

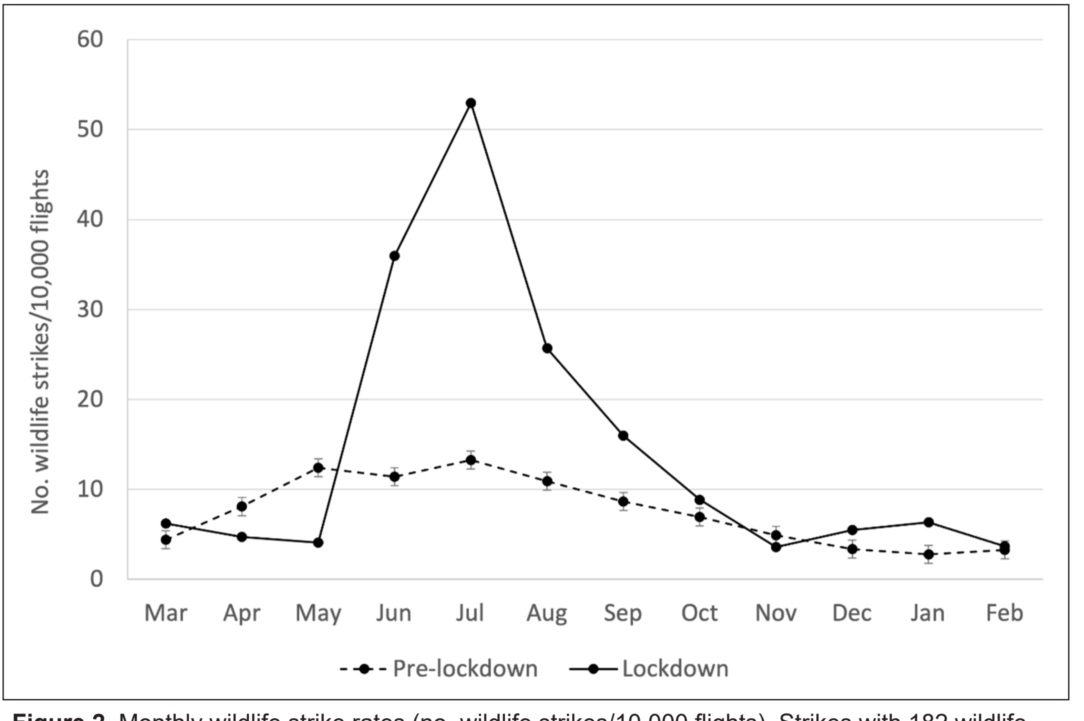

Figure 2. Monthly wildlife strike rates (no. wildlife strikes/10,000 flights). Strikes with 182 wildlife taxa at 157 European airports, from March 1, 2017 to February 28, 2021. “Pre-lockdown” shows the averages of the years 2018 to 2020. Error bars represent 2x standard deviation. “Lockdown” shows the data of year 2021.

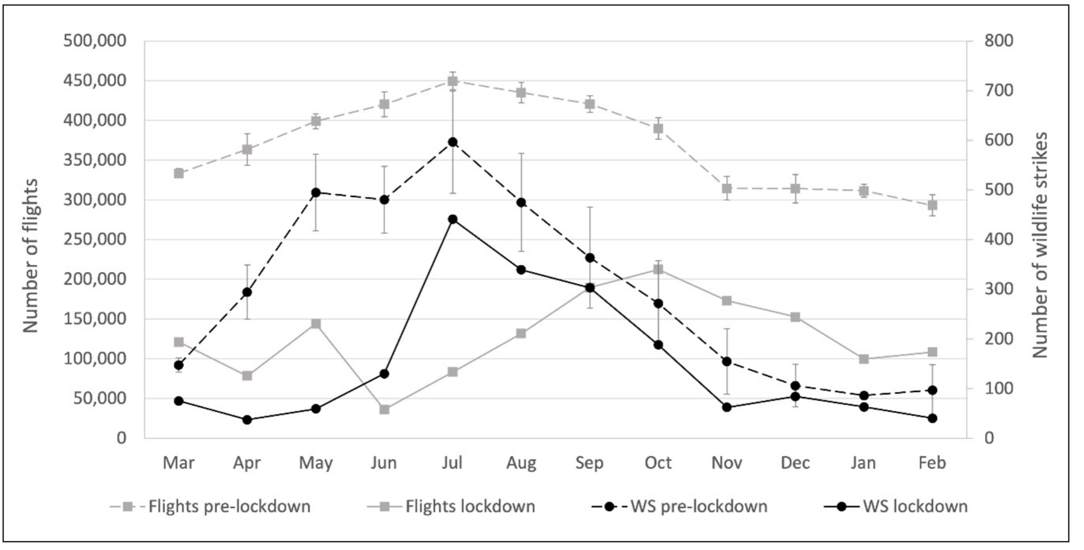

Figure 3. Monthly flights and wildlife strikes (WS) with 182 wildlife taxa at 157 European airports from March 1, 2017 to February 28, 2021. "Pre-lockdown" shows the averages of the years 2018 to 2020. Error bars represent 2x standard deviation. "Lockdown" shows the data of year 2021.

In the lockdown period, about 80 strikes per month were reported in March and April. The number slowly increased from May to June with a substantial increase in July. From July to November, the number of strikes continuously decreased to a constant level of about 50 strikes per month between November and February. In the pre-lockdown period, numbers steeply increased from March to July, when the maximal number of strikes was noted. From July onward, the number of strikes continuously decreased until December, leveling off at about 100 strikes per month until February (Figure 3).

Groups of species and wildlife strikes

One hundred and eighty-two different taxa were involved in 12,528 wildlife strikes for our study period, including "unknown" taxon (Table 4). Of the 8,097 strikes recorded with identified taxa, only 0.2% involved reptiles, 93% of which were tortoises. Mammal strikes accounted for 6.1% of the strikes with identified taxa and they mainly involved European hares. Bird strikes represented 93.7% of the occurrences where the taxon was identified: 27.0% were with diurnal raptors (mainly European kestrels), 21.5% were with swifts or swallows (mainly barn swallows and common swifts), and 17.0% were with gulls (mostly yellow-legged gulls).

The overall distribution of wildlife strike rates per group of species before and during lockdown revealed clear differences for almost all groups of species between the 2 periods. There were 3 groups of species that showed an increase of >100% during lockdown (birds of prey: 150%, waders: 153%, and other birds: 102%), while swifts and swallows were the only group of species showing a decline (–17%).

The monthly distribution of wildlife strike rates before and during the lockdown highlighted a trend common to almost all groups of species (Figure 4). A substantial increase in wildlife strike rates during the initial summer months of lockdown (June to July) compared to the pre-lockdown period was observed. Similarly, starting in September, the strike rates decreased, returning to the values recorded during the pre-lockdown period for all groups of species except for mammals, which exhibited higher strike rates during the lockdown, from April to October. A second peak during the lockdown, in the month of January, was present for gulls, pigeons, owls, and waders (Figure 4).

Lighting conditions and wildlife strikes

The level 1 chi-square test revealed difference between observed and expected wildlife strike frequencies (χ^2 [6] = 29.99, P < 0.001; Table 5). Therefore, level 2 analyses were carried out for each pair of years. Differences were found for the comparison between each pre-lockdown year (2018, 2019, 2020) and the lockdown year

Table 4. Taxa involved in 12,528 wildlife strikes at 157 European airports from March 1, 2017 to February 28, 2021 and number of strikes. Taxonomy and nomenclature according to Wilson and Reeder (2005), Clements et al. (2021), and Rhodin et al. (2021).

Taxon	No. strikes
Reptiles	
Reptiles (Reptilia unknown)	1
Spur-thighed tortoise (*Testudo graeca*)	2
Hermann's tortoise (*Testudo hermanni*)	1
Marginated tortoise (*Testudo marginata*)	11
Mammals	
Crested porcupine (*Hystrix cristata*)	1
Mouse (*Mus* or *Apodemus* sp.)	2
Coypu (*Myocastor coypus*)	1
Bats (Chiroptera unknown)	27
European mole (*Talpa europea*)	1
European hedgehog (*Erinaceus europaeus*)	56
Roe deer (*Capreolus capreolus*)	2
Domestic dog (*Canis lupus familiaris*)	4
Red fox (*Vulpes vulpes*)	77
Domestic cat (*Felis catus*)	2
Least weasel (*Mustela nivalis*)	1
European badger (*Meles meles*)	4
European hare (*Lepus europaeus*)	267
European rabbit (*Oryctolagus cuniculus*)	51
Birds	
Ducks, geese, waterfowl (Anatidae unknown)	19
Graylag goose (*Anser anser*)	4
Barnacle goose (*Branta leucopsis*)	4
Canada goose (*Branta canadensis*)	1
Egyptian goose (*Alopochen aegyptiaca*)	4
Common shelduck (*Tadorna tadorna*)	1
Northern shoveler (*Spatula clypeata*)	1
Gadwall (*Mareca strepera*)	4
Eurasian wigeon (*Mareca penelope*)	1
Mallard (*Anas platyrhynchos*)	66
Green-winged teal (*Anas crecca*)	3
Tufted duck (*Aythya fuligula*)	3
Gray partridge (*Perdix perdix*)	17
Ring-necked pheasant (*Phasianus colchicus*)	26
Common quail (*Coturnix coturnix*)	2
Red-legged partridge (*Alectoris rufa*)	5
Domestic turkey (*Meleagri gallopavo*)	1
Greater flamingo (*Phoenicopterus roseus*)	2
Pigeons and doves (Columbidae unknown)	6
Rock pigeon (*Columba livia domestica*)	449
Stock dove (*Columba oenas*)	4
Common wood-pigeon (*Columba palumbus*)	281
European turtle-dove (*Streptopelia turtur*)	4
Eurasian collared-dove (*Streptopelia decaocto*)	16
Little bustard (*Tetrax tetrax*)	24
Eurasian nightjar (*Caprimulgus europaeus*)	5
Swifts (Apodidae unknown)	2
Alpine swift (*Apus melba*)	5
Common swift (*Apus apus*)	700
Pallid swift (*Apus pallidus*)	3
Spotted crake (*Porzana porzana*)	1
Eurasian moorhen (*Gallinula chloropus*)	2
Eurasian coot (*Fulica atra*)	1
Eurasian thick-knee (*Burhinus oedicnemus*)	64
Black-winged stilt (*Himantopus himantopus*)	2
Pied avocet (*Recurvirostra avosetta*)	1
Eurasian oystercatcher (*Haematopus ostralegus*)	4
Waders (Charadridae unknown)	6
European golden-plover (*Pluvialis apricaria*)	16
Northern lapwing (*Vanellus vanellus*)	138
Common ringed plover (*Charadrius hiaticula*)	8
Little ringed plover (*Charadrius dubius*)	5
Eurasian dotterel (*Charadrius morinellus*)	2
Sandpipers and allies (Scolopacidae unknown)	1

Table continued on next page...

Table continued from previous page...

Whimbrel (*Numenius phaeopus*)	1
Eurasian curlew (*Numenius arquata*)	4
Red knot (*Calidris canutus*)	1
Ruff (*Calidris pugnax*)	3
Dunlin (*Calidris alpina*)	1
Eurasian woodcock (*Scolopax rusticola*)	6
Common snipe (*Gallinago gallinago*)	2
Collared pratincole (*Glareola pratincola*)	15
Gulls, terns, and skimmers (Laridae unknown)	41
Black-headed gull (*Chroicocephalus ridibundus*)	337
Little gull (*Hydrocoloeus minutus*)	1
Mediterranean gull (*Ichthyaetus melanocephalus*)	14
Common gull (*Larus canus*)	54
Herring gull (*Larus argentatus*)	73
Yellow-legged gull (*Larus michahellis*)	718
Lesser black-backed gull (*Larus fuscus*)	34
Great black-backed gull (*Larus marinus*)	10
Little tern (*Sternula albifrons*)	1
Gull-billed tern (*Gelochelidon nilotica*)	3
Common tern (*Sterna hirundo*)	1
Great crested tern (*Thalasseus bergii*)	1
Sandwich tern (*Thalasseus sandvicensis*)	1
White stork (*Ciconia ciconia*)	4
Great cormorant (*Phalacrocorax carbo*)	3
Herons, egrets, and bitterns (Ardeidae unknown)	4
Gray heron (*Ardea cinerea*)	55
Great egret (*Ardea alba*)	2
Little egret (*Egretta garzetta*)	14
Cattle egret (*Bubulcus ibis*)	15
Diurnal raptors (Accipitriformes unknown)	24
Osprey (*Pandion haliaetus*)	2
Black-winged kite (*Elanus caeruleus*)	10
European honey-buzzard (*Pernis apivorus*)	2
Eurasian marsh-harrier (*Circus aeruginosus*)	18
Hen harrier (*Circus cyaneus*)	3
Pallid harrier (*Circus macrourus*)	1
Montagu's harrier (*Circus pygargus*)	7
Eurasian sparrowhawk (*Accipiter nisus*)	6
Red kite (*Milvus milvus*)	22
Black kite (*Milvus migrans*)	30
Rough-legged hawk (*Buteo lagopus*)	5
Common buzzard (*Buteo buteo*)	325
Owls (Strigiformes unknown)	19
Barn owl (*Tyto alba*)	96
Eurasian scops-owl (*Otus scops*)	1
Eurasian eagle-owl (*Bubo bubo*)	3
Little owl (*Athene noctua*)	54
Tawny owl (*Strix aluco*)	5
Long-eared owl (*Asio otus*)	31
Short-eared owl (*Asio flammeus*)	57
Eurasian hoopoe (*Upupa epops*)	5
European bee-eater (*Merops apiaster*)	43
European roller (*Coracias garrulus*)	4
Eurasian green woodpecker (*Picus viridis*)	1
Falcons (Falconidae unknown)	7
Lesser kestrel (*Falco naumanni*)	7
Eurasian kestrel (*Falco tinnunculus*)	1,531
Red-footed falcon (*Falco vespertinus*)	19
Merlin (*Falco columbarius*)	4
Eurasian hobby (*Falco subbuteo*)	12
Peregrine falcon (*Falco peregrinus*)	14
Monk parakeet (*Myiopsitta monachus*)	1
Small passerines (Passeriformes unknown)	12
Red-backed shrike (*Lanius collurio*)	1
Woodchat shrike (*Lanius senator*)	1
Crows, jays, and magpies (Corvidae unknown)	7
Eurasian jay (*Garrulus glandarius*)	2
Eurasian magpie (*Pica pica*)	33
Eurasian jackdaw (*Corvus monedula*)	10
Rook (*Corvus frugilegus*)	14
Carrion crow (*Corvus corone*)	49
Hooded crow (*Corvus cornix*)	147
Great tit (*Parus major*)	2

Table continued on next page...

Table continued from previous page...

Larks (Alaudidae unknown)	3
Greater short-toed lark (*Calandrella brachydactyla*)	3
Eurasian skylark (*Alauda arvensis*)	172
Crested lark (*Galerida cristata*)	15
Swallows (Hirundinidae unknown)	77
Bank swallow (*Riparia riparia*)	37
Barn swallow (*Hirundo rustica*)	737
Red-rumped swallow (*Cecropis daurica*)	6
Common house-martin (*Delichon urbicum*)	64
Wood warbler (*Phylloscopus sibilatrix*)	1
Sylviid warblers (Sylviidae unknown)	1
Lesser whitethroat (*Curruca curruca*)	1
Greater whitethroat (*Curruca communis*)	1
Goldcrest (*Regulus regulus*)	1
Eurasian wren (*Troglodytes troglodytes*)	1
European starling (*Sturnus vulgaris*)	158
Spotless starling (*Sturnus unicolor*)	1
Thrushes and allies (Turdidae unknown)	10
Mistle thrush (*Turdus viscivorus*)	3
Song thrush (*Turdus philomelos*)	7
Eurasian blackbird (*Turdus merula*)	11
Fieldfare (*Turdus pilaris*)	1
Spotted flycatcher (*Muscicapa striata*)	1
European robin (*Erithacus rubecula*)	8
Common redstart (*Phoenicurus phoenicurus*)	1
Black redstart (*Phoenicurus ochruros*)	1
Blue rock-thrush (*Monticola solitarius*)	2
Whinchat (*Saxicola rubetra*)	2
Northern wheatear (*Oenanthe oenanthe*)	8
House sparrow (*Passer domesticus*)	184
Western yellow wagtail (*Motacilla flava*)	7
Citrine wagtail (*Motacilla citreola*)	1
White wagtail (*Motacilla alba*)	21
Tawny pipit (*Anthus campestris*)	1
Meadow pipit (*Anthus pratensis*)	16
Rock pipit (*Anthus petrosus*)	1
Finches and allies (Fringillidae unknown)	5
Common chaffinch (*Fringilla coelebs*)	6
Brambling (*Fringilla montifringilla*)	1
European greenfinch (*Chloris chloris*)	5
Eurasian linnet (*Linaria cannabina*)	2
Common redpoll (*Acanthis flammea*)	2
European goldfinch (*Carduelis carduelis*)	10
European serin (*Serinus serinus*)	6
Corn bunting (*Emberiza calandra*)	3
Cretzschmar's bunting (*Emberiza caesia*)	1
Unknown	4,431

(2021), all P-values ≤0.008 (Table 6). Further level 3 analyses to determine which lighting conditions produced the differences revealed shifts of wildlife strike frequencies between night and twilight for the comparison 2018 vs. 2021, $P < 0.001$, and between night and day for the comparison 2018 versus 2021, $P < 0.001$, and 2019 versus 2021, $P = 0.002$ (Table 7). No differences could be found between lighting conditions for the comparison 2020 versus 2021. The differences we found followed similar patterns. In 2021, as compared to the other years, fewer nightly wildlife strikes were observed than would have been expected, resulting in more strikes during twilight or day than expected (Table 7).

The distribution of flights per lighting conditions was almost identical for the 4 years (Table 8), with variances of <1% between the years. Comparing the pre-lockdown years to the lockdown year, we observed a very slight shift from twilight to nighttime and daytime flights.

Discussion

Wildlife strike rates at European airports did not decline during the COVID-19 lockdown period despite changes in flight frequency and ground operations. Our analysis to compare reporting quality by assessing the ratio between reported damaging and non-damaging wildlife strikes (United Kingdom Civil Aviation Author-

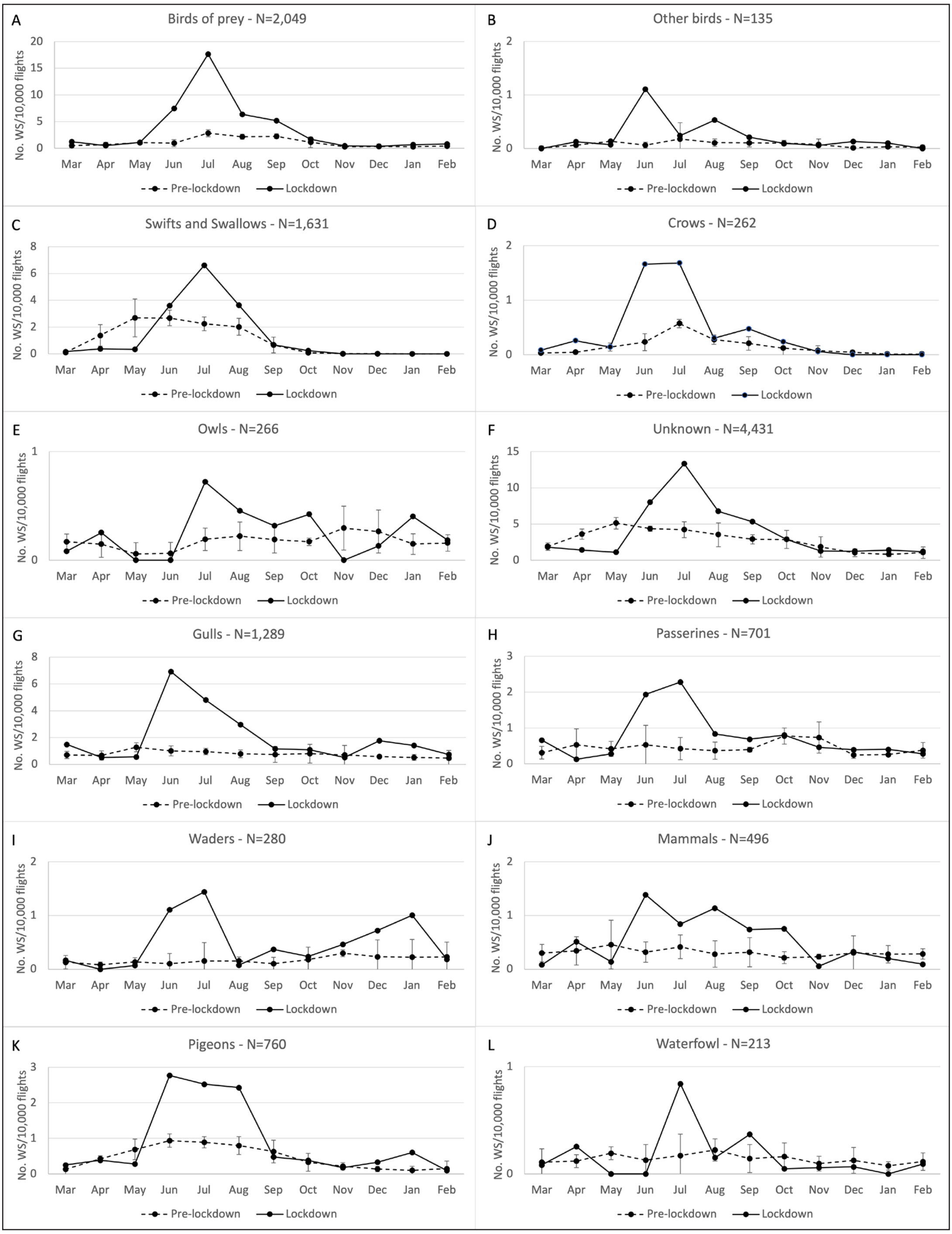

Figure 4. Monthly strike rates (no. wildlife strikes [WS]/10,000 flights) with 182 wildlife taxa at 157 European airports, per group of species from March 1, 2017 to February 28, 2021. "Pre-lockdown" shows the averages of the years 2018 to 2020. Error bars represent 2x standard deviation. "Lock-down" shows the data of year 2021.

Table 5. Observed frequencies of wildlife strikes per year with 182 wildlife taxa at 157 European airports from March 1, 2017 to February 28, 2021 per year and lighting conditions (data basis for the chi-square tests, percentages [%] of condition per year in parentheses).

	Frequency of wildlife strikes			
Year	Night	Twilight	Day	Total number
2018	575 (19.58)	108 (3.68)	2253 (76.74)	2936 (100)
2019	544 (17.17)	126 (3.98)	2498 (78.85)	3168 (100)
2020	629 (16.79)	149 (3.98)	2969 (79.24)	3747 (100)
2021	279 (13.89)	96 (4.78)	1634 (81.33)	2009 (100)

ity 2006, Dolbeer 2015, Allan et al. 2016) in the pre-lockdown and the lockdown period did not reveal any substantial change in reporting behavior. Therefore, the results are discussed based on the assumption of comparable reporting quality between the 2 periods of interest.

Flights and wildlife strikes

Overall, the annual wildlife strike rates displayed an increase in medians across the entire analyzed period between March 2017 and February 2021 with the highest median observed in the lockdown year. However, when comparing the pre-lockdown years to the lockdown year, the difference was only significant between 2019 and 2021 and not for the other years. Because our dataset included many small airports with few flights, these results have to be interpreted with caution. Wildlife strike rate is the commonly agreed measure in wildlife strike prevention studies, so we applied it here. However, our findings cast doubt on its suitability, especially for small airports where 1 wildlife strike per year is enough to highly increase the strike rate and bias overall results.

Comparing the monthly strike rates between the entire pre-lockdown and the lockdown period, the 3- to 4-fold surpassing of the values between June and August of the lockdown period stood out. Even though a peak in wildlife strike occurs worldwide during summer (ICAO 2017, Samson and Giordano 2021), our results suggest that during the lockdown the increase in reported strike rates was higher than usual because the strike rate during the pre-lockdown period can be considered as a reference value for the previous years.

When considering the monthly changes in flight and strike numbers, the high strike rate observed resulted from an over-proportional increase of strikes between June and July, once the flight numbers started recovering. A similar trend was observed in the United States when traffic numbers started to rise again in spring 2020 (Parsons et al. 2022). There is literature suggesting limited to no correlation between the number of wildlife strikes and number of flights at an airport (Soldatini et al. 2010, Dolbeer and Begier 2012) due to habituation of animals to noise levels. However, our findings indicate that a sudden and substantial increase of flights at a given airport may influence wildlife strike levels. Nonetheless, other factors such as the beginning of the fledging period, for example, may have contributed to the increase in wildlife strikes observed in July 2020.

Groups of species and wildlife strikes

We observed an increase in bird strike rates during the late spring and summer months during the lockdown period. We attribute this to a well-known phenomenon in the Northern hemisphere, namely the reproductive period of wildlife species during these months (ICAO 2017, Montemaggiori 2021*a*, Samson and Giordano 2021). Offspring, and thus less experienced animals, fall victim to aircraft strikes more easily (Kelly et al. 2001). As for mammals, the increase of the strike rates is observed from June to October, confirming what has already been found globally (Ball et al. 2021).

For most of the groups of species, during the lockdown the seasonal trend of wildlife strikes was comparable to the one recorded during the years before, but wildlife strike rates resulted to be much higher. We recorded a substantial increase of strike rate in the birds of prey group (e.g., Eurasian kestrels). A larger number of kestrels could have been attracted by the air-

Table 6. Results of the level 2 (pairwise comparisons of years) chi-square tests for wildlife strikes with 182 wildlife taxa at 157 European airports from March 1, 2017 to February 28, 2021 and lighting conditions.

Year[s]a	χ^2	*P*-value
2018 vs. 2019	6.07	0.048
2018 vs. 2020	8.85	0.012
2018 vs. 2021	29.12	<0.001*
2019 vs. 2020	0.18	0.913
2019 vs. 2021	11.13	0.004*
2020 vs. 2021	9.66	0.008*

Table 7. Results of the level 3 (pairwise comparisons of lighting conditions) chi-square tests for wildlife strikes with 182 wildlife taxa at 157 European airports from March 1, 2017 to February 28, 2021 and lighting conditions.

Years[a]	Lighting condition	χ^2	*P*-value
2018 vs. 2021	Night vs. twilight	14.90	<0.001*
	Night vs. day	25.53	<0.001*
	Twilight vs. day	2.00	0.157
2019 vs. 2021	Night vs. twilight	6.63	0.010
	Night vs. day	9.23	0.002*
	Twilight vs. day	1.20	0.273
2020 vs. 2021	Night vs. twilight	6.29	0.012
	Night vs. day	7.62	0.006
	Twilight vs. day	1.38	0.241

[a] df = 1. Bonferroni-corrected alpha level for 9 comparisons: $\alpha = 0.006$. Significant comparisons marked with an asterisk (*).

Table 8. Distribution of flights at 157 European airports from March 1, 2017 to February 28, 2021 during different lighting conditions.

	Distribution of flights (%)		
Year	Night	Twilight	Day
2018	25.47	4.16	70.37
2019	25.97	4.15	69.88
2020	25.98	4.13	69.89
2021	26.11	3.89	69.99

ports' less busy surfaces for hunting.

Similarly, strike rates involving gulls increased by 96% during the lockdown. Usually, gulls use the airside areas for roosting and may have taken advantage of less disturbance experienced during the lockdown. There is a first indication that quieter airports were more conducive to breeding during the lockdown period (Ebert 2021). This may have favored a greater production of offspring (Manenti et al. 2020) and possibly a greater number of strikes. Moreover, the lower number of flights during the lockdown may have had an influence on the behavior of animals, especially young ones, reducing their ability to learn about the danger of the aircraft themselves (Kelly et al. 2001). Having data on the age class of wildlife strike victims would be of great help in supporting this hypothesis. Finally, the fact that the increase of the strike rates of mammals lasted until October, during the lockdown, seems to support the above hypothesis, given that the reproductive period of these species is usually longer than the one of birds (Ball et al. 2021).

When we compared our data with the U.S. Federal Aviation Authority wildlife strike multiyear database (Dolbeer et al. 2021), we found similar patterns of strikes per group of species. In our dataset, the species was identified for 65% of strikes, while this is the case for 58% of strikes in the U.S. database. Of those, bird strikes made up 93.7% in our data and 96.2% in the U.S. data. A slightly higher share of strikes with terrestrial mammals was observed in our study (5.8% vs. 2.1%). This initial comparison indicates a similar reporting culture as well as a similar strike pattern in the Northern Hemisphere.

Lighting conditions and wildlife strikes

Our analysis of the number of strikes reported for individual lighting conditions showed a slight trend toward more strikes during daytime and twilight and fewer nighttime strikes during the lockdown period in comparison to the individual pre-lockdown years, with some of the comparisons revealing significant differences. In contrast, the distribution of flights per lighting conditions was almost identical for all years, with a slight shift of twilight to daytime and nighttime flights. Hence, we could not identify a direct connection between the changes in flight and wildlife strike patterns. In addition, the local observations of less flights during nighttime were not confirmed by the data.

Long-term data from the United States (Dolbeer et al. 2021) indicated that mammals cause more strikes during night while birds are involved in more strikes during daytime. Considering the changes in strike rates per groups of species identified in our study, the increase in strike rates with bird species was larger than the one with mammals. In addition, due to the much higher number of strikes involving birds than mammals, the total number of strikes was biased toward collisions with the former. These factors could explain the shifts in strikes per lighting conditions without a comparable shift in air traffic numbers. Reduced aeronautical activities might have altered the timing of wildlife activities as well, for example due to shorter opening hours and thus less artificial light on airports, which is known to attract birds and insects (Byrkjedal et al. 2012, Rebke et al. 2019).

Finally, other variables than the ones identified in our study, such as climate change (Dunn and Pape Møller 2019) and acute weather phenomena (Shamoun-Baranes et al. 2006), might be substantial parameters affecting wildlife strikes irrespective of the lockdown period. For example, in 2020 Germany and France experienced the second warmest February since the end of the nineteenth century (Deutscher Wetterdienst 2020, Lemoine and Pineaud 2020*a*). Moreover, from February to May 2020, the general situation over Europe was driven by a higher-than-normal pressure over the Azores and eastern Europe, resulting in warm, dry, and sunny weather (Lemoine and Pineaud 2020*a*, *b*).

Management implications

The lockdown due to the COVID-19 pandemic affected European air traffic and in turn also wildlife strikes. Our study showed changes in strike rates and in the distribution of strikes across the time of day during the COVID-19 pandemic. However, our analyses rely heavily on a sound and comparable reporting culture for wildlife strikes. Emphasis shall be placed by the National Aviation Authorities, airport operators, and airlines on a reporting culture with a commonly accepted definition of what a confirmed wildlife strike is, what is reported, in which form, and how performance is evaluated for each airport wildlife hazard management program. A well-built reporting culture necessitates correct identification of wildlife species involved in aircraft strikes, not only as taxonomic classification of group of species but at a species level, including age class when possible. In addition, a harmonization of taxonomy in the European Central Repository for occurrences (ECR-ECCAIRS) database will be most helpful for future studies. Intensive application of airport habitat management and wildlife control measures shall continue during seasons with low air traffic. An effective implementation of such a program should be based on integrated wildlife dispersal methods continuously and intensively applied at an airport, even in times with reduced flights. Modifications of wildlife behavior to changing traffic patterns shall be closely observed and wildlife hazard management programs and risk assessment by all aviation stakeholders adjusted correspondingly. Thereby, emphasis should be placed on times with increasing numbers of air traffic operations.

Acknowledgments

This paper was the result of a pan-European working group. The authors would like to thank A. de Hoon, D. Nygaard, M. Glorieux, M. Hansen, and W. van der Wal for the fruitful discussions and their input, which was vital to complete the paper. In addition, we would like to express our gratitude to T. Rehman, S. Méson-Mancha, and T. de Lange for their valuable support in accessing the data, which we required to perform our analyses. Finally, we thank D. Whisson, HWI associate editor, and 3 anonymous reviewers for their constructive feedback on our initial draft of the manuscript.

Literature cited

Abraham, J. O., and M. A. Mumma. 2021. Elevated wildlife–vehicle collision rates during the COVID-19 pandemic. Scientific Reports 11:1–10.

Allan, J., A. Baxter, and R. Callaby. 2016. The impact of variation in reporting practices on the validity of recommended birdstrike risk assessment processes for aerodromes. Journal of Air Transport Management 57:101–106.

Anaconda. 2022. Anaconda/packages/ephem 4.1.2. PyEphem, <https://rhodesmill.org/pyephem/>. Accessed August 2, 2022.

Australian Transport Safety Bureau. 2019. Australian aviation wildlife strike statistics 2008 to 2017. Australian Transport Safety Bureau, Canberra, Australian Capital Territory, Australia.

Ball, S., A. Caravaggi, and F. Butler. 2021. Runway roadkill: a global review of mammal strikes with aircraft. Mammal Review 51:420–435.

Barras, S. C., and T. W. Seamans. 2002. Habitat management approaches for reducing wildlife use of airfields. Proceedings of the Vertebrate Pest Conference 20:309–315.

Bíl, M., R. Andrášik, V. Cícha, A. Arnon, M. Kruuse, J. Langbein, A. Náhlik, M. Niemi, B. Pokorny, V. J. Colino-Rabanal, C. M. Rolandsen, and A. Seiler. 2021. COVID-19 related travel restrictions prevented numerous wildlife deaths on roads: a comparative analysis of results from 11 countries. Biological Conservation 256:109076.

Blackwell, B. F., T. L. DeVault, E. Fernández-Juricic, and R. A. Dolbeer. 2009. Wildlife collisions with aircraft: a missing component of land-use planning for airports. Landscape and Urban Planning 93:1–9.

Budd, L., G. Bloor, and S. Ison. 2022. The impact of COVID-19 related flight reductions on bird prevalence and behaviour at Manchester Airport, UK. Proceedings of the World Birdstrike Association Europe Conference, London, United Kingdom.

Byrkjedal, I., T. Lislevand, and S. Vogler. 2012. Do passerine birds utilise artificial light to prolong their diurnal activity during winter at northern latitudes? Ornis Norvegica 35:37–42.

Clements, J. F., T. S. Schulenberg, M. J. Iliff, S. M. Billerman, T. A. Fredericks, J. A. Gerbracht, D. Lepage, B. L. Sullivan, and C. L. Wood. 2021. The eBird/Clements checklist of birds of the world: v2021. eBird, Cornell Lab of Ornithology, Ithaca, New York, USA.

Deutscher Wetterdienst. 2020. Pressemitteilung Februar 2020. Deutscher Wetterdienst, Offenbach, Germany.

DeVault, T. L., J. L. Belant, B. F. Blackwell, and T. W. Seamans 2011. Interspecific variation in wildlife hazards to aircraft: implications for airport wildlife management. Wildlife Society Bulletin 35:394–402.

Dolbeer, R. A. 2006. Height distribution of birds recorded by collisions with aircraft. Journal of Wildlife Management 70:1345–1350.

Dolbeer, R. A. 2008. Feathers in the fan. Aerosafety World 3:22–26.

Dolbeer, R. A. 2015. Trends in reporting of wildlife strikes with civil aircraft and in identification of species struck under a primarily voluntary reporting system, 1990–2013. Other Publications in Zoonotics and Wildlife Disease 188.

Dolbeer, R. A., and M. J. Begier. 2012. Comparison of wildlife strike data among airports to improve aviation safety. Proceedings of the 30th International Bird Strike Conference, Stavanger, Norway.

Dolbeer, R. A., M. J. Begier, P. R. Miller, J. R. Weller, and A. L. Anderson. 2021. Wildlife strikes to civil aircraft in the United States, 1990–2020. National Wildlife Strike Database serial report 27. Office of Airport Safety and Standards and Certification, Federal Aviation Administration, Washington, D.C., USA.

Dolbeer, R. A., S. E. Wright, and E. C. Cleary. 2000. Ranking the hazard level of wildlife species to aviation. Wildlife Society Bulletin 28:372–378.

Dolbeer, R. A., S. E. Wright, J. R. Weller, and M. J. Begier. 2014. Wildlife strikes to civil aircraft in the United States, 1990–2013. National Wildlife Strike Database serial report 20. Office of Airport Safety and Standards and Certification, Federal Aviation Administration, Washington, D.C., USA.

Driessen, M. M. 2021. COVID-19 restrictions provide a brief respite from the wildlife roadkill toll. Biological Conservation 256:109012.

Dunn, P. O., and A. Pape Møller. 2019. Effects of climate change on birds. Second edition. Oxford University Press, Oxford, United Kingdom.

Ebert, J. J. 2021. Skylarks as bioindicators for airports. Proceedings of the 1st World Birdstrike Association Virtual Conference, January 13–14, 2021.

Ente Nazionale per l'Aviazione Civile. 2021. Dati di traffico, Ente Nazionale per l'Aviazione Civile, Rome, Italy, <https://www.enac.gov.it/trasporto-aereo/compagnie-aeree/dati-di-traffico>. Accessed October 26, 2021.

EUROCONTROL. 2021. Airport traffic. Daily IFR arrivals and departures by airport. EUROCONTROL, Brussels, Belgium, <https://ansperformance.eu/download/xls/Airport_Traffic.xlsx>. Accessed December 13, 2021.

EUROCONTROL. 2022. Aviation outlook 2050. Main report. EUROCONTROL, Brussels, Belgium, <https://www.eurocontrol.int/archive_download/all/node/13448>. Accessed October 4, 2023.

European Parliament and the Council. 2014. Regulation (EU) No 376/2014 of The European Parliament and of The Council of 3 April 2014. Official Journal of the European Union.

European Parliament and the Council. 2015. Commission implementing regulation (EU) 2015/1018 of 29 June 2015. Official Journal of

the European Union, European Union.
European Union Aviation Safety Agency (EASA). 2020*a*. Preparation of aerodromes to resume operations. Safety Information Bulletin: Aerodromes. European Union Aviation Safety Agency SIB no. 2020-07.
European Union Aviation Safety Agency (EASA). 2020*b*. Preparation of aerodromes to resume operations. Safety Information Bulletin: Aerodromes. European Union Aviation Safety Agency SIB no. 2020-07R1.
European Union Aviation Safety Agency (EASA) 2022. Easy access rules for air operations. Regulation (EU) no. 965/2012.
Fraport Greece. 2021. Annual wildlife hazard management review 2020. Fraport Greece, Maroussi, Attica, Greece.
Giordano, M. 2021. Impact of the COVID-19 pandemic on wildlife hazard in 2020. French Civil Aviation Technical Center, Bonneuil-sur-Marne, France.
Gleizer, H., P. Bar, O. Bahat, E. Groner, and O. Ovadia. 2005. The effect of habitat productivity and structure on bird spatial distribution in an airfield located at a semi-arid region. Proceedings of 27th International Birdstrike Committee, Athens, Greece.
Hovey, P. W., D. A. Skinn, and J. J. Wilson. 1991. Study of the engine bird ingestion experience of the Boeing-737 aircraft (October 1986–September 1989). DOT/FAA/CT-90 28. Federal Aviation Administration Technical Center, Atlantic City, New Jersey, USA.
IBM Corp. 2020. IBM SPSS statistics for Windows. Version 27.0. IBM Corp, Armonk, New York, USA.
International Civil Aviation Organization (ICAO). 1989. Manual on the ICAO Bird Strike Information System (IBIS). Third edition. Doc 9332/AN909. International Civil Aviation Organization, Montreal, Quebec, Canada.
International Civil Aviation Organization (ICAO). 2017. 2008–2015 Wildlife strike analyses (IBIS). Electronic bulletin. International Civil Aviation Organization, Montreal, Quebec, Canada.
International Civil Aviation Organization (ICAO). 2021. Effects of novel coronavirus (COVID-19) on civil aviation: economic impact analysis. International Civil Aviation Organization, Air Transport Bureau, Montreal, Quebec, Canada.
JASP Team. 2022. JASP, version 0.16.2. University of Amsterdam, Amsterdam, The Netherlands.
Kelly, T. C., R. Bolger, and M. J. A. O'Callaghan. 1999. The behavioural responses of birds to commercial aircraft. Bird Strike Committee-USA/Canada Joint Annual Meeting 1:77–82.
Kelly, T. C., R. Bolger, M. J. A. O'Callaghan, and P. D. Bourke. 2001. Seasonality of birds strikes: towards behavioural explanation. 2001 Bird Strike Committee-USA/Canada, Joint Annual Meeting 3:205–208.
Kitowski, I. 2011. Civil and military birdstrikes in Europe: an ornithological approach. Journal of Applied Sciences 11:183–191.
Lemoine, A., and A. Pineaud. 2020*a*. Bulletin climatique Février 2020. Météo France, Direction de la Communication et de la Commercialisation, Saint-Mandé, France.
Lemoine, A., and A. Pineaud. 2020*b*. Bulletin climatique Mai 2020. Météo France, Direction de la Communication et de la Commercialisation, Saint-Mandé, France.
MacKinnon, B. 2004. Sharing the skies: an aviation industry guide to the management of wildlife hazards. Transport Canada, Ottawa, Ontario, Canada.
Malka, I. 2021. Évaluation et analyse des risques de l'aviation civile pendant la période de faible activité 2020. Direction de la sécurité de l'Aviation civile, Mission Évaluation et Amélioration de la sécurité, Paris, France.
Manenti, R., E. Mori, V. Di Canio, S. Mercurio, M. Picone, M. Caffi, M. Brambilla, G. F. Ficetola, and D. Rubolini. 2020. The good, the bad and the ugly of COVID-19 lockdown effects on wildlife conservation: insights from the first European locked down country. Biological Conservation 249:108728.
McKee, J., P. Shaw, A. Dekker, and K. Patrick. 2016. Approaches to wildlife management in aviation. Pages 465–488 *in* F. M. Angelici, editor. Problematic wildlife. Springer, Cham, Switzerland.
Metz, I. C., J. Ellerbroek, T. Mühlhausen, D. Kügler, and J. M. Hoekstra. 2020. The bird strike challenge. Aerospace 7:26.
Montemaggiori, A. 2021*a*. Wildlife strike relazione annuale 2020. Ente Nazionale per l'Aviazione Civile – Birdstrike Committee Italy, Rome, Italy.
Montemaggiori, A. 2021*b*. Wildlife strike hazard and lockdown at Italian airports. Proceedings of the 1st World Birdstrike Association Virtual Conference, January 13–14, 2021.
Mountain, P., and M. Giordano. 2020. Wildlife haz-

ard management guide. European Union Aviation Safety Agency, Cologne, Germany.

Ntampakis, D. 2021. Annual wildlife hazard management review 2020. Proceedings of the 1st World Birdstrike Association Virtual Conference, January 13–14, 2021.

Parsons, D., M. Malouf, and W. Martin. 2022. The impact of COVID-19 on wildlife strike rates in the United States. Human–Wildlife Interactions 16(3).

Parveen, M. 2020. Challenges faced by pandemic Covid 19 crisis: a case study in Saudi Arabia. Challenge 63:349–364.

Rahman, N. A. A., S. A. Rahmin, M. F. Ahmad, and B. A. M. Hafizuddin-Syah. 2020. Exploring COVID-19 pandemic: its impact to global aviation industry and the key strategy. International Journal of Advanced Science and Technology 29:1829–1836.

Rebke, M., V. Dierschke, C. N. Weiner, R. Aumüller, K. Hill, and R. Hill. 2019. Attraction of nocturnally migrating birds to artificial light: the influence of colour, intensity and blinking mode under different cloud cover conditions. Biological Conservation 233:220–227.

Rhodin, A. G. J., J. B. Iverson, R. Bour, U. Fritz, A. Georges, H. B. Shaffer, and P. P. van Dijk. 2021. Turtles of the world: annotated checklist and atlas of taxonomy, synonymy, distribution, and conservation status. Ninth edition. Chelonian Research Monographs 8:1–472.

Rutz, C., M. C. Loretto, A. E. Bates, S. C. Davidson, C. M. Duarte, W. Jetz, M. Johnson, A. Kato, R. Kays, T. Mueller, R. B. Primack, Y. Ropert-Coudert, M. A. Tucker, M. Wikelski, and F. Cagnacci. 2020. COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. Natural Ecology and Evolution 4:1156–1159.

Samson, B., and M. Giordano. 2021. Collisions animalières 2020. Bulletin statistique. Direction Générale de l'Aviation Civile, Service technique de l'aviation civile. Bonneuil-sur-Marne, France.

Shamoun-Baranes, J., E. van Loon, H. van Gasteren, J. van Belle, W. Bouten, and L. Buurma. 2006. A comparative analysis of the influence of weather on the flight altitudes of birds. Bulletin of the American Meteorological Society 87:47–62.

Shilling, F., T. Nguyen, M. Saleh, M. K. Kyaw, K. Tapia, G. Trujillo, M. Bejarano, D. Waetjen, J. Peterson, G. Kalisz, R. Sejour, S. Croston, and E. Ham. 2021. A reprieve from US wildlife mortality on roads during the COVID-19 pandemic. Biological Conservation 256:109013.

Soldatini, C., V. Georgalas, P. Torricelli, and Y. V. Albores-Barajas. 2010. An ecological approach to birdstrike risk analysis. European Journal of Wildlife Research 56:623–632.

Suau-Sanchez, P., A. Voltes-Dorta, and N. Cuquéro-Escofet. 2020. An early assessment of the impact of COVID-19 on air transport: Just another crisis or the end of aviation as we know it? Journal of Transport Geography 86:102749.

Thorpe, J. 2010. Update on fatalities and destroyed civil aircraft due to bird strikes with appendix for 2008 and 2009. Proceedings if the 29th Meeting of the International Bird Strike Committee, Cairns, Australia.

United Kingdom Civil Aviation Authority. 2006. CAA paper 2006 / 05. The completeness and accuracy of birdstrike reporting in the UK. Research and Strategic Analysis Department, Safety Regulation Group, Civil Aviation Authority, Aviation House, Gatwick Airport South, West Sussex, United Kingdom.

Washburn, B. E., S. C. Barras, and T. W. Seamans. 2007. Foraging preferences of captive Canada geese related to turfgrass mixtures. Human–Wildlife Interactions 1:214–223.

Wilson, D. E., and D. M. Reeder, editors. 2005. Mammal species of the world: a taxonomic and geographic reference. Third edition. Johns Hopkins University Press, Baltimore, Maryland, USA.

Zellmer, A. J., E. M. Wood, T. Surasinghe, B. J. Putman, G. B. Pauly, S. B. Magle, J. S. Lewis, C. A. M. Kay, and M. Fidino. 2020. What can we learn from wildlife sightings during the COVID-19 global shutdown? Ecosphere 11(8): e03215.

Associate Editor: Desley Whisson

Isabel C. Metz is a postdoctoral researcher at the Institute of Flight Guidance of the German Aerospace Center, specialized in real- and fast-time simulations of Air Traffic Management concepts and procedures. In her position, she heads the institute's 360° Apron- and Tower simulator, supervising human-in-the loop simulations with air traffic controllers, validating newly developed procedures and supporting tools. Her main research focus lies on operational wildlife strike prevention, involving air traffic controllers and pilots in the process. She received her B.Sc. and M.Sc. degrees in transportation engineering (cum laude) from the University of Technology in Braunschweig, Germany, and her Ph.D. degree from Delft University of Technology in the Netherlands.

Marta Giordano, Ph.D., is an ornithologist at the French Civil Aviation Technical Centre. She conducts wildlife hazard assessments on aerodromes and research on hazardous wildlife and risk mitigation techniques. She also creates training courses for airport, military, and Civil Aviation Authority personnel. She assists the International Civil Aviation Organization and the European Union Aviation Safety Agency with the development of international guidance regarding wildlife hazards on and within the vicinity of airports.

Dionysios Ntampakis is a highly motivated professional specialized in wildlife surveys, training, wildlife strike risk assessment, wildlife hazard management programs, and biodiversity conservation. He holds an M.S. degree in wildlife management, conservation, and control (University of Reading, United Kingdom) and a Master in Aviation Management (Technical University of Applied Sciences Wildau, Berlin, Germany). He has >15 years of experience in conflict mediation between wildlife and aviation safety.

Marianna Moira has worked for the Operations Division of Fraport Greece since 2017. She is responsible for assisting in the planning and coordination of daily wildlife hazard management procedures implemented by >150 employees. Some of her main tasks include training the airport operations staff on wildlife hazard management, analyzing trends in wildlife activity and strikes, and reporting results to senior management and the civil aviation authority. She graduated with a distinction in her master's degree in agricultural sciences and engineering from the Agricultural University of Athens.

Anneke Hamann is a researcher and Ph.D. student at the German Aerospace Center (DLR). She received her bachelor's and master's degrees in psychology from University Jena and Technical University Dresden. She joined the Institute of Flight Guidance at DLR Braunschweig in 2018 as a researcher and human factors expert for a European project on multiple remote tower operations. In her Ph.D. project, she focuses on the fNIRS- and EEG-based assessment of human performance for cockpit applications.

Rosanne Blijleven has been working for Amsterdam Airport Schiphol since 2012. She graduated in wildlife management, has agricultural roots, and has >10 years of experience working in aviation safety. From bird control and habitat management to corporate responsibility, her passion is to unite safety and sustainability in her professional activities. Since 2020, she has been the chair of the ACI Wildlife Trafficking Taskforce to combat wildlife trafficking.

Jurgen J. Ebert is the head of the Team Wildlife & Animal Services of Fraport. In this capacity, he takes care of the wildlife hazard prevention and animal welfare at Frankfurt Airport, Germany. He also manages the forest and agricultural land owned by Fraport as well as the ecological compensation measures. He holds a master's degree in biology with an emphasis on nature conservation from the Philipps-University in Marburg, Germany.

Alessandro Montemaggiori, Ph.D., is an ornithologist and wildlife conservation and management expert with >30 years of experience in wildlife strike risk mitigation at airports. As an associate researcher at Sapienza University of Rome, he is the scientific advisor of the Italian Bird Strike Committee and advisory wildlife control expert at several international airports. He worked for several national and international organizations and institutions including International Civil Aviation Organization, European Commission, Italian Ministry of Environment, Italian Institute for Environmental Protection and Research, Italian Civil Aviation Authority, World Wildlife Fund, and International Union for Conservation of Nature. His main research topics are wildlife conflicts mitigation at airports, bird migration, and conservation.