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An ecological approach to birdstrike risk analysis

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Abstract Airports are peculiar developed habitats that, besides being extremely noisy and unappealing to some bird species, are highly attractive to others. Bird–aircraft collisions, or birdstrikes, cause losses in terms of human lives, direct monetary losses and associated costs for the civil aviation industry. In recent years, birdstrike risk assessment studies have focused on the economical aspects of the damage caused by wild animals and the hazards of wildlife–aircraft collisions, while an ecological approach, taking into account animal behaviour for the analysis of such events, has seldom been adopted. We conducted a risk analysis for birdstrikes at the Venice Marco Polo International Airport (VCE), Italy. We defined the key variables involved in these events and summarised their interactions in a single metric risk index we called the "Birdstrike Risk Index" (BRI). Our aim was to provide a tool for birdstrike risk analysis that described the risk on the basis of the actual presence of birds at airports. The application of the BRI at VCE allows relative risks across species to be defined, providing information for prioritising management actions. Furthermore, due to the seasonality of bird species presences, the application of the BRI to a long-term data series should give clues of birdstrike risk in future scenarios. This new ecological approach that we applied to a particular airport could easily be adapted for use at other airports worldwide and integrated into risk assessment procedures. The study results and the BRI tool are addressed to scientific consultants of airport safety managers.

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Introduction

Airports are highly attractive areas for birdlife, besides providing services for aerial transport operations. Despite varied levels of disturbance to local ecosystems, airport habitats offer a variety of niches to wildlife. Some primary characteristics of airport habitats are meadows and well-drained paved surfaces that are occasionally close to ponds or small rivers and channels (Robinson 2005). Thus, for birds, airports provide suitable habitats for roosting, feeding and breeding, while disturbance may be a minor factor (Mallord et al. 2007a). Disturbance effects from aircraft traffic and human activities may be negligible for some bird species; often they habituate to intensive acoustic disturbance (Conomy et al. 1998; Soldatini et al. 2008) and maintain their normal activity patterns (Baudains and Lloyd 2007; Rees et al. 2005). At disturbed sites, lower densities of birds may result in higher foraging success because of lower competition for the same resources (Mallord et al. 2007b; Mallord et al. 2007a; Sutherland 2007).

The primary food supplies at airports are grasses and other vegetation (Barras et al. 2000; Barras and Seamans 2002; Gleizer et al. 2005), insects and strike victims (insects, birds and small mammals that have collided with aircrafts). Bird species frequenting airport areas are mainly herbivorous/seed eaters (ducks, geese and some passerine species), insectivorous (kestrels, starlings and other passerine species) and scavengers (corvids and gulls). Herons and birds of prey may be present, depending on the presence of amphibians or small mammals (Barras et al. 2000; Gleizer et al. 2005).

The presence of birds in airport areas poses substantial hazards to aviation. Bird–aircraft collisions (hereafter “birdstrikes”) cause losses of human lives (Thorpe 1996; Thorpe 2005) as well as direct monetary losses and associated costs for the civil aviation industry (Matijaca 2005). Hazardous wildlife species are those species causing strikes with aircrafts; however, not all species pose a birdstrike threat. A species’ distribution at airports depends on the geography and surrounding habitats; therefore, it is expected that different bird communities will be present at different airports.

For example, the most dangerous birds in terms of the total number of strikes and the cost per strike in the USA, according to the National Wildlife Strike Database, are geese, vultures, rock doves, ducks and gulls (Dolbeer et al. 2000). On the other hand, in Italy, gulls, lapwings, starlings and hooded crows were recorded as dangerous species at Rome Fiumicino Airport (Montemaggiori 1998), and herons and gulls were reported as the most dangerous at Venice Marco Polo International Airport (hereafter “VCE”) in this study.

Until now, airport management protocols lack a universally accepted protocol for quantitatively assessing the risk of birdstrikes and a defined level of risk acceptability. The International Civil Aviation Authority (Convention on International Civil Aviation) and national authorities (CAA 1998; ENAC 1999; ENAC 2007; FAA 2004) provide a series of standards and recommended practices in airport management. One of these recommendations is to conduct an accurate environmental study to monitor bird presence in airport areas. Most airport managers and national regulators adopt the “as low as reasonably practicable” approach to birdstrike management (Allan 2000; Allan 2006; Dekker and Buurma 2003), meaning that bird numbers have to be kept at the lowest levels possible. In order to prevent birdstrikes, the most common management practice is the use of deterrents (e.g. falconry, lasers or acoustic disturbances), although these techniques are seldom combined with an appropriate monitoring protocol.

In recent years, mathematical approaches have been proposed for ranking wildlife hazard levels (Dolbeer et al. 2000; Morgenroth 2003). Generally, these approaches suggest that economics should be used to prioritise management decisions towards addressing the species that cause the most damage (Allan 2006; Blockpoel 1976). In fact, the majority of the birdstrike studies that have been conducted have focused on the economic costs caused by wild animals (Dolbeer et al. 2000), or on hazardous species’ spatial and temporal distributions (Anagnostopoulos 2003; De Fusco et al. 2005; Dolbeer et al. 1997; Fennessy et al. 2005; Leshem et al. 2005; Lovell and Dolbeer 1999). A more integrative approach, taking into account animal behaviour (e.g. Schafer et al. 2007) in the analysis of birdstrikes, is missing from most risk assessment procedures. Admittedly, both aircraft traffic and bird movements can be very difficult to quantify. Finally, risk assessment may be more accurate if a single metric could embody all of the available information.

It has been widely documented that collisions of aircrafts with birds are more common at altitudes lower than 500 ft (Dolbeer 2006) mainly during takeoff and landings (Barras and Dolbeer 2000; Barras and Wright 2002; Blockpoel 1976; Dolbeer et al. 2000; Dolbeer 2000). Because aircraft manoeuvrability is extremely limited during takeoff and landing, management options to reduce birdstrikes must of necessity focus on bird behaviour. The main factors influencing birdstrike severity to aircraft are aircraft speed (Dolbeer 2006), bird body mass (Dolbeer et al. 2000) and the number of birds involved in the incident, i.e. the probability of bird flocking behaviour. Bird flocking is extremely variable seasonally due to factors related to resource distribution and availability and to predator and disturbance pressure (Clinchy et al. 2004; Fitzpatrick and Bouchez 1998; Rose and Nagel 2006; Soldatini et al. 2006; Woolnough et al. 2006). Bird foraging behaviour and prey distribution (i.e. insects vs. seeds) may influence bird distributions at airports and their reactions towards approaching aircraft (Sirot 2006).

In our view, risk assessment is needed in order to reflect present conditions. Furthermore, risk assessment can be used to make birdstrike predictions based on long-term bird presence and abundance data and on scheduled flight data. Therefore, the aim of this study was threefold: (1) To DESCRIBE bird habitat use in the airport area by species, (2) to develop a basic analytical tool for birdstrike risk assessment that combined the main ecological and behavioural patterns of bird species relative to aircraft traffic and (3) to define risk levels for particular periods, areas and bird species. The analytical tool proposed here is addressed to scientific consultants of airport safety managers. The information provided will help airport administrators to decide when preventive actions should be taken.

Materials and methods

Study area and data collection

From January 2006 to December 2007, we recorded bird abundance and distribution at the VCE (Italy), located on the inland border of the lagoon of Venice. The lagoon hosts a large bird community and is a Special Protection Area, SPA (Bird Directive 79/409/EEC, European Economic Community).

The study area, consisting of runways and all airport structures, was divided into quadrats (dimensions 370× 370 m) to create a spatially referenced grid. A total of 24 quadrats were selected for their proximity to the sensitive area (runways) (Fig. 1). Habitats in each quadrat were subdivided into the following classes: water (channels, shallow water and salt marshes), fields (grass fields), runways (both runways and the airplane parking area) and buildings (airport buildings including the tower, hangars and service structures). The grid allowed us to associate each bird observed roosting or foraging with a certain quadrat and to the lager-scale habitat characteristics of the area. Information about maintenance and deterrents were recorded during the surveys, and temperature was provided by the airport meteorological station.

All observations were conducted from a single vantage point, from which all of the quadrats could be observed over each of the study periods. We used a telescope equipped with a ×20–60 zoom lens. Habitat type was noted for each roosting or foraging bird or flock observed on the ground. Observations were made twice a month on an hourly basis starting 1 h before sunrise and ending 1 h after sunset. During surveys, the abundances of all bird species present in the airport area were recorded, along with their reference location. With mixed flocks, we recorded each species separately. Birds flying up to a height of c. 300 ft were recorded in accordance with the Italian National Civil Aviation Advisory Circular APT01-A (ENAC 2007), and their flight direction was noted.

Airport traffic information (i.e. birdstrike events and aircraft movements) was provided directly from the airport authorities. Data on bird presence and aircraft movements used in this study were collected from January 2006 to December 2007, while data pertaining to birdstrike events were collected from 2002 to 2007. In order to simplify data management, we grouped bird species according to their ecological characteristics (habitat and diet), body size and social behaviour (flocking vs. non-flocking species; see Table 1).

Statistical analysis on indices of habitat use

Because bird presence in certain areas of an airport does not necessarily increase risk (e.g. waterfowl on ponds near the air operations area), for our analysis, we selected four groups of species with a mean annual number of birdstrike events greater than 1 during the past 6 years: “small birds of prey”, “large gulls”, “small gulls” and “swifts and swallows” (Table 1, data in bold). We decided to focus only on certain groups of species, as some groups (e.g. grebes) never cross the runway and have no history of birdstrikes, or have a very low probability of occurring.

Estimates of relative abundance for these groups were log-transformed as the data did not fit a normal distribution. We tested for the independence of samples for habitat use

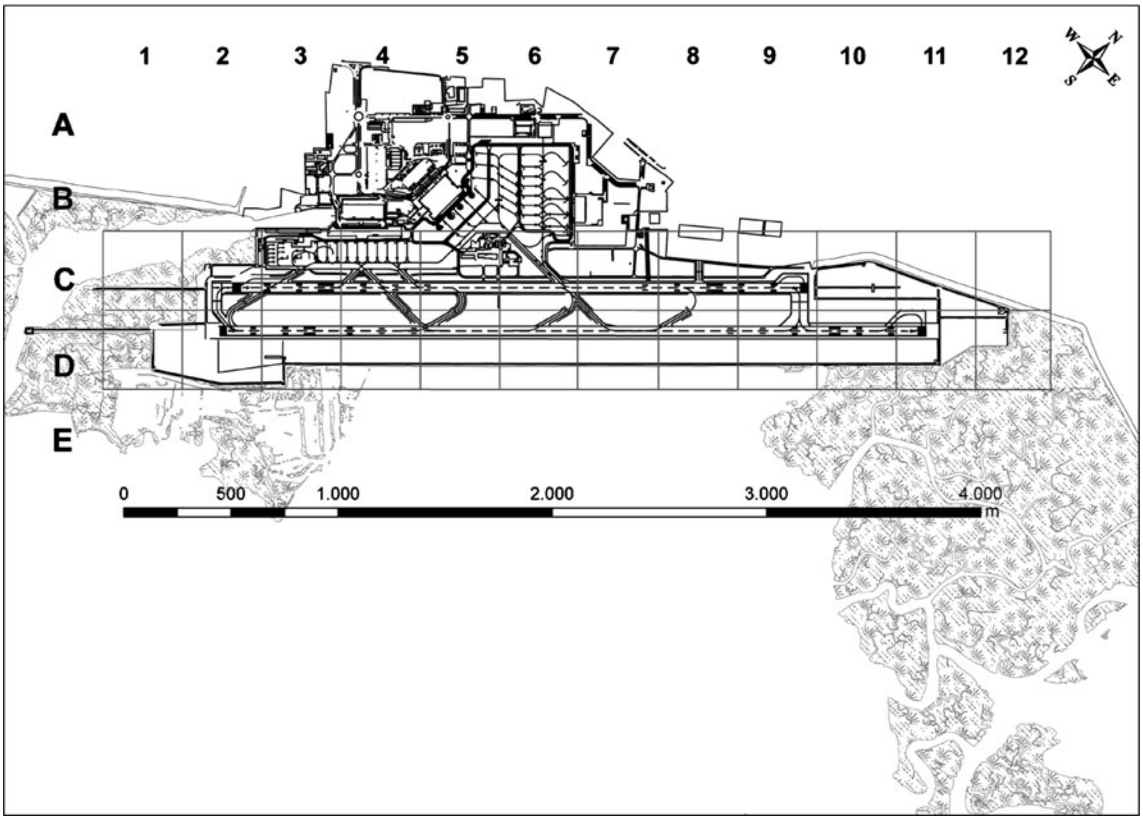


Fig. 1 Study area subdivided in 24 quadrats

Table 1 Bird species grouped according to their ecological patterns (habitat and diet), body size and social behaviour (flocking vs. non-flocking species)

ID group	Species group	Some examples	AvW (gr)	Ag	GFstd	EOFmax
1	Grebes	*Tachybaptus ruficollis. Podiceps nigricollis*	250	2	0	0
2	Cormorant	*Phalacrocorax carbo*	2,300	3.310	0.008	1
3	Herons	*Ardea cinerea. Casmerodius albus*	937.5	1.978	0.006	4
4	Ducks	*Anas platyrhynchos. Tadorna tadorna*	4,050	4.245	0.219	4
5	Birds of prey—large	*Buteo buteo. Circus aeruginosus*	562.5	1.028	0.001	1
6	**Birds of prey—small**	***Falco peregrinus. Falco tinnunculus***	**433.333**	**1.428**	**0.041**	**2**
7	**Gulls—large**	***Larus michahellis. Larus argentatus***	**900**	**5.638**	**0.372**	**4**
8	**Gulls. terns—small**	***Larus ridibundus. Sterna hirundo***	**175**	**9.546**	**0.325**	**4**
9	Waders	*Charadrius alexandrinus. Recurvirostra avosetta. Tringa totanus*	225.714	5.688	0	0
10	Doves	*Columba livia. Streptopelia decaocto*	300	6.75	0.007	1
11	Owls	*Athene noctua. Tyto alba*	100	1	0.000	1
12	**Swifts and swallows**	***Apus apus. Hirundo rustica***	**27.333**	**7.319**	**0.009**	**2**
13	Corvids	*Corvus corone cornix. Pica pica*	365	3.314	0.003	1
14	Non-flocking passerines	*Erithacus rubecula. Motacilla alba. Turdus merula*	30.058	3.294	0	1
15	Flocking passerines	*Sturnus vulgaris*	41	63.862	0.008	1

The main characteristics are described by three variables: AvW (average weight), Ag (median flock size recorded at the study area) and GFstd (standardised group factor). Data in bold indicate groups selected for analysis

using the Durbin–Watson test. Differences in habitat use by species group were analysed using ANOVA. We used MANOVA to determine what factors influenced the occurrence and distribution of the species groups. We used the number of individuals as the dependent variable and season, maintenance works (grass cutting and collecting recorded as presence/absence of works), deterrents, ground condition (wet or dry) and habitat as independent variables. Data were pooled by phonological period. They included wintering (Nov–Jan), breeding (May–July) and fall (Aug–Oct) and spring (Feb–Mar) migrations. All data were analysed using Statistica 6.0 (StatSoft 2003) and SPSS 13 (SPSS 2004).

Birdstrike Risk Index

Birdstrike risk can be decomposed into several factors, including bird biology and ecology (bird factor), the association of different bird species with similar characteristics (group factor) and the birdstrike event history, meaning the number of birdstrike (and relative effects on flight) recorded for the species in the particular airport (birdstrike factor). Since bird weight and flock size are of critical importance to the magnitude of a birdstrike event, average weights (AvW) corresponding to each group of species were calculated based on Cramp and Simmons (1983). An aggregation factor (Ag) was determined for each group corresponding to the median flock size recorded in the study area (Table 1). The probability of a birdstrike event occurring depends on both bird abundance and aircraft movements; thus we included in the index the mean daily number of flights for each month (takeoff, landing or both) divided in two time periods, 5:00–12:00 and 13:00–20:00. We excluded night hours because of the difficulty of assessing bird presence due to darkness.

Another critical factor for calculating the Birdstrike Risk Index (BRI) is related to the birdstrike history recorded by the airport safety unit. The "birdstrike factor" summarises an airport-specific evaluation of the degree of hazard each species poses. Information collected continuously by airport operators on the number of impacts, the species involved and effects on aircraft can be summarised in two variables, which we term here BS and EOF. BS is the ratio of impacts recorded per year per number of flights in that year; from this, we calculated the mean number of standardised birdstrikes observed each year for each species group (mBSstd). EOF is defined as the effect of a birdstrike on the aircraft and includes the effect categories: none, minor, substantial, serious and catastrophic; from this, we determined the maximum damage that had been recorded for that species (EOFmax; Table 2). We used a conservative approach by using the higher *EOF* recorded each year for each species group. "Bird and birdstrike factors", as described above, define each species group pattern and history at a given airport and are combined in the "group factor", GF, that can be calculated as in Eq. 1, where *i* is the species group.

$$\mathrm{GF}_i = \mathrm{AvW}_i \times \mathrm{Ag}_i \times \mathrm{mBSstd}_i \times \mathrm{EOF}_{\max i} \qquad (1)$$

Table 2 Categories of effect on flights (EOF) caused by birdstrike events

Rank EOF	Categories—definition
1	None—not reported. No sufficient information
2	Minor—Flight continued as scheduled although delays due to inspections
3	Substantial—Take-off abortion. emergency landing—aircraft may be rendered airworthy by simple repairs
4	Serious—Take-off abortion. Emergency landing. Engine shutdown—serious damages. Structural failure. Aircraft stopped for repairs
5	Catastrophic—damage sustained makes it inadvisable to restore aircraft

For the applicability of the BRI at different airports where different species are present, GFi can be standardised (Eq. 2).

$$\mathrm{GFstd}_i = \frac{\mathrm{GF}_i}{\sum_{i=1}^{15} \mathrm{GF}_i} \qquad (2)$$

The GFstd_i (standardised group factor) is calculated for each species group (i), while the group specific risk, GSR, is calculated by multiplying GFstd by the mean daily number of birds in the ith group (mDB_i) present in the airport calculated for each month (Table 1; Eq. 3). Finally, the BRI is equal to the GSR multiplied by the mean daily flight traffic (mDF) (Eq. 4).

$$\mathrm{GSR} = \mathrm{GFstd}_i \times \mathrm{mDB}_i \qquad (3)$$

$$\mathrm{BRI} = \sum_{i=1}^{15} (\mathrm{GSR}_i) \times \mathrm{mDF} \qquad (4)$$

The BRI was calculated for each month from January 2006 to December 2007, and the results were compared to birdstrike events recorded in the same period using ANOVA, with season or month as independent variables and BRI as the dependent variable. Since birdstrike events are concentrated on runways and in approaching corridors areas, the reference grid adopted allowed the isolation of this zone for detailed analysis.

The relationship between the BRI and actual birdstrike events was analysed over a 2-year period for the entire main runway area and then for morning vs. evening periods and for two different portions of the runway (due to prevailing winds traffic flow at VCE is rarely inverted, so these regions corresponded to landing and take-off areas) using ANOVA.

On the basis of the average annual presence of birds at the VCE, we calculated the BRI value threshold according to the Advisory Circular APT01-A by ENAC (Italian National Civil Aviation Agency) (ENAC 2007), setting a limit of five birdstrike events (regardless of the EOF) for every 10,000 flights. We tested the reliability of our index by calculating the number of birdstrike events the index would predict for each month and compared it to the real number of birdstrikes recorded.

Results

Indices of habitat use

The mean monthly temperatures recorded during 2007 were higher (+2°C) than those recorded in 2006, although these differences were not significant (Mann–Whitney *U* test, $U=3.500$, $P=0.662$). This difference in temperatures may have influenced birds' activity patterns in the summer months, concentrating their activities in cooler hours. In the airport area and its vicinity, we observed a total of 68 bird species. Of these, 19% were resident and present during the whole study period (e.g. herons, yellow legged and black headed gulls, corvids and starlings).

We considered samples from different habitats to be independent according to Durbin–Watson test results ($d=1.5735$, $P<0.01$, dL=1.52 and dU=1.56). We observed that the four species groups had different habitat preferences. Large gulls concentrated in water areas (one-way ANOVA, $F_{3,20}=7.389$, $P=0.002$), and when inside the airport, they were mainly observed on runways and fields (Fig. 1) where they roosted and occasionally fed. Small gulls were more homogeneously distributed (one-way ANOVA, $F_{3,33}=0.463$, $P=0.710$) as they regularly fed in the fields and used mainly buildings, runways and fields as roosting areas (Fig. 2). Swifts and swallows reached the status of potentially dangerous species, although they were present only in

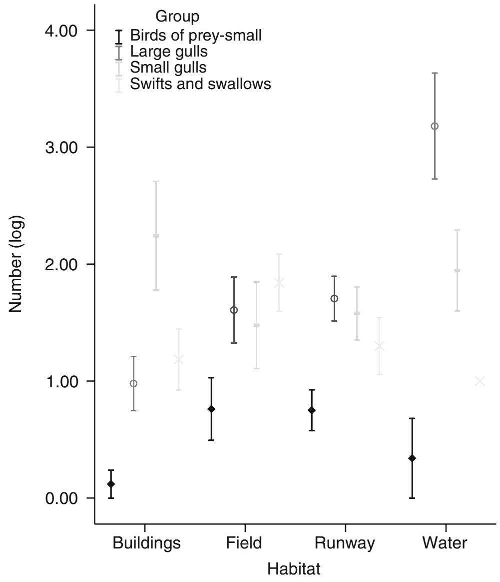


Fig. 2 Distribution of birds groups responsible of the majority of birdstrikes in the four habitats present at the airport

spring/summer and were abundant in the whole area (one-way ANOVA, $F_{3,26}=1.520$, $P=0.236$) (Fig. 2). Small birds of prey were also present in the whole airport area and distributed in all habitats (one-way ANOVA, $F_{3,22}=1.008$, $P=0.411$) (Fig. 2).

In both years, there were no significant differences in bird numbers between seasons (in all cases $P>0.05$), while differences in distribution between habitats were significant (MANOVA, $F_{3,92}=176.030$, $P=0.001$). The effect of maintenance works (grass cutting) on habitat use and abundance were positive (MANOVA, $F_{4,38}=8.681$, $P<0.001$). On the other hand, ground conditions (wet/dry) had no effect on habitat use and abundance (MANOVA, $F_{1,123}=0.111$, $P<0.739$). Patterns relating to habitat use are not significantly affected by dissuasive activities (in all cases $P>0.05$).

Birdstrike risk index

For the two time periods and the two portions of the runway considered, BRI trends were not significantly different (in all cases $P>0.05$) (Fig. 3). A season effect in BRI average values was evident in 2006 (repeated-measures ANOVA, $F_{3,8}=5.459$, $P=0.024$), while such an effect was not significant in 2007 (repeated-measures ANOVA, $F_{3,8}=1.291$, $P=0.342$) (Fig. 4). In 2006, BRI values were significantly higher during autumn migration (Aug–Oct) compared to wintering (Nov–Jan) and breeding (Apr–Jun) periods ($P=0.031$ and $P=0.043$, respectively, Tukey-HSD test). During late summer months, we obtained higher BRI values, although not significantly different, in the morning hours and in the landing portion of the runway, while the take-off portion of the runway had high BRI values in the morning hours in April (2006 and 2007) and August (2006) (Fig. 3).

Considering the whole runway and its approaching corridors, we observed higher average BRI values in August and lower values in winter months (Fig. 4), although no significant differences were observed. Comparing the BRI to the number of birdstrike events recorded for 2006–2007, we found no significant difference. As observed for the number of birdstrikes recorded in 2006–2007 (Mann–Whitney *U* test, $U=64.000$, $P=0.644$), the BRI index values were similar in the 2 years (Mann–Whitney *U* test, $U=44.000$, $P=0.106$), although bird abundances differed (Mann–Whitney *U* test, $U=3667.000$, $P=0.0003$), with 2007 being a poorer year. Species group abundances in the 2 years were mostly not significantly different (factorial ANOVA, interaction year × species group: $F_{14,174}=1.212$, $P=0.275$), the only difference being the lower number of large gulls observed in 2007 ($P=0.051$, Tukey-HSD test).

Comparing the number of birdstrike events recorded with the number expected according to the BRI (Fig. 5), we obtained a measurement of the reliability of the BRI calculated in the 2 years (2006–2007). In both years, differences between the numbers of expected (BRI) and observed birdstrikes are not significant (2006: $X_{11}{}^{2}=15.603$, $P<0.156$; 2007: $X_{11}{}^{2}=11.678$, $P<0.388$). There was greater uncertainty in the prediction made by the BRI in the summer period, and the difference between expected and observed was generally lower in 2007 than in 2006 (Fig. 5).

Discussion

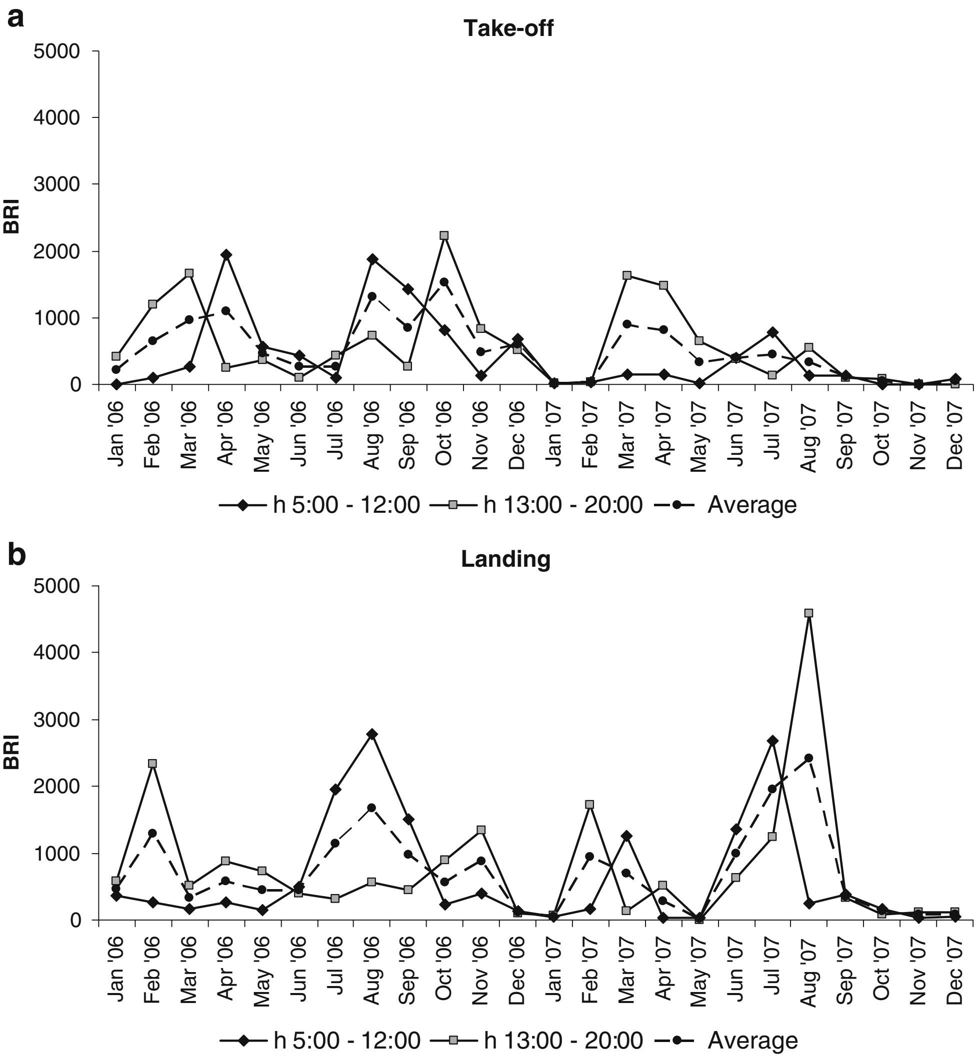
Airport safety managers typically face the problem of a diversity of wildlife species, mainly birds, present in airport areas that may collide with aircraft. Moreover, some wildlife management plans undertaken in airport areas to discourage certain species, as suggested by international authorities (CAA 1998; ENAC 1999; ENAC 2007; FAA 2004), may in fact result in an increase in the abundance of other species (Dolbeer et al. 2000). Thus a general overview of species exploiting airport areas is needed in order to evaluate present conditions, management efficacy, and to have a clearer picture of risk in order to adapt wildlife management plans. An ecological study of an airport area, lasting at least 1 year, is the minimum needed to evaluate seasonal bird presence (ENAC 1999; ENAC 2007) and to observe behavioural aspects of bird species frequenting the area and exploiting its resources. Although the method does not record the presence of birds 24/7, it gives a good description of the dynamics in the area. A longer-term monitoring programme would give insights about bird presence fluctuations and yield more information for further analysis (De Fusco et al. 2005). Safety managers' scientific consultants may use the BRI as a sharable tool to help manage complex databases.

We analysed species by groups to concentrate attention on those species with similar ecological needs and behaviours (e.g. species that soar in the Runway Protection Zones). Furthermore, grouping species facilitates the interpretation of the results to a broader audience.

In concordance with other authors (Barras et al. 2000; Barras and Seamans 2002), we observed a positive effect of grass maintenance works on bird presence in the study area. Grass maintenance activities in fact may attract several insectivorous species. Studies on active airports are frequently confounded because the presence of hazardous birds close to the runways immediately results in a dispersal action by the bird control staff. Deterrence efforts are therefore concentrated in areas and habitat types that are regularly frequented by birds. Nevertheless, patterns relating to habitat use are not significantly affected by dissuasive activities.

In this case study the BRI index, although only based on 2 years of data, offered a description of birdstrike risk at the

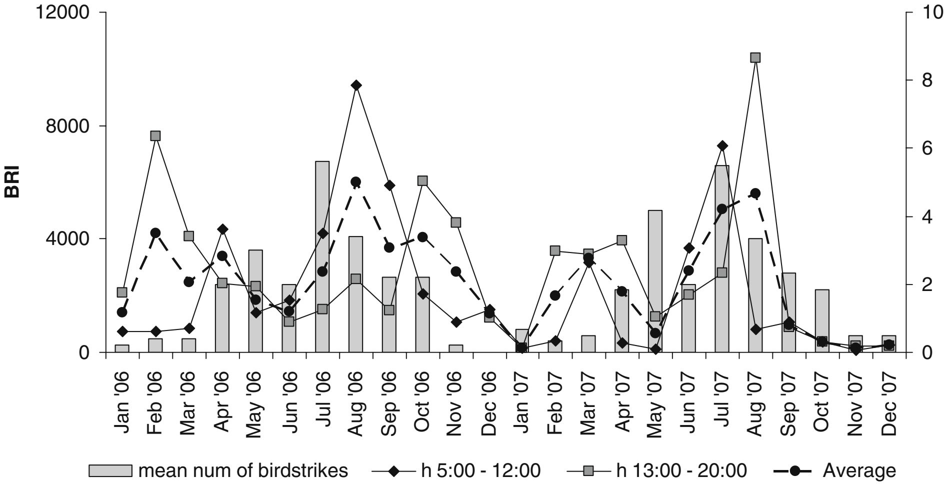
Fig. 3 The Birdstrike Risk Index (*BRI*) trend in landing (**a**) and take-off (**b**) runway areas. The BRI is expressed as a daily average and for different time periods



VCE that was reliable over time (Fig. 4). This reliability could be attributed to the ecological characteristics of the area and the distribution of attractive areas inside and outside the airport consistently influenced birds' movements (Fig. 2).

Since the variables used to calculate the BRI did not contain any information on monthly birdstrikes, the index calculation on selected data for different time periods and in different portions of the airport (Fig. 3) allowed a more

Fig. 4 Overall Birdstrike Risk Index (*BRI*) trends calculated for the main runway and approaching and leaving corridors related to the mean number of birdstrikes recorded in the study year and in the previous 4 years (for 2006 and 2007, respectively, 2002–2006 and 2003–2007)



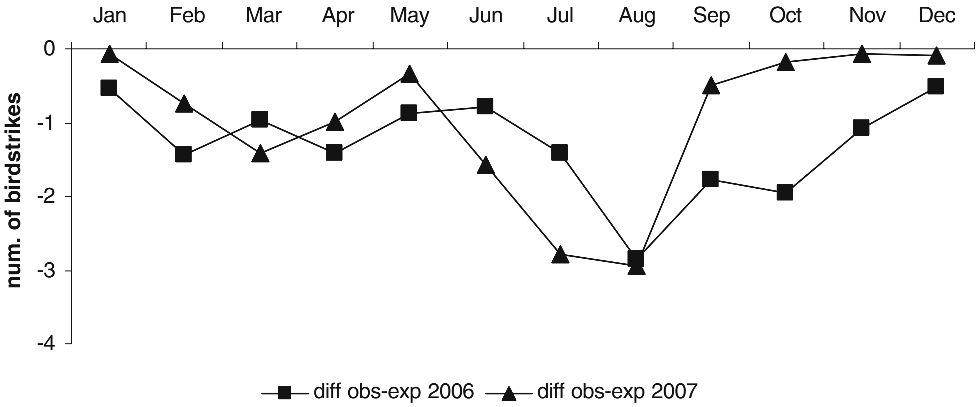


Fig. 5 Differences between the number of birdstrikes recorded (observed) and the number expected according to BRI in 2006 and 2007

thorough analysis of the birdstrike risk. Our results highlighted a seasonal effect of bird presence on birdstrike risk. This effect could be attributed to changes in community composition and birds' mobility influenced by different phases of the biological cycle (i.e. wintering species vs. breeding species). In order to facilitate management decisions, the BRI was also calculated for different spatial sub-units of the airport (runways, take-off and landing areas of runways) and during different times of the day, allowing for dissuasive activities to be targeted at priority areas and periods.

Although our results make it possible to project BRI trends in the future, considering the average bird presence recorded in the area, longer-term data sets would be beneficial for a more robust application of the BRI. From analysing the predictions obtained in the 2 years considered (Fig. 5), it is evident that there was an improvement in the BRI's prediction capability over time. Thus, we expect that with longer data series' of bird abundance, the BRI predictions could be considerably more reliable. The higher number of birdstrikes predicted by the BRI in the summer period is due to our "cautious approach" in defining variables (i.e. EOFmax), while for a longer data series, the median value of EOF would probably be more suitable. If a new species arrives at the airport, such as with translocations etc., the BRI considers the presence of these new species; however, the new species will only have an effect on BRI when there is a collision with an aircraft; or if preferred, data can be borrowed from other airports where the species is present and has had birdstrike events.

Although the BRI is an instrument that indicates the potential risk of birdstrikes, highlighting critical areas and time periods, it does not convey the necessary information to direct wildlife management at an airport. However, one of its components, the GSR, allows the identification of the group of species responsible of such critical factors. From a management standpoint, the critical groups selected according to the higher GSR values could be plotted on a geographical information system in order to evaluate, together with the spatial analysis of the BRI, which are the critical areas and species on which to focus management actions.

National and international authorities (CAA 1998; ENAC 1999; ENAC 2007; FAA 2004) provide standards in airport management, but thresholds requiring management action are usually expressed as a limit above which the airport should take action to further reduce the risk (e.g. 5 impacts/10,000 flights for the Italian standards) (ENAC 2007). Following the example of the Italian authorities' prescription (ENAC 2007), the BRI value corresponding to the provided threshold is 8,000 (calculated for the runway area using average daily presence of birds), but this can be adapted for different countries according to national policies. Based on this value, it is possible to further define thresholds above and below the Italian authorities' limit that would allow a more sensitive definition of the situation. These limits could be defined together with the acceptability of the risk according to a socio-economic evaluation that could be defined by national authorities.

Recent risk assessment studies have proposed mathematical approaches for ranking wildlife hazard levels (Dolbeer et al. 2000) concentrating on the species causing damage (Allan 2006; Blockpoel 1976), economic aspects (Dolbeer et al. 2000; Lovell and Dolbeer 1999) and on species' spatial and temporal distribution analysis (De Fusco et al. 2005; Dolbeer et al. 1997; Fennessy et al. 2005; Leshem et al. 2005). Our study, as many others (Barras et al. 2000; Barras and Dolbeer 2000; Dolbeer et al. 1993; Fennessy et al. 2005; Schafer et al. 2007), was conducted at one airport; however, our findings can be generalised and applied to other airports making it possible to compare results.

In general, there are a number of problems associated with modelling the dynamics of multi-species mixtures. These include measuring and modelling different responses of species to the same environmental conditions or interactions between species. As bird populations within airports are generally maintained at low densities through control, we would expect seasonality and habitat preferences to play a minor role in determining their dynamics. In our study, we found seasonal and habitat effects suggesting the need for implementation of control methods. Hence, the kind of analysis presented in this paper takes a useful step towards analysing the dynamics of bird communities in airports and could be a useful tool for decision makers. Management actions to be undertaken are necessarily related to specific airport situations (e.g. budgets and environmental characteristics) and local laws; thus, defining management actions was beyond the scope of this study.

Our data and approach have allowed us to describe the interaction between different factors that cause birdstrikes and, on this basis, generate predictions of the dynamics within a system and can cope with spatial and temporal variability. In the future, such approaches and models may be capable of generating predictions as to where and under which circumstances to enforce management actions, such as falconry, given the fact that such activities require careful planning in order to avoid habituation (Conomy et al. 1998; Runyan and Blumstein 2004; Soldatini et al. 2008).

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