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A Methodology for Classifying Attractive Sources Related to Airport Birdstrike by Using Geospatial Tools

Domenico Trifilò, Provvidenza Rita D'Urso * and Claudia Arcidiacono

Department of Agriculture, Food and Environment, Building and Land Engineering Section, University of Catania, via Santa Sofia 100, 95123 Catania, Italy; trifilodomenico@gmail.com (D.T.)
* Correspondence: provvidenza.durso@unict.it

Abstract: The urban and rural environment around airport grounds, being an attractive site for wildlife, is subjected to special attention in relation to the risk of wildlife collision with aircrafts according to specific aviation norms. Therefore, investigation into significant attractive sources in airport surroundings is needed to contribute to 'wildlife strike' monitoring in order to activate efficient countermeasures for limitation and control in view of aviation safety while at the same time increasing wildlife protection. On this basis, the study was focused on attractive sites related to the birdstrike hazard in airport surroundings. The methodology described in this paper investigated the spatial distribution characteristics of bird strike influencing factors with an open-access approach to data handling. Remote sensing imagery and open-source GIS tools were utilised to apply suitability analysis to the surfaces involved, such as airport obstacle limitation surfaces, protected areas, vegetation, and water bodies. The methodology was applied to a case study of the airport of Catania, Italy. The results showed that application of geospatial tools to suitability analysis allowed for the identification of areas that have the greatest influence on the birdstrike hazard for aviation. This approach has made it possible to analyse these areas from the point of view of airport safety and the monitoring of ecological areas and corridors of high naturalistic value in order to protect them, providing a contribution toward sustainable management of the birstrike issue.

Keywords: wildlife strike; sustainable management; remote sensing; GIS; overlay analysis

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1. Introduction

Among the hazards for aviation, the risk of wildlife strike, i.e., the collision between wildlife and an aircraft during takeoff and landing, is of relevance for aviation safety. Wildlife hazard management (WHM) related to aviation safety and nature protection is recognised in both civil and military documents, such as those by the ICAO and NATO. According to the ICAO (International Civil Aviation Organisation), in fact, <<The presence of wildlife (birds and other animals) on, or in the vicinity of an aerodrome poses a serious threat to aircraft operational safety>> [1], since approximately 90% of wildlife strikes occur inside or near airports, especially during takeoff and landing [2]. Specifically, the authors of [3] highlighted a study developed in the UK and Canada from 1990 to 2007 where 57% of birdstrikes occurred during takeoff and landing, 39% during climb and approach, about 1% during en-route flight, and 3% during taxi and parking. An FAA report [4] highlighted that the majority (71%) of birdstrikes from 1990 to 2021 occurred at an altitude of about 0–153 m AGL, mostly during the arrival phase (62%) compared to departure (34%). At higher altitudes above 153 m, reported birdstrikes reduced by 32% for each 305 m height increase [4]. Birdlife dispersing methods such as deterrents and repellents at airport grounds have limited efficacy in areas at risk of birdstrike at an altitude below 1000 m [3]. Therefore, mitigation of birdstrike hazards should be expanded beyond airport grounds. On this basis, the ICAO suggests conducting an inventory of wildlife attracting sites within a 13 km circle centred on the ARP (Aerodrome Reference Point) and that particular attention should be paid to sites close to the airfield and the approach and departure corridors.

From an ecological point of view, a reduction in the number of wildlife strikes is a key objective in preventing declines in local wildlife populations. In research studies on birdstrike risk assessment, analysis of the vegetation layer and the presence of water are the main parameters considered in surface analysis, whereas airport area parameters include distance from taxiways and runways, with attractants considered in terms of shelter and food parameters [5]. The structure and composition of the landscape surrounding the airport has a great influence [6]; farmlands, wetlands, and the NDVI have been found to affect bird species number and richness, especially in water birds and herbivorous birds [7]. This kind of spatial and temporal information related to the contribution of habitats in attracting birds could be valuable for airport managers and local authorities when reducing birdstrike hazards by planning specific interventions [8].

On this basis, the methodology described in this paper contributes to investigation of the spatial distribution characteristics of the main significant birdstrike attracting sites (namely those providing shelter, food, and water), including protected areas, in relation to the specific features of obstacle limitation surfaces (OLS) through an open-access approach to data handling. Innovative aspects of the research include the following:

- Study of the relation between aviation hazards and wildlife protection from a sustainability perspective and at the landscape scale;
- Definition of a methodology for localisation and multi-temporal monitoring of the main attractive sources for birdlife in the area around airports based on open-source data and software;
- Analysis of the interaction between airport OLS (obstacle limitation surfaces) and the main areas with high naturalistic value by using geostatistical analyses aimed at the identification of habitats and priority corridors that wildlife is mostly present in terms of dependence on the significant attractive sources.

Application of the proposed methodology could constitute a suitable tool for decision support systems aimed at reducing aviation hazards while also improving aviation sustainability and the efficiency of air traffic management systems and preserving wildlife and ecosystems.

2. Materials and Methods

The proposed methodology includes the following phases:

(1) Acquisition or production of the thematic maps of the surfaces involved in the birdstrike hazard. In this phase, maps of protected areas and other significant attractive sources (e.g., vegetation, water bodies, landfills, and feed industries) should be acquired or produced and georeferenced so that they can be handled by a GIS. Corine Land Cover and Landsat imagery are open data sources available for this purpose. However, the low resolution of these data is a drawback for the intended purpose. Acquisition of remote sensing (RS) imagery would be necessary when production of the thematic map is carried out by performing an automated classification through application of pixel-based or GEOBIA methodologies. In this case, very high resolutions could be achieved by using satellite products having these characteristics. In this study, supervised classification of Copernicus programme RS images (https://land.copernicus.eu/pan-european/high-resolution-layers accessed on 1 October 2022) was carried out and images were compared to ready-to-use high-resolution layers (HRLs) available within the same programme; Copernicus HRLs are 10 m or 20 m resolution maps describing, for instance, grasslands, forests, and water and wetness.

(2) Acquisition or production of OLS (obstacle limitation surfaces) and OFZs (obstacle-free zones), specifically approach surfaces (ASs) with 3D information. In this phase, OLS are overlaid to the urban and rural land around the airport in order to identify the possible birdstrike hazard.

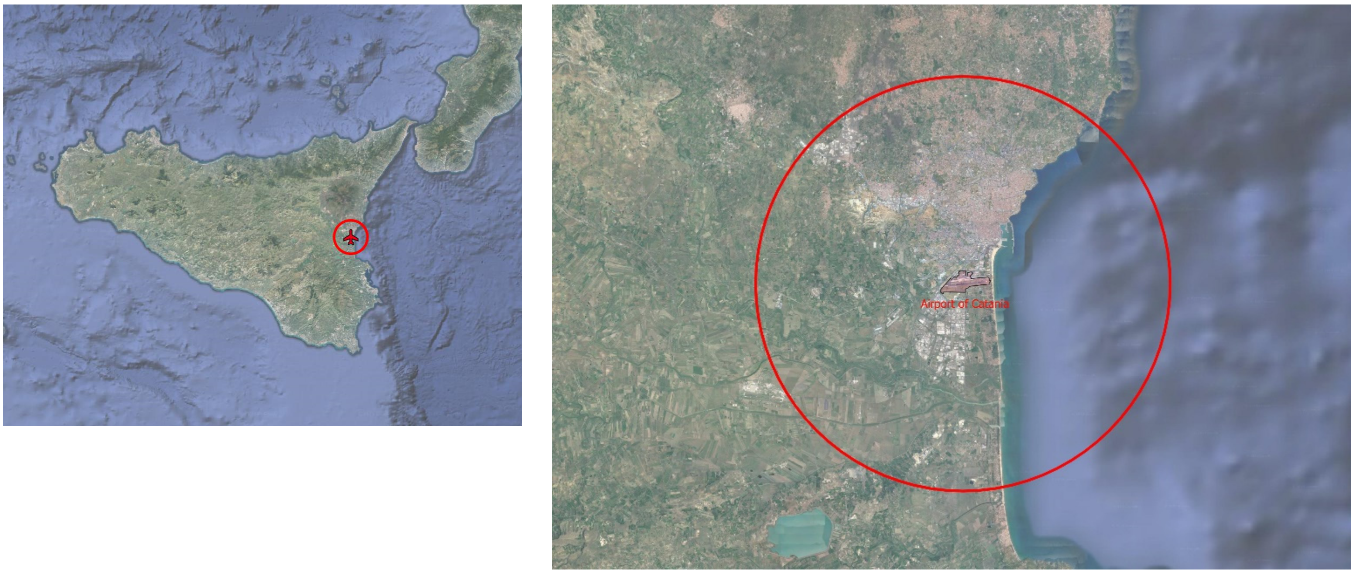
(3) Production of the weighted thematic maps for each data type. In detail, each factor (e.g., distance from the ARP, the type of attractive surface, and OFZs) should be

mapped and then classified by associating suitable values; finally, the maps are overlaid. In detail, the areas at various distance from the ARP were mapped, and weights were then attributed to each one, thus allowing for the production of weighted maps for each factor. Those maps are then overlaid to produce a specific map where the territory is subdivided into a number of areas having a different potential risk of birdstrike. The higher the value, the higher the risk and the lower the suitability of the aircraft route.

(4) Analysis of clusters 360° around the ARP to obtain the potential directions where interactions between birdlife and aircraft are more likely to occur. This is achieved by using GIS tools.

2.1. Case Study of Catania Airport

In this study, the study area was identified in compliance with aviation norms [2] as the area within 13 km of the ARP (Aerodrome Reference Point) of Catania International Airport in Sicily (Italy), which is located south of the Metropolitan City of Catania (Figure 1). This 13 km buffer from the airport encompasses urban and rural areas. Specifically, the city centre of Catania and the villages composing the outer metropolitan area are in the north of the buffer, whereas the rural areas are located in the south and southwest of the buffer; the eastern part of the buffer includes the coastal areas and part of the Ionian Sea.



(**a**) (**b**)

Figure 1. Location of the airport of Catania in Sicily (Italy) (**a**) and the buffer zone extending 13 km from the airport ARP (**b**).

2.2. Production of the Maps of Attracting Sources

The land use data, utilised in this study to produce the maps related to bird-attracting sources, were acquired from the open-source multispectral remote sensing imagery made available within the Copernicus programme. Specifically, in this study, Sentinel-2 data were acquired as multispectral raw data and as high-resolution Layers (HRLs).

Sentinel-2 multispectral raw data were acquired from the Copernicus "Open Access Hub" and then elaborated by applying SNAP 6.0 (Sentinel Application Platform) software made available by the ESA (European Space Agency). In detail, for multi-spectral image handling, the software tools "Sentinel-2 Toolbox", "Sen2Cor", and "Sen2Res" were utilised; the "Sen2Cor" plugin executes the atmospheric correction from BOA (bottom of atmosphere) to TOA (top of atmosphere), thus producing Sentinel-2 Level 2A imagery. Since the multi-spectral images have different spatial resolutions in the different bands, the "Sen2Res" plugin was utilised to make the Sentinel-2 imagery resolution equal to 10 m/pixel while still preserving image reflectance.

In the application of the proposed model, three days representative of the summer period and the autumn and spring migrations (24 June and 27 October 2017 and 17 February 2018) were considered. In these days, the cloud cover in the considered area was almost absent, which allowed for better visibility of the scene and therefore optimised the search for attractive sites. The choice of the three periods in which to carry out the analyses was founded on the literature and on ENAC guidelines, which state that [9] "June and July are the months of the year in which the risk of birdstrike is greatest, given the presence of large numbers of inexperienced birds that have just left their nests. At the end of summer then the young of many species born in spring, such as gulls, are looking for food, and this creates the conditions for large gatherings of animals that often move in groups along the coast line, the shores of lakes and open landfills. The spring migration is concentrated between February and May, the autumn one between the end of August and the end of October".

On the corrected Sentinel images, band combinations made available in SNAP were considered, and supervised classification based on a Maximum Likelihood Classifier (MLC) was applied. The band combinations utilised for this case study were agriculture (bands 11-8-2), shortwave infrared (bands 12-8-4), and geology (bands 2-4-12); from the classified maps showing the highest accuracy measures, the vegetation and surface water layers were extracted.

2.3. Maps of Habitat Areas and Obstacle-Free Zone for GIS Analyses

The GIS project was enriched with naturalistic information besides vegetation and surface water layers for the three days considered in order to support the following analyses on the complex territorial framework. This information included 'Rete Natura 2000 (SIC/ZSC and ZPS)' areas and 'Important Birds Areas—IBAs'. These areas represent protected priority habitats with high naturalistic and faunistic value; their consideration in the model allows for a more objective vision of the examined territory by showing the position of the environments to be protected and their location in relation to both the significant birdlife-attracting sources and the aerodrome.

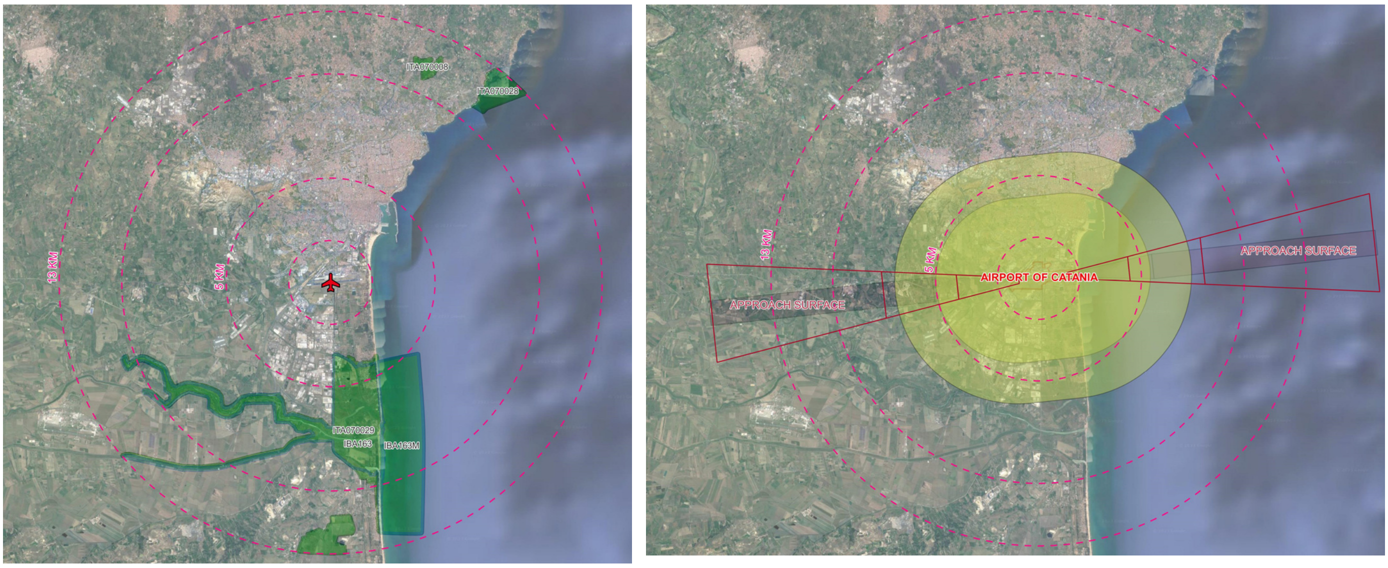
The IBA national inventory was drawn up by the LIPU (Lega Italiana Protezione Uccelli—Italian League for Bird Protection). The first publication of the Italian IBA inventory dates back to 1989, while in 2000 a second updated inventory was published, which was updated in 2016, on the basis of studies on major shearwater carried out between 2008 and 2014 which led to the identification of 4 new Marine IBAs, and subsequently in 2019, in order to solve some discrepancies with the boundaries of the ZPSs and the natural and anthropic elements of the landscape. In the same years, the first and second European IBA inventories were also published. The IBAs are essentially identified on the basis of the fact that they possess at least one of the following characteristics: hosting a significant fraction of populations of rare or threatened species, being part of a type of area that is important for the conservation of particular species (e.g., wetlands), or being an area where a particularly large number of migrating birds are concentrated.

The BirdLife International IBA inventory based on quantitative ornithological criteria was recognised by the European Court of Justice as a scientific tool for the identification of sites to be protected as ZPSs. It therefore represents the reference system in the assessment of the degree of compliance with the Birds Directive in terms of the subject of the designation of ZPSs.

Specifically, within a 13 km radius from the ARP, there are three SICs/ZPSs, namely ITA070008, ITA070028, and ITA070029, which were acquired in shape format. IBA criteria in those areas are A4iii, i.e., the site regularly hosts more than 20,000 water birds or 10,000 pairs of one or more seabird species, and C4, i.e., the site regularly hosts at least 20,000 or at least 10,000 pairs of migratory seabirds.

Bird species of concern in these protected areas include, among others, the Black headed Gull (*Chroicocephalus ridibundus*), Mediterranean Gull (*Ichyaetus melanocephalus*), White Stork (*Ciconia ciconia*), and Marsh Harrier (*Circus aeruginosus*). The criteria for bird species includes C6, i.e., the site is one of the 5 most important in its administrative region for a species or subspecies included in Annex 1 of the Birds Directive (this policy applies if the site contains more than 1% of the national population, and this 1% threshold criterion does not apply to species with less than 100 pairs in Italy).

Furthermore, the main 'obstacle-free zones' (OFZs), besides airport grounds, were uploaded to the GIS project with specific attention to 'approach surfaces' (Figure 2).



(**a**) (**b**)

Figure 2. Habitat areas (Rete Natura 2000 and IBAs) (**a**) and obstacle-free zones (OFZs), i.e., "approach surfaces", "takeoff surface", "outer approach surface", "inner approach surface", "transitional surface", and the runway strip (**b**).

2.4. Factor Definition for the Territorial Areas Apt to Be Naturalistic Corridors at Risk of Birdstrike

The geostatistical analyses in this study have been aimed at better identifying the main naturalistic corridors located in airport surroundings. To this aim, overlay analysis of the territorial areas apt to be naturalistic corridors at risk of birdstrike within OFZs was carried out based on the main surfaces with high naturalistic value, the OFZ surfaces, and the distance from the ARP.

Different weights were attributed to these surfaces in relation to their location, ecological functions, and risk of collision with aircraft in order to produce heatmaps.

Weights were attributed to the areas according to the following selected criteria on factors affecting the aviation hazard:

- Distance from the ARP—the highest risk was assigned to the area inside the airport grounds, and decreasing values were attributed to buffer zones 2, 5, 10, and 13 km from the ARP; the closer to the airport ground, the higher the weight
- Areas with high naturalistic value—a higher risk was associated to attractive sources located in areas having high naturalistic value, i.e., SICs/ZSCs (Sites of Community Importance/Special Conservation Areas), ZPSs (Zones of Special Protection), and IBAs (Important Bird Areas);
- OFZ weight ("approach surface")—a higher risk was recognised for those attractive sources located under the "approach surface". In this study, the takeoff and landing surfaces were not differentiated from the approach surfaces in terms of weights since there were not specific data concerning bird movement height.

Therefore, the suitability approach used in this study considered an increasing weight with distance from the ARP for attractive surfaces (vegetation or water), which increased by 1 for attractive surfaces in areas with high naturalistic value and by 2 for attractive surfaces in areas with high naturalistic value categorised as approach surfaces.

The weights derived from the factors considered and the maximum possible weight for an area (overall weight) are summarised in Table 1 and visualised in Figure 3. In detail, increasing weights were considered at increased distance from the ARP, and an additional weight equal to one was added whenever the point was localised into a surface of high naturalistic value and/or on an approach surface.

Table 1. Weights associated to the factors affecting birdstrike considered in the case study.

Buffer Radius (km)	Distance from ARP Weight	Areas of High Naturalistic Value Additional Weight	Approach Surfaces Additional Weight	Overall Weight
13	1	1	1	**3**
10	2	1	1	**4**
5	3	1	1	**5**
2	4	1	1	**6**
inside the airport grounds	5	1	1	**7**

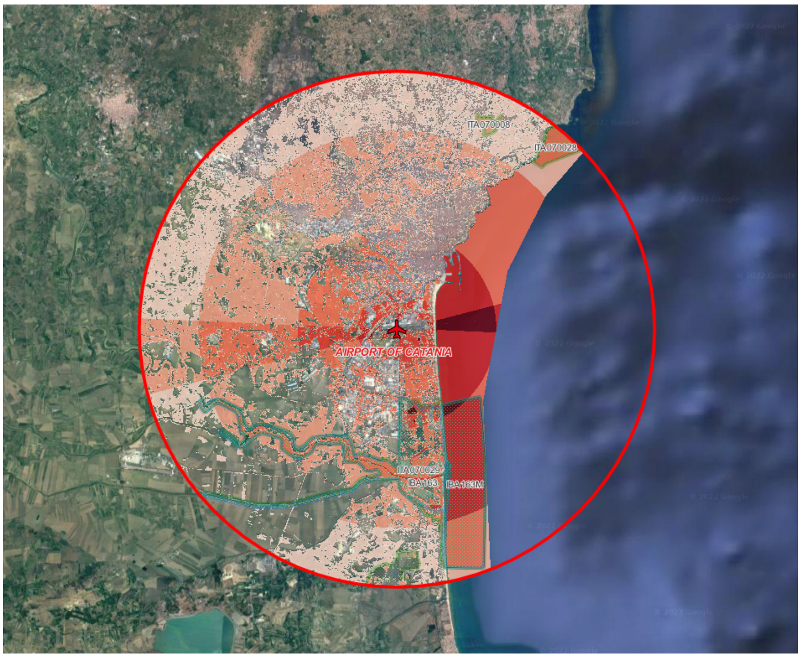


Figure 3. Visualisation of the different surfaces considered in the weight definition (buffers within 13 km from the ARP, approach surfaces, and surfaces of high naturalistic value) and vegetation/water coverage. Areas with darker colours correspond to a higher weight associated to factors affecting birdstrike.

The GIS tools utilised to produce the results encompassed the extraction of centroids from raster pixels, the selection of pixels by position in relation to the defined surfaces, the adding of fields for weights, the use of a field calculator to attribute the weights to the new fields and compute the overall weight, and heatmap production. Moreover, one-way analysis of variance (ANOVA) was applied to statistically assess differences between the weights of attractive surfaces among the different sectors (groups) with a level of significance equal to 0.05. Differences between groups were shown using Tukey's post hoc analysis.

3. Results of Application of the Methodology to the Case Study

The results for the automated classification of vegetation and water surfaces in the different periods considered are reported in Table 2. Those values were compared to the high-resolution layers (HRLs) for 2018, made available by the ESA within the Copernicus programme (https://land.copernicus.eu/pan-european/high-resolution-layers accessed on 1 October 2022). In detail, three layers related to the average coverage in 2018 were acquired: water and wetness (WAW); grassland (GRA), and tree coverage density (TCD).

Table 2. The surfaces of birdlife attractants in summer and migration periods obtained by supervised classification of the 13 km radius area compared with surfaces derived from high-resolution layers (HRLs) provided by the Copernicus programme.

	Summer	**Autumn Migration**	**Spring Migration**
Vegetation cover (km^2) and % over the 13 km area	51.24 (9.7%)	162.41 (30.6%)	212.10 (40.0%)
Surface water (km^2) and % over the 13 km area	179.37 (33.8%)	177.61 (33.5%)	178.42 (33.6%)

Comparison between the produced maps for the different seasons and the HRLs showed that the surface areas of the attractive sources considered (i.e., vegetation and surface water) were moderately underestimated (Table 2). Specifically, WAW was equal to 227.93 km^2 and the summation of GRA (51.36 km^2) and TCD (114. 22 km^2) was 165.58 km^2.

The GIS-based analysis produced a heatmap (Figure 4) where the importance of attractive sources was ranked depending on their location in protected areas and airport OLS, as well as their distance from the ARP. The results obtained from geostatistical analyses of the model highlighted several areas on which to focus attention for the monitoring of attractive sources. The methodology used made it possible to identify the sites most sensitive to the problem investigated with greater precision, outlining the most critical areas.

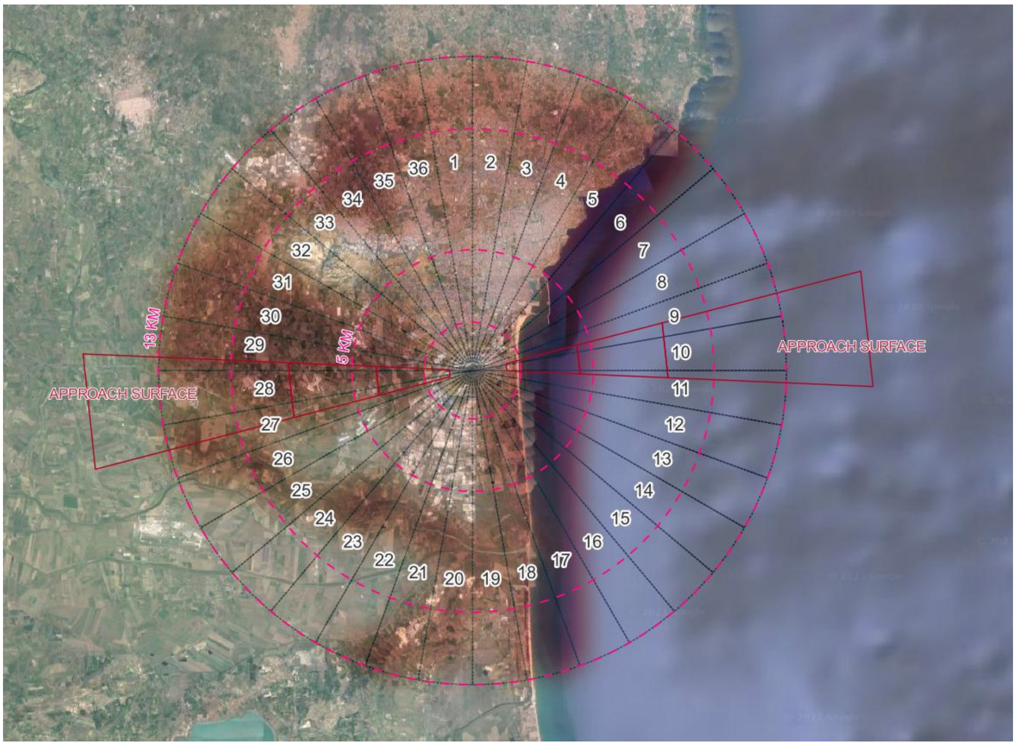


Figure 4. Heatmap of attractive sources for the 13 km study area around the airport of Catania (related to data acquired for autumn migration) and subdivision of the 13 km area into 10-degree sectors.

The computation of weights within sectors at angular steps of 10 degrees on the heatmap (Figure 4) made it possible to detect the most critical areas due to the presence of attractive surfaces. The frequency of the points with different weights for each 10-degree sector is quantified in Figure 5. The overall frequency for each sector is the total number of points related to the attractive surfaces. Based on the results of one-way ANOVA ($p < 0.001$), the average weight provides information on the risk from each 10-degree sector (starting from the north). Tukey's post hoc analysis (Table 3) highlighted the main directions of potential interactions between birdlife and aircraft. The results show that the highest risk of birdstrike in the airport surroundings occurs in sectors 9, 10, and 11, which corresponds to the approach surface close to the sea. Sectors 3 and 4 have the lowest risk since these sectors correspond to urban areas.

Table 3. Results of one-way ANOVA for the overall weights at the different 10-degree sectors moving clockwise starting from the north. Rows with a different letter are significantly different.

Sectors	Mean of the Overall Weighs	Tukey Post Hoc Test
10	3.97	A
11	3.23	B
9	3.17	C
16	3.11	D
12	3.10	D
13	3.09	D
15	3.04	E
14	2.93	F
28	2.83	G
17	2.74	H
8	2.68	I
18	2.49	J
7	2.38	K
23	2.29	L
25	2.27	L
24	2.27	L
19	2.19	M
27	2.18	M
29	2.00	N
26	1.99	N
22	1.97	O
6	1.89	P
20	1.80	Q
33	1.76	R
31	1.76	R
30	1.75	S
34	1.72	T
32	1.72	T
35	1.69	U
5	1.68	U
1	1.66	V
21	1.66	V
2	1.63	W
36	1.63	W
3	1.54	X
4	1.54	X

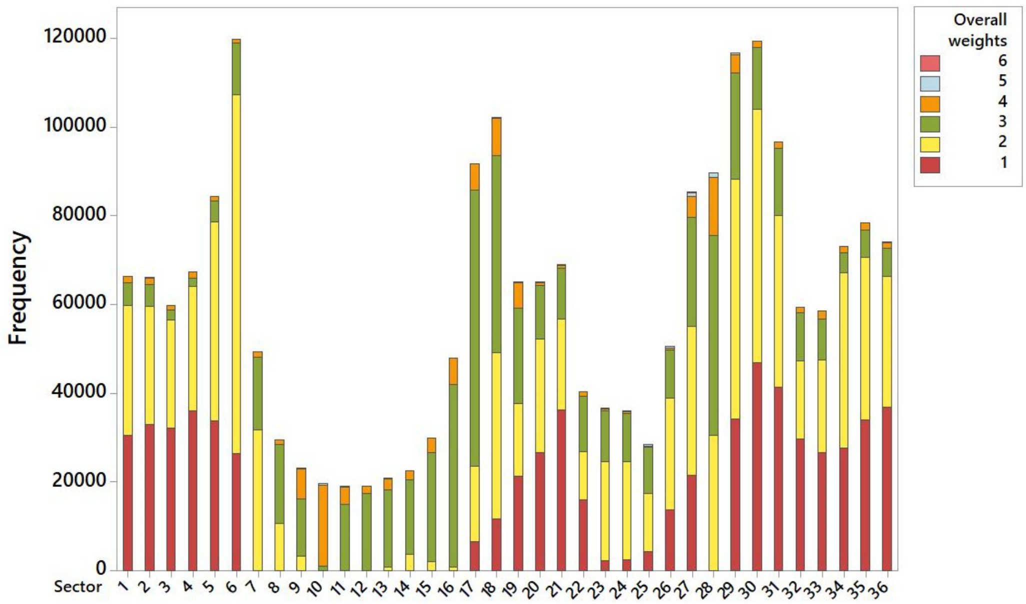


Figure 5. Frequency of points with different weights related to the attractive surfaces in the 10-degree sectors. Each sector represents a 10-degree direction moving clockwise starting from the north.

4. Discussion

The development of a methodology that integrates, through the use of geospatial tools, the sources of attraction for avifauna (mainly identified in the surface waters and vegetation) with sites of high naturalistic value and the main airport surfaces was valuable for the purpose of analysing the distribution of attractive sources for aviation birdstrike. This could be key information for studies investigating interactions between territorial governance and airport safety management [10,11] in view of GIS and BIM interoperability.

The outcomes of this study were achieved through supervised classification of open-access multispectral satellite images that was confirmed to be successful in achieving the required thematic information. In fact, the HRL surfaces were found to be in good accordance with those computed, even when bearing in mind that the HRLs are related to a yearly average. Even with all the limitations, derived mainly from the spatial resolution (10–20 m) of Copernicus data, reliable results were obtained with respect to the use of Corine Land Cover or low-resolution imagery, as also found by other authors [12]. Moreover, it allows localisation and monitoring over time of birdlife-attracting sources. In fact, the temporal resolution of the acquisition system, equal to 5 days, is adequate for the problem, whereas cloudiness or the presence of other particles in the lower atmosphere is a drawback that reduces the number of days suitable for investigation, especially in winter.

The significant vegetation increase from summer to spring migration periods suggests that the risk connected with the existence of habitat corridors couples with spring migration and was intensified in the case study, since the area is situated along a migratory flyway. In fact, when spatial and seasonal variations have been considered in birdstrike in the literature, the risk has been found to be lower in winter compared to spring and autumn migrations [3,13] when agricultural fields and wetlands become favourable sites for wildlife, though in wintering areas the risk could be higher. Moreover, the probability of the presence of birds increases when the distance of land-uses from the airport decreases [8].

The values of weights associated to the factors affecting birdstrike that were considered in the case study were based on distance from the ARP, localisation into a surface of high naturalistic value, and whether or not the area was on an approach surface. Multicriteria analysis could be applied to produce weights that take into account several factors and expert opinions [14], support from Montecarlo analysis [15], and evaluation of the probability of the presence of species [16–19]. Furthermore, in this study, the takeoff and landing surfaces were not differentiated from approach surfaces since there were no specific data available on bird movement height. Further studies could easily consider an additional weight for this height to be included into the overlay analysis.

It should be highlighted though that the IBA concept works very well for species that reach high concentrations in a few sites that are easily identifiable. This is the case for colonial birds and many waterfowl, for example. Other species, conversely, have a widespread distribution (even if perhaps low density) which therefore makes it difficult to identify sites of particular importance for their conservation. This means that a site-by-site approach will not be entirely sufficient to ensure the survival of all species. In fact, complementary approaches are also needed, such as species-specific conservation measures, and above all it is important to guarantee the quality of the environment, even outside of priority areas. A classic example of an environment that hosts many species with a widespread distribution and which requires adequate generalised conservation policies is the agricultural one. Moreover, bird species occurrence and their number vary with the depth and size of water habitats.

Utilisation of GIS software, aimed at strengthening the proposed decision model by adding further land data related to sites of high naturalistic value and the main aviation surfaces of interest, made it possible to exploit the potential of the geostatistical analyses offered by GIS software for improved interpretation of the investigated territory. GIS-based approaches coupled with remote sensing allow risk trends to be identified [5]. The utilisation of georeferenced data specific to the analysed territory, through GIS tools, allowed for more precise analysis to be performed regarding the complexity and unicity of each airport surrounding. Moreover, weighted suitability analyses allowed for the importance attributed to the character of each considered surface to be taken into account when ranking them.

The proposed methodology could be improved by adding specific data on birdlife monitored in the considered areas, as well as data on their daily and seasonal habits besides migration patterns and transfers in the territory. These data can greatly increase our capability to foresee wildlife transfers between habitats and provide more detailed information on the naturalistic corridors utilised by wildlife. However, this kind of information is not always available for airport surroundings [20]. In Italy, the Birdstrike Risk Index (BRI) is computed yearly [21] based on the number of birdstrikes and airport traffic, yet specific surveys on bird presence in the various OLS would be necessary to analyse potential hazards for aviation, as well as airport siting [22]. Specific information for northern Europe and other continents (America and Australia) can be found in surveys carried out during special projects [5,23] or contained in specific databases of civil aviation authorities [3,6], whereas in Italy few studies are based on monitored birdlife [8].

5. Conclusions

The airport wildlife strike hazard draws attention not only to a problem linked to the safety of air travel, but also to the safeguarding of priority habitats in airport surroundings.

This study defines an operational model for sustainable management of the birdstrike problem by providing a geospatial information tool that allows for detailed analysis of the territory surrounding an airport. The proposed methodology uses specific spatial data for each airport infrastructure and can be repeated over time to evaluate the various habitats in the various seasons of the year.

Innovative aspects of the methodology proposed in this study include the combined use of remote sensing and a GIS to perform geospatial analyses. This allowed for the birdstrike issue to be considered from the point of view of landscape characteristics and geographic location, which are two of the main factors affecting it.

Therefore, this study provides stakeholders with a decision tool for wildlife habitat and corridor identification in relation to the detected attractive sources. Through a methodology implementing precise geostatistical analyses, territorial governance is facilitated in actions that limit the presence of wildlife-attracting sources in airport surroundings while at the same time protecting priority habitats for wildlife species. Moreover, the outcomes of this study are of considerable applicative interest to airport managers whose main aim is to protect flight safety. Hazard identification and assessment studies would also profit from the habitat analyses provided. In addition, the open approach applied to the method brings considerable advantages from an economic point of view for its application on a large scale.

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