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Cumulative Effect Quantification of the Spatial Interaction Between Wind Turbines and Birds: A Case Study of Adult White Storks at Eastern Flyway

Pavel Zehtindjiev, Valko Biserkov, Jordan Biserkov, and Nikolay Yordanov
Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Bulgaria

Abstract: The strong demand for energy pushes governments to find solutions in new technologies such as wind power. It is generally considered green, but many aspects of wind power impacts on biodiversity need deeper understanding. In the same time high tech GPS tracking of birds and available public data allow evaluation of spatial interactions between birds and wind farms. In or study we use public resources in order to evaluate cumulative effect of wind turbines on migratory bird species — white stork. White storks are typical soaring birds which use up going thermal air slows for initial start of soaring flights. The species forms flocks up to 15000 individuals during seasonal migrations between Europe and Africa. Therefore, the white storks are used in our study as model species for evaluation of impact on potentially all soaring birds with similar behaviour at migration. The polygon of our study area covers a part of the Eastern fly way of white storks. In our analysis, we consider all 22,885 wind turbines and all 1,207,130 locations of white storks tracked by GPS devices in the area. We obtain 605,609 target points after processing the total of 1,207,130 points in the target territory. According to our results the main component for cumulative impact is density of wind turbines. Our results indicate avoidance of the territories with over 6 turbines per square kilometres and negligee effect of turbines when the density is lower. We provide a new quantitative instrument for calculation of the cumulative consequences of wind power development in large territories and demonstrate how it can be applied for evaluation of impact in respect to location and density of turbines along the Eastern flyway of white storks.

Key words: wind farm, bird migration, barrier effect, displacement

1. Introduction

Climate change is predicted to harm bird populations by affecting breeding or migration patterns and altering their habitats [1, 2]. There is an urgent need for alternative non-carbon-based energy production, and one rapidly developing technology in this field is the generation of electricity from wind power.

The strong dependence of Eastern Europe on coal, gas and petrol has resulted in delays in the development of alternative resources for electricity production in this region. The slow development of renewable energy usage in Eastern Europe is partly due to a lack of knowledge regarding the effect of wind turbines on birds, which is often used for complaints against renewable energy development in this geopolitical region (for example in a court case against Bulgaria: Court of Justice of the European Union 2016).

Wind power generation has increased over the last decades and this growth is expected to continue in the forthcoming years, with a predicted annual increase of 5% until 2020 [3, 4].

Soaring flight is a characteristic of the ecological group of large birds, allowing them to travel over long distances with reduced energy costs [5, 6]. However, soaring depends on updrafts, which are relatively scarce and scattered across the landscape [7, 8]. The main limiting factor for soaring flight is thermal uplift formed during the daytime due to the heating of the

Corresponding author: Pavel Zehtindjiev, Ph.D., Professor; research areas: evolutionary biology, biodiversity conservation, bird migration. E-mail: pavel.zehtindjiev@gmail.com.

land surface by solar radiation [9]. This is also the reason why soaring birds are not able to travel over open bodies of water.

Throughout the last century, birds have been affected by different kinds of disturbances and impacts resulting from man-made structures such as highways [10], power lines [10-12], radio and television towers [13-15], wind farms [16, 17] and glass windows [18, 19], and from human activities such as poisoning [20] or other more direct forms of persecution [21].

Collision mortality is only one of several potential impacts of wind farms on birds. If flying birds are displaced from the airspace in, around or over a wind farm, then their movements may be prevented or additional energy may be required to fly further to avoid the wind farm's airspace — the so-called "barrier effect".

A barrier, by definition, is a tangible (e.g., wind facility) or an intangible (e.g., radiation or infrasound) disturbance that restricts the free movement, mingling, or interbreeding of individuals or populations of a species (Merriam-Webster Online Dictionary). The barrier effect is thus an important consideration to address when locating and designing wind farm facilities.

The barrier effect has been well documented in several offshore wind parks [22-27], where macro-avoidance behaviours by various bird species have been recorded at distances of between approximately 330 feet and 1.9 mi from turbine arrays [22, 28, 29]. Some reports even show avoidance of up to 2.5 mi by several waterbirds [30]. Barrier effects from land-based wind energy developments have been less frequently observed, but some instances have been documented. In a four-year monitoring programme of six land-based wind facilities in the Beauce region of France, preliminary results showed that 70-99% of migrating birds changed path a few hundred yards out to avoid the facilities, especially where turbines were densely clustered (European Commission [EC], 2010).

According to Masden E. A. et al. (2009, 2010) [31, 32], the barrier effect occurs when birds are forced to increase their energy usage to circumvent the turbine area. The level of impact of barrier effects may vary dependent on species presence, turbine layout, wind facility size, season, and the birds' ability to compensate for energy losses [33]. Some studies have reported that a barrier created by a wind farm between breeding and feeding areas may have a particularly significant impact [33-35]. In contrast, Masden E. A. et al. (2010) [32] show that potential adverse effects on breeding seabirds' energy budgets are far greater than for migrating seabirds, because the distance involved in avoiding a wind farm represents a larger proportion of the overall distance travelled on each of their flights, and such flights are repeated very frequently during the course of a breeding season. The theoretical level of impact varies between species due to differences in morphology and flight mode.

The combined barrier effect of multiple adjoining wind facilities is also a concern as wind energy development becomes more prevalent [34]. It is likely that this will be less of a potential issue for migrating birds than for breeding birds, but the cumulative effect of increasing numbers of turbines must be evaluated according to the relevant EC Environmental Impact Assessment (EIA) (reference to the directives).

The impacts of wind turbines, including the barrier effect, can be localised and may not occur at every site [35]. Therefore, turbine layout and facility location should be evaluated on a site-specific basis by experienced wildlife biologists on the basis of available information regarding local and migratory bird and bat species in, around or passing through the proposed site, in order to ensure that any possible barrier effects are minimised or avoided.

The long-term impacts of these barrier effects are still uncertain, and further research is needed to address this issue [35]. However, given the mounting evidence of such macro-avoidance effects resulting from development of both on- and offshore wind power facilities, and the possibility of population effects over time [34], wind energy developers need to assess the potential impacts on species prior to and following development. Knowledge of spatial distribution of birds is a vital resource for answering many fundamental questions regarding evolutionary ecology and ornithology, as well as for identifying practical solutions.

Here, we provide a new quantitative instrument for calculation of the cumulative consequences of wind power development in large territories and demonstrate how it can be applied for evaluation of impact in respect to location and density of turbines along the Eastern flyway of white storks.

2. Materials and Methods

2.1 Study Area

The polygon of our study area covers a part of the Eastern fly way of white storks. In our analysis, we consider all 22,885 wind turbines and all 1,207,130 locations of white storks tracked by GPS devices in the area, as described in Fig. 1. Technical details about the GPS devices and the period of the study have also been previously published [36]. Data regarding the number of turbines and their coordinates are obtained from OpenStreetMap®, provided under the Open Data Commons Open Database License (ODbL) by the OpenStreetMap Foundation (OSMF).

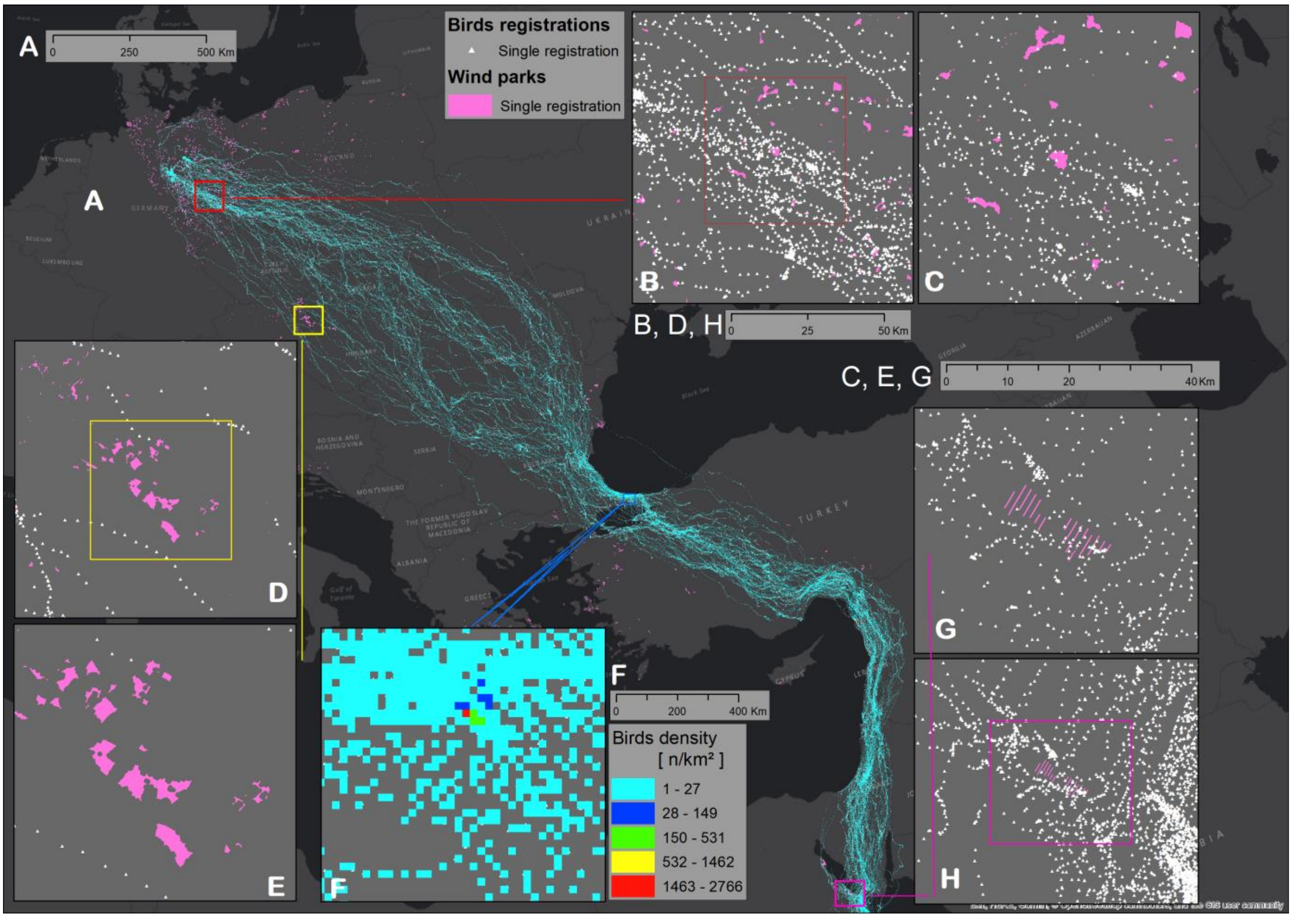

Fig. 1 Study area and examples of investigated wind farms.

2.2 Number of GPS Positions and Processing Details

We obtain 605,609 target points after processing the total of 1,207,130 points in the target territory. The remaining 139,597 points are excluded from the analysis based on technical reasons, mainly due to our upper limit of acceptable change in height of 2 metres/sec (600 metres in five minutes — the interval between records). Higher values are replaced by the average of their two adjacent points. In a “block” of consecutive anomalies, the values are replaced by a smooth transition between the neighbouring block’s normal values.

2.3 Obtaining Accurate Figures for Above-Sea-Level Altitudes of Birds

Surface data are relative to the geoid model of the Earth and GPS bird height (column height) is relative to the Earth’s ellipsoidal model. To compare the two heights, that of the bird is converted to the geoid as follows.

In the Geoidal_separation column, we take the value of the space difference between geoid and ellipsoid from the raster include with ArcGIS (\ArcGIS\Desktop10.6\ pedata\geoid\WGS84.img). In the column true_height = [height] - [Geoidal_separation]

2.4 Calculation of the Height of Birds Over the Terrain

For the real altitude of birds over the terrain, we use the recommended calculations given in e-obs GPS-Tags WGS84-Height Application Note and maps from the Global Topographic 30 Arc-Second Digital Elevation Model (released 1996), available at https://earthexplorer.usgs.gov/Datasets.

An upper limit of acceptable change in height of 2 metres/sec (600 metres in five minutes — the interval between records) is applied. Higher values are replaced by the average of their two adjacent points. In a “block” of consecutive anomalies, the values are replaced by a smooth transition between the neighbouring block’s normal values.

2.5 Calculation of Flight Direction

For calculation of the flight direction the following procedure for transformation of consecutive points into flight direction of tracked birds has been applied[1].

The following transformation of obtained results into North-based angular directions were performed:

Select by attribute: DirectionJB < 0

Calculate field DirectionJB = 360 + DirectionJB

Clear selection

Calculate field DirectionJB = (360 – DirectionJB + 90)%360

2.6 Definition of Single Turbines and Wind Farms

We have selected a buffer of 500 meters for a distance between turbines as critical for groups or single turbine definition. The Buffer around the group of turbines defined as Wind Park is 80 meters (20 meters: Windparks with an 80-meter (500 + -420) buffer zone from the final turbines).

For the analysis’ of the impact of wind turbines we have selected three types of territories:

- Territories where wind parks are present
- Territories neighbor to wind parks
- Territories away from wind parks

2.7 Statistical Methods

Standard statistical methods for comparison of mean altitudes of flight and density of flying white storks are applied. Directionality of birds has been analyzed with circular statistics software Oriana[2]

3. Results

3.1 Density of Birds and Wind Turbines

We have discovered variation of wind turbine density in respect to migratory flow of adult white storks in spring migration along the Eastern flyway. The density of wind turbines in specific locations varied between 0 and 20 per km^2.

[1] Available online at: https://community.esri.com/blogs/dan_patterson/2016/09/01/distance-calculations-using-the-field-calculator, Angle between consecutive points.

[2] Available online at: https://www.kovcomp.co.uk/oriana/index.html.

3.2 Density of Bird Flights in Respect to Number of Wind Turbines

The number of white storks registrations in 300 m above the terrain as well as the birds flying lower 300 m over the areas with wind turbines was significantly lower than the number of storks flying over the areas without turbines (Fig. 2).

3.3 Altitude of Birds in Respect to Turbine Density

We have not observed any change in the altitude of birds flying over 300 m above the terrain in the areas with wind farms in comparison with the areas without wind turbines.

Birds flying in altitudes up to 300 m above the ground level have increased the altitude in the vicinity of wind farms. The observed increase was gradual and dependent on the density of the turbines at the ground. (Fig. 3).

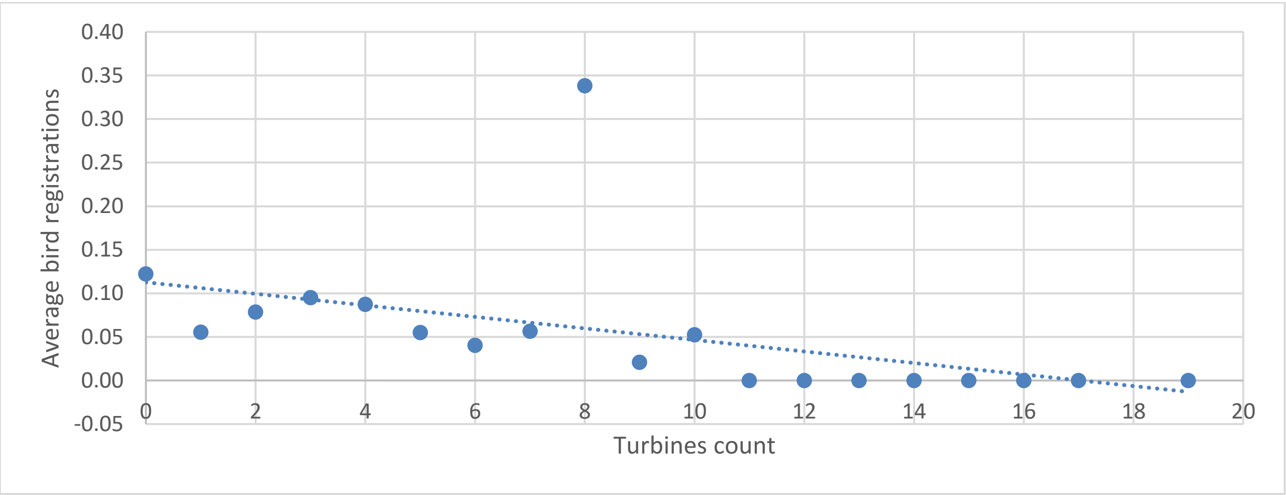

Fig. 2 Pattern of established number of birds and turbine density along the eastern flyway of white storks.

Table 1 Average density of flying White storks.

Flight altitude above the ground	Average number of birds in km^2	
	With Turbines	Without Turbines
< 300 m	**0.07**	**0.12**
All	**0.11**	**0.16**

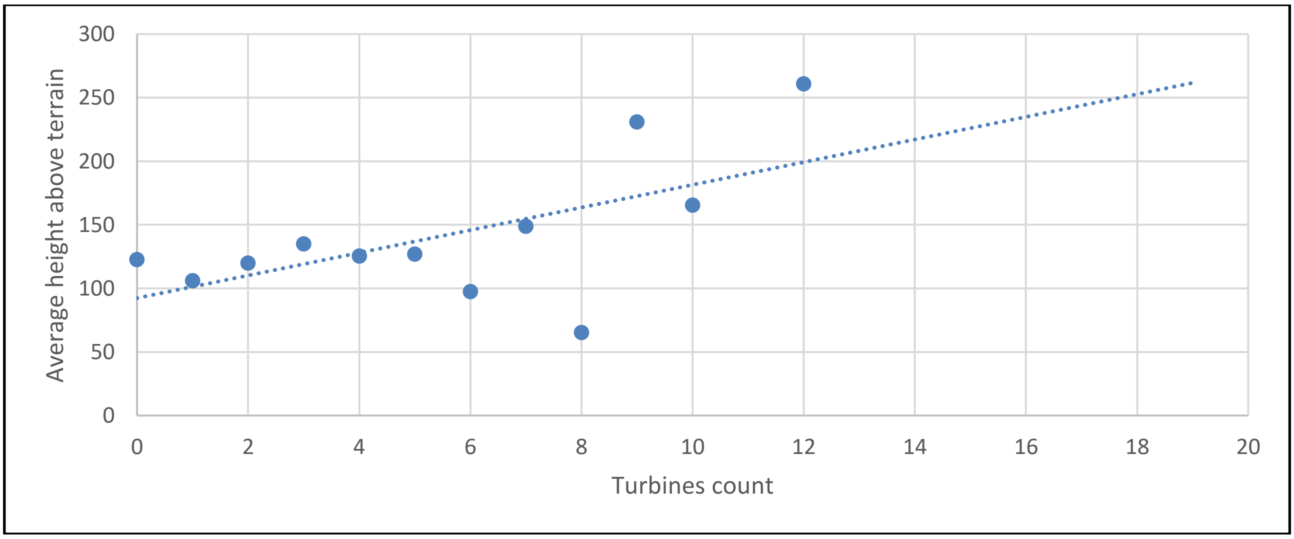

Fig. 3 Trend of the dependence between turbine density and mean flight height.

We have used 266 stork tracks near Wind turbines. The average distance to the nearest turbine was 385 m (min = 26 m, max = 1171 m, std = 233). There are four registrations of flying white Storks in less than 50 m distance from the wind turbine although we do not know if the rotor of the turbine was rotating or not.

3.4 The Direction of Flights

Fig. 4 shows the distribution of flight directions of migrating white storks in respect to wind farm territories in two main stages of spring migration. Details of the sample size and statistical significance are given in Table 2.

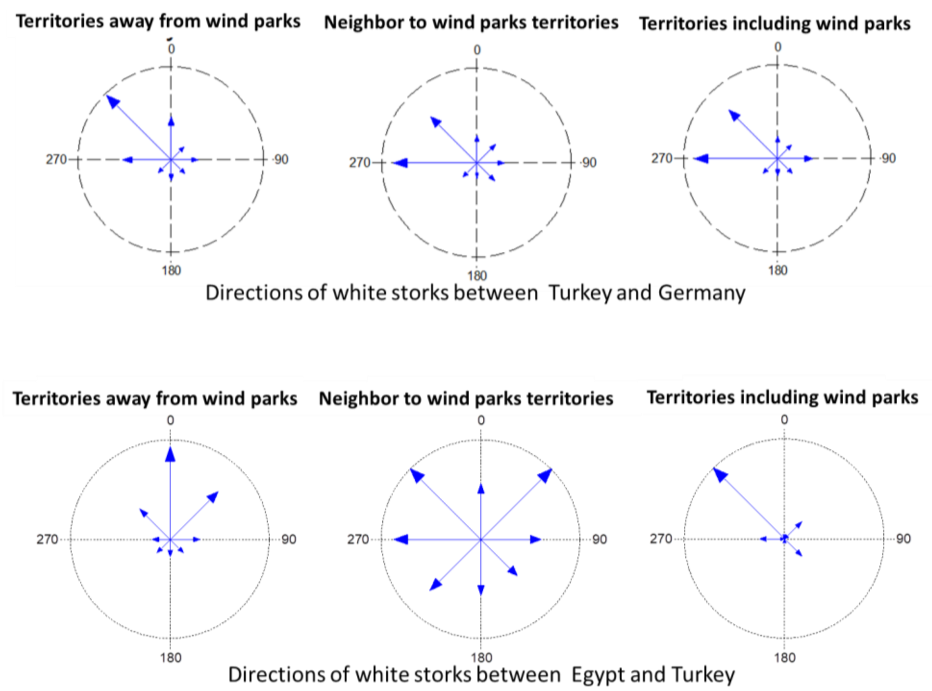

Fig. 4 The direction of flights.

Table 2 Basic statistics for the circular distribution of observed flight directions of white storks.

Variable	Turkey – Germany away from WP	Turkey – Germany Neighbour to WP	Turkey – Germany Territories including WP	Egypt-Turkey away from WP	Egypt-Turkey Neighbour to WP	Egypt-Turkey Territories including WP
Number of Observations	921	921	921	921	146	7
Mean Vector (μ)	314 °	300 °	296 °	13 °	318 °	318 °
Length of Mean Vector (r)	0,363	0.321	0.333	0.446	0,134	0.561
Median	312 °	293 °	292 °	14 °	306 °	307 °
Concentration	0.7	0.6	0.7	0,9	0,2	1,1
Circular Variance	0.6	0.6	0.6	0,5	0,8	0,4
Circular Standard Deviation	81 °	86 °	85 °	72 °	114 °	61 °
Standard Error of Mean	3 °	4 °	3 °	2 °	24 °	26 °
95% Confidence Interval (-/+) for μ	307 °	292 °	288 °	8 °	269 °	265 °
	321 °	307 °	303 °	19 °	6 °	11 °
99% Confidence Interval (-/+) for μ	305 °	289 °	286 °	6 °	254 °	248 °
	323 °	310 °	306 °	20 °	22 °	27 °
Rayleigh Test (Z)	121.22	94.655	101.89	182.8	2.633	2.204

4. Discussion

For the first time we have quantified cumulative impact of wind turbines in a large area on the soaring birds migrating along the eastern flyway. We have observed decrease of birds over the areas with increasing number of turbines as well as increase of the flight altitudes over dense turbine areas. Our results show clear increase of the effect when the turbine density reaches 8 per km$^{2.}$ (Fig. 5). The observed impact was highly significant in flights under 300 m above the terrain.

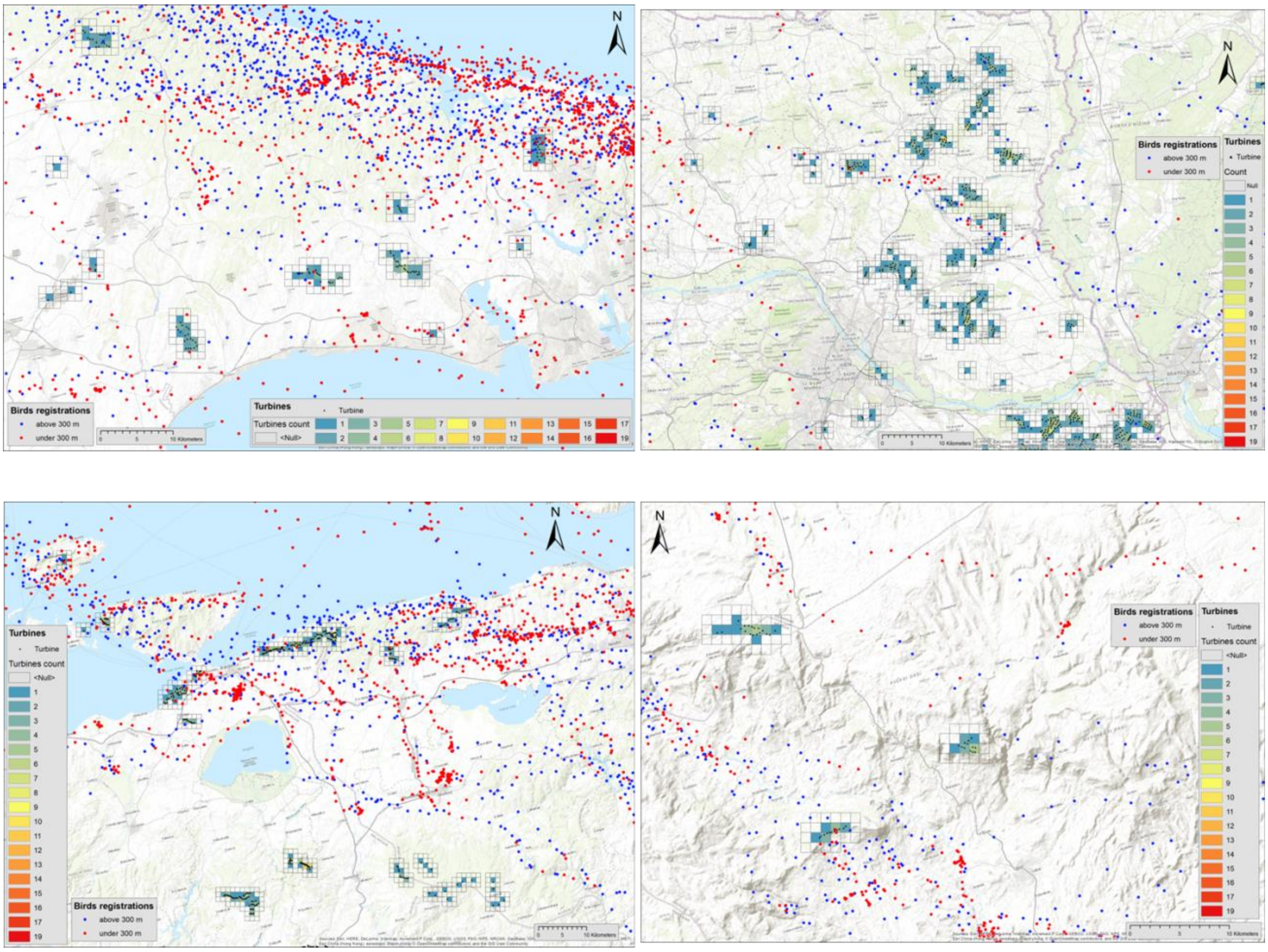

Fig. 5 Examples of bird number in different geographic regions.

Despite the obvious differences in the turbine densities the number of the migrating white Storks in spring varied by geographic regions with no obvious correlation to the number of turbines. The number of storks per km land was highly associated with the land surface along the migratory flow.

To demonstrate the difference in use of airspace over the territory of the wind farms and beyond their border area, the areas are represented in 1×1 km ETRS grid for both the HR and the border area.

Based on this grid, the turbine density [number/km^2] and the density of the GPS locations of birds [number/km^2] were calculated.

In the case of migrating storks along the Eastern migratory fly way, existing wind farms appear as an obstacle, but do not seem to have a significant barrier effect. The storks avoid wind farms with the necessary precision and find precise multivariate solutions for the passage through territories, even at a high density of the turbines per unit area, as is in Germany, and some parts of the territory of Austria and Egypt.

When the flight direction has been added to the impact assessment we have observed a slight increase of the scatter in closer distance to the wind turbines. In majority of wind farms the observed deviation seems to happen in distance less than 1km from the wind farm. The deviation from the main vector of spring migration is likely common behaviour in order to of avoid the direct collision and does not indicate large scale displacement from the territories with wind farms indicated as barrier effect in the literature (References).

Despite of the general patterns discovered in our study the observed effect of wind farms on soaring birds like white storks seems highly variable in real environmental conditions and obviously depends on a complex of physical features as well as topography of the terrain.

In order to see what are the environmental factors impacting estimation of wind farm turbines on soaring birds we have tried to consider all available examples of situated along Eastern fly way of soaring birds wind farms.

The main factor for the correct evaluation of cumulative impact based on the density of turbines is the proportion of the land and open water surface at certain stage of bird migration. In the large terrestrial part of the eastern flyway — the continental part of the migratory flow we observe mainly avoidance of the mountains and wide front of migration in the lowland of Europe (Fig. 6).

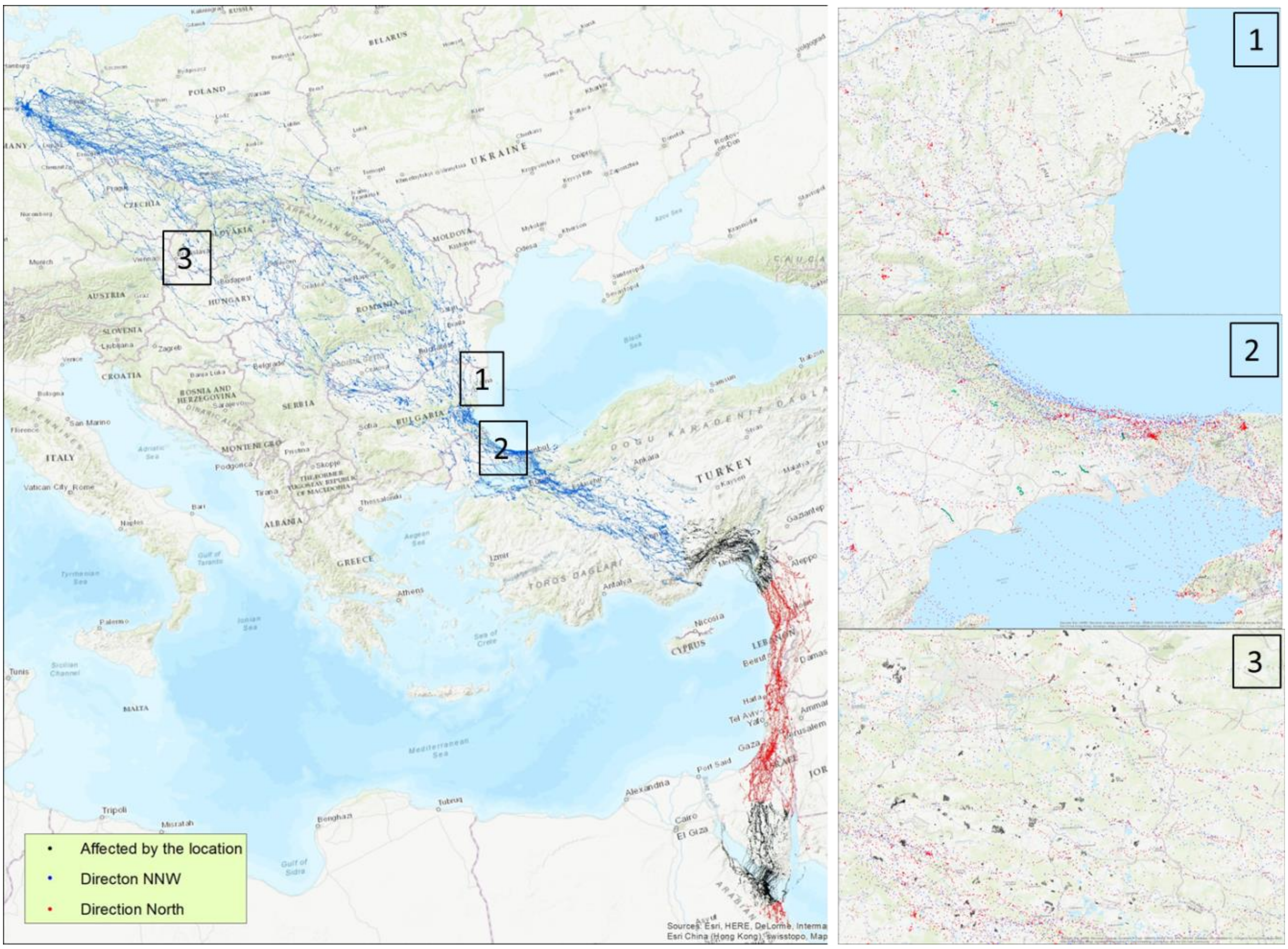

Fig. 6 Distribution of migrating white storks in respect to wide land and open water bodies along the eastern fly way.

The wide land territories of Eastern Europe provide opportunities for the migrating white storks for opportunistic behaviour when they have to choose directions and probably most suitable winds while the narrow front closer to the Bosporus has been indicated as bottleneck of migrating soaring birds (Fig. 7 Monograph of white stork migration 2012, References). Soaring white storks tend to avoid the open water and therefore close distance to the sea coast (Fig. 7(1)). In case where no choice exists, and birds have to pass in narrow land bridges the effect of topography is probably stronger and results in observed concentration of birds.

In our study we propose a quantitative limit of the wind turbines which can be considered critical for the decision of white storks to migrate through or circumvent the area with wind turbines. The effect of density we have quantified is observed in both narrow bottleneck territories as well as in the large flat areas along the Eastern Flyway (Fig. 8). Therefore, it can be a measurement applied in the future Environmental Impact Assessments when the cumulative impact of all projects in a certain territory must be considered.

Fig. 7 Distribution of migrating white storks in respect to wide land and open water bodies along the eastern fly way.

Although white storks are model species for the group of soaring birds there are many raptor species which migrate in much smaller flocks or separated. For all the soaring birds we need urgently more information in order to quantify all spatial interactions between birds and wind turbines. Our results also indicate strong power of satellite and GSM tracking data obtained in last decades. We would strongly recommend new projects in collaboration between wind power energy sector and conservation policy makers to be performed with more target bird species in order to estimate quantitative limits of turbine densities for the rest of migrating birds.

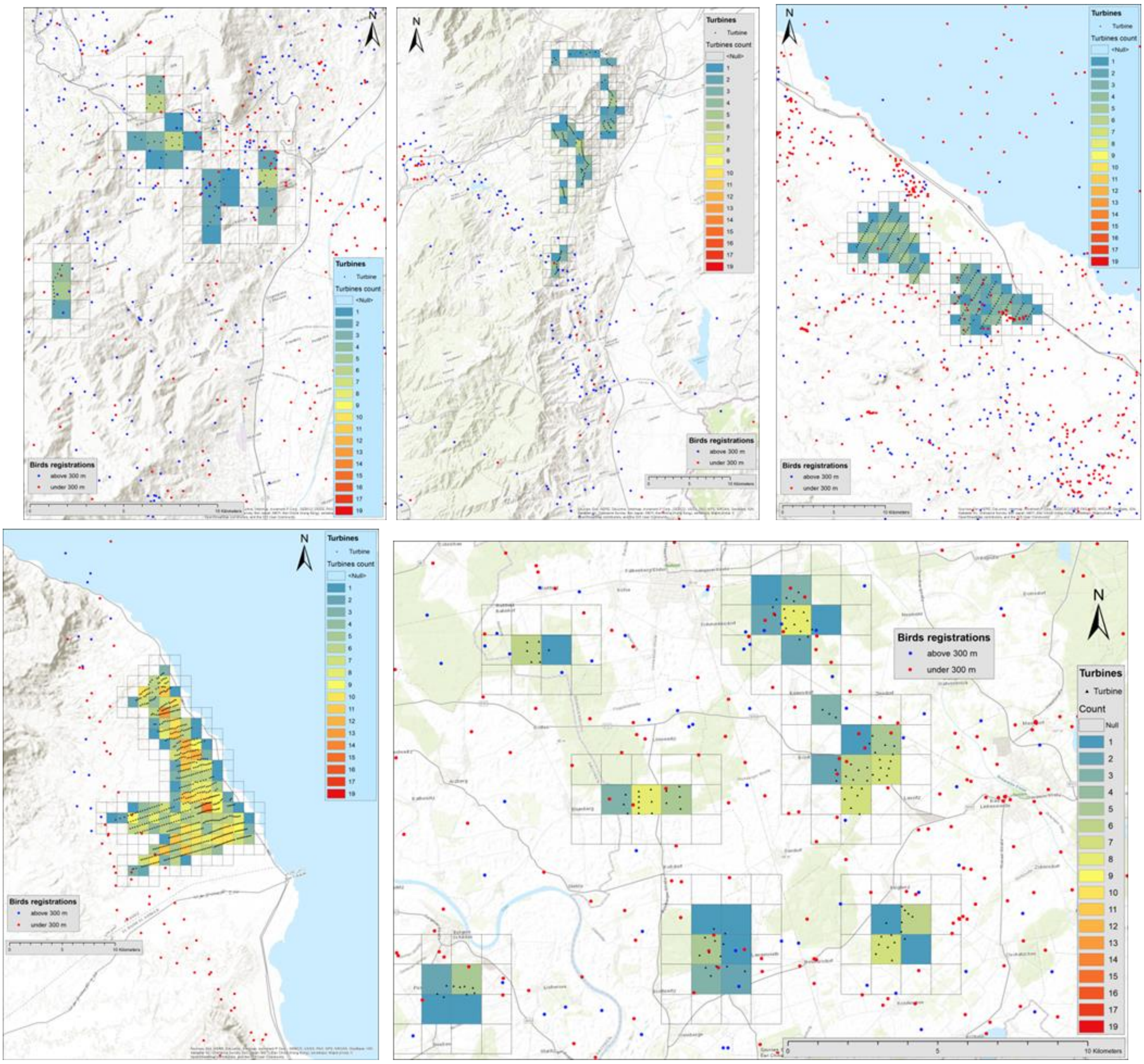

Fig. 8 Examples of varying wind turbine density per km^2 established in this study.

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