CHAPTER 17

ASSESSMENT OF THE CUMULATIVE IMPACT OF WIND STATIONS ON SEASONAL BIRD COMPLEXES WITHIN THE BOUNDARIES OF MAN-MADE TERRITORIES OF THE NORTHWESTERN AZOV REGION

Sydorenko Andrii
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INTRODUCTION

Bird migration corridors are among the most important ecological components to be considered during the planning and operation of wind energy facilities. Although wind power plays a key role in reducing greenhouse gas emissions and supporting the transition to renewable energy, poorly sited wind farms may adversely affect birds through collision mortality, habitat displacement, and barrier effects. Consequently, understanding the spatial and temporal characteristics of bird migration is essential for minimizing environmental impacts while ensuring sustainable wind energy development.

The Azov–Black Sea region of Ukraine represents one of the major migratory systems in Eastern Europe, forming part of the Adriatic–Black Sea flyway that connects breeding grounds across northern Eurasia with wintering areas in the Mediterranean Basin and Africa. Every year, millions of birds belonging to a wide range of ecological groups, including water birds, raptors, and passerines, pass through this region during seasonal migrations. However, migration intensity is spatially heterogeneous and largely determined by the distribution of coastal habitats, estuaries, river valleys, and suitable stopover sites[1].

The Zaporizhzhia Wind Farm is located within the Molochna–Korsak interfluve, adjacent to the Azov–Black Sea coastal ecological corridor. Although this region lies close to one of Eastern Europe's principal migration flyways, the actual distribution of migration routes and stopover areas at the local scale

[1] Sydorenko A. I., Gorlov P. I., Siokhin V. D. Assessment of the impact of technogenic monitoring sites on seasonal migration ornithocomplexes. *IOP Conference Series: Earth and Environmental Science*. 2022. Vol. 1049, No. 1. Art. 012060. DOI: https://doi.org/10.1088/1755-1315/1049/1/012060.

requires detailed assessment to evaluate potential interactions between birds and wind energy infrastructure. Such information is particularly important for estimating collision risk, barrier effects, and cumulative impacts associated with existing and planned wind farms.

This study evaluates the ornithological significance of the Zaporizhzhia Wind Farm area using long-term (2007–2022) field observations, migration surveys, and collision risk assessment. Particular attention is given to the spatial organization of seasonal migration, the identification of key stopover habitats, flight altitude distributions, and the potential cumulative effects of multiple wind farms operating within the region. The results provide a scientific basis for assessing the compatibility of wind energy development with bird conservation and contribute to evidence-based environmental management within one of the most important migratory regions of Eastern Europe.

1. Migration Corridors within the Zaporizhzhia Wind Farm Area

The Zaporizhzhia Wind Farm (WPP) is located within the Molochna–Korsak interfluve, which forms part of one of the most important avian migration flyways in Eastern Europe–the Azov–Black Sea (Southern) Flyway. The significance of this migration route has been recognized since the late nineteenth century. It connects northern Africa and the Mediterranean Basin with southeastern Europe, western Siberia, and Kazakhstan through the seasonal movements of millions of migratory birds (Fig. 1).

More comprehensive ornithological studies conducted during the first half of the twentieth century identified two additional major migration routes across the territory of Ukraine. One of these, the Polissia Flyway, extends latitudinally across northern Ukraine and links the Pannonian Plain of Central Europe with the northern regions of Eurasia. The second route, oriented predominantly in a meridional direction, follows the floodplain of the Dnipro River, connecting the Azov–Black Sea Flyway with the Polissia Flyway. This corridor is used annually, primarily during spring migration, by several bird populations moving towards northern Eurasia[2].

In addition to these three principal flyways, several secondary meridional migration corridors exist, most of which follow the valleys of large and medium-sized rivers where suitable habitats provide opportunities for stopovers, allowing birds to replenish energy reserves or shelter during adverse weather conditions. The only major meridional corridor not associated with river valleys

[2] Черничко Й. І. Значення Азово-Чорноморського узбережжя України в підтримці внутрішньоматерикових міграційних шляхів куликів у Східній Європі. Частина 1. Особливості розміщення та міграції. *Вісник зоології. Монографічна серія.* Окремий випуск № 33. Київ, 2015. 120 с.

is the Bosporus Flyway. This route is used predominantly by water birds, birds of prey, and several other taxa migrating from the Anatolian Peninsula across the Black Sea to Crimea, where it merges with the Azov–Black Sea Flyway[3].

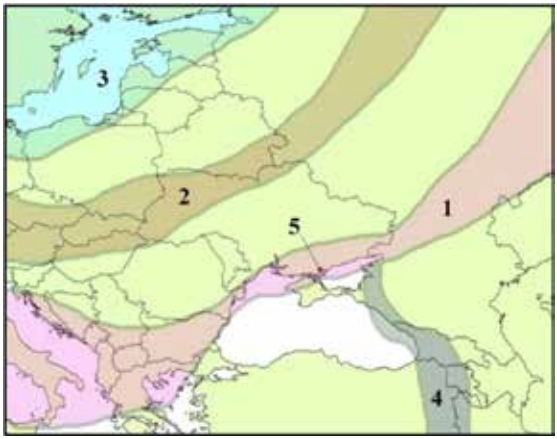

Fig. 1. Principal migration flyways of Eastern Europe: (1) the Azov–Black Sea Flyway as part of the larger Adriatic–Black Sea Flyway; (2) the Polissia Flyway within the Central European–Siberian migration corridor; (3) the Baltic migration corridor forming part of the East Atlantic Flyway; (4) the eastern branch of the Black Sea–Mediterranean Flyway, including the Don–Caucasian migration corridor; (5) the Zaporizhzhia Wind Farm

Consequently, the spatial configuration of major flyways and subsidiary migration corridors is highly complex, as illustrated schematically in Fig. 2.

For the conservation of migratory birds, particularly water birds, an accurate understanding of the spatial organization of seasonal migration routes is essential during the planning and development of wind energy projects.

The widespread occurrence of birds across virtually all inland and especially coastal landscapes has led some researchers to question the existence of clearly defined migration corridors. When bird occurrence is considered without reference to species abundance, encounter frequency, or landscape characteristics, such an interpretation may appear plausible.

[3] Черничко Й. І. Значення Азово-Чорноморського узбережжя України в підтримці внутрішньоматерикових міграційних шляхів куликів у Східній Європі. Частина 2. Біологічні та популяційні особливості міграцій окремих видів, міграційні шляхи та їх структура. *Вісник зоології. Монографічна серія*. Окремий випуск № 33. Київ, 2016. 258 с.

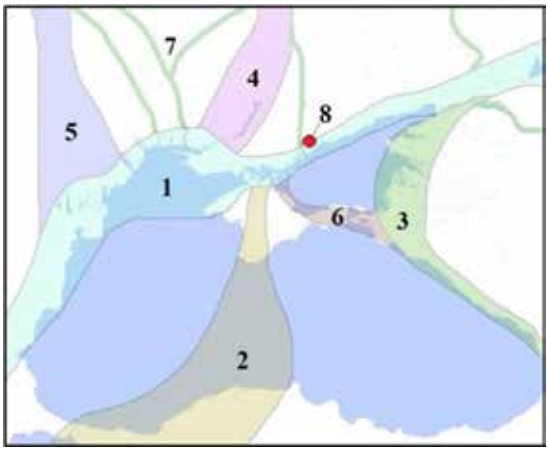

Fig. 2. Principal migration routes of southern Ukraine: (1) Azov–Black Sea; (2) Crimean–Bosporus; (3) Don–Caucasian; (4) Dnipro–Meshchera; (5) Prut–Dnister; (6) Taman; (7) secondary migration corridors following river channels (shown in a common colour); (8) the Zaporizhzhia Wind Farm

However, extensive ornithological investigations conducted during recent decades, covering large geographical regions and employing quantitative analyses of migration intensity, have demonstrated that exceptionally high concentrations of migrating birds occur only within specific geographical areas.

These findings have stimulated several hypotheses concerning the formation of migration corridors, including the guiding influence of coastlines and river basins, particularly for water birds.

More recently, the application of satellite telemetry and light-level geolocators has provided compelling evidence for well-defined spatial patterns in bird migration, confirming the existence of stable migration routes across broad geographic scales.

Although migration pathways may shift laterally from year to year in response to prevailing weather conditions, their overall spatial configuration remains remarkably stable and is characterized by a network of key stopover sites. The persistence of these stopover areas largely determines the long-term stability of migration routes, even for different populations of the same species.

This principle represents one of the fundamental concepts of practical ornithological management: effective conservation requires precise knowledge of which species or populations form the largest concentrations, where these concentrations occur, and during which migration season. Such information

enables the implementation of targeted conservation measures while minimizing potential conflicts between migratory birds and human infrastructure, including wind energy facilities.

Within the Azov–Black Sea region, where ornithological activity remains high throughout the annual cycle, the identification of permanent migration routes and key stopover sites continues to be of critical importance. Future research should therefore focus on developing a comprehensive inventory of these areas together with scientifically based management and conservation strategies that reconcile biodiversity conservation with regional economic development.

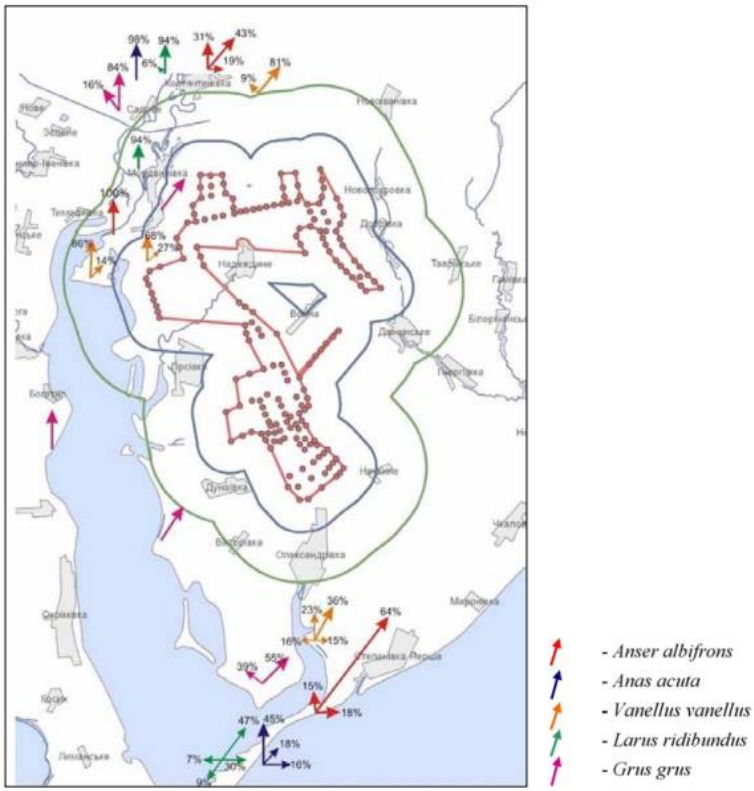

Fig. 3. The Azov–Black Sea Coastal and Marine Ecological Corridor (ABSCMEC), including the Berdiansk, Obytichna, Molochnyi Lyman, Utliuk, Kulykivka, Botiieve and Tubal conservation cores, and the location of the Zaporizhzhia Wind Farm

The Azov–Black Sea Flyway, which constitutes the eastern continuation of the broader Adriatic–Black Sea Flyway, gradually merges into the Azov–Caspian migration system. Within Ukraine, one of the most important transcontinental ecological corridors for migratory birds is the Azov–Black Sea Coastal and Marine Ecological Corridor (Fig. 3). According to the regional ecological network of Zaporizhzhia Oblast, the Zaporizhzhia Wind Farm is situated adjacent to this corridor rather than directly within its core conservation areas[4].

The ecological corridor extends for more than 150 km. Its maximum width, within the Molochnyi Lyman estuary and the adjacent sector of the Sea of Azov, approaches 50 km. The estimated area of the corridor within Zaporizhzhia Oblast is approximately 2.730 km². Nearly 90% of the corridor consists of open marine and estuarine waters, whereas slightly more than 10% comprises coastal spits and shoreline habitats (Fig. 3).

2. Seasonal Characteristics of Migration and Population Connectivity. Stopover Sites within the Study Region

Bird migration should be analysed within a seasonal framework because spring and autumn migrations differ fundamentally in terms of migration intensity, species composition, population structure, and geographical connectivity.

First, the number of migrating birds is influenced by population dynamics, including long-term fluctuations in breeding populations, as well as by weather conditions, which may either intensify migration or prolong its duration. The most important factor, however, is demographic structure. During spring migration, recently fledged juveniles are absent from the migratory population, whereas in autumn juvenile birds may constitute more than half of the migration flow in several species, particularly among passerines.

Second, the timing of spring migration is regulated by weather conditions and habitat availability in species such as waterfowl and herons, whereas in most bird species migration is initiated primarily by genetically controlled responses to increasing photoperiod. For species breeding at high latitudes of Eurasia, migration timing is additionally influenced by large-scale climatic processes and temperature anomalies associated with atmospheric circulation. Consequently, spring migration is generally more synchronized and occurs within a shorter time window than autumn migration.

[4] Сіохін В. Д., Черничко Й. І., Сідоренко А. І., Горлов П. І., Алейнікова К. Г. Кумулятивна оцінка впливу вітрових станцій на природні комплекси в межах техногенних територій північно-західного Приазов'я. Повідомлення 2. Сезонні комплекси птахів. *Моніторинг та охорона біорізноманіття в Україні: прикладні аспекти моніторингу та охорони біорізноманіття. Серія «Conservation Biology in Ukraine»*. Київ ; Чернівці : Друк Арт, 2020. Вип. 16, т. 3. С. 152–168.

Third, many species and populations use different geographical routes during spring and autumn migration. Although the migration network across southern Ukraine appears highly complex, individual species often exhibit distinct patterns of geographical connectivity reflecting their evolutionary history, ecological requirements, and migration strategies.

Based on the evidence presented above, the principal potential stopover sites for migratory birds within the study area can be identified. Previous ornithological surveys conducted across selected parts of the study region have demonstrated that intrazonal landscape elements serve as important stopover habitats during seasonal migration. These areas provide opportunities for resting, intensive foraging, and the accumulation of fat reserves required for subsequent long-distance flights. The most important stopover sites are associated with the Molochnyi and Tubalskyi estuaries, river channels, and floodplain systems. Meadow habitats, pastures, and agricultural fields adjacent to river valleys also provide favourable conditions for migratory birds (Fig. 4).

Fig. 4. Distribution of the principal migratory stopover sites within the study area (1 – Zaporizhzhia Wind Farm)

Artificial forest plantations represent another important habitat type. Their greatest extent occurs along the western (right) bank of the Molochnyi Estuary, together with mature shelterbelts located mainly outside settlements. Particular attention should also be paid to the narrow coastal strip of the Sea of Azov, where dense concentrations of migratory passerines accumulate within shrub vegetation on undisturbed coastal sections during migration periods. Adjacent marine waters provide nocturnal roosting sites for geese, ducks, gulls, and

grebes. In addition to these species, gulls and other waterbirds perform regular daily movements between the coastal waters of the Sea of Azov and inland feeding areas or the shallow upper sections of estuaries, where suitable foraging conditions are available.

As shown in Figure 4, the majority of important stopover sites are associated with intrazonal estuarine and riverine landscape elements. Nevertheless, large aggregations occurring over the marine waters of the Sea of Azov also constitute a key component of the regional migration system.

Spring Migration. According to long-term ornithological observations conducted during 2009–2021, spring migration over the Molochnyi Estuary and its coastal zone begins in late February and generally ends during the final ten days of April. The principal migration directions of selected model species are presented in Figure 5.

The duration of continuous field observations in different years had relatively little influence on the cumulative number of species recorded within the study area. However, despite a cumulative total of 102 migratory species, annual species richness varied considerably, ranging from only 14 to as many as 69 species. These pronounced interannual differences reflect the combined effects of multiple environmental factors, among which weather conditions during March play the dominant role.

Species diversity along the Sea of Azov coastline is generally higher than within inland areas, although no substantial differences are observed in the total number of species recorded farther inland.

During March, the most abundant taxonomic groups comprise waterfowl (Anseriformes), passerines (Passeriformes), and shorebirds (Charadriiformes). Passerines consistently dominate either in terms of abundance or species richness because they account for more than half of the regional avifauna.

In April, the proportion of species migrating during the night increases substantially. Consequently, many shorebirds, passerines, and even geese become difficult to observe directly during migration flights. Their movements are more effectively monitored at stopover sites where birds rest or forage. During this period, the total number of recorded migratory species increases to approximately 110.

By early May, migration of most waterfowl, herons, grebes, and gulls has largely been completed, resulting in a reduction of transit migrants to approximately 37 species. Of these, 31 species are shorebirds, predominantly Arctic breeders, whose migration reaches its seasonal peak during early May. Migration intensity remains highest within the coastal zone due to extensive local bird movements. The farther observations are conducted inland, the lower the overall migration intensity becomes.

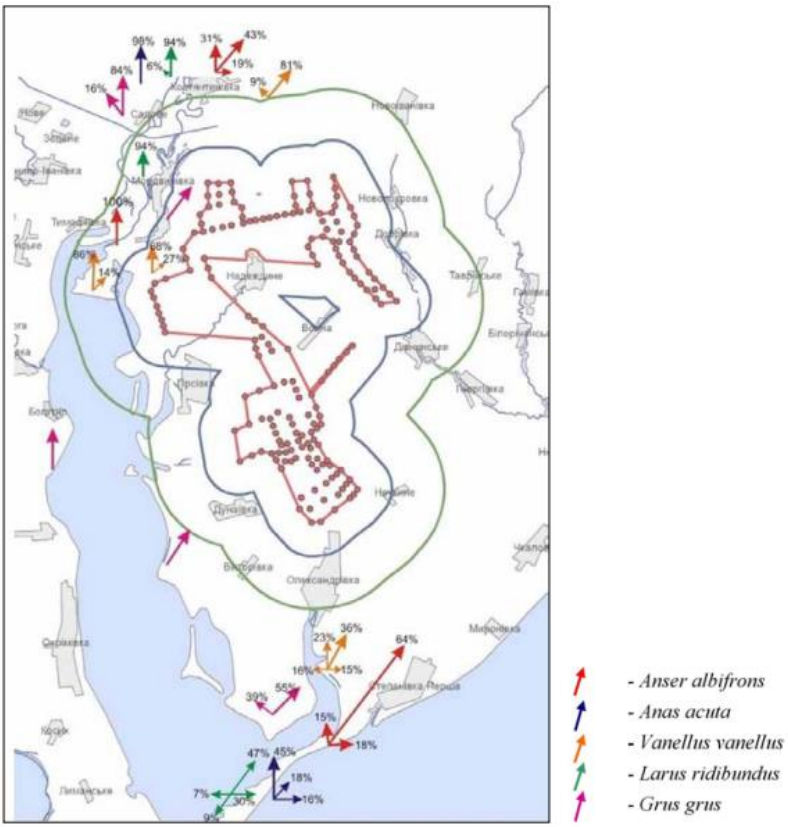

Fig. 5. Principal spring migration routes of selected waterbird species within different sectors of the Molochnyi Estuary (long-term mean values)

July–August. During July and August, the majority of transit migrants belong to shorebirds (Charadriiformes) and terns (Sternidae), although several duck species, including the Garganey (*Anas querquedula*), also initiate seasonal migration during this period. Most other abundant species form post-breeding concentrations on wetlands and perform only short-distance foraging flights. At this time, the principal migration route for most species follows the Azov Sea coastline, whereas only isolated flocks or single individuals migrate along the valleys of small rivers and ravines (Fig. 6).

Fig. 6. Main flight directions in July–August

Autumn migration along the Azov–Black Sea coast generally begins during the second half of July. Migration intensity gradually increases from mid-August, reaches its maximum during September and the first half of October, and usually ends by the middle of November. Subsequently, during the second half of November and early December, pre-winter movements occur, involving primarily geese and ducks arriving from continental regions where deteriorating weather conditions force birds to relocate towards milder coastal habitats. Similar seasonal movements are also characteristic of Common Starling (*Sturnus vulgaris*), thrushes, Rook (*Corvus frugilegus*), and several other passerine species.

The intensity of bird movements across the wind farm area begins to increase markedly in September owing to the migration of ducks, diurnal raptors, starlings, and wagtails. During late September and October, these movements are supplemented by migrating geese and cranes, while in November ducks and geese constitute the dominant component of migration across the wind farm.

A notable characteristic of autumn migration is that the majority of passerine species follow the elevated western bank of the Molochnyi Estuary. Only larks and swallows migrate across the wind farm in a broad front, but the operational

wind turbines exert virtually no measurable influence on these species. Moreover, swallows and several falcon species regularly use wind farm infrastructure, including temporarily inactive turbines, as resting perches during migration.

During the night, most transit migrants fly at considerably higher altitudes than those occupied by wind turbines. Only flocks stopping at the estuary or adjacent coastal habitats may occasionally descend into the rotor-swept zone. The probability of such events, however, is estimated to be below 0.1%.

September–October. September and the first half of October represent the peak migration period for the majority of bird species, including not only waterbirds but also numerous terrestrial ecological groups. During this period, migration intensity increases markedly over the Molochna River valley and across most sections of the wind farm. Birds migrate along a broad front extending approximately 30–50 km inland from the coastline (Fig. 7).

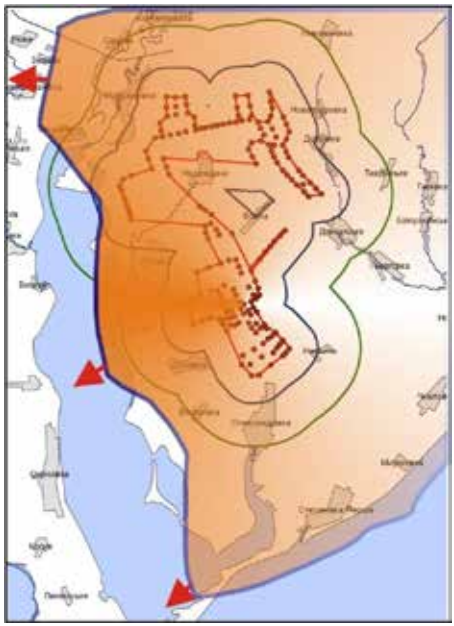

Fig. 7. Main flight directions in September–October

Late October–November. The second half of October and November marks the completion of Common Crane (*Grus grus*) migration and the period of maximum migration intensity for the Greater White-fronted Goose (*Anser albifrons*), Great Bustard (*Otis tarda*), several duck species, particularly

diving ducks, Northern Pintail (*Anas acuta*), Common Goldeneye (*Bucephala clangula*), Rook (*Corvus frugilegus*), Common Starling (*Sturnus vulgaris*), and other species. With regard to migration corridors and flight altitudes, no substantial changes occur compared with the previous period, except for a considerable increase in local bird movements within the coastal zone of the Azov Sea. In addition to the dominant latitudinal migration routes, this period is characterized by the emergence of a pronounced north–south migration corridor associated primarily with the seasonal movements of ducks and geese from continental regions of Ukraine (Fig. 8).

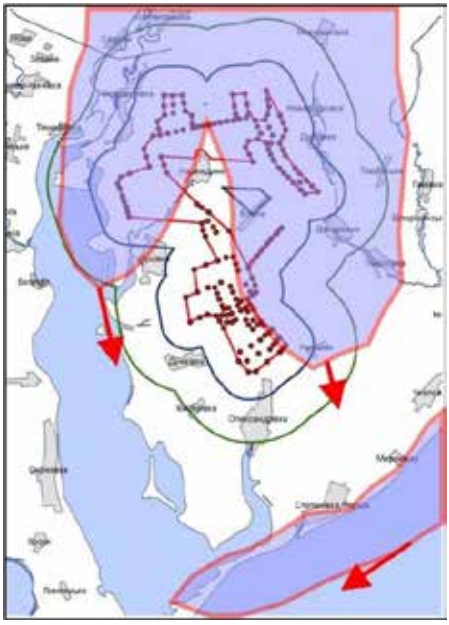

Fig. 8. Main flight directions in November

Thus, we observe the following situation: the regional migration system involves 265 bird species, including 37–110 species recorded during spring migration and 65–184 species during autumn migration. The taxonomic composition remains relatively stable and includes representatives of 13 avian orders, with waterfowl (Anseriformes), shorebirds (Charadriiformes), and passerines (Passeriformes) consistently representing the most abundant groups.

Daily migration intensity is strongly influenced by the geographical location of the survey area. The highest migration activity is consistently observed in

coastal habitats. During spring, daily numbers range from approximately 0.7 to 2.1 thousand individuals, while during autumn migration the abundance increases substantially to 1.2–20.8 thousand individuals per day. Daily migration patterns also differ seasonally. In spring, the highest migration intensity occurs during the morning hours throughout the migration period. In contrast, during July and September, evening migration exceeds both morning and daytime activity. Nevertheless, the first hour after sunrise consistently represents the period of highest migration intensity throughout the year.

Flight altitude depends not only on the geographical position of the study site but also on the species composition of migrating birds. The proportion of birds crossing the monitored areas within the rotor-swept zone potentially posing a collision risk to wind turbines averages 13.6% during spring migration and 6.3% during autumn migration.

The closer a study site is located to the seacoast, the greater the diversity of migration directions observed. This pattern reflects the high proportion of local daily movements associated with feeding, roosting, and stopover behaviour in coastal habitats.

The assessment of migration intensity within the study area should consider not only the absolute abundance of birds recorded in different functional landscape zones but also the spatial distribution of migratory movements. The principal conclusion consistently supported by long-term observations is that the highest migration intensity occurs within the coastal strip due to extensive local bird movements associated with marine and estuarine habitats. Migration intensity progressively decreases with increasing distance inland from the Azov Sea coast.

3. Cumulative Impacts within the Wind Farm Area

Wind turbines located along migration flyways, long-distance flight routes, or regular local movements between feeding, roosting, and breeding sites may potentially interfere with bird movements and create a barrier effect[5].

To evaluate the actual significance of this effect, the results of long-term studies conducted at the Nysted offshore wind farm in Denmark provide an illustrative example. Since 2005, migratory flight routes in the vicinity of the wind farm have been monitored using radar techniques. Each year, approximately 200,000–300,000 geese migrate through the area during spring and autumn while travelling to agricultural feeding grounds[6]. Monitoring began prior to wind farm construction and has continued throughout its operational

[5] European Commission. Guidance document on wind energy developments and EU nature legislation. Brussels : Publications Office of the European Union, 2020. 184 p. DOI: https://doi.org/10.2779/095188.

[6] Gémard C., Duriez O., Chappe O., Duclos G., Besnard A. Towards a better understanding of avian collision in wind energy facilities using automatic detection systems. *Journal of Applied Ecology*. 2025. Vol. 62, No. 6. P. 1437–1448. DOI: https://doi.org/10.1111/1365-2664.70055.

period. The results demonstrate that birds consistently avoid the wind farm by deviating approximately 500 m from their original flight paths. Considering that the overall migration distance exceeds 1.400 km, this detour results in only a minor increase in energy expenditure regardless of species endurance. Even the need to circumvent approximately 160 similar wind farms along an entire migration route would result in an estimated body mass loss of only about 1%[7].

As illustrated in Figures 9 and 10, migrating birds are able to detect and avoid wind farms during flight.

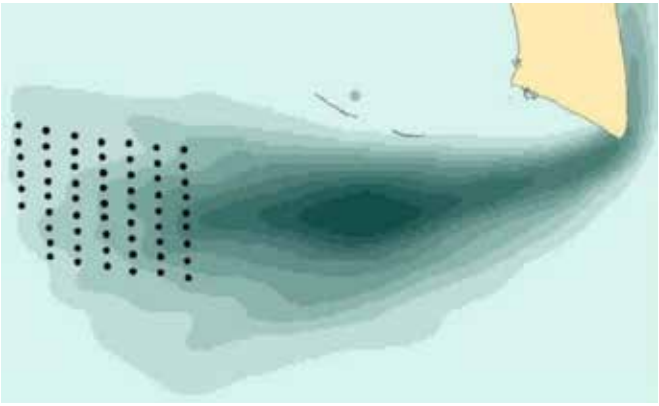

Fig. 9. Flight trajectories of migratory birds at the Nysted offshore wind farm (Denmark) before construction. Black dots indicate the planned turbine locations, while grey dots represent radar detections of birds[8]

These findings indicate that the barrier effect should be regarded as a significant impact only under specific circumstances, particularly where intensive local bird movements occur or where multiple large wind farms are concentrated over extensive areas along major seasonal migration routes.

Numerous studies have documented avoidance behaviour in many bird species, especially waterbirds and passerines. However, this response is strongly species-specific. During daylight hours, birds generally maintain distances of approximately 100–3.000 m from wind farms, whereas at night these avoidance

[7] Keane A., Nisbet I., Calvo G., Pickering G., Tulloch J., More G., Koronka N. Wind farm cumulative induction zone effect and the impact on energy yield estimation. *Renewable Energy*. 2022. Vol. 181. P. 1209–1222. DOI: https://doi.org/10.1016/j.renene.2021.09.056.

[8] Petersen I. K., Christensen T. K., Kahlert J., Desholm M., Fox A. D. Final Results of Bird Studies at the Offshore Wind Farms at Nysted and Horns Rev, Denmark. Rønde : National Environmental Research Institute, 2006. 161 p. URL: https://tethys.pnnl.gov/sites/default/files/publications/NERI_Bird_Studies.pdf (дата звернення: 08.07.2026).

distances may be considerably reduced[9]. Although avoidance behaviour clearly reduces the immediate risk of collision, altered flight routes inevitably require additional time and energy expenditure. In theory, repeated energetic costs over long periods could influence individual condition and consequently affect demographic parameters such as survival and reproductive success.

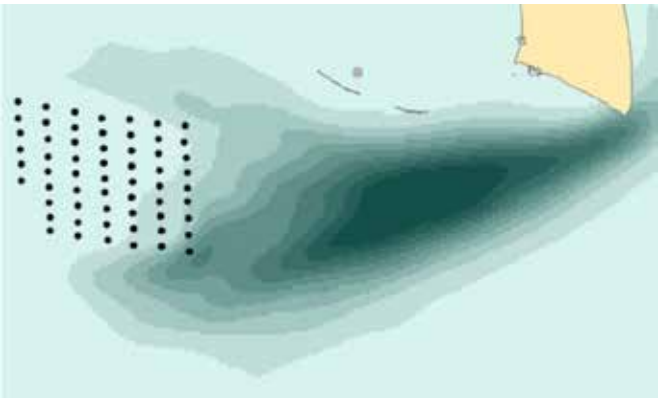

Fig. 10. Flight trajectories of migratory birds at the Nysted offshore wind farm (Denmark) during the operational phase. Black dots indicate turbine locations, while grey dots represent radar detections of birds[10]

Available scientific evidence nevertheless indicates that the barrier effect alone is unlikely to have measurable consequences at the population level[11]. However, potential cumulative impacts resulting from multiple wind farms located along a migration corridor should not be disregarded[12]. The magnitude of the barrier effect depends largely on wind farm design, including turbine dimensions, spatial configuration, and distances between turbines. Consequently, optimization of wind farm layout is widely recognized as one of the most effective measures for minimizing interference with bird migration.

[9] Christiansen N., Daewel U., Schrum C. Cumulative hydrodynamic impacts of offshore wind farms on North Sea currents and surface temperatures. *Communications Earth & Environment*. 2026. Vol. 7. Art. 164. DOI: https://doi.org/10.1038/s43247-026-03186-8.

[10] Petersen I. K., Christensen T. K., Kahlert J., Desholm M., Fox A. D. Final Results of Bird Studies at the Offshore Wind Farms at Nysted and Horns Rev, Denmark. Rønde : National Environmental Research Institute, 2006. 161 p. URL: https://tethys.pnnl.gov/sites/default/files/publications/NERI_Bird_Studies.pdf (дата звернення: 08.07.2026).

[11] Drewitt A. L., Langston R. H. W. Collision effects of wind-power generators and other obstacles on birds. *Annals of the New York Academy of Sciences*. 2008. Vol. 1134. P. 233–266.

[12] Yordanov N., Zehtindjiev P., Whitfield D. P. Long-term decline in bird collisions at operational wind farms: evidence from systematic monitoring to support sustainable wind energy development (2010–2024). *Sustainability*. 2026. Vol. 18, No. 2. Art. 992. DOI: https://doi.org/10.3390/su18020992.

Birds flying within the rotor-swept zone frequently avoid potential collisions by altering either their flight direction or flight altitude. The energetic cost of bypassing a single wind turbine is generally negligible because the resulting detour typically increases the flight path by only 5–10% relative to the original trajectory. Considering that most migration routes extend over more than 1,000 km, such additional energy expenditure is minimal and comparable to that required to compensate for lateral wind drift[13, 14].

Early assessments estimated that approximately 99.5% of birds successfully avoid collisions with wind turbines, implying that only about 0.5% enter the rotor-swept zone. More conservative assessments subsequently reduced the avoidance rate to 98.0%, providing a precautionary estimate for collision risk modelling. For the White-tailed Eagle (*Haliaeetus albicilla*), the avoidance rate has been estimated at 92.5%[15].

4. Barrier Effects and Cumulative Impacts of Wind Farms on Birds

During ornithological surveys conducted within the Zaporizhzhia Wind Farm project area, particular attention was given to assessing the barrier effect and potential flight obstruction. Bird species using the wind farm site as a feeding area generally fly at altitudes below 50 m above ground level. Consequently, the operational impact of wind turbines on these local movements is considered low and, for most species, negligible. In contrast, the technical characteristics of wind turbines, particularly the rotor-swept area, create a potential collision hazard for migratory birds flying within the altitude range of approximately 50–170 m (or, depending on turbine specifications, 40–180 m).

According to ornithological surveys conducted between September 2017 and May 2018 using fixed observation points and standardized transects, a total of 10.258 migrating birds were recorded within the project area. Most individuals (8.065; 78.62%) flew below the rotor-swept zone. A further 1,750 individuals (17.06%) migrated above the operational height of the turbines, typically at altitudes of 300–400 m. Only 443 individuals (4.32%) were observed within the rotor-swept zone, where collision risk exists.

Surveys carried out in 2019 revealed a similar pattern. A total of 21.250 birds were recorded during migration, of which 16.755 individuals (78.85%) flew

[13] Masden E. A., Cook A. S. C. P., McCluskie A., Bouten W., Burton N. H. K., Thaxter C. B. When speed matters: The importance of flight speed in an avian collision risk model. *Environmental Impact Assessment Review*. 2021. Vol. 90. Art. 106622. DOI: https://doi.org/10.1016/j.eiar.2021.106622.

[14] Desholm M., Fox A. D., Beasley P. D. L., Kahlert J. Remote techniques for counting and estimating the number of bird–wind turbine collisions at sea: a review. *Ibis*. 2006. Vol. 148, Suppl. 1. P. 76–89.

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below rotor height, while 4.400 individuals (20.71%) were recorded above the turbines. Only 95 birds (0.44%) were observed within the collision-risk zone.

These results accurately reflect the general ornithological situation in the region and are consistent with observations from other wind farm sites. Long-term monitoring conducted at the operational Botiieve Wind Farm between 2013 and 2019 demonstrated that the overwhelming majority of birds moved outside the collision-risk zone, either below 50 m above ground level or above 150 m, and most frequently at altitudes exceeding 200 m. Only 252 individuals (0.86%) were recorded within the potentially hazardous altitude interval of 51–150 m, indicating that bird movements through the rotor-swept zone were infrequent and represented a typical migration pattern for the region[16, 17].

Bird movements within potentially hazardous flight altitudes were not recorded every year. No birds were observed within the 51–150 m altitude interval during 2013, 2015, 2016, 2018 or 2021. In the remaining years, the proportion of birds flying within the collision-risk zone never exceeded 6%, accounting for 3.64% in 2014, 5.90% in 2017, 4.35% in 2019 and 4.44% in 2020. Similar patterns have also been documented during three-year monitoring programmes at the Prymorska, Orlivska, and Prymorska-2 wind farms.

Cumulative impacts may arise when several wind farms and their associated infrastructure are located within areas supporting consistently high bird abundance, along major migration corridors, or where wind energy developments interact with other forms of human activity. Importantly, cumulative impact should not be interpreted simply as the arithmetic sum of impacts from individual wind farms. Depending on ecological conditions and species-specific responses, cumulative effects may be either greater or smaller than the sum of individual project impacts.

For example, a single wind farm may cause a relatively low level of bird mortality that remains well within the natural recovery capacity of the affected population and therefore has little influence on its long-term viability. However, when mortality associated with multiple wind farms is combined, total losses may exceed the population's capacity for compensation, ultimately resulting in population decline. Consequently, although the impacts of individual projects may each be considered insignificant, their combined effect may become

[16] Горлов П. І., Сіохін В. Д., Долинний В. І., Сидоренко А. І. Сезонні орнітологічні особливості території Ботієвського вітропарку (Запорізька область) за результатами спостережень у весняні періоди 2013–2014 років. *Бранта :* збірник наукових праць Азово-Чорноморської орнітологічної станції. 2014. № 17. С. 19–38. URL: https://branta.org.ua/ua/branta-issues/branta-17/17-02.html (дата звернення: 08.07.2026).

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ecologically significant and influence planning decisions for both existing and proposed developments.

The principal objective of cumulative impact assessment is therefore to determine the threshold at which the combined effects of habitat loss (including permanent habitat removal), habitat fragmentation, barrier effects associated with increased energetic costs of flight, and collision mortality become ecologically significant.

Cumulative assessment must also consider the interaction of the proposed development with other existing or planned projects within the surrounding landscape, including developments unrelated to wind energy. While the environmental effect of an individual project may be negligible, its combination with other plans or activities may produce significant cumulative consequences. Habitat fragmentation should likewise be incorporated into cumulative impact assessments because it may adversely affect population structure, connectivity, and long-term demographic dynamics across a broad range of bird species.

During the planning phase of the Zaporizhzhia Wind Farm and the associated 330 kV transmission line, comprehensive ornithological field surveys were conducted in 2014–2016 and 2017–2018 to identify local bird populations and develop appropriate mitigation measures. Based on the survey results, the avifauna of the study area was found to be typical of the region. Most of the project area consists of agricultural landscapes, including arable fields and shelterbelts. Consequently, the areas designated for the wind farm and its associated infrastructure – including underground cable lines and the 330 kV overhead transmission line connecting the proposed Nadezhdyne substation to the existing Melitopol 330 kV substation – were not considered to be of high conservation value or of particular importance for biodiversity protection.

Monitoring conducted at the Zaporizhzhia Wind Farm during 2017–2018 recorded a relatively large number of birds (13.113 individuals). However, this result primarily reflects the high intensity of ornithological observations rather than an exceptional attractiveness of the project area for birds. This conclusion is supported by the very low proportion of rare species recorded during the survey period. Between September 2017 and May 2018, species of conservation concern accounted for only 0.37% of all recorded individuals. Subsequent monitoring in 2019–2021 likewise revealed no important local migration routes crossing either the wind farm site or the associated 330 kV transmission line. Accordingly, both facilities were assessed as unlikely to produce significant adverse impacts on birds and were considered environmentally acceptable within the proposed project boundaries.

The abundance of threatened bird species within the project area was consistently low. To evaluate conservation significance, three principal conservation reference

lists were analysed: the Red Data Book of Ukraine, the European Red List, and the IUCN Red List of Threatened Species. Particular attention was given to species classified as Critically Endangered (CR) or Endangered (EN) by the IUCN, as well as species listed as Endangered in the Red Data Book of Ukraine. The spatial distribution of these threatened species recorded within the project area between 2007 and 2021 is presented in Figure 11. In total, 111 individuals representing seven threatened species were recorded. The Eurasian Curlew (*Numenius arquata*) was the dominant species, accounting for 58 individuals (52.3%), followed by the Pallas's Gull (*Larus ichthyaetus*) with 22 individuals (19.8%) and the European Roller (*Coracias garrulus*) with 15 individuals (13.5%).

As illustrated in Figure 11, most records of bird species classified as Endangered or Critically Endangered were concentrated in adjacent wetlands, particularly the Tubalskyi Estuary and the upper reaches of the Molochnyi Estuary. Only four individuals (3.6%) representing two threatened species were recorded within the actual project area.

Cumulative impacts resulting from several neighbouring wind energy projects may become significant where turbine layouts overlap with key bird habitats, including important feeding areas, migration corridors, regular commuting routes between feeding and breeding sites, or major stopover locations. However, the available monitoring data indicate that the wind farm complex investigated in this study is not situated along any major migration corridor and is therefore unlikely to interfere with regular bird movements. Furthermore, because the individual wind farms are located within extensive agricultural landscapes and are spatially separated, their cumulative effects on bird populations are expected to remain relatively limited[18].

Collision Risk Modelling (CRM)[19] predicted that the Zaporizhzhia Wind Farm would result in approximately 31 bird fatalities per year, assuming the operation of 167 wind turbines. Importantly, monitoring conducted during the construction phase demonstrated that predicted collisions primarily involved common and abundant species typical of open agricultural landscapes, including the Eurasian Skylark (*Alauda arvensis*), Common Buzzard (*Buteo buteo*), Common Swift (*Apus apus*), and Northern Raven (*Corvus corax*). In addition, several water-associated species recorded within the project area, including the Yellow-legged Gull (*Larus cachinnans*) and Grey Heron (*Ardea cinerea*), were also identified as potentially susceptible to collisions.

[18] Josimović B., Bezbradica L., Manić B., Srnić D., Srebrić N. Cumulative impact of wind farm noise. *Applied Sciences*. 2023. Vol. 13, No. 15. Art. 8792. DOI: https://doi.org/10.3390/app13158792.

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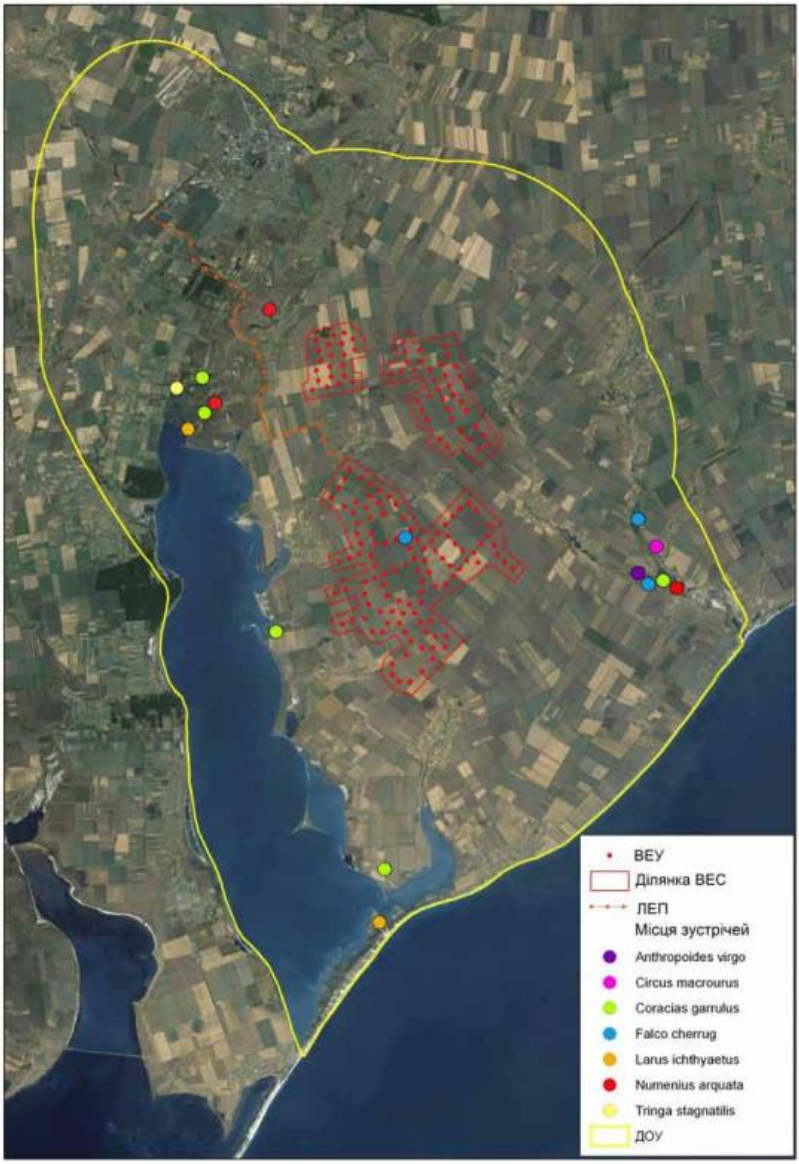

Fig. 11. Distribution of bird species classified as Endangered or Critically Endangered within the environmental assessment area during 2007–2021

Unfortunately, no ornithological monitoring data are available for the Azov Wind Farm ("Zofia") for 2019, including information on bird abundance, species composition, or migration intensity within the project area. Consequently, it is not possible to estimate collision mortality directly for this facility. Nevertheless, according to published estimates[20], wind farms cause an average mortality of approximately 0.1 bird per MW of installed capacity per year. Assuming an installed capacity of 750 MW and approximately 167 operating wind turbines, the Zofia Wind Farm could theoretically result in about 75 bird fatalities annually. Owing to the similar landscape characteristics of both wind farms, the assemblage of species potentially affected at the Zofia Wind Farm is expected to be broadly comparable to that recorded at the Zaporizhzhia Wind Farm.

Potential Biological Removal (PBR)[21] analysis further demonstrated that the predicted collision mortality at the Zaporizhzhia Wind Farm remains below the maximum biologically sustainable level for all assessed species. Consequently, the expected losses are not anticipated to have measurable adverse effects on the long-term viability of local or regional bird populations.

If the predicted annual mortality is expressed as a percentage of the species-specific Potential Biological Removal (PBR) threshold, a similar pattern emerges. For most species, this proportion is very low, ranging from 0.04% to 9.24%. Consequently, the combined mortality predicted for the Zaporizhzhia and Azov wind farms is also unlikely to exceed the allowable PBR threshold, since most species occurring in the area do not use fixed migration corridors and are widely distributed throughout the region.

Theoretically, the spatial arrangement of turbines belonging to several neighbouring wind farms could alter the foraging behaviour and breeding territory configuration of certain species, particularly birds of prey, through displacement effects. However, the abundance of these species in the vicinity of the wind farms considered in this study is relatively low; therefore, this potential impact is expected to be negligible.

Large numbers of wind turbines may also potentially create a barrier to migrating birds. Nevertheless, the study area is situated outside the principal migration routes. Although the Zaporizhzhia Wind Farm and the Zophia Wind Farm are located relatively close to one another (the shortest distance between

[20] Oglęcki P., Dąbrowski P., Gnatowski T., Małuszyńska I., Małuszyński M. J., Przybyłowski J., Pawluśkiewicz B. Bird collision risk at the interface of solar and wind farms – a cumulative effect? *Journal of Water and Land Development*. 2025. No. 66. P. 152–161. DOI: https://doi.org/10.24425/jwld.2025.155311.

[21] Punt A. E., Siple M., Francis T. B., Hammond P. S., Heinemann D., Long K. J., Moore J. E., Sepúlveda M., Reeves R. R., Sigurðsson G. M., Vikingsson G., Wade P. R., Williams R., Zerbini A. N. Robustness of potential biological removal to monitoring, environmental, and management uncertainties. *ICES Journal of Marine Science*. 2020. Vol. 77, Issue 7–8. P. 2491–2507. DOI: https://doi.org/10.1093/icesjms/fsaa096.

them is approximately 12 km), the turbine layout provides sufficient open space for bird movements. The main migration corridor between the two facilities, extending over the waters of the Molochnyi Estuary, remains unaffected by either project. Furthermore, numerous studies have demonstrated that 92.5–98% of birds are able to avoid wind turbines located in open agricultural landscapes, even during regular migratory flights. With respect to the Botiieve Wind Farm, the distances separating it from the two aforementioned projects (15.5 km and 37 km, respectively) are sufficiently large to preclude any meaningful barrier effect in the conventional sense. Long-term monitoring conducted by the authors has shown that bird concentrations within the Botiieve Wind Farm and adjacent areas reach their highest levels along the coastal zone and over the Sea of Azov, exhibiting behavioural patterns very similar to those documented at the Nysted Offshore Wind Farm in Denmark (Figs. 9–10)[22].

Moreover, the wind turbines are located within extensive agricultural landscapes corresponding to areas of relatively low bird density. Consequently, the partial loss of these habitats is unlikely to be ecologically significant, even when potential displacement effects resulting in reduced breeding bird densities near turbines are taken into account. Habitat transformation associated with wind farm construction, including the development of access roads and crane pads, may locally influence the abundance of bird species characteristic of open, dry agricultural habitats associated with human activities, such as the Corn Bunting (*Emberiza calandra*), European Stonechat (*Saxicola rubicola*), and Crested Lark (*Galerida cristata*).

Overall, the wind farms considered in this assessment are not expected to cause significant increases in mortality of species of conservation concern, substantial habitat loss, changes in land-use patterns, or cumulative barrier effects[23].

Despite the implementation of mitigation measures, a residual risk of collisions between birds or bats and wind turbines cannot be completely eliminated. Therefore, post-construction monitoring has been planned for the above-mentioned projects. The results of this monitoring will provide an empirical basis for evaluating the operational impacts of the wind farms on bird and bat populations.

[22] Williams K. A., Gulka J., Cook A. S. C. P., Diehl R. H., Farnsworth A., Goyert H., Hein C., Loring P., Mizrahi D., Petersen I. K., Peterson T., Press K. M., Stenhouse I. J. A framework for studying the effects of offshore wind energy development on birds and bats in the Eastern United States. *Frontiers in Marine Science*. 2024. Vol. 11. Article 1274052. DOI: https://doi.org/10.3389/fmars.2024.1274052.

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CONCLUSIONS

This study demonstrates that the Zaporizhzhia Wind Farm is located adjacent to the Azov–Black Sea migration system, one of the principal flyways in Eastern Europe, while the wind farm itself is situated outside the areas of highest migration intensity. Seasonal bird movements are concentrated primarily along the coastal zone of the Sea of Azov, the Molochnyi Estuary, and associated river valleys, whereas the project area is characterized by comparatively low migration density and the absence of stable, high-intensity migration corridors.

Long-term ornithological monitoring confirmed that the overwhelming majority of birds crossed the study area either below or above the rotor-swept zone, with only a small proportion of individuals recorded within collision-risk heights. The observed flight altitude distribution was consistent across monitoring years and comparable to results obtained at other wind farms in the Azov–Black Sea region, indicating that the project area presents a relatively low level of collision risk.

The analysis of barrier effects indicates that birds generally avoid wind turbines by making minor adjustments to their flight direction or altitude, resulting in negligible additional energetic costs. Consequently, under the existing turbine layout, the Zaporizhzhia Wind Farm is unlikely to create a significant obstacle to seasonal migration or to disrupt ecological connectivity between key migration stopover sites.

Assessment of cumulative impacts further suggests that the combined operation of the Zaporizhzhia Wind Farm with neighbouring wind energy projects is not expected to result in biologically significant adverse effects. The spacing between wind farms, the preservation of major migration corridors, the predominantly agricultural character of the surrounding landscape, and the low density of sensitive species collectively reduce the likelihood of cumulative barrier effects or population-level consequences.

Collision Risk Modelling (CRM) and Potential Biological Removal (PBR) analyses indicate that the predicted annual mortality remains well below biologically sustainable thresholds for all assessed species. The projected collision rates represent only a small fraction of the allowable population losses defined by PBR, suggesting that wind farm operation is unlikely to compromise the long-term viability of local or migratory bird populations.

Rare and threatened bird species were recorded only sporadically within the project area, with the majority of observations occurring in adjacent wetlands rather than within the wind farm itself. This spatial distribution further supports the conclusion that the project does not overlap with habitats of critical conservation importance.

Overall, the available evidence indicates that the Zaporizhzhia Wind Farm has a low ornithological impact with respect to collision risk, habitat loss, barrier effects, and cumulative impacts. Nevertheless, continued post-construction monitoring remains essential to verify predicted impact levels, detect any long-term changes in bird behaviour or migration patterns, and support adaptive management. Such an approach will ensure that renewable energy development is implemented in accordance with biodiversity conservation objectives and international best practices for environmentally sustainable wind energy planning.

SUMMARY

The rapid expansion of wind energy requires reliable assessments of its potential impacts on migratory bird populations, particularly within internationally important flyways. This study evaluates the ornithological significance of the Zaporizhzhia Wind Farm, located adjacent to the Azov–Black Sea migratory corridor in southeastern Ukraine. Long-term field observations, migration surveys, flight altitude analyses, and collision risk assessments were used to characterize seasonal bird movements and estimate potential impacts of wind turbines. The results demonstrate that the highest migration intensity is concentrated along the Sea of Azov coastline, estuaries, and river valleys, whereas the wind farm is situated outside the principal migration corridor. Most birds were recorded either below or above the rotor-swept zone, while only a small proportion of individuals crossed the area at collision-risk heights. The predicted collision mortality remained within biologically acceptable limits according to Collision Risk Modelling (CRM) and Potential Biological Removal (PBR) assessments. Rare and threatened bird species occurred only sporadically within the project area and were primarily associated with adjacent wetland habitats. Evaluation of cumulative impacts indicated that the existing configuration of neighbouring wind farms is unlikely to create significant barrier effects or adversely affect bird populations at the regional scale. The findings suggest that the Zaporizhzhia Wind Farm has a low overall impact on migratory birds when appropriate siting principles and environmental planning measures are applied. Continued post-construction monitoring is recommended to verify long-term predictions and support adaptive biodiversity management.

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Information about the author:
Sydorenko Andrii,
Senior Lecturer at the Department of Biology and Physical Rehabilitation
Bogdan Khmelnitsky Melitopol State Pedagogical University
59, Naukovoho mistechka Street, Zaporizhzhia, Ukraine