THE POSEIDON WIND FARM: BIRD MIGRATION AT SKAGEN AND THE WEST COAST OF SWEDEN – SPRING 2024

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Technical Report from DCE – Danish Centre for Environment and Energy

2025

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Abstract: In spring 2024, bird migration observations from Skagen, Denmark, to the Swedish west coast were compiled to assess collision risks with wind turbines at the planned Poseidon offshore wind farm in Kattegat. Data on bird numbers, flight direction, and flight altitude of the most common migrants were recorded from March to June using visual observations, a laser rangefinder, and radar. Flight altitude of nocturnal bird migration was recorded with vertically positioned radar. To assess the flight altitude behaviour of raptors over open sea, data from GPS-tagged raptors across Europe were included. Based on this data, species-specific collision risk assessments were calculated for the planned Poseidon Wind Farm.

Keywords: Offshore wind farm, collision, migratory bird, vertical radar, GPS-tracking.

Front page photo: White-tailed Eagle. Photo: Thomas Kjær Christensen

Number of pages: 79

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1 Introduction

In 2024, Ottvall Consulting AB, in collaboration with DCE - Danish Centre for Environment and Energy, Aarhus University, was commissioned by Zephyr/Vattenfall and Eolus Vind to undertake investigations of bird spring migration at Skagen, Denmark and at the Swedish west coast. The project continued similar investigations carried out in 2022 and 2023. The aim of the investigations was to assess the potential risk of collisions between birds and wind turbines in the planned offshore wind farms Poseidon Nord, Poseidon Syd (both managed by Zephyr/Vattenfall) and the windfarm Västvind (managed by Eolus) in the Swedish part of Kattegat and Skagerrak. Unlike the previous years, the offshore developer KonTiki commissioned and funded most of the migration study in 2024, and likewise commissioned, in collaboration with Eolus, the specific part of GPS-tagged raptors.

This report presents the results of the investigations carried out in 2024 in relation to the Poseidon project. It also includes the results from 2022 and 2023, highlighting similarities and differences in the bird migratory pattern between the three years. The data collected in 2024 will also support the assessment of the potential impact on birds from the Västvind project, but this is reported elsewhere on request from Eolus. The results from spring 2022 and 2023 have previously been reported by Christensen et al. (2023a, b, c).

As in 2022 and 2023, the 2024 study was conducted during the main spring migration period of birds, from March to June. In all years, the study design was set up to obtain data to support the assessment of the potential impact of the wind farm on migratory birds. The positions of the Poseidon wind farm areas are shown in Figure 1.

Figure 1. The location of the designated wind farms Poseidon Nord and Poseidon Syd in the offshore area between Denmark and Sweden.

The study focused on estimating species-specific migration volume, flight altitude and direction of the substantial spring migration of birds occurring at the northernmost tip of Denmark, Skagen (Figure 1). For geographical reasons terrestrial bird species migrating over land, are concentrated at the Skagen peninsula on their way to breeding areas in northern Scandinavia, and substantial numbers of migrants cross the sea towards Sweden and Norway from this point. Observations were also made at the Swedish coast to record arriving migrating birds.

In all study years, special attention was given bird species of high conservation interest, specifically those listed in Annex 1 of the EU Birds Directive, as well as other regularly occurring migratory species.

The design of the study was created in a collaboration between Aarhus University and Ottvall Consulting. The aim was to provide data on species specific migration volumes, flight altitudes and flight direction of individuals and flocks of birds leaving the coast. This data would allow us to estimate the magnitude of bird numbers that will pass the planned wind farm areas and to provide estimates of the potential risk of collision with wind turbines for relevant bird species.

The present report presents data of the third year of the pre-construction investigations, which took place from mid-March to mid-June during spring 2024. Data from 2022 and 2023 (see Christensen et al. 2023a b, c) is included for comparison in the present report when appropriate. Estimates of the collision risk between birds and wind turbines based on our observations from all study years are also presented. The role of Ottvall Consulting was to organize and conduct observations of migratory birds along the Swedish west coast. Data from these surveys was delivered to Aarhus University, who conducted the collision risk analyses.

In the 2022 report, the estimation of collision risk was based on a preliminary designation of the wind farm areas, including both the Poseidon and Västvind projects. A later reduction in the size of the designated areas means that collision rates presented for the 2022 data (Christensen 2023a, b) have been lowered accordingly. The collisions rates for the updated wind farm areas are now based on new calculations presented in the present report, covering 2022, 2023 and 2024.

2 Methods and study design – Denmark

2.1 Study sites

In 2024, based on our experiences from the two previous study years, data on species specific migration and flight altitudes (visual and radar observations) was obtained from a different observation point to optimize the data collection (Figure 2). The observation point used in 2023 (both visual and radar observations) was also used for visual observations in 2022. In 2022 the radar was positioned at the Grå Fyr (Figure 2).

Figure 2. Map of the area at Skagen with the location of observation points used during spring migration in 2024. The locations used in 2022 and 2023 is also shown.

In all years, the radar location was not optimal for tracking migratory birds over land, due to extensive ground clutter from dunes and vegetation. Consequently, radar recordings almost exclusively covered birds migrating/moving in the coastal zone and over the sea.

2.2 Focal species

The study focused on migrating raptor species, which accomplish their long-distance migrations predominantly by soaring on thermals. They are generally reluctant to fly over water bodies, where thermals are weak or absent. Consequently, raptors pass the narrowest part of Kattegat between Skagen, Denmark and the west coast of Sweden. This pattern has been documented through observations performed over many years (Salomonsen 1938, Holm et al. 2023). Despite this, little is known about the flight behaviour and overall migration pattern '*en route*' from Skagen to Sweden and Norway, and high numbers of raptors may potentially pass the planned offshore wind farms each spring. In addition, recent studies suggest that offshore windfarms may potentially attract migrating raptors, since the birds may perceive the wind farm as an island (Skov et al. 2016, Jacobsen et al. 2019). Although migrating raptors attracted towards offshore windfarm generally show avoidance behaviours, either turning around or passing the wind farm in safe distances of the turbines (Jacobsen et al. 2019), this 'island effect' may potentially increase the risk of collisions between raptors and offshore wind turbines.

In addition to raptors, the study also included other diurnal migratory bird species, e.g., pigeons, cranes and corvids, and nocturnal migrants, e.g. sparrows, warblers and thrushes. Gulls, gannets and sea ducks were not systematically recorded during the study period, since a very high number of locally staging birds making daily movements in the coastal area obscured separation of migrating birds through the area.

We registered flight altitude and flight direction of individual birds and flocks by the combined use of laser range finder (binocular) and tracking by radar. However, since these methods are limited with respect to the distance at which data can be obtained, GPS tracking of individual birds (raptors) was planned to obtain information about the migration route and flight altitude of birds of prey when these species make passages over open sea.

2.3 Weather data 2022, 2023 and 2024

Bird migration is generally acknowledged to be highly affected by prevailing weather conditions (e.g., Maransky et al. 1997, Bildstein 2018). In particular, this is the case for bird species dependent on optimal thermals, and when these species have to pass areas that pose a risk, e.g., large deserts or waterbodies. Consequently, seasonal variation in migration patterns is known to be the result of varying weather conditions, especially with respect to wind direction and speed, which influence both the timing of migration and the numbers of birds occurring at a specific migratory hotspot.

To be able to assess the seasonal variation in bird migration volume and flight direction recorded at Skagen during 2022, 2023 and 2024, we compiled data on wind direction and wind speed recorded by the Danish Meteorological Institute (DMI) at Skagen Fyr.

Figure 3A and 3B shows the weekly averages of wind direction and wind speed compiled from daily averages for the period from 15 March to 15 June in 2022, 2023 and 2024.

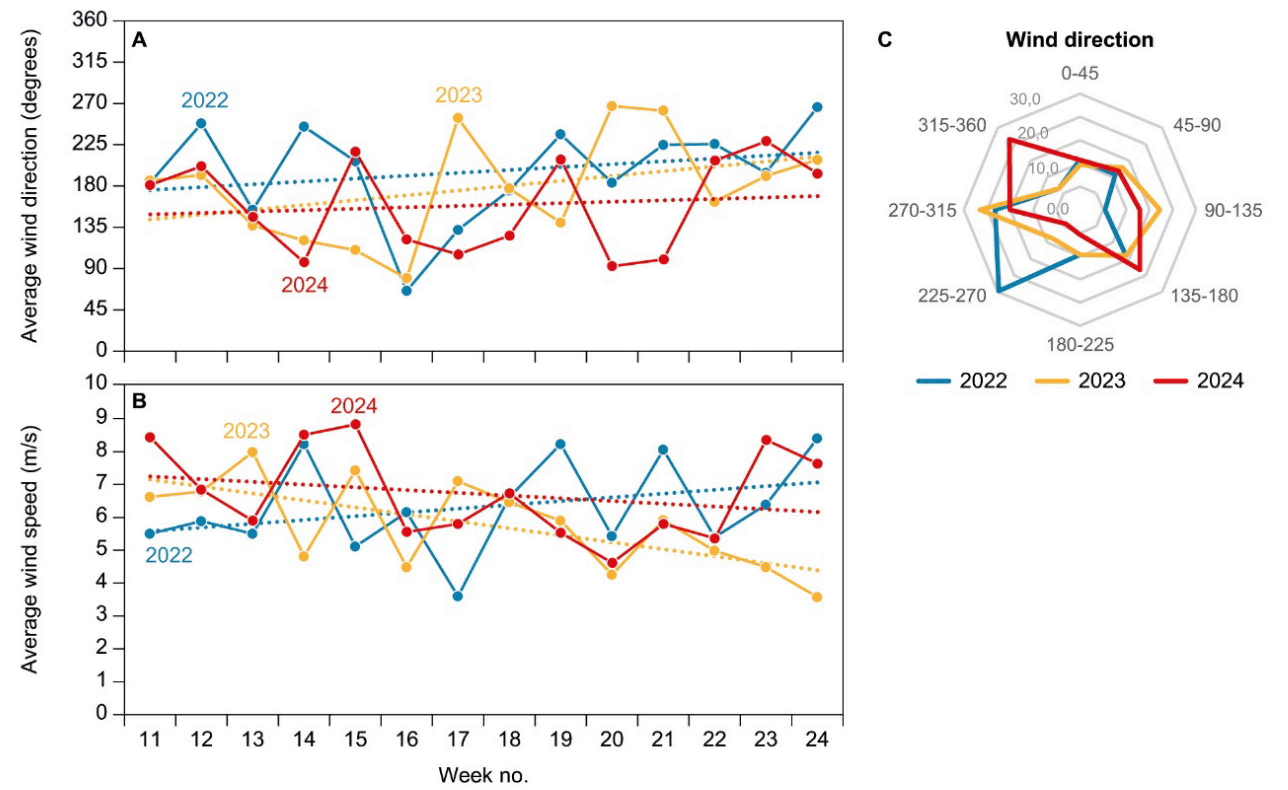


Figure 3. The weekly averages of wind direction (A) and wind speed (B), and the relative distribution of daily average wind directions divided into angle intervals of 45 degrees (C) recorded at Skagen Fyr during the period 15 March (week 11) to 15 June (week 24) in 2022, 2023 and 2024. Data from DMI.

Wind directions and wind speed show variable patterns between the three seasons (Figure 3A and 3B). In 2024, easterly wind directions dominated for longer periods than in both 2023 and 2022. Summing the numbers of days with wind directions divided into 45-degree intervals for the full spring migration period (15 March to 15 June), show that the wind regime slightly differed between years, with prevailing winds dominating from south-west in 2022, west in 2023 and north-west in 2024 (Figure 3C).

2.4 Setup and plan for visual observations

Visual bird observations were conducted to provide data on the number of birds that migrated from Skagen towards Sweden (migration volume) and to obtain data on species specific flight directions and flight altitudes. To obtain this data, visual bird observations included systematic transect counts and the use of a laser rangefinder.

As in 2022 and 2023, visual bird observations in 2024 were planned to cover 35 days during the main spring migration period, corresponding roughly to three observation days per week from mid-March to mid-June (week 12 to week 24).

During each week, three days of observations were planned to cover at least 6 hours each day. The timing of observations was planned to ensure coverage from sunrise to late afternoon over the three-day period.

In 2024, a total number of 41 observation days were covered from 20 March to 12 June (33 days in 2022, 34 days in 2023). In 2024 visual observations covered a total of 354 15-minute transect counts, corresponding to 88 hours and

30 minutes of observation. For comparison, the total number of 15-minute counts was 203 in 2022 (50 hours and 45 minutes), and 283 (70 hours and 45 minutes) in 2023.

The number of observation days per week in 2024 and the weekly distribution of the 354 15-minute transect counts in relation to time of day is shown in Table 1.

Table 1. The weekly coverage expressed as the number of days and number of 15-minute transect counts in relation to time of the day during week 12 to week 24 at Skagen during spring 2024. All counts were performed at Grenen (see Fig 2). For comparison, the sum of 15-minute counts is shown for 2022 and 2023. The grey areas indicate periods with no observations.

2024		Time of day (hour)															**2024**	**2023**	**2022**
Week	**Days**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**SUM**	**SUM**	**SUM**
12	2				2	2	2	1	2	2	2	2	1				16	9	19
13	3				3	3	4	3	3	3	4	3	2	1			29	19	22
14	4				2	3	4	4	4	4	4	3	1	1			30	26	4
15	3			1	2	1	2	2	2	2	1		1	1			15	27	40
16	3				3	3	3	3	3	3	3	1	1				23	20	17
17	3				4	3	3	3	3	3	2	1	1				23	24	16
18	6		1	5	5	6	6	6	6	6	6	5	4	3	2	1	62	21	18
19	2			2	2	2	2	2	3	2	2	2	2	1	1		23	24	6
20	4			2	2	3	4	4	4	3	2	2	2	2	1		31	15	18
21	3		3	3	3	3	3	3	3	3	3	3	2	2			34	30	8
22	4		1	2	3	3	3	3	3	2	3	2	1	2			28	24	17
23	2			2	2	2	2	2	2	2	2	2	1	1			20	29	12
24	2		1	2	2	2	2	2	2	2	2	1	1	1			20	15	6
SUM	41		6	19	35	36	40	38	40	37	36	27	20	15	4	1	354	283	203

Transect counts

During each observation day visual observations included transect counts during an observation period of exactly 15 minutes every hour. On each transect count the number of birds crossing the transect line in each direction (forward or return) was noted. Transects were placed perpendicular to the main migration direction (average transect orientation NW-SE) and extended as far as birds could be detected and determined to species.

Observers used binoculars and tripod mounted telescopes to detect and identify migratory bird species.

Laser rangefinder

In between the transect counts observers operated a VECTOR IV laser rangefinder (LRF) to obtain instantaneous measurements of flight altitude and tracks of migrating birds.

The laser rangefinder is a hand-held binocular system programmed with the observer's location and elevation. It provides georeferenced locations and altitudes of the birds targeted by the observer. This allows for the recording of the exact distance from the observer, the direction to, and the altitude of the bird (corrected for observer elevation). Through sequential measurements of the same bird or bird flock, a three-dimensional mapping of the flight paths of birds is readily obtained.

Observers were instructed to make multiple measurements of the same bird or bird flock during active migration. Measurements should ideally start before the birds were leaving the coastline and continue until no further measurements could be obtained. Depending on bird size, individual large birds or dense bird flocks could be tracked up to a distance of 5 km from the observation points.

Each data measurement from the LRF was transferred via Bluetooth (Bluetooth adapter 2.0, class 2, model: BAF) to a smartphone app (LRF Data Viewer v1), where species names and numbers were assigned to each single or series of measurements of individual bird or bird flocks. Data, with logged information of date and time, was subsequently transferred to a server at Aarhus University and compiled in a database.

To describe patterns of flight altitude and flight directions of the recorded birds, all points measured by the LRF was subsequently processed in a Geographical Information System (ArcGIS Pro 2.9.0) and assigned with information of being over land or over the sea, distance to the coastline and the flight orientation (angle in degrees) between points in multiple measurements of the same bird or bird flock. The coastline used in the GIS analyses was the layer Kyst (coast) in GeoDanmark Datanettet.

2.5 Setup and plan for radar observations

Radar observations were conducted to record bird movements throughout the migration period. The radar used was an X-band 25 kW Furuno marine surveillance radar unit (FAR-1528-BB), by which birds can be detected up to a distance of several kilometres depending on bird size or flock size.

The radar observations were conducted to provide data of both the vertical distribution and horizontal movements of birds. Radars have the advantage of enabling detection of bird movements during periods of limited visibility as well as in total darkness, which makes the equipment very efficient in studies of nocturnal bird migration. Radars operated in a horizontal mode have an unsurpassed accuracy on a large spatial scale, as large birds may be tracked up to distances of approximately 20 km. It is essential to note that a radar provides no identification of the bird species, unless combined with visual observation.

Figure 4. The observation point at Grenen, Skagen 2024 with the trailer mounted radar.

As in 2023, the radar was mounted on a trailer that was placed at the observation point at Grenen (Fig 4). The radar antenna could be tilted 90 degrees for vertical recordings.

Horizontal radar

During days with visual observations, the radar was used in a horizontal position tracking migration of individual birds and flocks. Through coordination with the person(s) performing visual observations, species identification of individual bird tracks recorded on the radar, was obtained when possible. All bird tracks were digitized on the screen and assigned an identification number and species ID. The programmes used for the radar tracking were MaxSea and SeaSimule (http://comen.maxsea.fr/maxsea/, https://seasimule.software.informer.com/).

Horizontal radar recording took place on most days with visual observations. However, several days with low bird migration intensity or individually scattered birds that were undetectable on the radar screen, limited the number of recorded tracks with identified migrating birds. In 2024, visual identification and radar recording took place from the new point with a slightly lower position, which improved radar detection of birds at long distances compared to 2023.

Vertical radar

During nighttime, when other observation methods are hampered by limited visibility, the radar was operated in a vertical position to record flight altitude and to estimate relative migration intensity of nocturnal migration. The radar covered a 180-degree window from horizon to horizon at a range of 2 km and had a NW-SE-orientated transect.

Data collection from the vertically positioned radar was based on an automated screen dump system that archived pictures of the radar screen (PPI). Screen dump pictures were taken every 10 second during 31 nights between 25 March and 11 June 2024, producing at total of 67.161 images. All pictures were exported as red-green-blue (R-G-B) images using screen dumps.

Radar image processing

Data collected by vertical radar in 2024 has not been analysed. The analysis will be processed at a later time, and both data handling and analyses will follow the procedure outlined below, that was used in 2023.

Bird detection on the screen dump pictures was carried out for a subsample representing the first image of each minute, i.e., one per six recorded images, totalling 12.409 images. Image processing comprised four stages: a) precipitation filtering; b) artifact masking; c) bird detection; and d) post-processing, followed by the data analysing process.

a) Precipitation filtering
Precipitation events produced clear signatures across large areas of several radar images. Such images were filtered out based on a threshold mean R+G value of pixels within 180° above ground and within 2 km of the sensor. The threshold was manually selected to exclude images with clear evidence of precipitation. For each hour of recording, if more than five images had a mean R+G value above one, images within that hour were excluded from bird detection. We also excluded the hours before and after precipitation events.

b) Artifact masking
We defined artifacts as persistent non-bird signatures in radar images, often confined to specific regions of the image. Causes included interference and/or non-bird objects such as vegetation and landforms. We used a local thresholding approach to mask out the most spatially consistent artifacts. During each night, for images that did not exceed the precipitation threshold, we calculated the mean R+G value of each pixel throughout the night. We selected all pixels with a mean R+G exceeding 0.5 and carried out a one pixel dilation of those pixel clumps. The resulting area, combined with the area 180° below ground and more than 2 km from the sensor, was masked out completely during bird detection.

c) Bird detection
Bird detection was carried out using closed-source software developed by the Alexandra Institute, based on functionality from the OpenCV python package. The software requires as input a series of radar images, a mask for those images to exclude irrelevant areas, and a world file containing georeferencing information for the image. The software returns the locations and signal intensities of putative birds based on a combination of motion and blob detection.

d) Post-processing
The timing of putative bird detections was determined using radar image metadata. To minimize the prevalence of artifacts, which would present as extremely small or large blobs, we filtered out putative birds with intensity ≤30 or ≥100. The radar scan has an elevation angle range of 21°, such that birds are more likely to be detected at greater distances from the sensor. We accounted for this effect by expressing detections as detections m^{-1}, based on distance from the sensor and elevation angle range. We then aggregated detections within a 50 m resolution grid spanning horizontal (x) and a vertical (y) axis, accounting for the area that was masked during bird detection, expressing the density of putative birds in detections per cubed hectometre (detections hm^{-3}).

Many 50 m grid cells were excluded from further analyses to generate more accurate measures of bird density. Grid cells <50m from the ground or <20° from ground-level were excluded to minimize interference from vegetation and landforms. Grid cells >1400 m from the sensor at angles <80° from ground-level were excluded because we observed a high prevalence of artifacts in those regions. Grid cells which were more than 50 % masked during bird detection for that night were also excluded. Finally, remaining grid cells where the density of detections was more than five times the mean for that night were excluded as outliers.

Data analysis

We present the mean density of putative birds across dates of survey, and across 50 m intervals along vertical (height) and horizontal axes. To identify when during the night bird traffic is highest, we also present the mean relative count of birds (hourly bird counts divided by the maximum hourly count for the given night) from 17:00 to 7:00.

For collision analysis, we converted densities of birds (detections hm^{-3}) to flux (passes hm^{-2} h^{-1}) based on an assumption of perpendicular, unidirectional movement towards a surface at speeds of 10, 15 or 20 m s^{-1}. This entails simply multiplying the density by speeds in units of hm h^{-1} (360, 480 or 720 hm h^{-1}).

2.6 Diurnal migration intensity and volume

Data on species specific bird daytime migration intensity, i.e., the number of birds per hour migrating from the coast at Skagen, was calculated from the numbers of birds recorded during the 15-minute transect counts within each hour-interval. Weekly estimates on migration intensity were then obtained from averaging the migration intensity per observation-hour within separate weeks. Likewise, the diurnal pattern in migration intensity was obtained from averaging bird numbers per hour over the weeks of observations for each specific hour of the day.

Calculations of migration intensity were performed for both numbers of birds making actual migration and birds that returned (from a migration attempt). Subtracting the number returning from the number migrating forward allowed calculation of the net migration to provide an estimate of the number of migrating birds during the spring period.

Since several of the focal species were only observed in low numbers, migration intensity was estimated for species groups, e.g., falcons, harriers, kites, and corvids.

For these groups, migration volume, i.e., the total estimated numbers migrating from Skagen during the full spring migration period, was calculated based on the daily and weekly averages of migration intensity, using an average ‘migration day’ of 12 hours. However, the length of the ‘migration day’ for species migrating within restricted periods of the day, e.g. only during morning hours, the ‘daily migration period’ was adjusted to the actual number of hours during which migration took place.

To verify the representativeness of the estimated migration volume obtained from the transect count data, we compared this data to the total numbers recorded migrating at Skagen by random observers on a daily basis during weeks 12-24, as documented in the public database DOFBasen. These daily total numbers were compiled by the Skagen Bird Observatory and are screened for double registrations to obtain 'true' daily numbers of migrating individuals of each species.

2.7 Flight altitude and flight direction

Data on diurnal flight altitude was analysed based on the data generated by the LRF, whereas data on nocturnal altitude was analysed from data generated by the vertically positioned radar. Flight direction of individual birds or bird flocks migrating at Skagen was analysed from data obtained by operating the laser rangefinder and from the horizontally orientated radar.

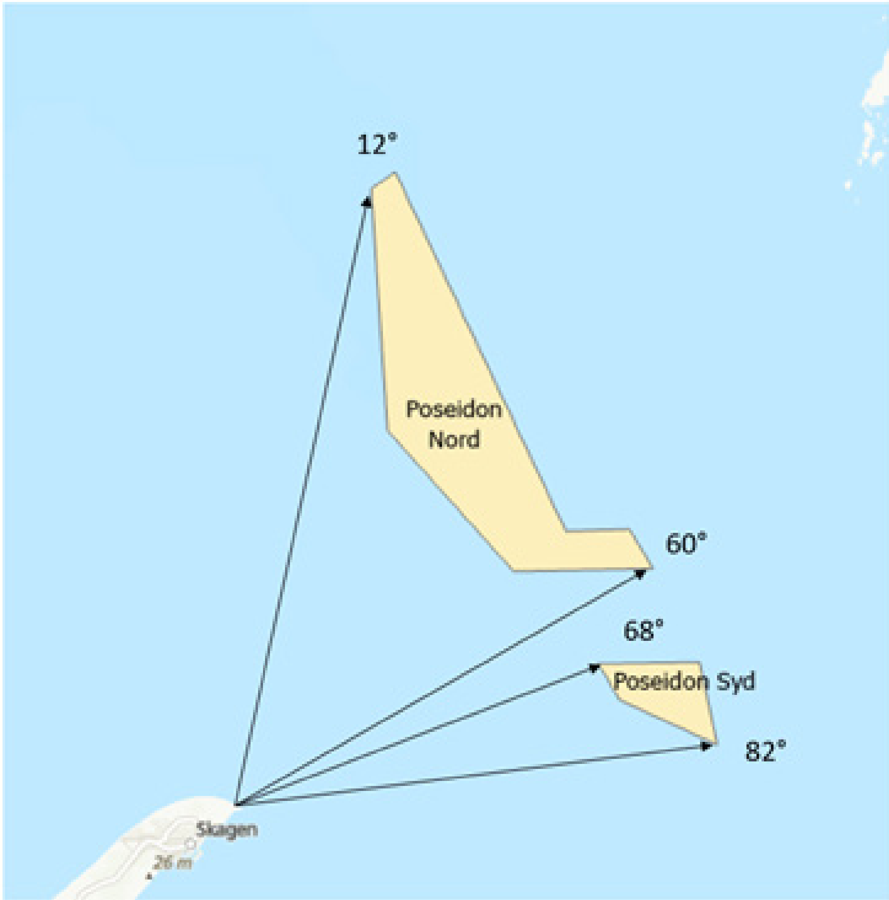
When operating the LRF, flight altitude of raptors and other larger bird migrating at Skagen, i.e., buzzards, kites, harriers, eagles, and cranes, could be obtained up to a distance approximately 2 km, in a few instances a bit further. For smaller species like sparrowhawk and falcons, the detection distance was shorter, generally below 1 km.

For some smaller bird species, flight altitude measurements were obtained at distances exceeding 1 km. These 'long-distance measurements' were recorded when these species were migrating together with larger species, as seen when, e.g. sparrowhawks were following/interacting with soaring groups of buzzards, which could be measured at longer distances than the individual sparrowhawk. In these cases, the tracks and measured points were subsequently divided into two species specific tracks with identical measurements.

The final migratory direction of birds leaving Skagen was calculated for species where at least two point-measurements were taken by the LRF, and from two digitized points in a bird track recorded by the horizontal radar. Final migratory direction was given by the direction between the last two points measured from each individual track and the direction were grouped into 45°-degree intervals for all species-specific tracks.

To estimate the proportion of migrating birds that potentially would pass the originally planned wind farm areas Poseidon Nord and Poseidon Syd, the percentage of tracks pointing towards Poseidon Nord (12°-60°) and Poseidon Syd (68°-82°) when leaving the Skagen area, was estimated separately, as was the proportion of birds that theoretically would pass the 8° (60°-68°) area between the two appointed wind farm areas (Figure 5). This assessment does not consider any potential attraction or avoidance by migrating birds towards the future wind farm.

Figure 5. The position of the designated wind farm areas Poseidon Nord and Poseidon Syd in relation to Skagen.



2.8 Estimates of collision risk

The migration volume of each species or group of species used in the collision model were the year totals (Table 4). For a number of species, where the migration volume was small, we merged the species into species groups. This applied to falcons, harriers and corvids. We used the migration direction observed with the laser rangefinder to estimate the proportion of the migrating birds expected to pass through each of the wind turbine areas (Table 5). The horizontal radar also offers information on direction, but to keep estimates between the three years comparable we use the observations from the laser range finder, which is the same parameters as previous years. Once the birds reach the wind turbine area the density, measured as the number of birds per kilometre, have decreased, due to the increased distance to the coast. We conservatively estimated the density at the edge of a circle with a radius of 23.5 or 25 km, which approximates the minimum distance between Skagen and the wind turbine areas. This approximation, however, overestimate density, due to the use of a smaller distance to the coast than most of the wind turbines will have. This issue applies particularly to Poseidon N where many of the wind turbines will be further away and thus have smaller density. The overestimated density will result in an overestimate of the number of collisions in the wind turbine park, as the distance and hence the dilution of density will increase with larger distance form Skagen.

Among the birds estimated to pass through the wind turbine areas, only a certain proportion of them will be migrating at risk height, i.e., in the area swept by the rotating blades. The altitude of the birds typically changes with distance to the coast. The use of GPS tags (see section 1.7 below) will eventually enable us to describe the relationship between the distance to the coast and altitude However, for now, we just estimated the proportion of flocks at risk height for every 200 m from the coast, if there were at least five observations in the distance interval and observations within or outside the risk altitude. We used the distance interval with the highest proportion at risk altitude in the 2024 observations. The values used for the nine species are listed in Appendix Table A1.

Since we do not know specifically, which wind turbine type will be used in the suggested areas, we estimated collision risk for two different wind turbine designs named alternative A and B (Appendix Table A2). The two designs differ in the diameter of the wind turbines. In the current collision model, we used the minimum distance between turbines at each site (Appendix Table A2). Additionally, this conservative approach will overestimate the collision risk.

We used Bands collision risk model to estimate the collision risk for the two areas. For all species, we estimated the collision risk using 99 %, 97.75 % and 95 % avoidance rates. Generally, the 99 % and even higher avoidance rates are accepted for most species for terrestrial wind turbine parks (Offshore Wind Directorate 2023) but little is known for offshore wind farms and therefore we also made collision estimates for lower avoidance rates. We used SAS vers. 9.4 (SASInstitute, Cary, NC) and Excel for all calculations associated with the collision risk modelling.

Collision risk estimates for the radar observations

The vertical radar estimates reflect the nocturnal migration, which is dominated by passerines. The radar does not allow us to discriminate between species, so the collision estimate reflects a amalgamated collision risk for nocturnal migrants. We converted the density estimates to a flux by multiplying it with the flight speed of the bird or bird flock. The estimate was multiplied by the rotor area, to get the number of birds passing the rotor area per second. This estimate was multiplied by the number of seconds in the night for April and May (548 hours). The remaining part of the calculation of collision estimates is like the ones made for the raptors. This approach assumes that birds fly at 15 m/s and fly perpendicular to the radar beam.

2.9 Flight trajectory and migration altitude of birds of prey

The GPS tags

To obtain information on flight paths and flight altitudes of migratory birds of prey, Ornitela OT-E10-G4 GPS tags were chosen. The tags are designed for harness attachment on birds. This GPS tag is a 10-gram device with a solar panel and G4 GMS communication facility, enabling communication with the device while within G4 GSM coverage.

An online communication platform enabled us to control communication intervals with the device as well as timing of data collection. Likewise, the battery status of the device could be monitored. The timing of intervals between position collection could be geographically segregated by the use of "geofences" defined as geographical areas within which data collection settings can be altered once the bird has entered that specific area.

Flight altitudes obtained from the tags are given as meters above sea level.

Ringing and attaching GPS tags

Adult birds of prey were captured for the purpose of attaching GPS tags. All birds were ringed with metal rings. The GPS tag was attached to the birds with a Teflon harness, placing the GPS tag on the central back of the bird. In some cases, back feathers may cover the solar panel of the GPS tag. This is the case for Common Buzzard. Therefore, a specially designed elevation "saddle" was produced. The saddle elevates the solar panel above the feathers. Such saddles were used on most of the Common Buzzards tagged in this project.

Birds were captured by two methods. Most birds were captured in walk in traps with a bait. Bait was dead birds, either chicken or road kills. The trap was equipped with a detector that record a catch and alert the ringer by a SMS message. Another method was catching birds in a large, meshed mist net, attracting birds of prey by placing a stuffed Eagle Owl under the net. Birds of prey attack the owl, and in that process gets caught in the net.

Data from INBO, Belgium

Based on a collaboration with Research Institute for Nature and Forest (INBO) in Belgium, the project got access to GPS data from birds of prey passing marine areas. Data from 5 Hen Harriers, 8 Marsh Harriers, 8 Montagu's Harriers and one Honey Buzzard have been included. Data derive from GPS tags delivering altitude measurements (here given as ellipsoid heights), and data has been collected specifically to provide information on flight altitudes during marine passages.

Lesser Kestrel, Skagen 2024.
Photo: Thomas Kjær Christensen

3 Methods and study design – Sweden

3.1 Study sites

Data on species specific migration and flight altitude of migrating birds arriving at the Swedish west coast was obtained from three locations in 2024, similar to the locations used in 2023 (Figure 6). In 2024, observations at Käringön were made from two local positions, Lotshuset and Sydudden, but data from these two sites were lumped. The locations were chosen as they represent some of the most westerly placed islands at the west coast of Sweden, located closest to the designated wind farm areas, and with known occurrence of spring migrating birds (Artportalen.se).

Although the migration of birds along the Swedish west coast is supposed to be much less concentrated compared to the Skagen area, some sites, e.g., capes and distant islands, may attract migrants approaching the Swedish coast.

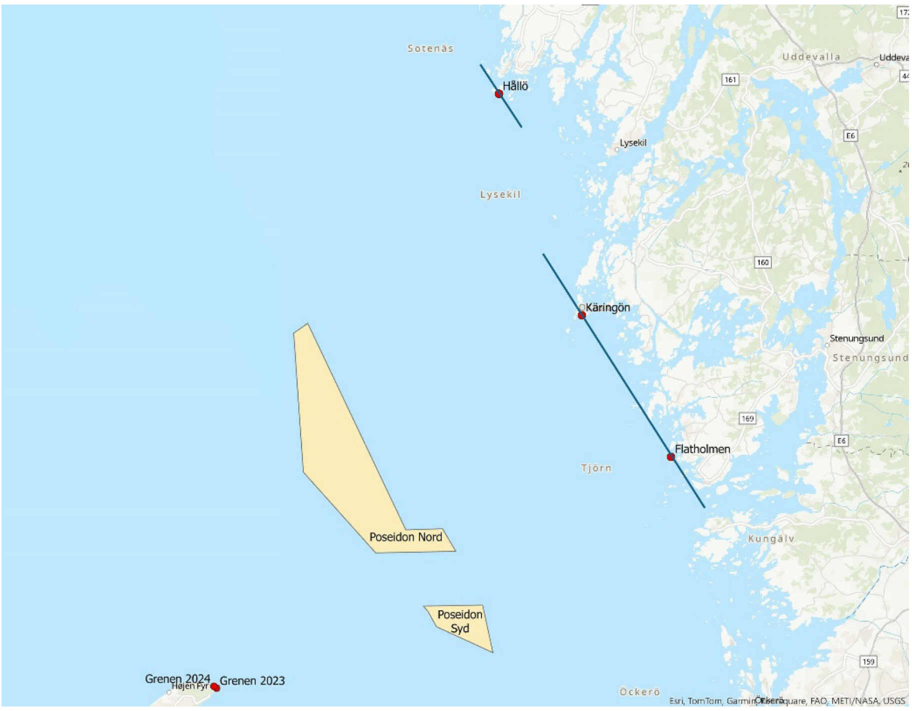


Figure 6. Map of the area designated for wind farm development and the location of observation points in Sweden used during spring 2024. The black lines indicate the artificial coastline used to divide bird observations at the Swedish coast into those made when the birds are over the sea and when they are over land.

3.2 Setup and plan for visual observations

Visual bird observations were planned to cover 21 days during the main spring migration period, from 15 April to 5 May. The observation hours were mainly set to monitor raptor migration, and the length of each observation day was determined on site, depending on raptor activity (migration intensity) and weather conditions.

The number of observation days per week and the weekly distribution of the observation hours at the locations in 2024 are shown in Table 2. Combining the observation days from all three locations Flatholmen (16 days), Käringön (17 days) and Hållö (15 days), a total of 48 days were covered by observations.

Table 2. The weekly distribution of observation days at the three locations and the number of observation hours at the Swedish west coast during spring 2023. The use of laser rangefinder is indicated with an X.

Week No.	Obs-days	Location	Hours	Rangefinder
16	7	Flatholmen	64,25	X
	5	Hållö	33,6	X
	4	Käringön	23	X
17	4	Flatholmen	37,5	X
	5	Hållö	34,85	X
	7	Käringön	43,75	X
18	5	Flatholmen	52,5	X
	5	Hållö	33	X
	6	Käringön	31,85	X
Sum	**48**		**354,3**	

On most days observations included between 6 and 8 hours of observation depending on weather conditions and bird migration activity. In total 354.3 hours of observation was carried out at the three locations in 2024 (Table 2).

Observations were performed by experienced observers and included continuous counts of all birds arriving at the coast from south-westerly directions, with a special focus on migrating raptors. Birds were observed with binoculars and telescopes to optimize both detection and species identification.

Throughout the days of observation observers operated a VECTOR IV laser rangefinder to obtain georeferenced information on bird location and of flight altitude and direction, by following individual migrating birds.

3.3 Migration intensity and volume

No systematic transect counts were carried out at the Swedish coast due to the scattered occurrence and low numbers of migrating birds. Observations included all observed arriving birds of relevance which were continuously counted. Numbers of relevant species were summed up in daily and weekly totals but were not extrapolated into estimates of migration intensity and total volume.

3.4 Flight direction and altitude

Flight direction and altitude of individual migrating birds or bird flocks approaching the coast of Sweden was obtained from measurements made with the LRF. Operation and data collection by the LRF is described for Denmark (see 1.5). Restrictions on the detection of smaller and larger species were similar to the Danish conditions, decreasing with distance from the observer. As, e.g., for larger birds/flocks (Whooper Swan, geese, Common Crane) the breaking point was at 3.7 km (a flock of Whooper Swans detected with LRF up to 5 km), larger sized raptors (buzzards) at 2.6 km and for smaller sized raptors (Eurasian Sparrowhawk) at 1.7 km.

Flight direction was estimated from the first two point-measurements, the last two point measurements and for all point measurements in each bird track record. Flight altitude was estimated from all point measurements but separated between points measured over the sea when birds were approaching the coast and points over land, when birds were migrating further north.

Both flight direction and altitude may be affected by the presence of smaller islands further offshore and by how bird migratory behaviour relate to islands under current weather conditions. In consequence, some birds may actually fly over land (smaller islands) although they are classified as being over the sea, according to the theoretical division between “Sea” and “Land” as defined in Figure 6.

4 Results – Denmark

4.1 Transect counts – Bird species and numbers recorded

A total of 57 different species of focal interest were recorded during the transect counts from week 12 to 24. Of these 20 species were raptors, while 37 species belonged to other families of birds. Table 3 shows the total number of birds recorded during transect counts passing the transects in a forward direction (northern/north-easterly migration attempt) and the numbers returning towards the coast (return migration) throughout the study period.

Table 3. The number of birds observed during the 15-minute transect counts performed at Skagen during the weeks 12-24 2024 showing numbers migrating forward (leaving the coast) and numbers returning from a migration attempt. Observations of gulls, terns, passerine and other species are not included.

Group	Species	Forward	Return	Group	Species	Forward	Return
Raptors	Common Buzzard	689	378	Pigeons	Wood Pigeon	5,630	1253
	Rough-legged Buzzard	17	8		Stock Dove	27	10
	Honey Buzzard	367	15	Corvids	Jackdaw	783	103
	Sparrowhawk	494	87		Crow	117	161
	Red Kite	31	20	Geese	Greylag Goose	134	1
	Black Kite	7	6		Pink-footed Goose	142	
	Black-shouldered Kite	1	1		White-fronted Goose	2	
	Marsh Harrier	42	2		Anser sp.	6	
	Hen Harrier	49	2		Barnacle Goose	22	
	Pallid Harrier	23	2		Brent Goose lb/db	23	
	Montagues Harrier	1			Canada Goose	15	
	Harrier sp.	1		Ducks[1]	Shoveler	7	
	Kestrel	137	6		Teal	29	
	Merlin	27	1		Wigeon	67	
	Peregrine Falcon	3			Shelduck	8	
	Eurasian Hobby	51	2		Seaducks[2]	5980	
	Red-footed falcon	5		Divers	Red-throated Diver	844	2
	Osprey	34			Black-throated Diver	1	
	White-tailed Eagle	4	4		Great Northern Diver	2	
	Steppe Eagle	1	2		Whooper Swan	13	
	Short-eared Owl		2	Other	Common Crane	24	6
					Grey Heron	23	3
					Great White Heron	2	1
					Waders[3]	130	3
	Total raptors	1,984	538	Total other species		14,031	1,543

[1]Numbers of ducks may not reflect true numbers, as these species were not systematically recorded.

[2]Seaducks comprises numbers of Eiders, Velvet Scoter, Black Scoter, Long-tailed Duck, Goosander and Redbreasted Merganser.

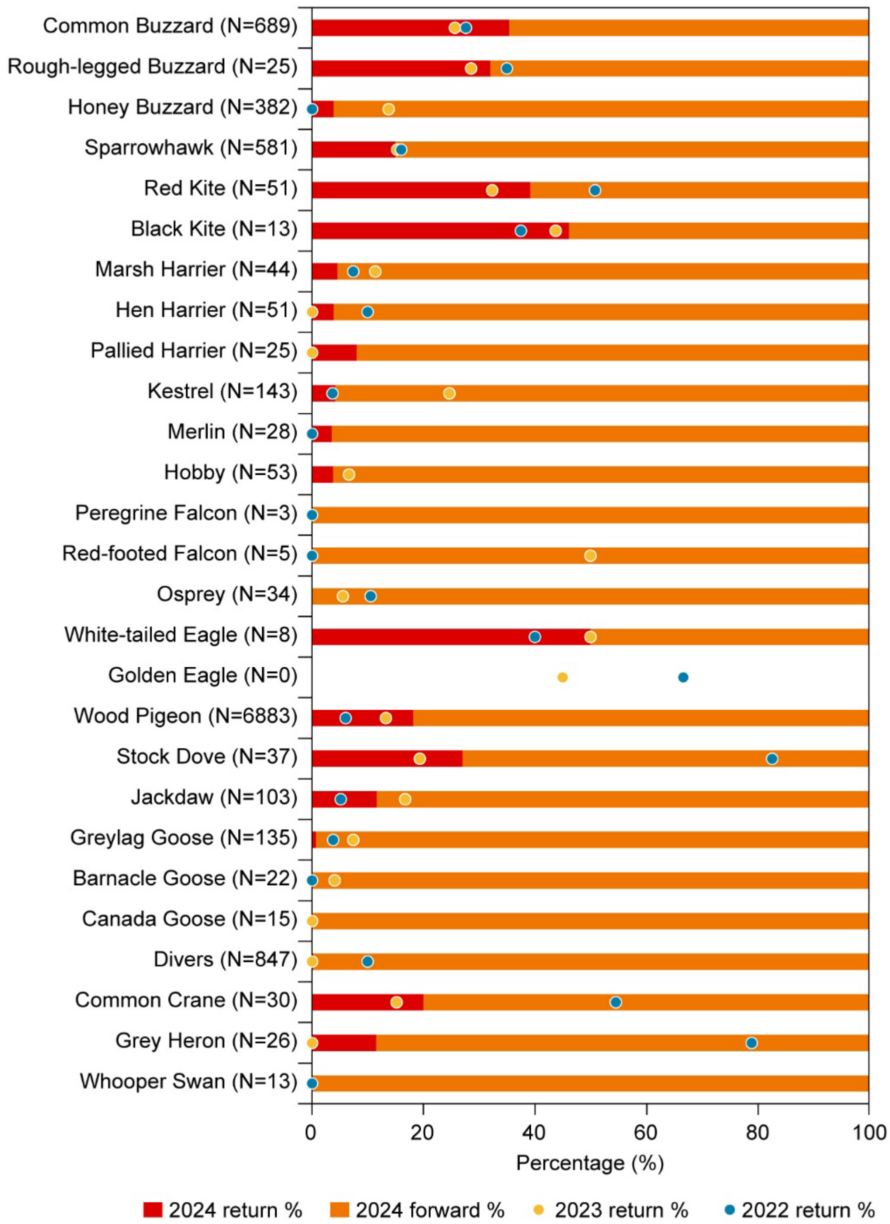
[3]Waders comprises numbers of Oystercatcher, Lapwing, Grey Plover, Greenshank, Spotted Redshank, Wood Sandpiper, Green Sandpiper, Whimbrel, Curlew and Bar-tailed Godwit.

As can be seen from the total numbers, raptors, pigeons and Jackdaw were the most numerous birds during the spring migration (Table 3). Of the raptor species, Common Buzzard, Honey Buzzard and Sparrowhawk were by far the most numerous species recorded, followed by Kestrel, Hen/Marsh Harrier and Red Kite. In 2024, a relatively high number of falcons were recorded compared to previous years. The large number of sea ducks recorded in 2024 is a result of more records of the daily movements of locally staging birds.

During the spring season, most birds observed were, as expected, migrating from the Skagen peninsula towards Sweden and Norway. However, the reluctancy of (some) bird species to fly over open water also resulted in many birds returning to the coast after a migration attempt. In general, for soaring birds such failed migration attempts are assumed to be affected by prevailing weather conditions, primarily wind direction and speed.

Based on the numbers of birds recorded during transect counts, the proportion of forward and return migration for the most numerous species is shown in Figure 7. Overall, an average of 21.2% of the raptors returned from a migration attempt, with the soaring species Red/Black Kite and Common /Rough-legged Buzzard showing the highest return rates (>30%), whereas the active flyers, i.e., falcons, harriers and Osprey, were the most determined migrants with low return rates. For the other species return rates were generally low, i.e., less than 20% (Figure 7). Most species showed comparable return rates between 2022, 2023 and 2024, with the exceptions of Stock Dove, Common Crane and Grey Heron, showing higher return rates in 2022. This was probably related to weather conditions during that year (see Figure 7).

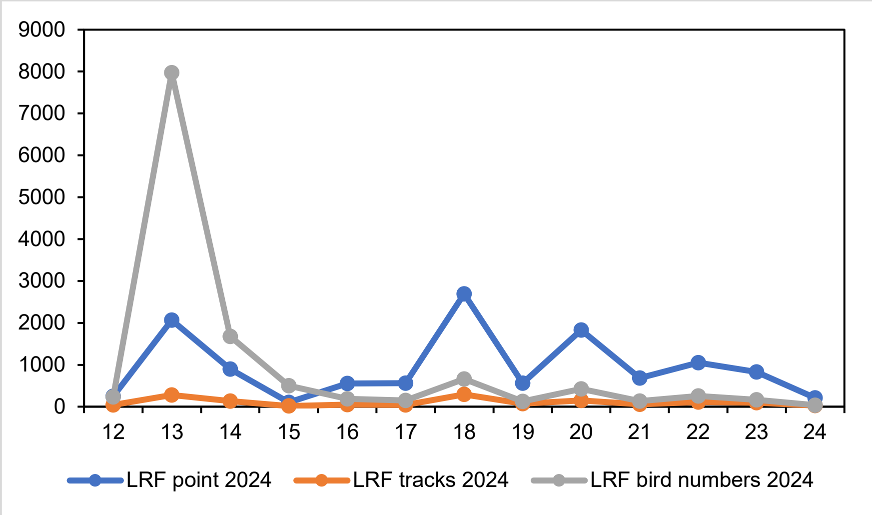
Figure 7. The proportion (%) of forward and return migration for birds recorded during daytime transect observations at Skagen in 2024 (bars), with the number of birds counted. The blue and yellow dots show the proportion of return migration recorded in 2022 and 2023, respectively.



4.2 Laser rangefinder – Bird species and numbers recorded

Figure 8 and Table 4 shows the total number of tracks, total number of measured points and the sum of birds in all tracks for all species recorded using laser rangefinder during week 12 to 24 during spring 2024. The 1,370 tracks included a total of 12,285 single point measurements, varying from 1 to 58 points in individual tracks. 63 individual tracks consisted of a single measured point and are therefore not real tracks. The total number of birds associated with the tracks or individual single points were 12,518 (Table 4).

Figure 8. The number of tracks, measured points and bird numbers obtained with the laser rangefinder at Skagen during week 12 to 24 in 2024.



Common Cranes on migration attempt, Skagen 2024. Photo: Thomas Kjær Christensen

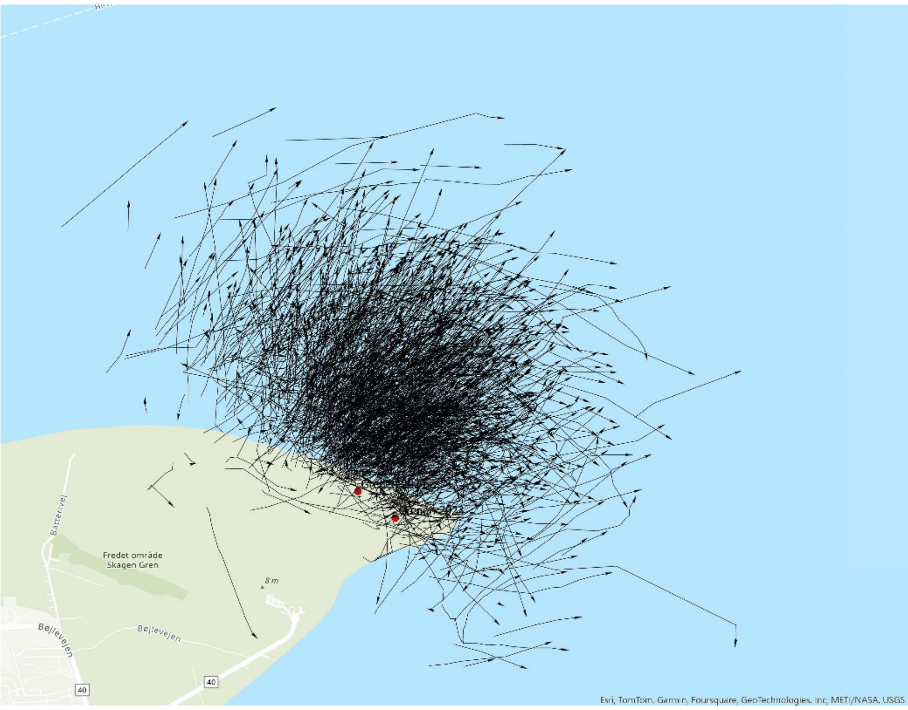
Table 3. The number of single points and tracks measured with the laser rangefinder at Skagen during week 12-24 in 2024. The number of birds involved in the measurements are also shown. The number of tracks include 63 'tracks' consisting of one point measurement and 75 'tracks' consisting of two point measurements.

Group	Species	Points	Tracks	Birds	Group	Species	Points	Tracks	Birds
Raptors	Common Buzzard	1,279	189	443	Pigeons	Wood Pigeon	227	33	7,020
	Rough-legged Buzzard	155	15	15		Stock Dove	39	7	29
	Honey Buzzard	2,184	191	525	Corvids	Jackdaw	50	5	310
	Sparrowhawk	1,434	177	198	Geese	Greylag Goose	100	11	53
	Red Kite	344	38	62		Pink-footed Goose	19	2	33
	Black Kite	112	11	16		Barnacle Goose	67	8	175
	Black-shouldered Kite	7	1	1		Brent Goose ssp	34	8	15
	Marsh Harrier	802	73	85		Canada Goose	12	3	41
	Hen Harrier	1,095	84	94		Anser sp.	8	1	73
	Montagues Harrier	31	2	2	Ducks[1]	Mallard	6	1	5
	Pallid Harrier	376	26	27		Shoveler	7	1	2
	Harrier sp.	11	1	1		Teal	89	15	281
	Kestrel	1,031	108	111		Wigeon	105	13	222
	Merlin	164	22	24		Pintail	5	1	2
	Hobby	532	63	64		Shelduck	21	2	16
	Peregrine falcon	115	14	14		Seaducks[2]	402	69	1,420
	Red-footed Falcon	43	5	5	Divers	Red-throated Diver	194	37	91
	Osprey	477	48	55		Black-throated diver	41	7	10
	White-tailed Eagle	61	4	5		Great Northern Diver	18	2	2
	Steppe Eagle	14	3	3	Other	Whooper Swan	11	2	6
						Common Crane	170	21	137
						Grey Heron	109	11	32
						Great White Heron	7	2	2
						Waders[3]	152	13	345
						Bird sp. (12 species)[4]	125	21	442
Total raptors		10,267	1,075	1,750	Total other		2,018	295	10,768
Total all species							12,285	1,370	12,518

[1]Track numbers of ducks may not reflect true occurrence, as these species were not systematically recorded.
[2]Seaducks comprises tracks numbers of Eiders (33%), Velvet Scoter, Black Scoter (43%), Long-tailed Duck, Goldeneye, Goosander, Redbreasted Merganser and Crested Grebe.
[3]Waders comprises numbers of Golden Plover, Lapwing, Redshank, Green Sandpiper, Whimbrel (17%) and Curlew (53%).
[4]Bird sp. comprises Arctic Skua, Black-headed Gull, Common Gull, Caspian Tern, Mute Swan, Sandhill Crane, Cormorant, European Beeeater, Hooded Crow (14%), Rook, Mistle Thrush and Starling (14%).

The spatial distribution of all recorded tracks (Figure 9) shows that the density of measurements is highest closest to the observation points and declining with distance. All the tracks were recorded from the observation point 'Grenen 2024' (see Figure 2).

Figure 9. Map showing tracks of migrating birds recorded at Skagen during spring 2024 using laser rangefinder. Red dots indicate the observation points at 'Grenen 2023 and 2024'.



4.3 Migration phenology

4.3.1 Seasonal migration pattern

Average seasonal net migration intensity (forward minus return migration), expressed as the average number of birds per hour recorded within separate weeks during the migratory seasons (week 12-24 in both 2022, 2023 and 2024) is shown for the most numerous raptor species in Figure 11 and for non-raptor species in Figure 10.

Black Scoters and Eiders loafing at Skagen 2024. Photo: Thomas Kjær Christensen.

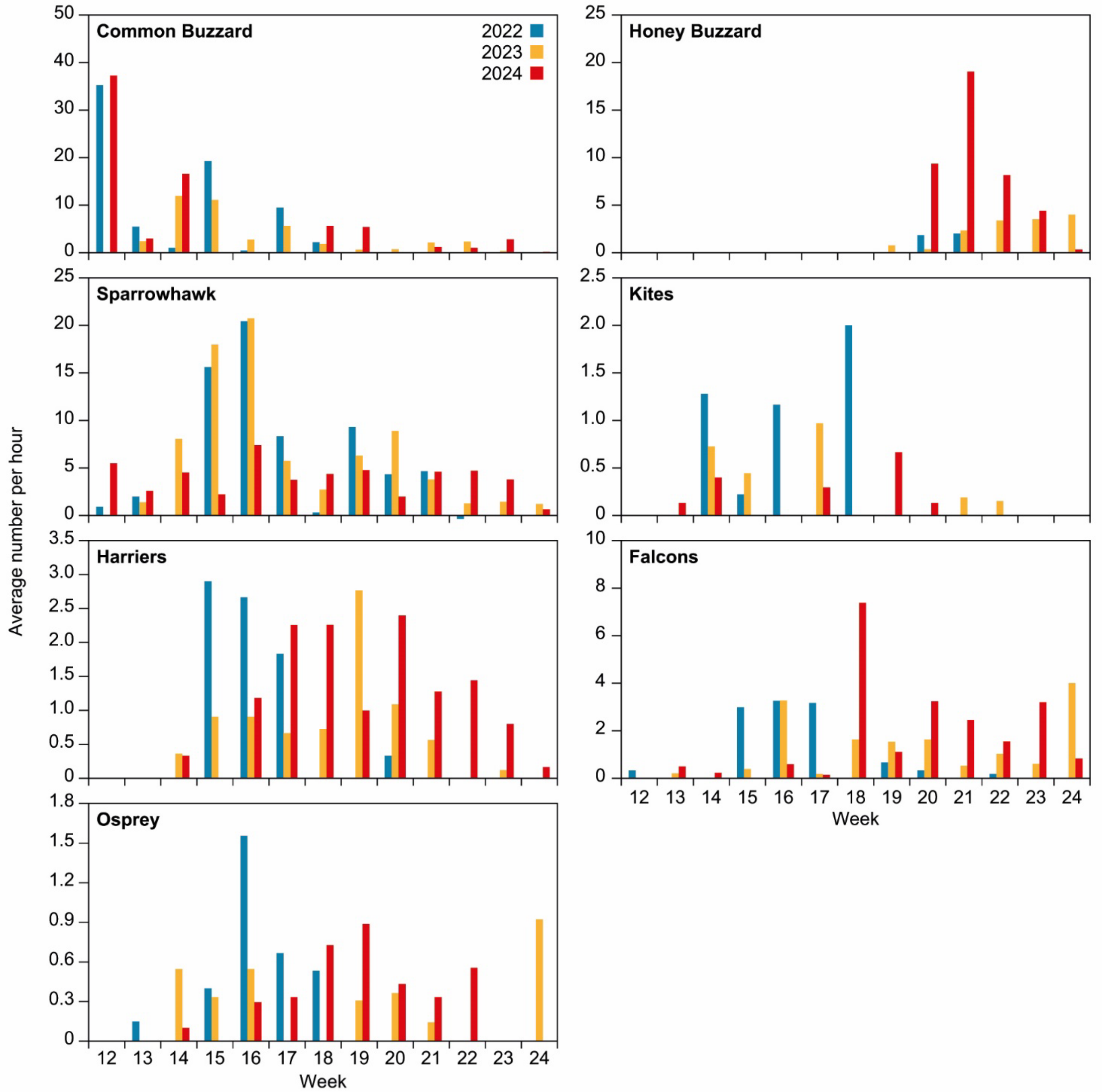


Figure 10. The net seasonal migration intensity (bird numbers per hour) of raptor species at Skagen. Data obtained by transect counts during week 12-24 in both 2022, 2023 and 2024.

In 2024, the seasonal pattern of migrating Common Buzzard again showed an early peak in late March. However, migration for harriers, kites, falcons and osprey showed a slightly later peak than in both 2022 and 2023, and Honey Buzzard showed a more concentrated peak in late May than in the previous years (Figure 11). This difference is most probably related to cold weather condition in mid- and late April, which have postponed migration of the species normally peaking during this month. Hence, the combination of rising temperature and dominating easterly winds in May 2024 (cf. Figure 3), have probably facilitated the concentrated migration movements observed in this month.

Although most variation in the seasonal timing of migration of raptors probably relates to varying weather conditions between years, some variation may be induced by observation methodology. This relates to observations covering only one 15-minutes count per hour performed over 6-9 hours per day during 2-3 observation days per week, which subsequently is extrapolated to a total migration estimate for a full 7-day period, potentially causing some uncertainty in final numbers.

Of the non-raptor species, both Wood Pigeon and Jackdaw have their peak migration in late March and early April. This pattern was roughly similar in all three study years (Figure 11).

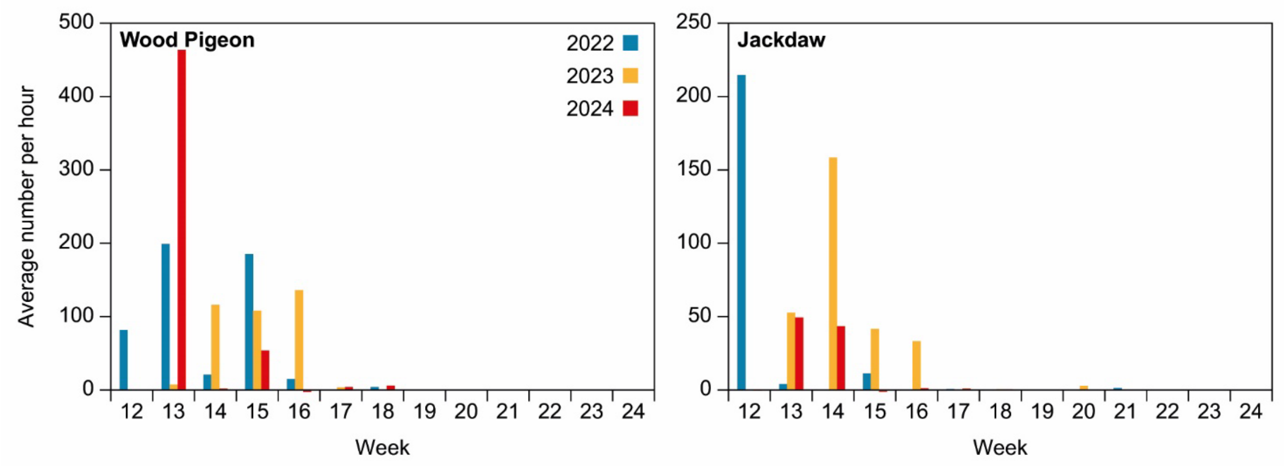


Figure 11. The net diurnal migration intensity (bird number per hour) of Wood Pigeon and Jackdaw at Skagen. Data obtained by transect counts during week 12-24 in both 2022, 2023 and 2024.

Red-footed Falcon, Skagen 2024.
Photo: Thomas Kjær Christensen

4.3.2 Diurnal migration pattern

Average diurnal net migration intensity (forward minus return migration) expressed as average number of birds per hour during the day (from sunrise to late afternoon) during week 12-24 in both 2022, 2023 and 2024, is shown for the most numerous raptor species in Figure 12 and for non-raptor species in Figure 13.

The overall diurnal migration of raptors generally shows similar daily patterns, with buzzards and kites showing a late morning-midday peak, and Sparrowhawk showing no peak periods, migrating at all times of the day. Falcons, harriers, and Osprey tend to have their peak migration period during late afternoon. However, most raptor species generally showed active migration attempts throughout the day from sunrise to late afternoon, and some may even have performed migration attempt until sunset, especially on days with optimal weather conditions. Of the non-raptor species both Wood Pigeon and corvids (mainly Jackdaw) have an early morning peak with migration activity ending at midday, resulting in a much more restricted diurnal period of migration than raptors.

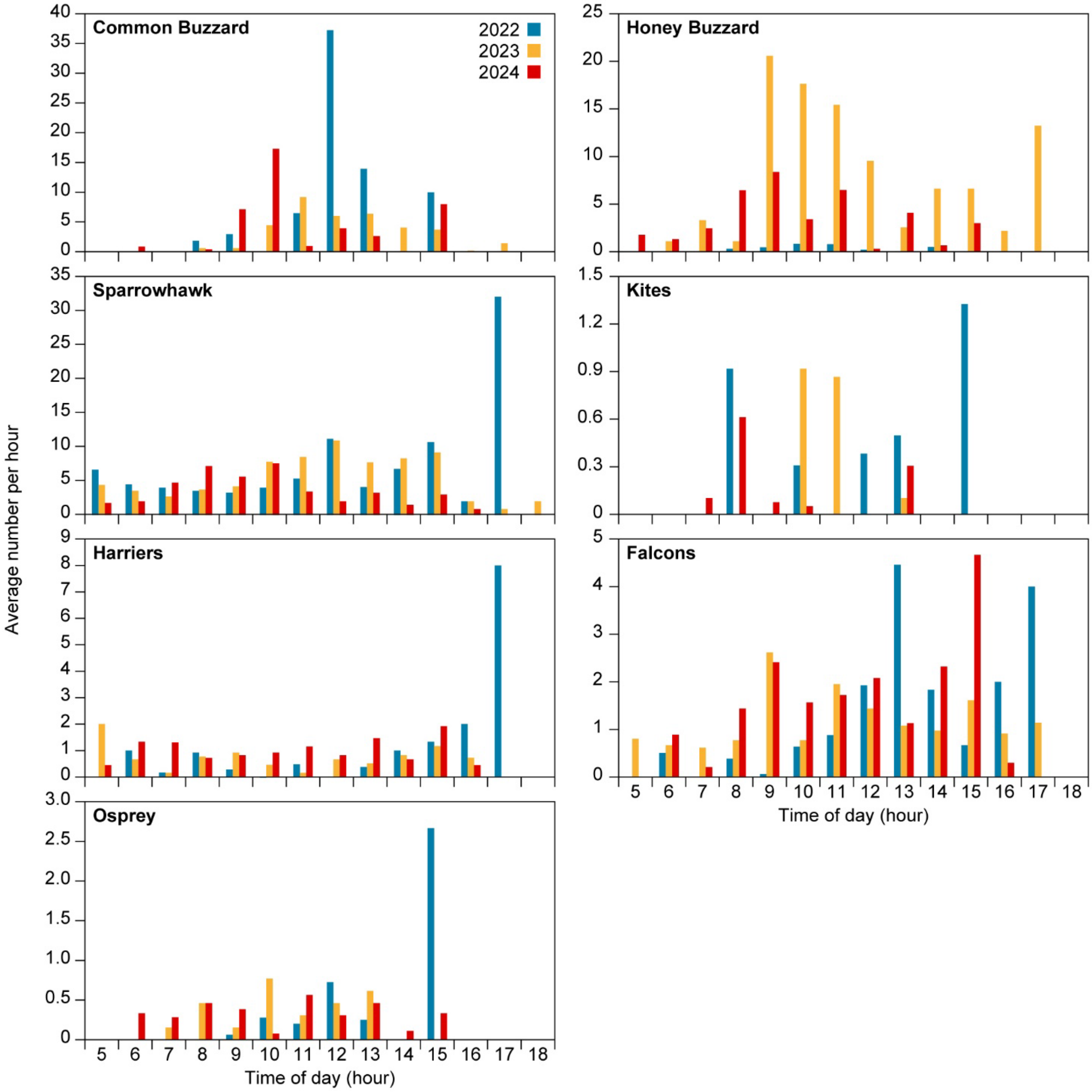


Figure 12. The diurnal net migration intensity (bird number per hour) of raptor species at Skagen. Data obtained by transect counts during week 12-24 in both 2022, 2023 and 2024.

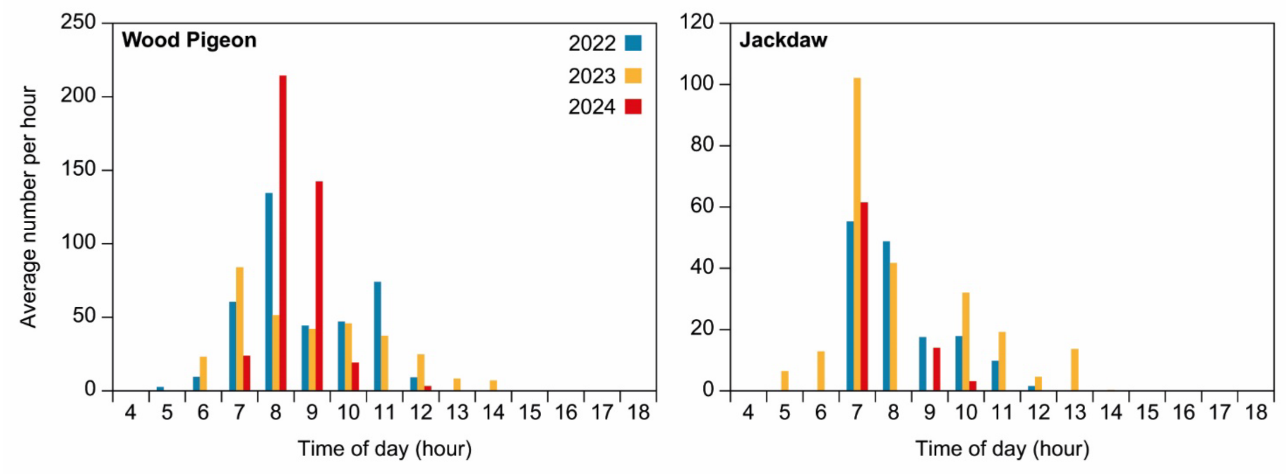


Figure 13. The diurnal migration intensity (bird number per hour) of Wood Pigeon and Jackdaw at Skagen. Data obtained by transect counts during week 12-24 in both 2022, 2023 and 2024.

4.4 Migration volume

The weekly migration volume for the different species and species-groups, calculated as the net migration (forward minus return) for the spring migration season 2024 between week 12 and 24, is shown in Table 5. The calculations take into account a 7-day week and the daily period in which migration occurs. For raptors, the daily period is set to 12 hours, whereas for pigeons this period is set to 9 and for Jackdaw 8 hours, based on the diurnal pattern recorded (see Figure 12 and Figure 13).

Likewise, Table 5 shows the total seasonal net migration of the most numerously occurring species for both 2022, 2023 and 2024. In general, the total migration numbers of most species are comparable between all three years, with only Honey Buzzard showing substantially higher numbers in 2024 than in both 2022 and 2023.

Some variation in the numbers of migrating species will always occur between years, due to different weather condition, and as a result of using 15-minute observation intervals. However, the estimated total migration volume in all years are strikingly consistent among the different species, with the exception of Honey Buzzard.

Overall, the present numbers of total migration from the present study are in general agreement with the total migration numbers of raptors estimated by the Skagen Bird Observatory, although these are somewhat higher (Figure 14). In comparison, migration totals from the Skagen Bird Observatory are based on the compiled numbers reported by voluntary ornithologist throughout the spring migration season, and not on 15-minute counts during 1-3 days per week. Most probably, the methodological differences explain the tendency for Skagen Bird Observatory numbers generally being higher for most species of migrating raptors (Figure 14).

Table 5. The total net migration of raptors and Wood Pigeon and Jackdaw estimated for the total spring migration period during week 12 to 24 2024. Calculations is based on transect counts and the number of days used as active migration for individual species is shown as superscripts. Colored numbers show negative values which indicate that more birds have been recorded on return migration than in forward migration. The estimated net seasonal totals are also shown for 2022 and 2023.

Week	Common Buzzard[12]	Honey Buzzard[12]	Harriers[12]	Sparrowhawk[12]	Falcons[12]	Kites[12]	Osprey[12]	Wood Pigeon[8]	Corvids[7]
12	2781	0	0	411	0	0	0	0	-25
13	249	0	0	218	42	11	0	29211	2768
14	1392	0	28	381	20	34	8	126	2432
15	0	0	0	168	0	0	0	4624	0
16	50	0	100	560	37	0	25	0	17
17	87	0	190	411	25	37	28	327	58
18	-16	0	69	-1	278	-12	24	-150	0
19	453	0	84	401	93	56	75	0	0
20	0	838	168	140	268	9	30	0	0
21	103	1601	107	387	205	0	28	0	0
22	84	686	121	397	131	0	47	0	0
23	214	336	61	290	244	0	0	0	0
24	14	28	14	56	70	0	0	0	0
Sum 2024	5410	3488	942	3819	1414	135	265	34138	5250
Sum 2023	3381	1222	682	6418	1179	83	269	24166	14178
Sum 2022	3996	215	509	5484	862	-72	234	28280	11345

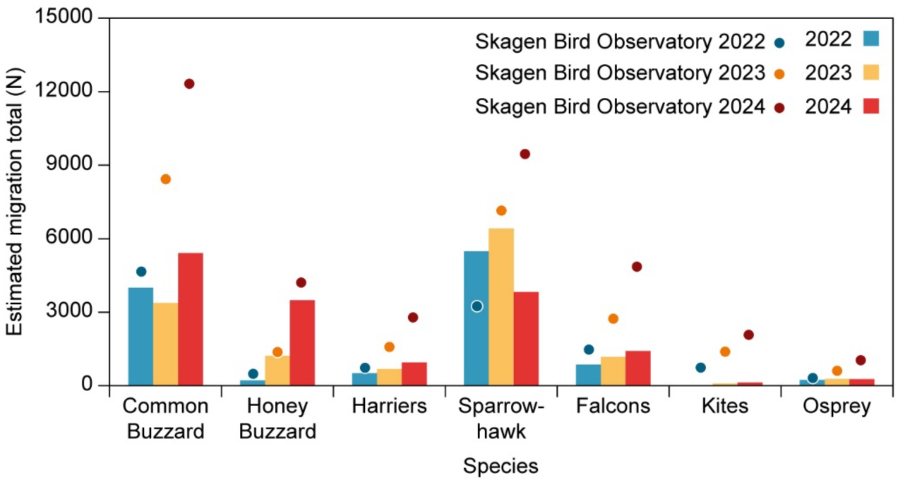
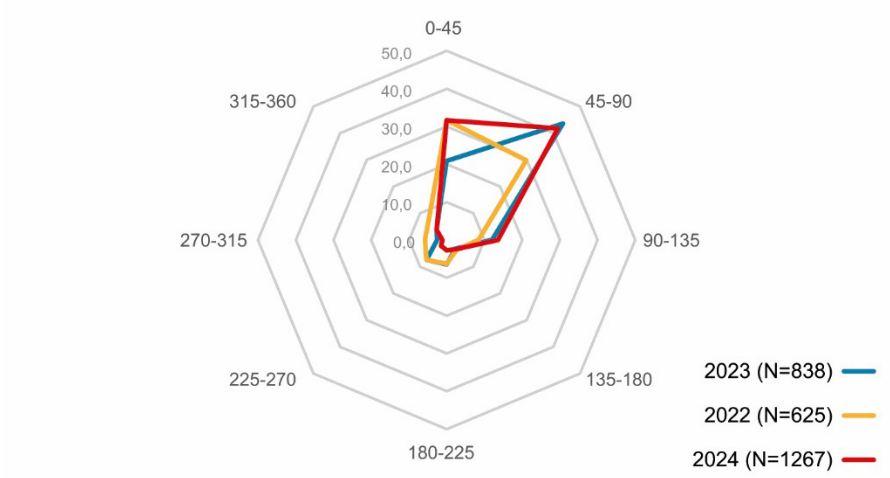


Figure 14. Estimated migration totals of selected species and species groups based on transect counts per hour (bars – this study) and the estimated totals compiled by the Skagen Bird Observatory in 2022, 2023 and 2024.

4.5 Flight direction

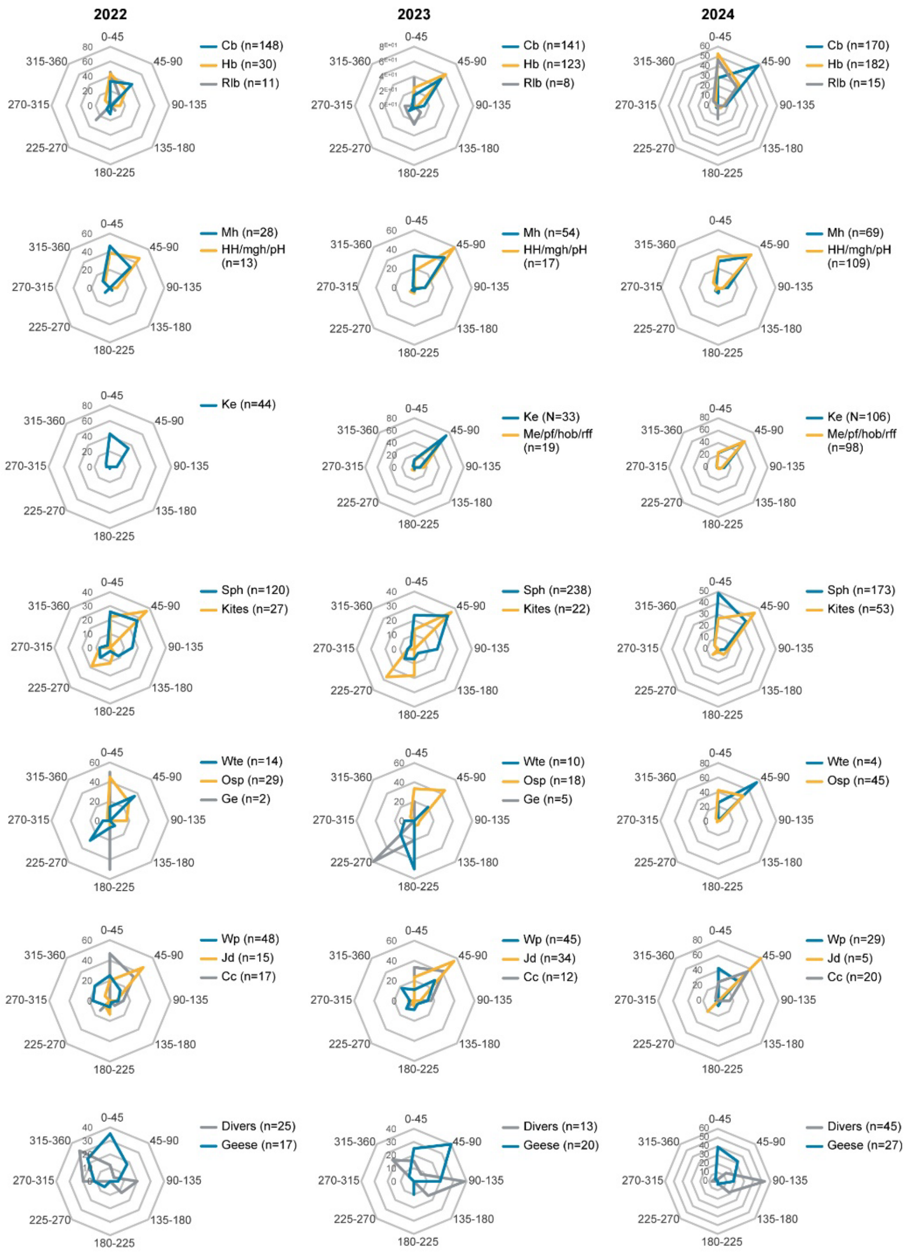
The overall flight direction of all migrating birds, measured as the direction between the last two points measured with the LRF, is shown for both 2022, 2023 and 2024 in Figure 15. In all years the main flight direction was between north and east, however, with a tendency to be slightly more easterly orientated in 2023 and 2024 than in 2022.

Figure 15. Migratory orientation of all bird tracks obtained at Skagen during week 12 to 24 in 2022, 2023 and 2024 shown as the proportion (%) of tracks in 45 degrees angle intervals. The number of tracks is given in brackets.



The overall flight direction of raptors and other bids migrating at Skagen during the spring 2022, 2023 and 2024 is shown in Figure 16.

Figure 16. Migratory orientation of raptor species at Skagen during March-June (week 12-23) in 2022, 2023 and 2024. Species abbreviations: Cb: Common Buzzard; Hb: Honey Buzzard; Rlb: Rough-legged Buzzard; Mh: Marsh Harrier; HH: Hen Harrier; Ke: Kestrel; Me: Merlin; pf: Peregrine Falcon, hob: Hobby and rff: Red-footed Falcon. Kites includes Red and Black Kite. Wte: White-tailed Eagle, Osp: Osprey, Ge: Golden Eagle. Wp: Wood Pigeon, Jd: Jackdaw, Cc: Common Crane. Divers include Red- and Black-throated Divers, Great Northern Diver and White-billed Diver, and Geese include Greylag Goose, Barnacle Goose, Brent Goose, White-fronted Goose and Canada Goose. The number of tracks is given in brackets; cf. Table 3.



The proportion of the bird migration that theoretically would pass the designated wind farm areas is shown in Table 6. These figures are calculated only for the most numerous species and separated into the proportions estimated to pass Poseidon Nord (12-62°), Poseidon Syd (68-93°) and the gap between these two areas (Figure 1) and includes only forward migration.

Table 6. The estimated proportions (%) of migrating birds and bird groups that migrate out from Skagen in 2024 and that theoretically would pass the designated wind farm areas Poseidon Nord and Poseidon Syd, as well as the free gab between the two areas. Note a few species has not been shown in the species list but are included in the figures given for 'All tracks'.

Group	Species	Tracks (N)	Poseidon Nord (12-60°)	Gap (60-68°)	Poseidon Syd (68-82°)	Sum (%)
Buzzards	Common Buzzard	170	55.2	8.2	15.9	79.4
	Rough-legged Buzzard	14	57.1	7.4	14.3	78.6
	Honey Buzzard	177	65.5	5.1	7.9	78.5
Hawks	Sparrowhawk	166	54.8	9.0	6.0	63.0
Kites	Red Kite	33	38.4	30.8	0.0	69.2
	Black Kite	10	20.0	0.0	0.0	20.0
Harriers	Marsh Harrier	53	50.7	10.1	5.8	69.8
	Hen Harrier	13	48.1	7.6	12.7	76.9
	Montagues Harrier	2	100.0	0.0	0.0	100.0
	Pallid Harier	23	56.5	4.3	17.4	100.0
Falcons	Kestrel	104	49.0	8.7	22.1	79.8
	Merlin	19	57.9	10.5	26.3	94.7
	Hobby	58	48.3	15.5	13.8	77.6
	Peregrine falcon	12	50.0	25.0	8.3	83.3
	Red-footed falcon	4	75.0	0.0	25.0	100.0
Ospreys	Osprey	45	68.9	8.9	8.9	86.7
Eagles	White-tailed Eagle	4	25.0	25.0	50.0	100.0
Pigeons	Wood Pigeon	29	69.0	3.4	10.3	82.8
Corvids	Jackdaw	5	80.0	0.0	0.0	80.0
Geese	Greylag, Barnacle, Brent, Canada Goose, Pink-footed Goose and Anser slp.	27	48.1	7.4	14.8	70.3
Ducks	Mallard, Pintail, Shoveler, Teal, Wigeon and Shelduck	33	6.1	0.0	7.4	13.5
Seaducks	Eider, Common Scoter, White-winged Scoter, Long-tailed Duck, Goldeneye, Red-breasted Merganser, Goosander	66	1.5	0.0	14.8	16.3
Divers	Red/Black-throated, Great Northern and spp. divers	45	42.2	0.0	0.0	42.2
Other	Common Crane	20	55.0	10.0	10.0	75.0
	Grey Heron	9	55.6	0.0	11.1	66.7
	Wooper Swan	1	100.0	0.0	0.0	100.0
All tracks		1,263	48.6	7.4	11.4	67.5

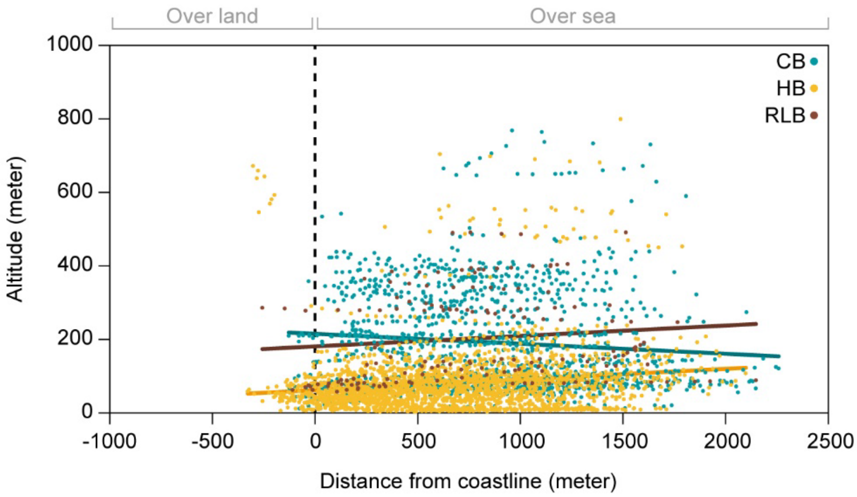
4.6 Flight altitude

In the following section, flight altitude is shown for selected species and species groups. Based on preliminary inspection of the data, altitudinal data is presented as species averages for some species and as individual track data for other species. This differentiation is chosen to obtain the most meaningful presentation of data. In the data presented below, the altitudinal behaviour during migration can in many cases be followed for individual birds/bird flocks, as consecutive measurements appearing as a line of dots, which represents single bird tracks.

4.6.1 Buzzards

The flight altitudes of the three species of buzzards recorded in 2024 (Figure 17) show some differences, with Honey Buzzards flying at lower altitudes than both Common Buzzard and Rough-legged Buzzard. Most Honey Buzzards fly at altitudes below 200 meters, whereas Common Buzzard occur evenly up to an altitude of 400 meter. In 2024 relatively few records of buzzards at altitudes above 400 meters were made.

Figure 17. Flight altitude of Common Buzzard (1,279 points measurements), Honey Buzzard (2,184 points) and Rough-legged Buzzards (155 points) relative to distance to the coast when migrating at Skagen spring 2024. Trend lines are only indicative of general altitudinal changes.



Flight altitude for Common Buzzard and Honey Buzzard in 2022, 2023 and 2024 is shown in Figure 18. Common Buzzard flight altitude tended to be lower and having a declining trend with distance from the coast in 2024, which is different to the pattern recorded in the previous years. In 2024 Honey Buzzard were likewise recorded at lower altitudes during migration than in 2023, but comparable to altitudes recorded in 2022, where few migrating birds were observed. In all years, however, Honey Buzzards showed an increasing trend in flight altitude with distance from the coast.

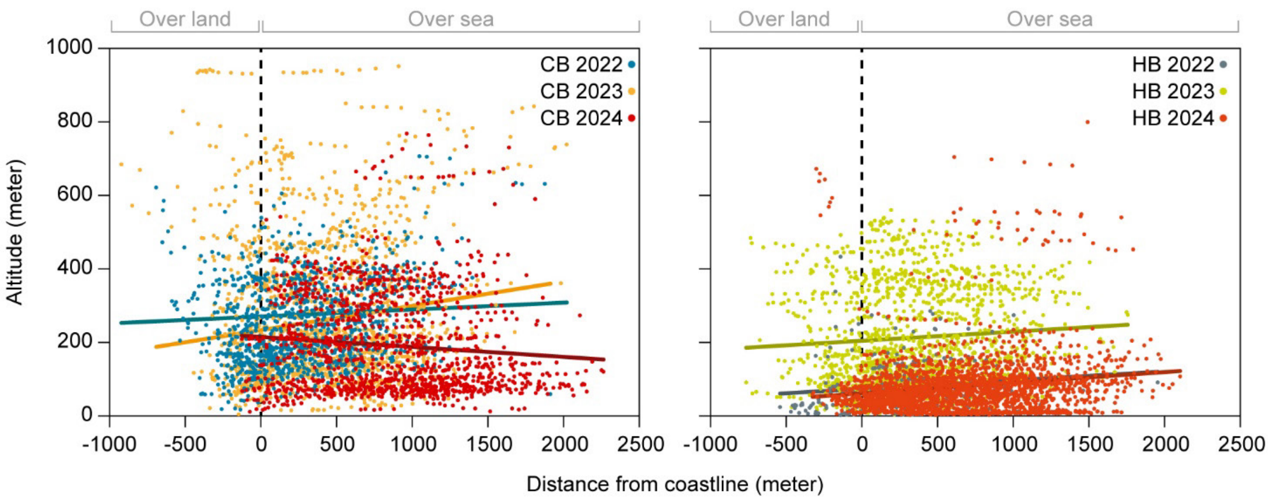


Figure 18. Flight altitude of Common Buzzard (CB) and Honey Buzzard (HB) recorded at Skagen in 2022, 2023 and 2024 when birds are moving from land towards the sea. Trend lines are only indicative of general altitudinal changes.

4.6.2 Sparrowhawk

The flight altitudes of Sparrowhawk recorded at Skagen in 2022, 2023 and 2024 is shown in Figure 19. In all years, most migration of individual birds took place at altitudes below 300 meters, with measurements of birds higher than 500 meters and farther than 800 meters from the coast representing birds following migrating buzzards.

In 2024, flight altitude was generally lower than in previous years and with no obvious altitudinal change with distance from the coast.

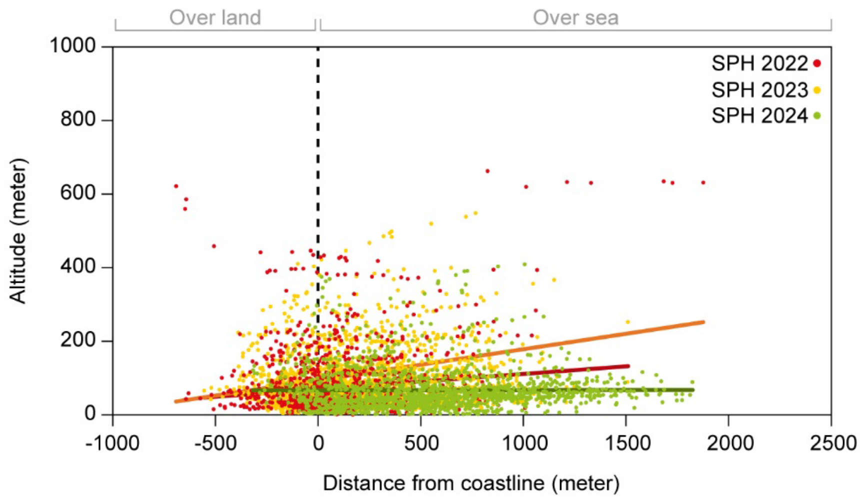


Figure 19. Flight altitude of Sparrowhawk (SPH) recorded at Skagen in 2022, 2023 and 2024 when birds are moving from land towards the sea. Trend lines are only indicative of general altitudinal changes.

4.6.3 Other raptor species

The flight altitudes measured for Kites, Marsh Harrier, Kestrel and Osprey are shown in Figure 20. With the exception of Osprey, that show similar altitudinal distribution as in 2022, flight altitudes in these species were generally lower in 2024 than observed in the previous years. The pattern of Kites shows a clear tendency to increase altitude when leaving the coast, whereas the altitudinal change in both Kestrel and Osprey show much less change. Marsh Harrier show a declining trend in altitude with distance to the coast, which is opposite to the pattern found in previous years.

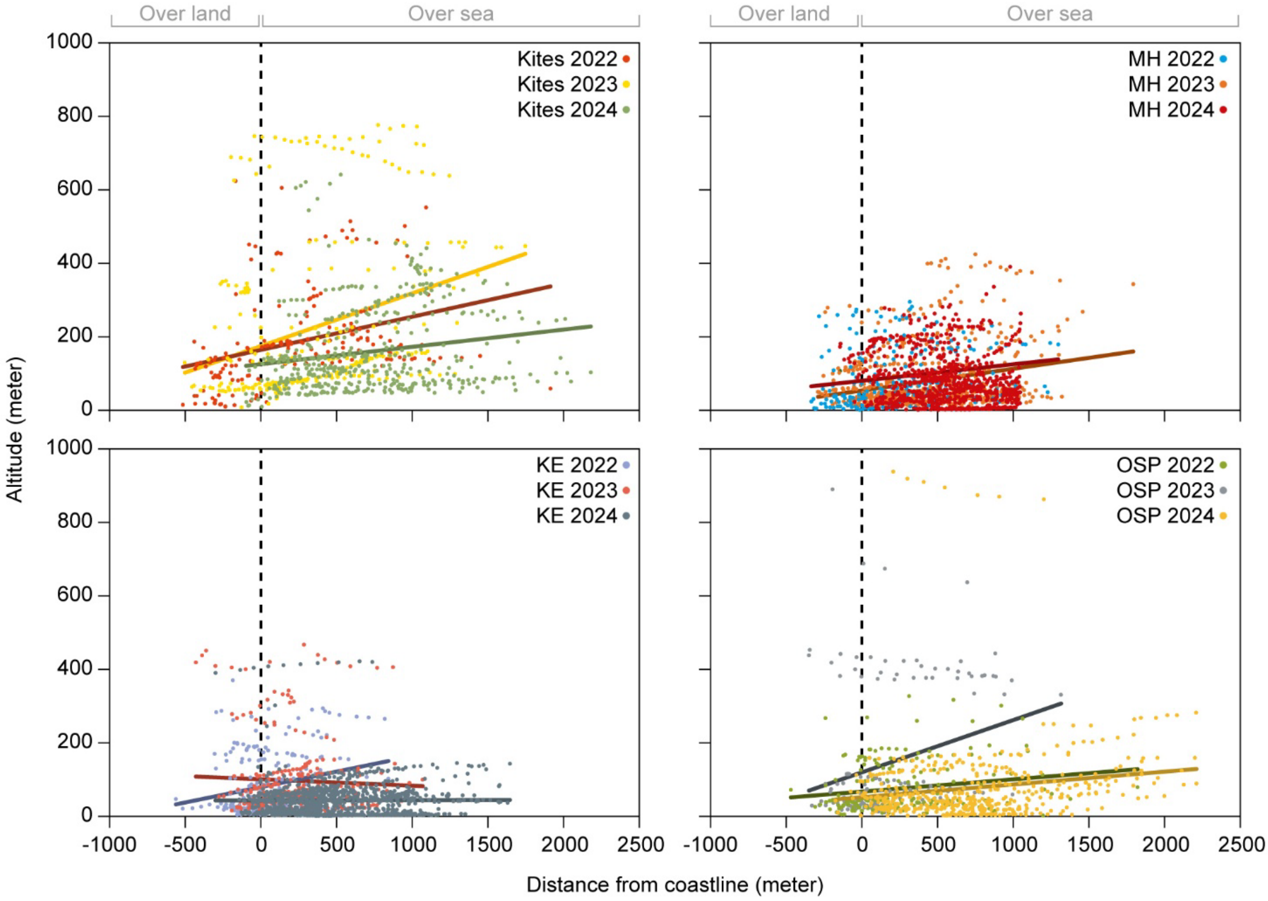


Figure 20. Flight altitude of Kites (Red and Black Kite), Marsh Harrier (MH), Kestrel (KE) and Osprey (OSP) recorded at Skagen in 2022, 2023 and 2024 when birds are moving from land towards the sea. Trend lines are only indicative of general altitudinal changes.

4.6.4 Non-raptor species

Flight altitudes of Wood Pigeon, Jackdaw and Common Crane in 2022, 2023 and 2024 are shown in Figure 21. Wood Pigeon and Jackdaw show a clear increasing trend with increasing distance from the coast, which is almost identical in all years. Common Crane show a more consistent altitudinal pattern, with a tendency to slightly decline with distance to the coast, as also seen in 2022.

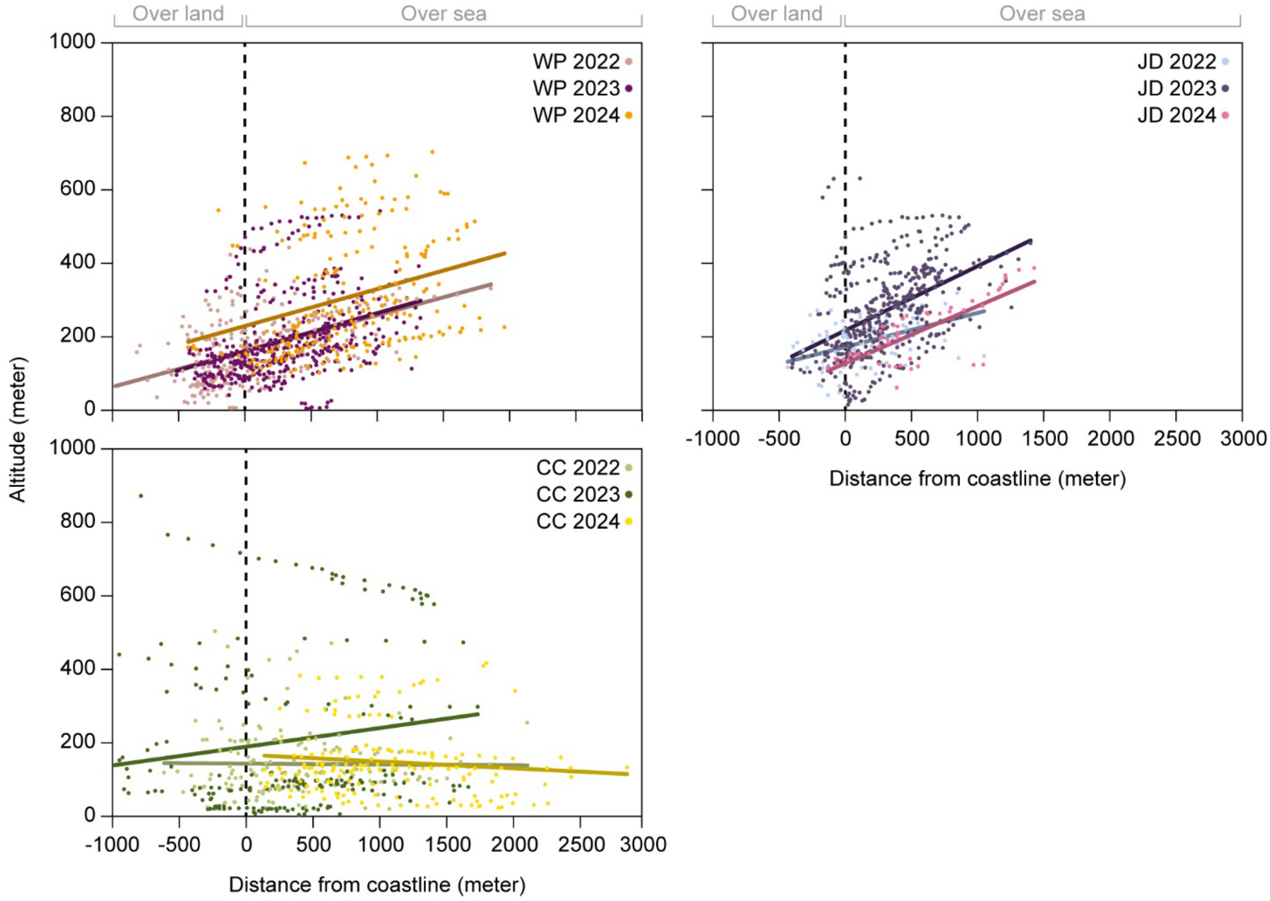


Figure 21. Flight altitude of Wood Pigeon (WP), Jackdaw (JD) and Common Crane (CC) recorded at Skagen in 2022, 2023 and 2024 when birds are moving from land toward the sea. Trend lines are shown as indicative of general altitudinal changes

The average flight altitude at various distance intervals from the coast in both 2022, 2023 and 2024 is shown in Figure 22 for selected raptor and non-raptor species. In general, migration altitude patterns were consistent between the study years. The lower overall average migration altitude of raptors in 2024 (cf. Fig. 20) is apparent in most species. Marsh Harrier, Kestrel and Osprey all show a similar pattern of gaining high altitudes just after leaving the coast followed by a decline to lower levels with longer distances. This migrating behaviour is only recorded in 2024. Wood Pigeon, Jackdaw and Common Crane show average flight altitudes that are comparable to the altitudes observed in the previous years. Wood Pigeon and Jackdaw show a marked increase in migration altitude with distance to the coast, whereas cranes show a steadier and more stable altitudinal pattern. For all years it should be noted that the number of data points at longer distances from the coast is very small for some species, and the average altitude should therefore be interpreted with caution.

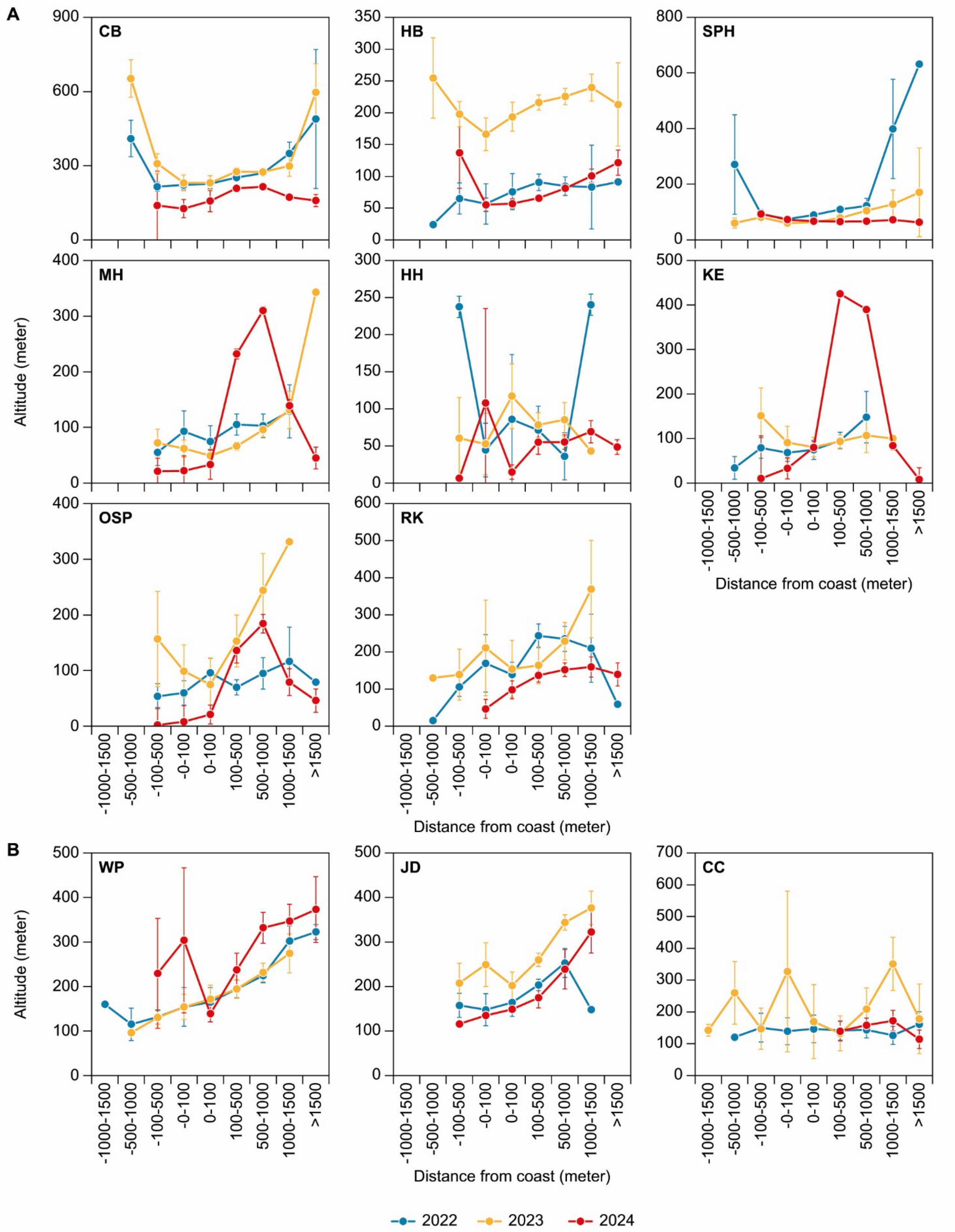


Figure 22. Flight altitude in relation to the distance to the coast at Skagen for selected raptor and non-raptor species migrating towards Sweden in 2022, 2023 and 2024. CB: Common Buzzard, HB: Honey Buzzard, SPH: Sparrowhawk, MH: Marsh Harrier, KE: Kestrel, OSP: Osprey, WP: Wood Pigeon, JD: Jackdaw, CC: Common Crane. Notice that y-axis values are scaled differently.

4.7 Radar results

Horizontal radar

In total, 433 tracks were recorded by radar in 2024. The recorded tracks are shown in Figure 23 and the number of species specific tracks are shown in Table 7. The proportions of tracks that have a direction towards the planned wind farm areas and the gap between these is also shown in Table 7.

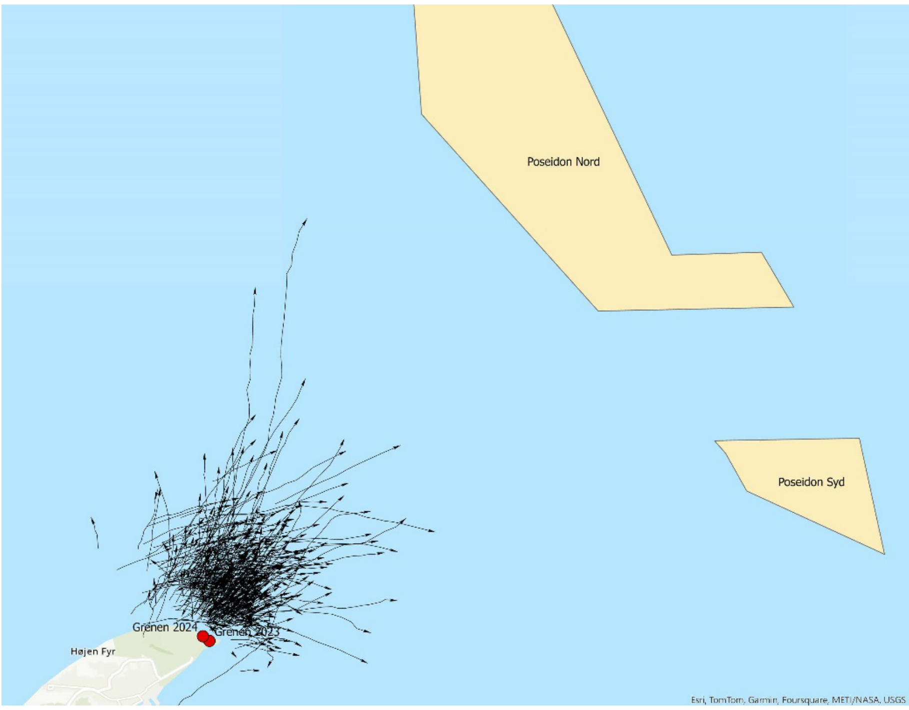


Figure 23. Bird tracks recorded by radar at Skagen during spring 2024 (N=301). The tracks are digitized on the radar PPI. The red dots show the position of the radar in 2023 and 2024.

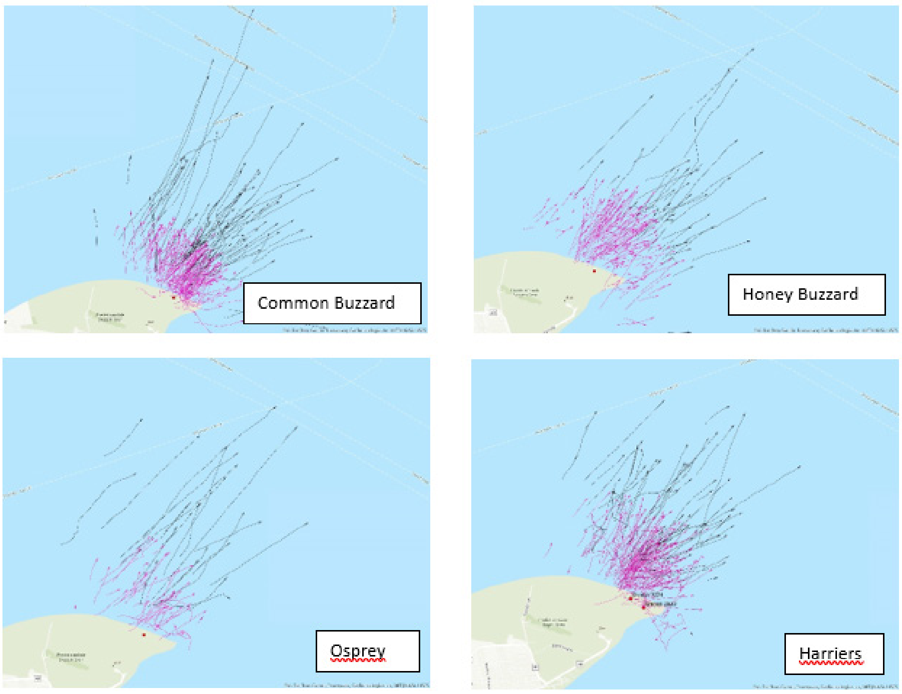
Table 7. The total number of bird tracks recorded with the horizontally oriented radar at Skagen during the spring 2024, and the proportion (%) of tracks that have a direction towards the planned wind farm areas Poseidon Nord and Poseidon Syd and the gap between the two areas.

Species	Number of tracks 2024	Proportion (%) headed towards Poseidon Nord (12-60°)	The gap between areas (60-68°)	Proportion (%) headed towards Poseidon Syd (68-82°)
Common Buzzard	36	52,8	22,2	13,9
Rough-legged Buzzard	5	100	0	0
Honey Buzzard	70	68,6	11,4	7,1
Sparrowhawk	2	0	0	50,0
Red Kite	8	62,5	12,5	0
Black Kite	3	66,7	0	33,3
Marsh Harrier	25	68,0	12,0	12,0
Hen Harrier	25	72,0	8,0	8,0
Kestrel	2	50,0	50,	0
Hobby	5	80,0	0	0
Osprey	22	77,3	9,1	4,5
White-tailed Eagle	4	75,0	25,0	0
Wood Pigeon	33	54,5	0	0
Jackdaw	1	0	0	0
Common Crane	10	60,0	10,0	10,0
Common Eider	5	0	0	20,0

Common Scoter	71	2,8	5,6	26,8
Greylag Goose	13	53,8	0,0	23,1
Barnacle Goose	6	50,0	0	16,7
Brent, Pink-footed Goose, White-fronted Goose, goose sp.	9	22,2	33,3	11,1
Red-throated Diver	45	4,4	6,7	35,6
Grey Heron	3	33,3	0	33,3
Whooper Swan	2	50,0	0	50,0
Other species	15	39,1	4,3	17,4
Total	433	44,1	8,3	15,9

Species specific tracks for the most numerous species recorded by both radar and LRF are shown in Figure 24A and 24B. As evident, flight trajectory can be followed by radar of up to twice the distance than is possible with the LRF, especially for species that migrate in large flocks, e.g., Wood Pigeon and geese. The flight trajectory of most terrestrial species shows a clear direction towards northeast, whereas flight trajectories for the seaducks, Common Eider and Common Scoter and divers, reflects that these species pass around the Skagen pensinsula in a much more easterly direction.

Figure 24A. Flight trajectories of Common Buzzard and Honey Buzzard recorded at Skagen in the spring 2024 by radar (black tracks) and Laser Range Finder (LRF)(red tracks).



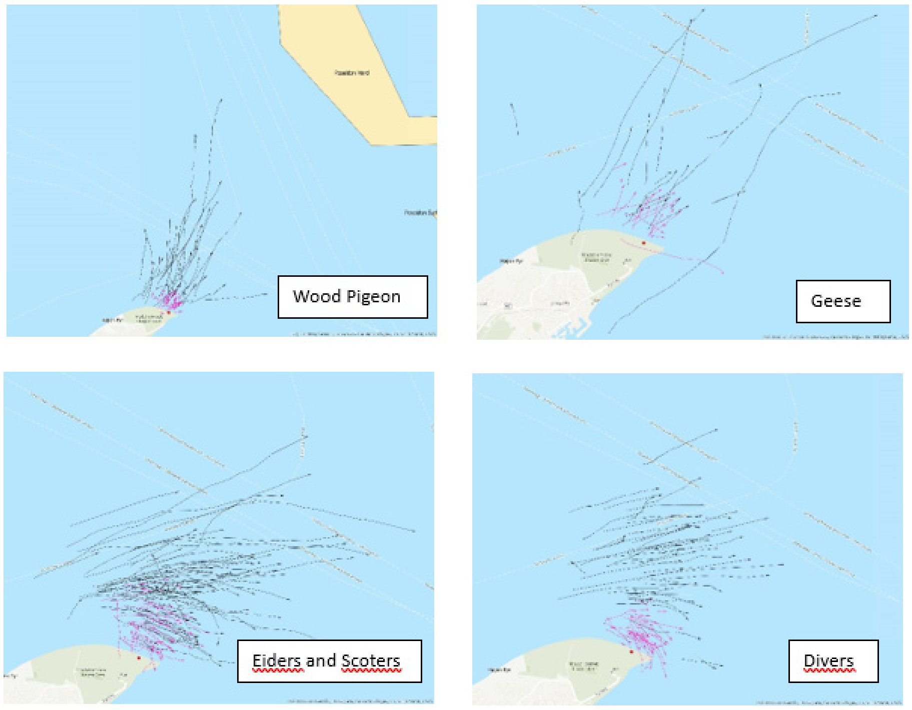


Figure 24B. Flight trajectories of Wood Pigeon, geese, Eiders and Scoters and divers recorded at Skagen in the spring 2024 by radar (black tracks) and laser rangefinder (LRF)(red tracks).

4.8 Collision estimates

Poseidon North:

The collision risk calculations revealed estimates for Sparrowhawk ranging from 0.34 to 2.07 collisions per year for wind turbine alternative A and 0.56 to 3.26 collisions per year for wind turbine alternative B (Appendix A2) for all avoidance rates (Table 8). For Common Buzzard the collision estimates ranged from 0.46 to 2.49 collisions per year for wind turbine alternative A and 0.78 to 4.05 collisions per year for wind turbine alternative B. Honey buzzards ranged from 0.41 to 2.47 collisions per year for wind turbine alternative A and 0.65 to 3.79 collisions per year for wind turbine alternative B. In addition, crows (mainly Jackdaws) showed collision estimates ranging from 0.71 to 4.56 collisions per year for alternative A and 0.37 to 2.33 collisions per year for alternative B (Table 8). Wood Pigeon had collision estimates ranging from 0.28 to 1.43 for alternative A and 0.48 to 2.40 for alternative B, whereas falcons, harriers, Osprey, and kites had collisions rates between 0.01 and 0.67 collisions per year for both alternatives (Table 8).

Poseidon South:

The collision risk analysis for all species analysed resulted in maximums of 0.19 collision per year for wind turbine alternative A and 0.31 collisions per year wind turbine alternative B (Table 10).

Comparison with other years:

The collision estimates for 2024 (table 9 & 11), 2023 and 2022 were quite similar for most species. Collision estimates for honey buzzards were only calculated for 2024 and 2023, because too few honey buzzards occurred in 2022.

Collision estimates will of course differ between years. Such differences could be caused by three factors: number of birds migrating, flight altitude and proportion migrating towards either Poseidon North or Poseidon South. While the number of birds migrating showed some variation between years. The proportion of birds migrating towards the wind turbine parks differed substantially between years for some of the species. One example was Common

Buzzard where the proportion migrating towards the wind turbine park differed almost 3-fold between 2022 and 2023 (Christensen et al. 2023). The flight altitude used in the collision models did not differ much between years and thus could not account for differences in collision estimates between years.

Table 8. Estimated collision risk at Poseidon Nord for the most numerous species/species groups migrating from Skagen in 2024 for the two wind turbine designs with either 61 turbines in total (Alternative A) or 94 wind turbines in total (Alternative B, see appendix A2). The estimates have been calculated with avoidance rates of 99 %, 97.75 % and 95 % and pitch of 7 or 12. Pitch is the angle of the turbine blade. Values are estimated number of collisions pr. Year for the spring migration.

Alternative	Pitch	Avoid-ance	Common Buzzard	Corvids	Falcons	Harriers	Osprey	Kites	Sparrow-hawk	Wood pigeon	Honey buzzard
A	7	0.99	0.46	0.71	0.08	0.07	0.03	0.01	0.34	0.28	0.41
A	7	0.9775	1.03	1.59	0.17	0.16	0.06	0.02	0.77	0.63	0.91
A	7	0.95	2.29	3.53	0.38	0.35	0.14	0.04	1.70	1.40	2.03
A	12	0.99	0.50	0.91	0.08	0.08	0.03	0.01	0.41	0.29	0.49
A	12	0.9775	1.12	2.05	0.18	0.18	0.07	0.02	0.93	0.65	1.11
A	12	0.95	2.49	4.56	0.41	0.41	0.16	0.04	2.07	1.43	2.47
B	7	0.99	0.78	0.37	0.13	0.12	0.05	0.01	0.56	0.48	0.65
B	7	0.9775	1.76	0.84	0.29	0.26	0.11	0.03	1.27	1.08	1.46
B	7	0.95	3.91	1.87	0.64	0.58	0.24	0.07	2.82	2.40	3.23
B	12	0.99	0.81	0.47	0.13	0.13	0.05	0.01	0.65	0.48	0.76
B	12	0.9775	1.82	1.05	0.30	0.29	0.12	0.03	1.47	1.08	1.70
B	12	0.95	4.05	2.33	0.67	0.65	0.26	0.07	3.26	2.40	3.79

Table 9. Estimated collision risk at Poseidon Nord in 2022 and 2023 for the most numerous species/species groups migrating from Skagen in 2022 for the two wind turbine designs with either 61 turbines in total (Alternative A) or 94 wind turbines in total (Alternative B, see appendix A2). The estimates have been calculated with avoidance rates of 99 %, the other avoidance rate can be found in the reports from 2022 and 2023. Pitch is set to either 7 or 12. Values are estimated number of collisions pr. Year.

Alternative	Pitch	Year	Common Buzzard	Crows	Falcons	Harriers	Osprey	Kites	Sparrow-hawk	Wood pigeon	Honey buzzard
A	7	2023	0.10	0.74	0.04	0.06	0.02	0.00	0.42	0.54	0.10
A	7	2022	0.32	0.63	0.06	0.03	0.02	0.06	0.36	1.70	
A	12	2023	0.11	0.95	0.05	0.07	0.02	0.01	0.51	0.55	0.12
A	12	2022	0.34	0.81	0.07	0.04	0.02	0.06	0.43	1.75	
B	7	2023	0.14	0.91	0.07	0.09	0.03	0.01	0.68	0.85	0.13
B	7	2022	0.54	1.00	0.11	0.06	0.04	0.10	0.55	2.72	
B	12	2023	0.15	1.14	0.08	0.10	0.03	0.01	0.79	0.85	0.15
B	12	2022	0.56	1.25	0.11	0.06	0.04	0.10	0.63	2.72	

Table 10. Estimated collision risk at Poseidon Syd for the most numerous species/species groups migrating from Skagen in 2024 for the two wind turbine designs with either 61 turbines in total (Alternative A) or 94 wind turbines in total (Alternative B, see appendix A2). The estimates have been calculated with avoidance rates of 99 %, 97.75 % and 95 % and pitch of 7 or 12. Pitch is the angle of the turbine blade. Values are estimated number of collisions pr. Year for the spring migration.

Alterna-tive	Pitch	Avoid-ance	Common Buzzard	Corvids	Falcons	Harriers	Osprey	Kites	Sparrow-hawk	Wood Pigeon	Honey Buzzard
A	7	0.99	0.04	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01
A	7	0.9775	0.08	0.00	0.02	0.01	0.00	0.00	0.02	0.02	0.03
A	7	0.95	0.18	0.00	0.04	0.02	0.00	0.00	0.05	0.05	0.07
A	12	0.99	0.04	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.02
A	12	0.9775	0.09	0.00	0.02	0.01	0.00	0.00	0.03	0.02	0.04
A	12	0.95	0.19	0.00	0.04	0.02	0.01	0.00	0.06	0.05	0.08
B	7	0.99	0.06	0.00	0.01	0.01	0.00	0.00	0.02	0.02	0.02
B	7	0.9775	0.13	0.00	0.03	0.01	0.00	0.00	0.04	0.03	0.05
B	7	0.95	0.30	0.00	0.07	0.03	0.01	0.00	0.08	0.08	0.10
B	12	0.99	0.06	0.00	0.01	0.01	0.00	0.00	0.02	0.02	0.02
B	12	0.9775	0.14	0.00	0.03	0.01	0.00	0.00	0.04	0.03	0.05
B	12	0.95	0.31	0.00	0.07	0.03	0.01	0.00	0.09	0.08	0.12

Table 11. Estimated collision risk at Poseidon Syd in 2022 and 2023 for the most numerous species/species groups migrating from Skagen in 2022 for the two wind turbine designs with either 61 turbines in total (Alternative A) or 94 wind turbines in total (Alternative B, see appendix A2). The estimates have been calculated with avoidance rates of 99 %, estimates for other avoid-ance rates can be found in the reports from 2022 and 2023. Pitch was either set to 7 or 12. Values are estimated number of collisions pr. Year.

Alterna-tive	Pitch	Year	Common Buzzard	Crows	Falcons	Harriers	Osprey	Kites	Sparrow-hawk	Wood pigeon	Honey Buzzard
A	7	2023	0.02	0.10	0.01	0.01	0.00	0.00	0.04	0.17	0.00
A	7	2022	0.00	0.09	0.00	0.01	0.00	0.00	0.03	0	
A	12	2023	0.02	0.13	0.01	0.01	0.00	0.00	0.05	0.17	0.01
A	12	2022	0.00	0.12	0.00	0.01	0.00	0.00	0.03	0	
B	7	2023	0.03	0.12	0.01	0.01	0.00	0.00	0.07	0.26	0.01
B	7	2022	0.00	0.14	0.00	0.01	0.00	0.00	0.04	0	
B	12	2023	0.03	0.15	0.01	0.01	0.00	0.00	0.08	0.26	0.01
B	12	2022	0.00	0.18	0.00	0.01	0.00	0.00	0.05	0	

4.9 GPS tagging of raptors

4.9.1 Common Buzzard

Between December 2022 and November 2024, a total of 37 Common Buzzards were tagged with GPS trackers in Denmark.

The Common Buzzards performed different movement behaviors. Some bird migrated to Sweden, performing sea passages. Others seemingly tried to cross to Sweden, but did never do so, while others again were very stationary. An overview of the tagged birds is given in Table 12.

Flight altitude of Common Buzzards is indicated in the figures, using the same scale for all birds. For transparency we display the entire scale, even if it includes clearly erroneous values.

Table 12. An overview of 37 GPS tagged Common Buzzards in Denmark. The data includes two recaptures of the same individual. Data on ringing area and migration status is given.

GPS ID	Species	Ringing Status	Area of ringing	Ringing/ Recapture date	Migration status
221287	Common Buzzard	New	Eastern Funen	2022-12-06	Migratory
221289	Common Buzzard	New	Eastern Funen	2022-12-10	Stationary
221290	Common Buzzard	New	Eastern Funen	2022-12-10	Stationary
221291	Common Buzzard	New	Eastern Funen	2022-12-05	Migratory
221292	Common Buzzard	New	Eastern Funen	2022-11-04	Stationary
221293	Common Buzzard	New	Eastern Funen	2022-11-05	Stationary
221294	Common Buzzard	New	Eastern Funen	2022-12-06	Migratory
221295	Common Buzzard	New	Eastern Funen	2022-12-12	Stationary
221296	Common Buzzard	New	Eastern Funen	2022-12-11	Stationary
221297	Common Buzzard	New	Eastern Funen	2022-12-12	Stationary
221298	Common Buzzard	New	Langeland	2022-10-31	Stationary
221299	Common Buzzard	New	Langeland	2023-01-22	Migratory
221299	Common Buzzard	Recapture	Langeland	2023-03-08	Migratory
221299	Common Buzzard	Recapture	Langeland	2023-12-15	Migratory
221300	Common Buzzard	New	Eastern Funen	2023-03-02	Migratory
221301	Common Buzzard	New	Djursland	2023-03-18	Stationary
221302	Common Buzzard	New	Northern Jutland	2023-04-10	Stationary
221303	Common Buzzard	New	Eastern Funen	2024-10-29	Stationary
221304	Common Buzzard	New	Northern Jutland	2023-05-28	Stationary
221305	Common Buzzard	New	Langeland	2024-11-27	Recently ringed
221306	Common Buzzard	New	Langeland	2024-12-01	Recently ringed
221307	Common Buzzard	New	Langeland	2024-12-05	Recently ringed
221308	Common Buzzard	New	Langeland	2024-12-10	Recently ringed
221309	Common Buzzard	New	Eastern Funen	2024-12-16	Recently ringed
221310	Common Buzzard	New	Langeland	2024-12-17	Stationary
221311	Common Buzzard	New	Eastern Funen	2023-10-17	Migratory
221312	Common Buzzard	New	Eastern Funen	2023-10-18	Migratory
221313	Common Buzzard	New	Western Funen	2023-11-17	Stationary
221314	Common Buzzard	New	Eastern Funen	2023-11-27	Stationary
221315	Common Buzzard	New	Western Funen	2023-11-29	Migratory
221316	Common Buzzard	New	Eastern Funen	2023-11-08	Migratory
221317	Common Buzzard	New	Langeland	2023-12-13	Stationary
221318	Common Buzzard	New	Western Funen	2023-12-13	Stationary
221320	Common Buzzard	New	Western Funen	2023-12-15	Migratory
243591	Common Buzzard	New	Eastern Sjælland	2024-11-19	Recently ringed
243592	Common Buzzard	New	Eastern Sjælland	2024-11-19	Recently ringed
243593	Common Buzzard	New	Langeland	2024-11-26	Migratory
243595	Common Buzzard	New	Langeland	2024-11-26	Recently ringed

The majority of Common Buzzards migrated across Sjælland, while a single bird crossed to Sweden from Skagen (Figure 25). This migration pattern wasexpected since most of the birds were tagged on Funen and Langeland. When crossing marine areas, the birds chose the most direct route when migrating over water, and several birds followed the bridge when passing the Great Belt.

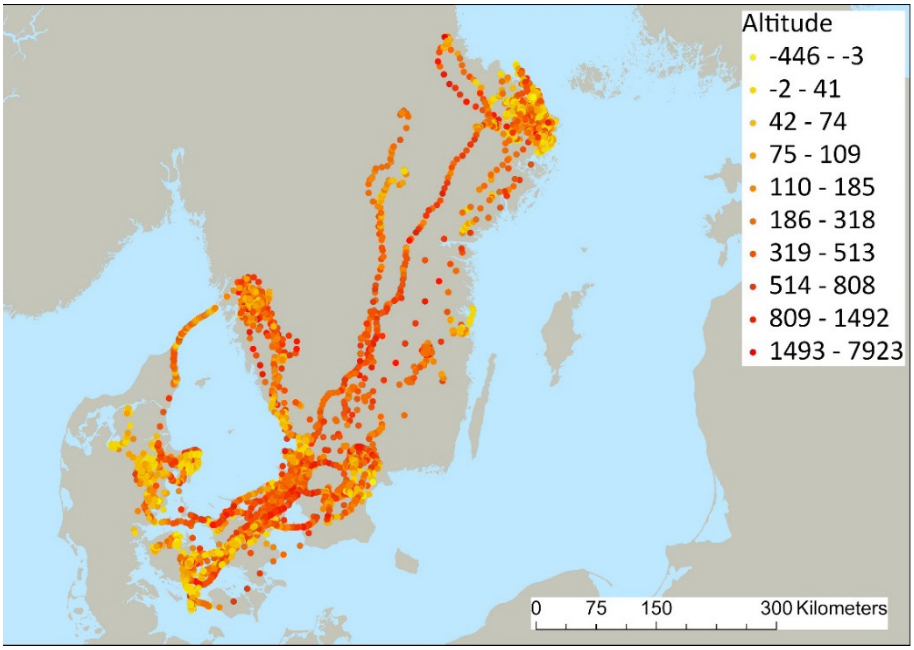


Figure 25. Positions of GPS tagged migratory Common Buzzards between 2022 and 2024. Flight altitude is indicated.

Some Common Buzzards left their wintering site, seeking northeast, seemingly trying to cross to Sweden. They never crossed but stayed in Denmark (Figure 26).

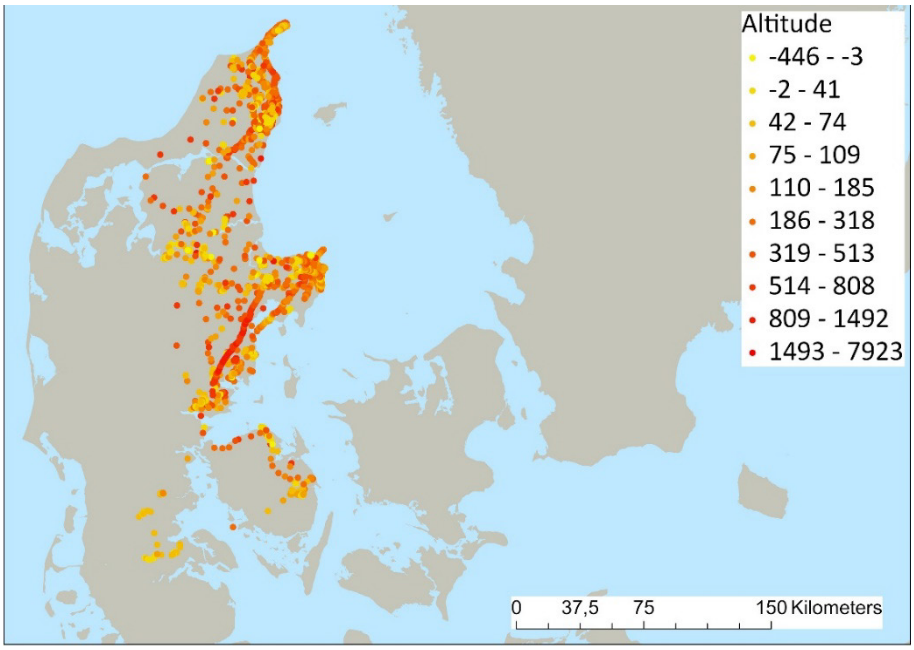
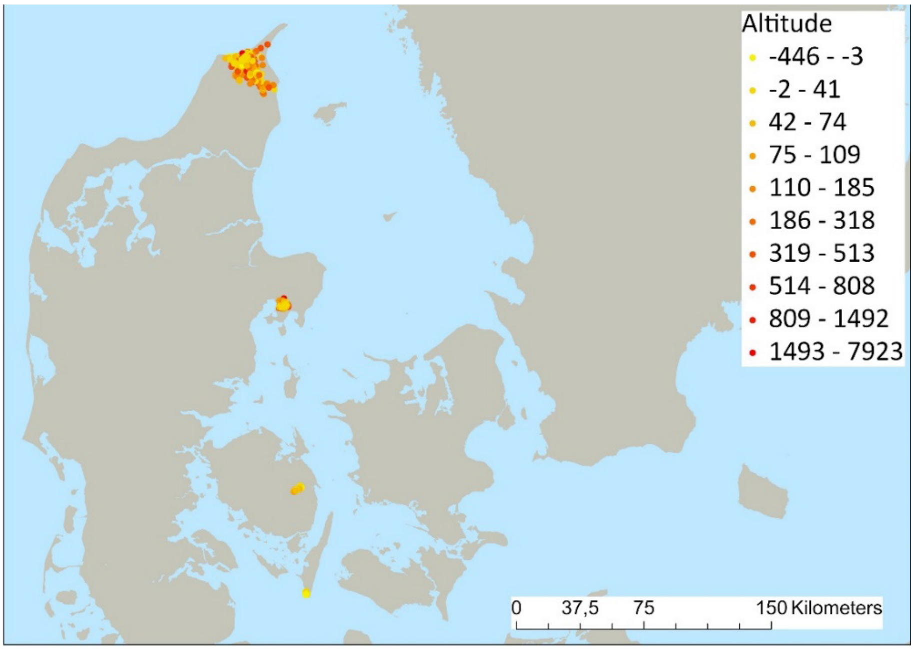


Figure 26. Positions of GPS tagged migratory Common Buzzards that stayed in Denmark, tagged between 2022 and 2024. Flight altitude is indicated.

Other Common Buzzards were very stationary and never left the area in which they were GPS-tagged (Figure 27).

Figure 27. Positions of GPS tagged stationary Common Buzzards that stayed in Denmark, tagged between 2022 and 2024. Flight altitude is indicated.



4.9.1 A Common Buzzard case story

Two Common Buzzards were captured and GPS tagged in western Funen Denmark. Bird no. 221315 was ringed on 27 November 2023, whereas 221320 was ringed on 15 December 2023. The birds stayed in the near vicinity of the ringing site until spring migration. Both birds migrated to Sweden, to two different areas ca. 130-160 km west of Stockholm (Figure 28). Migration from western Funen was initiated almost simultaneously but independently. 221315 started migrations on 22 March at 13:57 (all times are UTC time) while 221320 started its migration on 23 March at 08:46.

The two birds made very similar flight paths during migration, passing the same position at the northeastern edge of Lake Vättern on 26 March at 10:49 and 11:52, just over an hour apart.

The birds made three and four night stops *en route* to their summer residence. 221315 initially made a night stop on western Sjælland, Denmark and then three-night stops from 23 to 26 March just south and east of Jönköping, Sweden. 221320 made three might stops from 23 to 26 March just south of Jönköping. The night stop sites close by Jönköping were less than 20 km apart, with the two birds arriving almost simultaneously on the 23 March at 16:07 and 16:16 respectively. On 24 and 25 March the two birds made very little progress, likely due to adverse weather conditions for migration.

So, despite having very similar migration routes and almost synchronous timing, the two bird migrated independently.

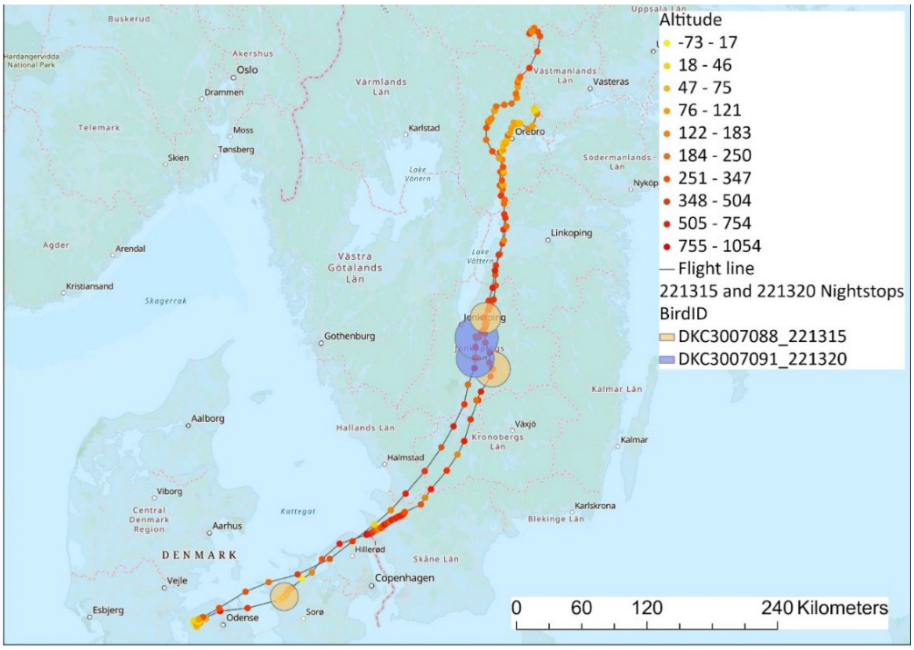


Figure 28. Almost synchronous migration path and timing of two Common Buzzards from western Funen, Denmark to Sweden, spring 2024. Stopover sites are indicated.

4.1 Actively flying birds of prey, tagged in Belgium

From the 2024 spring and autumn migrations data was provided by INBO, including data from Montague's Harrier, Marsh Harrier and Honey Buzzard. In total the data covers 37,033 point records.

4.1.1 Marsh Harrier

From INBO we received data on both spring and autumn migration of Marsh Harriers between Spain and North Africa and across the Bay of Biscay (Figure 29, 31 and 32).

Figure 29. Spring migration path of three Marsh Harriers crossing Gibraltar area in 2024. Flight altitude is indicated.

A Marsh Harrier from Funen made a short migration from its summer site to southwestern Jutland and returned to Funen (Figure 30).

Figure 30. A Marsh Harrier from Funen migrated from there to southwestern Jutland and returned to the same place on Funen in the late summer of 2024. Flight altitude is indicated.

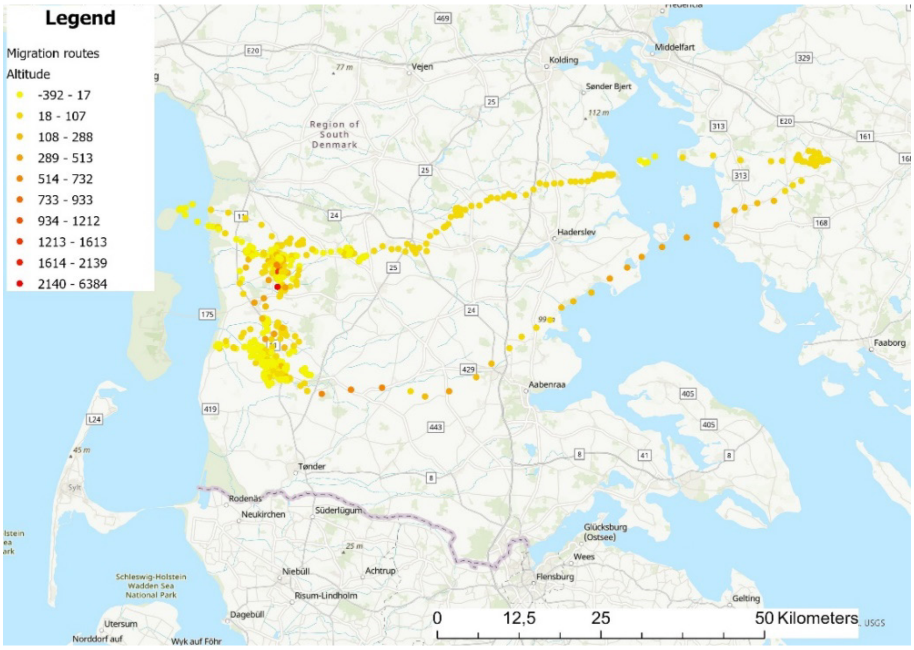


Figure 31. Autumn migration path of three Marsh Harriers crossing the Bay of Biscay in 2024. Flight altitude is indicated.

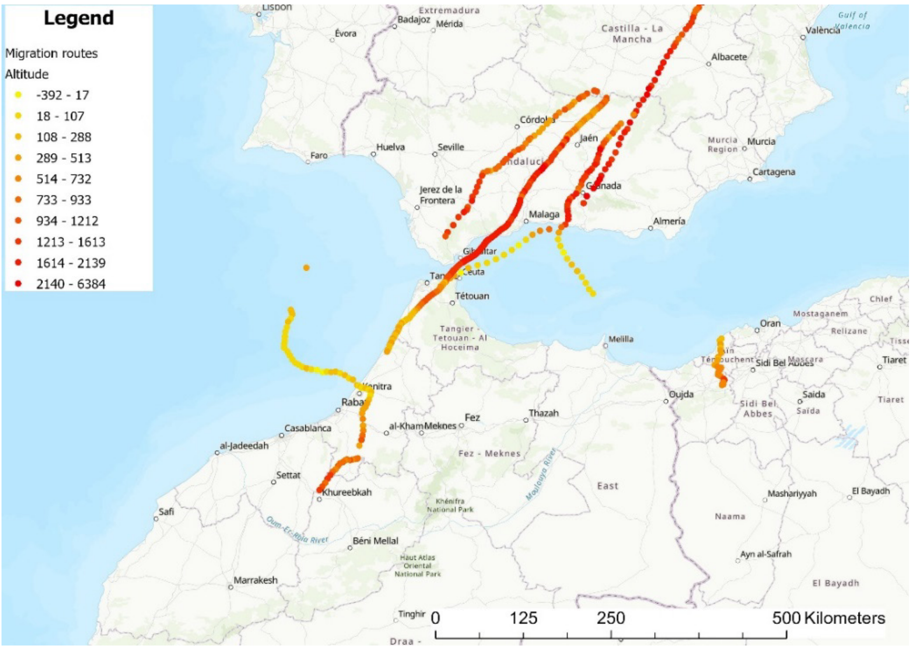


Figure 32. Autumn migration path of five Marsh Harriers crossing between Spain and North Africa in 2024. Flight altitude is indicated.

4.1.2 Honey Buzzard

A Honey Buzzard migrated from North Africa to Spain in the spring of 2024 (Figure 33).

Figure 33. Migration path of a Honey Buzzard passing from Morocco to Spain in spring 2024. Flight altitude is indicated.

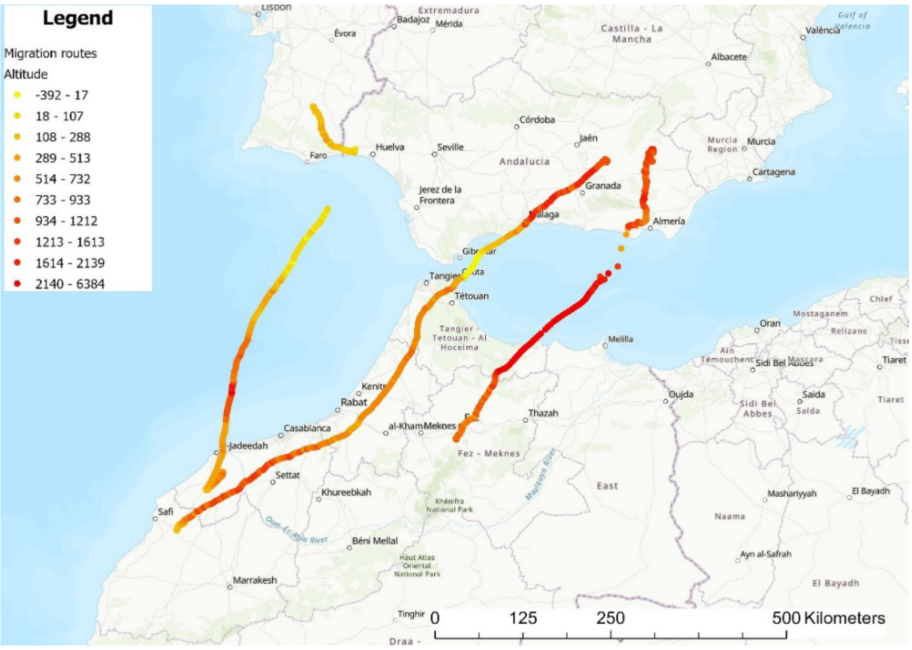
The same Honey Buzzard crossed from Spain to Morocco in the autumn of 2024 (Figure 34).

Figure 34. Migration path of a Honey Buzzard passing from Morocco to Spain in autumn 2024. Flight altitude is indicated.

4.1.3 Montague's Harrier

Three Montague's Harriers crossed from Morocco to Spain in the spring of 2024 (Figure 35).

Figure 35. Spring migration path of three Montague's Harriers crossing from North Africa to Spain in 2024. Flight altitude is indicated.



5 Results – Sweden

5.1 Bird species and numbers recorded

During the observation period in 2024 from week 16 to week 18, a total of 44 different bird species were recorded, including potential local breeding birds. Of these birds arriving from south-westerly directions, 16 species were raptors, 17 species belonged to various non-passerine families of birds, and 11 were passerine species. Table 13 shows the total number of the non-passerine birds recorded during the observation periods at the three locations Flatholmen, Hållö and Käringön.

Montagues Harrier. Photo: Thomas Kjær Christensen.

Table 13. Selected species and numbers approaching the coast of Sweden observed at Flatholmen, Hållö and Käringön during the weeks 16-18 in 2024. Sea birds, cormorants, divers, waterfowl, skuas, gulls, terns, auks as well as some local breeding species of coastal birds and passerines (e.g. Mute Swan, Greylag Goose, Common Redshank and Rock Pipit) are not included.

Group	Species	Flatholmen	Hållö	Käringön
Raptors & Owls	Common Buzzard	18	2	68
	Rough-legged Buzzard	2		7
	Honey Buzzard			
	Sparrowhawk	32	7	49
	Red Kite	2		2
	Black Kite	1		3
	Marsh Harrier	13	3	12
	Hen Harrier	13	5	12
	Montagu's Harrier			1
	Pallid Harrier	1	1	
	Pallid/Hen Harrier	2	1	1
	Kestrel	11	5	8
	Merlin	10	5	12

	Hobby	6	3	1
	Hobby/Red-footed Falcon	1		
	Peregrine Falcon	5		
	Osprey	6	3	14
	White-tailed Eagle			1
	Golden Eagle			
	Short-eared Owl	4	1	4
	Short/Long-eared Owl	1		
Other species	Wood Pigeon			1
	Jackdaw		4	13
	Hooded/Carrion Crow	9	1	21
	Rook	4		
	Grey Heron	4		4
	Great White Egret			1
	Common Crane	39		32
	Whooper Swan	3		4
	Curlew	164	27	198
	Wimbrel	8	12	148

5.2 Laser rangefinder – Bird species and numbers recorded

Table 14 shows the total number of tracks, total number of measured points and the sum of birds in all tracks for all species recorded by the laser rangefinder during the weeks 16 to 18 in the spring of 2024. The 103 tracks included a total of 784 single point measurements, varying from 1 to 37 points in individual tracks (average: 7.7 points/track). 22 individual tracks consisted of one single measured point and are thus not real tracks. Table 15 shows the corresponding numbers for each species.

Table 14. The number of tracks and points measured with the laser rangefinder at Flatholmen, Käringön and Hållö during the weeks 16-18 in 2024. The number of birds involved in the measurements are also shown. The number of tracks include 4 'tracks' with only one point registered.

Week	Location	Tracks	Points	Birds
16	Flatholmen	6	125	7
	Hållö	4	69	28
	Käringön	8	14	12
17	Flatholmen	9	134	9
	Hållö	5	54	8
	Käringön	11	36	12
18	Flatholmen	18	197	25
	Hållö	5	62	16
	Käringön	37	93	47
		103	784	164

Table 15. The species-specific number of tracks and points measured with the laser range-finder at Käringön and Klädesholmen during the weeks 15-18 in 2024. The number of tracked birds is also shown. The number of tracks include 4 'tracks' with only one point.

Species	Tracks	Points	Birds
Common Buzzard	10	23	12
Rough-legged Buzzard	1	2	1
Sparrowhawk	26	168	26
Red Kite	1	4	1
Marsh Harrier	8	104	8
Hen Harrier	13	87	13
Kestrel	8	58	8
Hobby	3	28	4
Merlin	9	61	9
Peregrine falcon	1	8	1
Osprey	12	97	12
Short-eared Owl	1	23	1
Jackdaw	1	25	4
Hooded Crow	1	25	1
Common Crane	4	46	23
Whooper Swan	1	1	2
Curlew	2	21	26
Whimbrel	1	3	12
Total	103	784	164

The tracks of migrating birds approaching the Swedish coast during spring 2024 are shown in Figure 36.

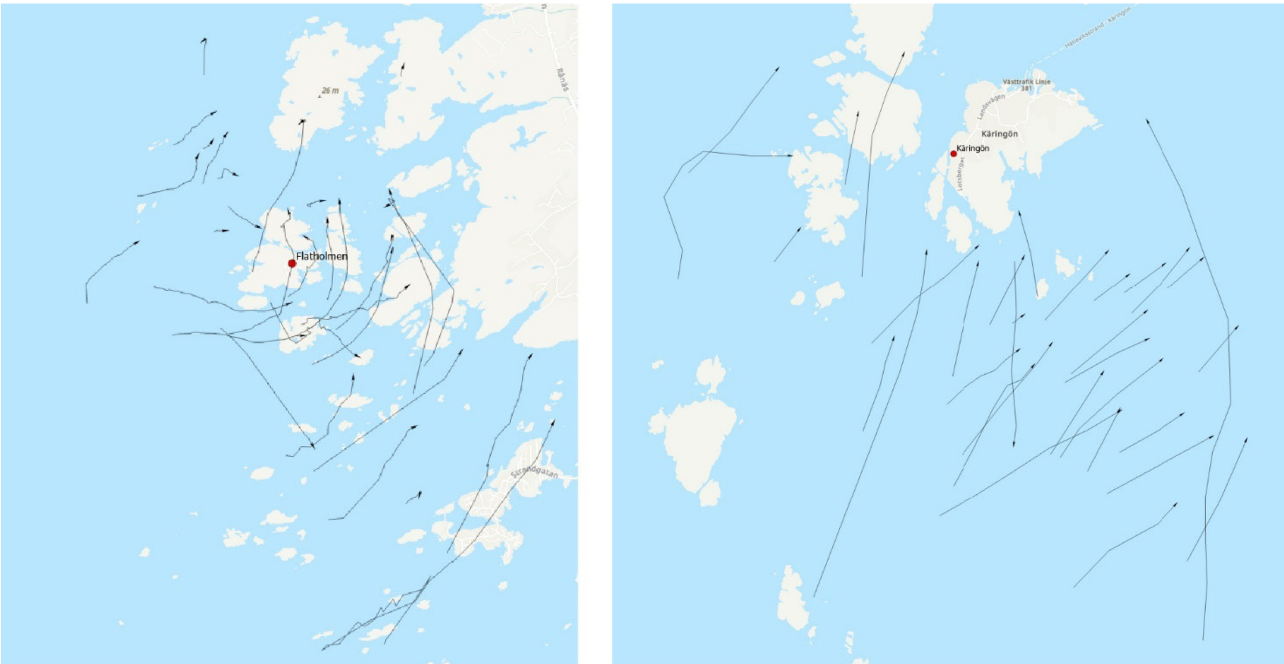


Figure 36. The spatial distribution of migrating birds at Flatholmen, Käringön and Hållö recorded with the laser range-finder during spring 2024 at the west coast of Sweden.

5.3 Migration counts

The weekly numbers of migrating birds for the larger and most numerous bird species observed at the coast of Sweden during weeks 16 to 18 in 2024 are shown in Figure 37. For comparison, the numbers observed in week 14-22 in 2022 and week 13 to 21 in 2023 (summed numbers from all locations) are shown.

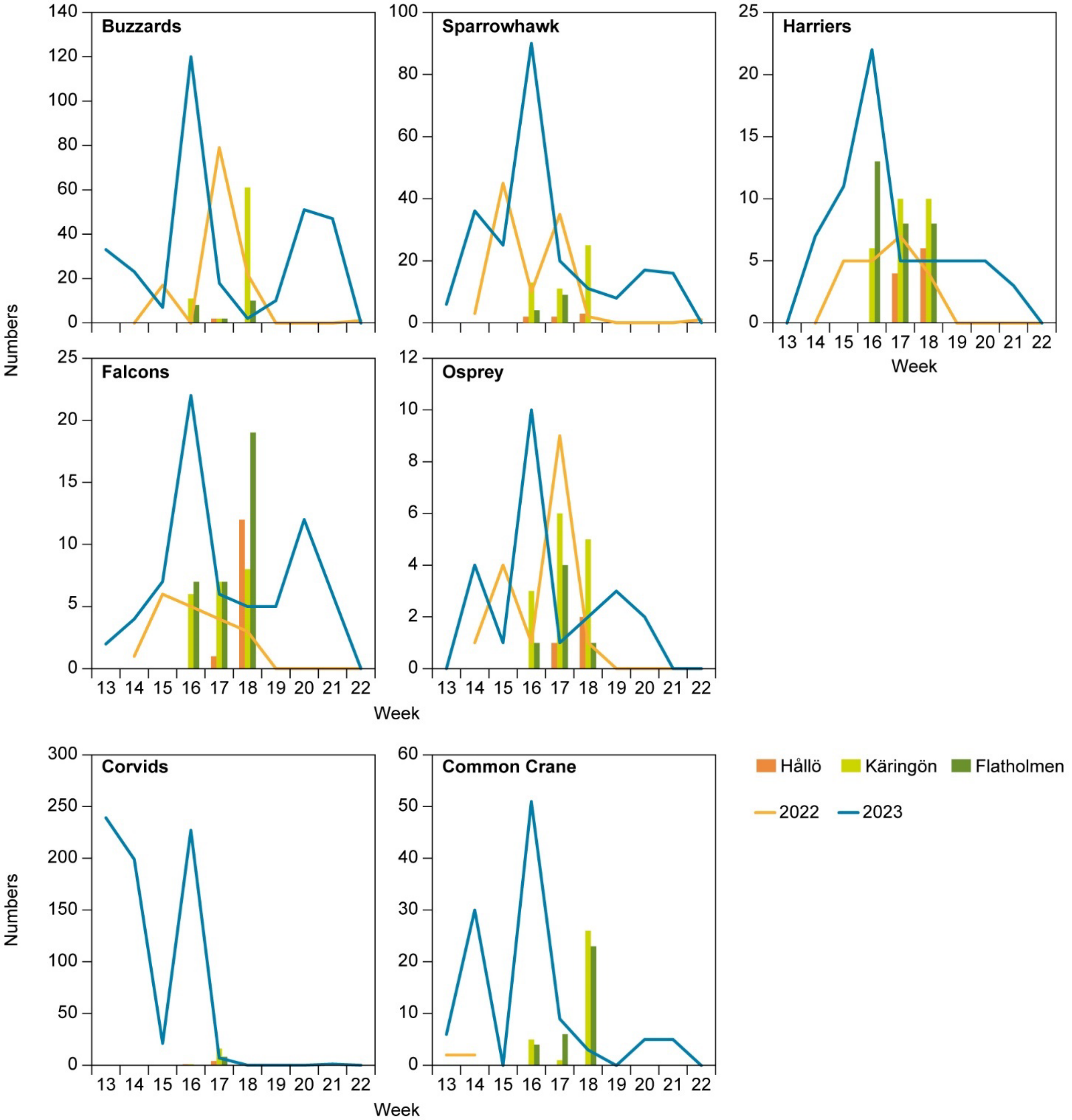


Figure 37. The total number per week of selected migrating bird species recorded during spring migration 2024 (week 16-18) at Hållö, Käringön and Flatholmen (bars), and the totals recorded during 2022 (week 14-22) and 2023 (week 13-21).

5.4 Flight direction

The overall mean flight direction of 77 migrating birds/bird flocks recorded with the laser rangefinder approaching the Swedish coast is shown in Table 16. The table shows the average flight direction between the first two measurements when the birds are over the sea, the direction of the last two measurements when the birds are over land, and the average direction of the full tracks (cf. the definition of 'over sea' and 'over land' in Figure 5).

Table 16. Average flight direction (degrees) from data recorded with laser rangefinder of birds observed at the Swedish west coast during the spring 2024. Mean direction is shown for the first record (the angle between the first two measurements taken on a bird/bird flock approaching from the seaside), the average of all directions between all point-measurements in a track (the full passage), and for the last record taken (the angle between the last two measurements taken of a bird moving further north, mainly over land or along the coast). Data only includes 77 tracks of birds or bird flocks that moved from the sea towards land. No selection has been made, so some estimates of flight direction potentially reflect the soaring behavior of some species.

	Mean flight direction			
Species	**First record (over the sea)**	**Full track**	**Last record (over land)**	**N**
Common Buzzard	35,9	36,6	36,8	8
Rough-legged Buzzard	61,6	61,6	61,6	1
Honey Buzzard	No observations in 2024			
Sparrowhawk	35,6	43,4	34,0	18
Red Kite	4,1	10,5	23,4	1
Marsh Harrier	71,5	74,0	131,3	7
Hen Harrier	89,5	64,9	69,1	12
Kestrel	105,9	62,3	177,9	5
Merlin	60,8	60,7	93,3	6
Hobby	28,1	35,7	29,5	3
Peregrine Falcon	39,5	347,7	236,4	1
Osprey	32,2	74,1	61,0	8
Short-eared Owl	349,9	18,1	72,0	1
Jackdaw	46,3	50,0	42,5	1
Common Crane	6,9	9,4	350,4	3
Eurasian Curlew	80,9	76,2	68,3	1
Whimbrel	44,9	46,0	46,2	1
Total mean direction (degrees)	68,3	67	95,9	77

For the most numerously recorded birds, Common Buzzard, Sparrowhawk, Hen Harrier and Marsh Harrier, flight direction when approaching the coast of Sweden is similar between 2024 and the two previous years, 2022 and 2023 (Figure 38). In all years, most birds showed flight directions between 45 and 90 degrees.

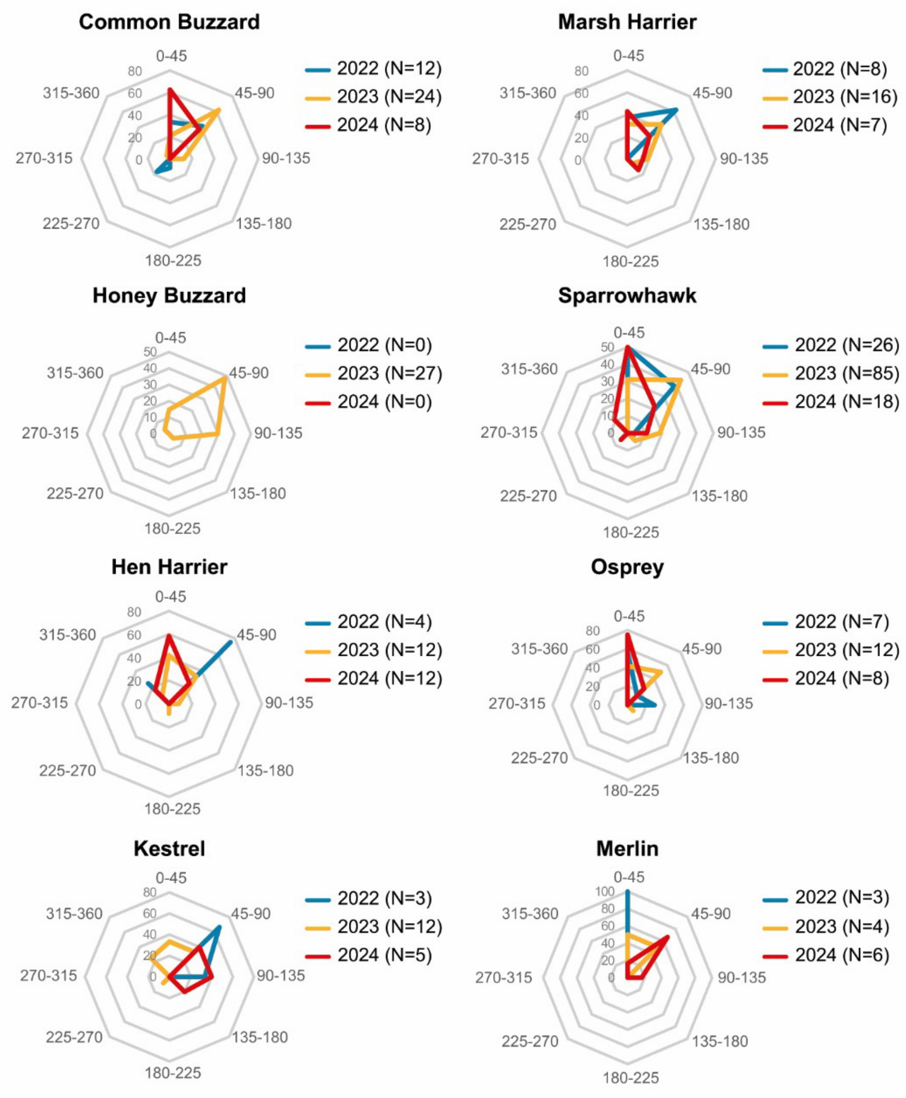


Figure 38. Flight of selected species showing the average direction measured between the first two points recorded by the LRF over the sea, when birds are observed approaching the western coast of Sweden during week 16-18 in 2024, week 13-21 in 2023 and week 14-22 in 2022. Honey Buzzards were only registered in 2023.

5.5 Flight altitude

In total, 780 measurements of altitudes were obtained from 19 species. Of these 455 were made over the sea and 325 over land as defined from the constructed theoretical coastline drawn from northwest to southeast (bearing 148 degrees, see Figure 5). The average flight altitudes of the individual bird species at sea and over land are shown in Table 20. Note that several, but not all, birds are measured in both areas. Table 17 also gives the number of measurements behind the average altitudes.

Table 17. The average flight altitude of migratory birds approaching the Swedish west coast during spring 2024 divided into birds measured over the sea and over land. The number of measurements is shown.

	Average altitude		Number of measurements	
Species	**Over sea**	**Over land**	**Over sea**	**Over land**
Common Buzzard	67,3	80,3	14	8
Rough-legged Buzzard	128,0	128,0	1	1
Sparrowhawk	20,2	34,0	129	39
Red Kite	63,3	63,0	3	1
Marsh Harrier	33,3	9,4	36	66
Hen Harrier	17,6	29,2	60	27
Kestrel	21,6	18,0	29	29
Merlin	9,1	24,0	25	36
Hobby	8,5	42,1	10	16
Red-footed Falcon/Hobby		22,0		1
Peregrine Falcon		75,5		8
Osprey	47,6	61,8	30	67
Short-earred Owl	10,6		23	
Jackdaw	53,6		25	
Hooded Crow	8,5		25	
Common Crane	161,0	79,5	27	19
Whooper Swan		1,0		1
Curlew	24,5	23,3	18	3
Whimbrel		18,0		3
Total	33,1	37,0	455	325

Flight altitude in relation to the ‘coastline’ of the most numerous species is shown in Figure 34. Thus, it appears that consecutive measurements (lines of dots), representing individual bird tracks, give a more detailed picture of the altitudinal movements of the migrating birds. Whereas some of these altitudinal tracks show slow and gradual changes in altitude during the movement from the seaside to the landside, several tracks of, e.g., Sparrowhawk, harriers, falcon and Osprey show abrupt vertical changes, which is a result of birds gaining altitudes in uprising thermals when approaching land. That some of the thermal soaring apparently takes place over the sea relate to the presence of wind-drifted rising air bubbles often occurring off the Swedish coast. Hence, thermals can occur several kilometres out at sea. This also to some degree bias the average flight direction as some of the raptors (and Common Crane), especially buzzards and kites, had already started thermal soaring when positioned with rangefinder and thereby show headings in many directions (Figure 39).

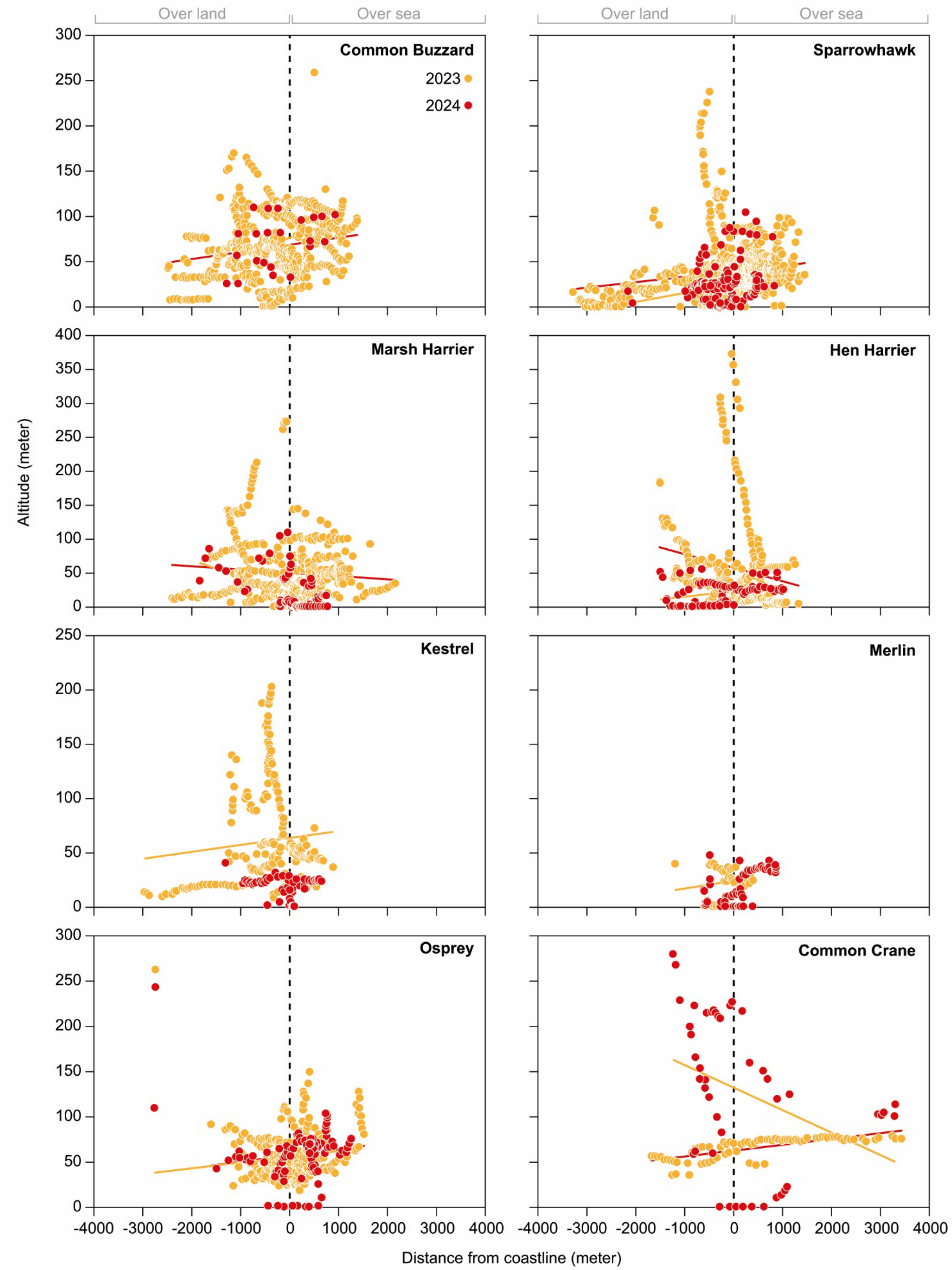


Figure 39. Flight altitude in relation to the 'coastline' of the most numerous bird species recorded at the Swedish west coast during week 13-21 in 2023 and 16-18 in 2024. Consecutive measurements, representing tracks of individual birds/bird flocks, appear as dotted lines.

6 Factors affecting return migration at Skagen

6.1 Background

During migration birds may have to cross seas or large water bodies. Many species, however, seem apprehensive about migrating across larger water bodies. It is well known that weather, especially wind and thermal conditions influence the decision to migrate across larger water bodies. For instance, Common buzzards are more dependent on favorable thermal and wind conditions than Sparrowhawks (Malmiga et al. 2014) and another study found honey buzzards to be more selective than marsh harriers regarding wind conditions (Panucicio et al. 2016). The dependency on weather conditions, therefore, may also affect the probability of failed migration attempts, here after "return migration". Return migration can be quantified as the number of individuals that attempted to migrate across the water bodies but gave up and returned to the area from where they initiated the migration attempt. In this chapter, we combined transect observations with local weather measurement to test if weather conditions such as wind speed, wind direction and visibility affected the probability of return migration. Likewise, we tested if return migration was related to short term changes in weather. In addition, we tested species and seasonal differences in probability of return migration.

6.2 Methods

To quantify the migration and the return migration, we used the 15 minute transect counts conducted each hour during observation days in the three years. Observation activity in each of the three years can be found in chapter 1 or 2 in the reports for each of the three years. We divided the migration season into three one-month periods, so period 1 was from match 15 to April 15, period 2 was from April 16 to May 15, and period 3 was from May 16 to June 15. For the analyses we estimated the total number of individuals, as the sum of the migration and the return migration in the 15-minute observation periods. This assumes that the individuals making return migration takes at least 15 minutes, which is probably not always the case. However, the inaccuracies of migration and return migration will likely balance each other out. Furthermore, the error is certainly smaller than assuming that all return migration occurs in less than 15 minutes if they migrate at the start of the observation and less than a minute at the end of the 15 min period.

The weather measures used came from the Danish Meteorological Institute's data base from the weather station "Skagens Fyr". Data was extracted from the MET database, which meant that missing data could occur. Weather measures included wind speed, wind direction and visibility, which were measured at 10 min intervals. We quantified weather as the hourly average of the 10 min measures.

As return migration could be induced by changes in weather we quantified short term changes in weather, as the difference in average weather conditions between the hour of observation and the previous hour.

6.2.1 Statistical analysis

In these analyses, we modeled the probability that a migrating individual makes return migration. We used the number of individuals migrating per day and the number of return migration per hour for modeling the response. We used a generalized mixed model with a binomial distribution with year as a random variable. The inclusion of year as a random factor accounted for between year differences.

To test the influence of weather or change of weather we tested this model:

Probability of return migration = wind speed + wind direction + visibility + wind speed*wind direction

If this model could not converge for a species, we reduced the model and present the model most similar to the original model, which could converge. The interaction between wind speed and wind direction tests if the effect of wind speed depends on the wind direction in a detectable manner. In the interpretation of the effect of wind direction, we refrained from testing pairwise differences for the species where an effect could be detected, because many species had strong preference for certain wind directions to even attempt migration. This means that the distribution of wind directions where migration occurred far from represent all directions.

When the analyses required post hoc pairwise comparisons, we used least square mean differences. We back-transformed the least square mean estimates from the generalized mixed models.

We tested if species differed regarding the probability of making return migration. This enables us to identify species, which are "determined migrators". In a separate test, we tested if the probability of return migration differed between the three periods for each species separately.

We used proc glimmix in SAS 9.4 (SASInstitute, Cary, NC).

6.3 Results

6.3.1 Species differences

The proportion of individuals that make return migration differed significantly between species (Figure 40, Generalized linear mixed model $F_{16,1500}$=43.9, p<0.001). Rough-legged buzzard, and Common buzzard had estimated probabilities for return migration above 0.40 (see Discussion). The probability for White-tailed eagle, Red kite, and Black kite also showed high estimates for probability of return migration, but these showed considerable uncertainty and did not differ significantly from zero (Table RS1).

In general, all falcons, harriers, Osprey, and Honey buzzards showed small probabilities (<0.10) of return migration (Table 21). Sparrowhawk, Jackdaw, and Wood pigeon showed probabilities of return migration between 0.14 and 0.17 (Table 18).

Figure 40. Estimated probability that an individual makes return migration within each species. The least square means were back transformed to get interpretable probabilities.

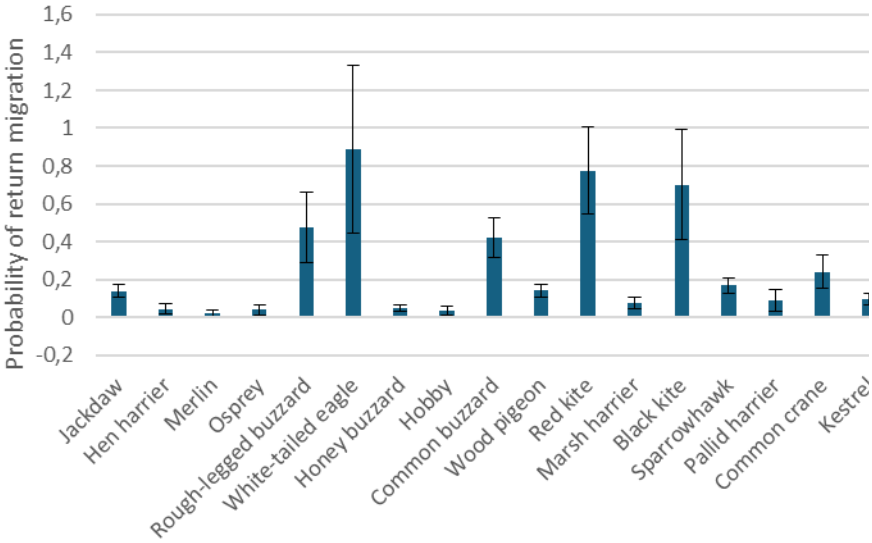


Table 18. Back-transformed probabilities for return migration, SE and tests of whether they differ from zero.

	Probability for return migration (back-transformed)	SE (backtransformed)	t	P
Jackdaw	0.14	0.03	-7.8	**<0.001**
Hen harrier	0.04	0.03	-5.5	**<0.001**
Merlin	0.02	0.02	-3.8	**<0.001**
Osprey	0.04	0.03	-5.1	**<0.001**
Rough-legged buzzard	0.48	0.19	-1.9	**0.057**
White-tailed eagle	0.89	0.45	-0.2	0.814
Honey buzzard	0.05	0.02	-9.7	**<0.001**
Hobby	0.03	0.02	-5.3	**<0.001**
Common buzzard	0.42	0.11	-3.4	**0.001**
Wood pigeon	0.14	0.04	-7.8	**<0.001**
Red kite	0.78	0.23	-0.8	0.397
Marsh harrier	0.08	0.03	-6.0	**<0.001**
Black kite	0.70	0.29	-0.9	0.391
Sparrowhawk	0.17	0.04	-7.0	**<0.001**
Pallid harrier	0.09	0.06	-3.7	**<0.001**
Common crane	0.24	0.09	-4.0	**<0.001**
Kestrel	0.10	0.03	-7.4	**<0.001**

6.3.2 Difference between periods

For most species the proportion of return migration appeared to increase as the seasons progressed, so the highest probability of return migration occurred at the end of the migration season (i.e. from May 16 to June 15) for most species (Figure 41). However, the probability of return migration over the periods only differed significantly for common buzzard, red kite, jackdaw, and wood pigeon (Table 19). In addition, the number of observations upon which the proportions were estimated differed considerably between species and periods. The number observed affects the certainty that can be subscribed to the estimates of the proportion of return migration (Figure 42). The issue of small sample size especially affects the last period.

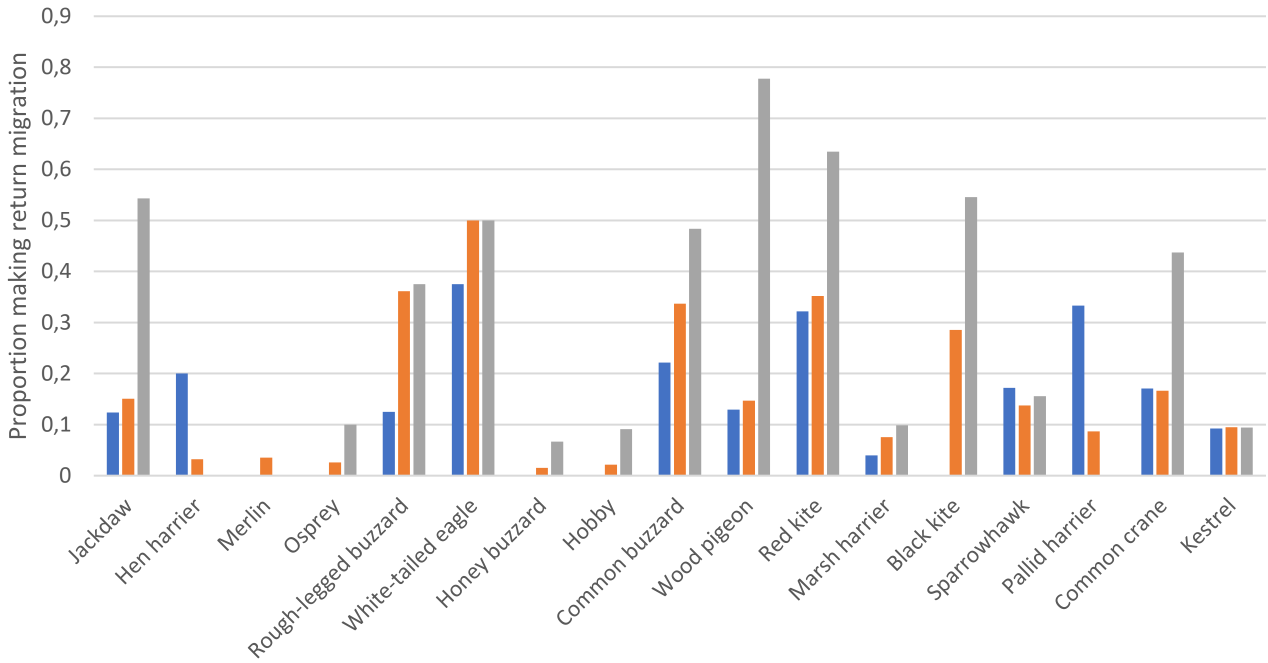


Figure 41. Proportion of individuals that make return migration in each of the three periods. Period 1 (Blue): March 15-April15, Period 2 (Orange): April 16-May 15, Period 3 (Grey): May 16- June 15.

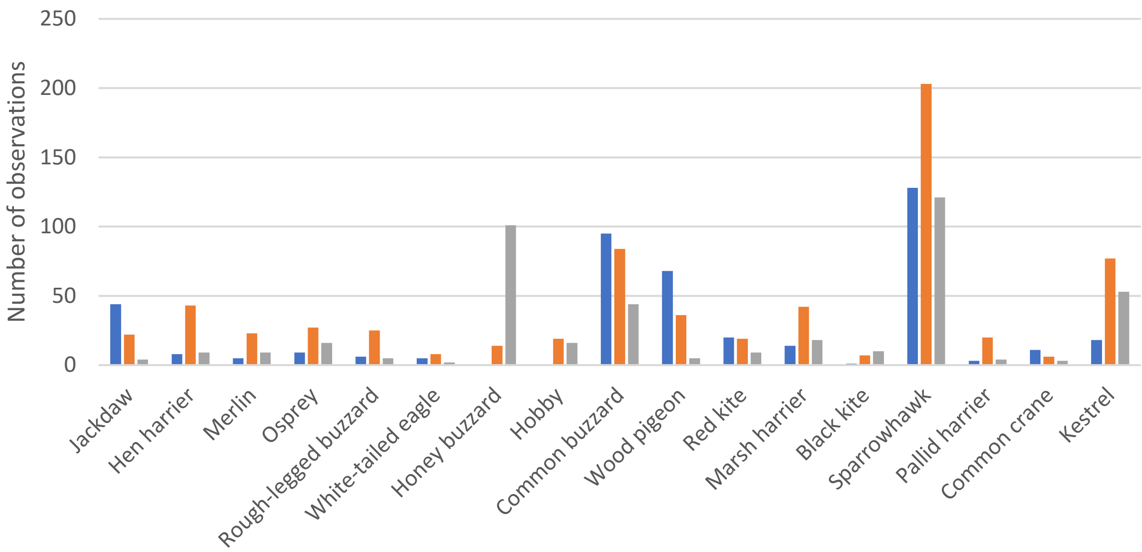


Figure 42. Number of individuals used in the estimation of the proportions in figure R2. Period 1 (Blue): March 15-April15, Period 2 (Orange): April 16-May 15, Period 3 (Green): May 16- June 15.

Table 19. Test if the probability of return migration changes over the three periods. The generalized linear models tested each species separately. Type indicates whether the model included year as a random effect.

Effect	df	F	p	Type
Jackdaw	2, 65	27.7	<0.001	with random
Hen harrier	2, 55	1.8	0.178	no random
Merlin	2, 33	0.0	1.000	no random
Osprey	2, 49	0.7	0.523	no random
Rough-legged buzzard	2, 30	0.7	0.482	with random
White-tailed eagle	2, 11	0.2	0.861	no random
Honey buzzard	1, 108	1.8	0.184	with random
Hobby	1, 31	1.6	0.210	with random
Common buzzard	2, 216	45.4	<0.001	with random
Wood pigeon	2, 104	116.2	<0.001	with random
Red kite	2, 42	7.1	0.002	with random
Marsh harrier	2, 65	0.5	0.631	with random
Black kite	2, 14	1.1	0.351	no random
Sparrowhawk	2, .441	1.4	0.246	with random
Pallid harrier	2, 24	0.7	0.520	no random
Common crane	2, 16	0.0	0.998	no random
Kestrel	2, 132	0.2	0.812	with random

6.3.3 Effect of weather on return migration

Weather affected the probability of return migration for several species (Table 20). Higher wind speed significantly increased the probability of return migration for Hen harrier, Sparrowhawk, Common crane, as indicated by the positive relation of wind speed (Table 20). Wind direction affected the probability of return migration significantly for Jackdaws, Common buzzard, and Wood pigeon (Table 20). For Red kite the effect of wind direction approached significance (Table 20). For the other species tested, wind direction did not relate to probability of return migration (Table 20).

The significant interactions between wind speed and wind direction for Jackdaw, Common buzzard, Wood pigeon, and Red kite (Table 20) suggested that the effect of wind speed depended on their direction. Wind direction did not have a significant effect on probability of return migration except in interactions with wind speed (Table 20).

Reduced visibility resulted in significantly higher probabilities for return migration for Wood Pigeon, Honey buzzard, Red Kite and Common Crane, as indicated by the negative relation with visibility (Table 20). Whereas jackdaw and Common buzzard showed positive relations indicating that longer visibility caused higher probability of return migration (Table 20).

Table 20. Test of how weather affects the probability of return migration. Note that models vary between species as the larger model could not converge for all species. We present the model most like the larger model, which could converge. Type indicates if a reduced model had to be used to achieve convergence.

Species	Parameter	df	F	p	Estimate	Model type
Jackdaw	Visibility	1, 59	8.1	**0.006**	0.019	
Jackdaw	Speed	1, 59	141.7	**<0.001**	0.365	
Jackdaw	Direction	3, 59	30.5	**<0.001**		
Jackdaw	Speed*Direction	3, 59	29.8	**<0.001**		
Hen harrier	Visibility	1, 53	0.0	0.932	0.006	Reduced
Hen harrier	Speed	1, 53	4.7	**0.035**	0.608	Reduced
Osprey	Visibility	1, 47	0.4	0.517	-0.036	Reduced
Osprey	Speed	1, 47	1.6	0.214	-0.394	Reduced
Rough-legged buzzard	Visibility	1, 24	0.2	0.698	0.016	
Rough-legged buzzard	Speed	1, 24	0.2	0.653	0.060	
Rough-legged buzzard	Direction	3, 24	0.6	0.596		
Rough-legged buzzard	Speed*Direction	3, 24	0.4	0.728		
White-tailed eagle	Visibility	1, 9	0.0	0.952	-0.003	Reduced
White-tailed eagle	Speed	1, 9	1.0	0.347	0.238	Reduced
Honey buzzard	Visibility	1, 101	3.0	0.084	-0.053	Reduced
Honey buzzard	Speed	1, 101	0.0	0.873	-0.343	
Honey buzzard	Direction	3, 101	1.1	0.363		
Honey buzzard	Speed*Direction	3, 101	1.1	0.343		
Hobby	Visibility	1, 30	3.6	0.068	-0.186	Reduced
Hobby	Speed	1, 30	1.9	0.176	-0.235	Reduced
Common buzzard	Visibility	1, 210	8.0	**0.005**	0.013	
Common buzzard	Speed	1, 210	14.1	**<0.001**	0.112	
Common buzzard	Direction	3, 210	27.6	**<0.001**		
Common buzzard	Speed*Direction	3, 210	24.4	**<0.001**		
Wood pigeon	Visibility	1, 98	9.3	**0.003**	-0.009	
Wood pigeon	Speed	1, 98	5.9	**0.017**	0.251	
Wood pigeon	Direction	3, 98	32.6	**<0.001**		
Wood pigeon	Speed*Direction	3, 98	118.0	**<0.001**		
Red kite	Visibility	1, 36	4.5	**0.041**	-0.043	
Red kite	Speed	1, 36	0.8	0.387	-0.026	
Red kite	Direction	3, 36	2.7	0.058		
Red kite	Speed*Direction	3, 36	3.0	**0.043**		
Marsh harrier	Visibility	1, 59	2.7	0.104	-0.064	
Marsh harrier	Speed	1, 59	0.0	0.983	-0.002	
Marsh harrier	Direction	3, 59	0.9	0.471		
Marsh harrier	Speed*Direction	3, 59	0.8	0.497		
Black kite	Visibility	1, 9	0.0	0.858	0.008	Reduced
Black kite	Speed	1, 9	0.8	0.397	0.233	Reduced
Black kite	Direction	3, 9	0.5	0.714		Reduced
Sparrowhawk	Visibility	1, 435	2.2	0.143	-0.010	
Sparrowhawk	Speed	1, 435	9.6	**0.002**	0.148	
Sparrowhawk	Direction	3, 435	0.1	0.951		
Sparrowhawk	Speed*Direction	3, 435	0.6	0.630		
Pallid harrier	Visibility	1, 22	0.6	0.436	-0.052	Reduced
Pallid harrier	Speed	1, 22	0.0	0.890	0.030	Reduced
Common crane	Visibility	1, 14	14.3	**0.002**	-0.196	Reduced
Common crane	Speed	1, 14	6.8	**0.020**	0.621	Reduced
Kestrel	Visibility	1, 126	0.1	0.787	-0.007	
Kestrel	Speed	1, 126	0.1	0.720	0.233	
Kestrel	Direction	3, 126	0.4	0.753		
Kestrel	Speed*Direction	3, 126	0.2	0.887		

6.3.4 Effect of change of weather on return migration

A change of weather could at least in theory induce return migration. We, therefore, tested if changes in weather related to the probability of return migration. Change in weather or visibility were quantified as the difference between weather in the current and previous hour.

The influence of changes in weather on the probability of return migration could only be detected in a few of the species analyzed. Increased wind speed, as indicated by the negative parameter estimate (Table 21) increased the probability of return migration for Jackdaw, Wood pigeon, and Red kite (Table 21). Whereas decrease in wind speed increased the probability of return migration for Common cranes (Table 21). The interaction between changes in wind speed and wind direction showed significance for Common buzzard and Marsh harrier (Table 21).

Increased visibility resulted in higher probability of return migration for Jackdaw, Honey buzzard and Common buzzard, as indicated by the negative parameter estimate (Table 21). Whereas reduction in visibility increased the probability of return migration for Wood pigeon (Table 21). Several of the species, where an effect could be detected, had relatively large sample sizes, as indicated by the number of degrees of freedom (Table 21).

Table 21. Test of how change of weather relative to previous hour affects the probability of return migration.

Species	Effect	df	F	p	Estimate
Jackdaw	Visibility	1, 63	117.3	**<0.001**	<0.001
Jackdaw	Wind speed	1, 63	117.6	**<0.001**	-0.834
Jackdaw	Direction	1, 63	17.8	**<0.001**	-0.013
Jackdaw	Wind speed*Direction	1, 63	1.7	0.192	
Hen harrier	Visibility	1, 51	0.1	0.718	<0.001
Hen harrier	Wind speed	1, 51	1.5	0.225	0.849
Hen harrier	Direction	1, 51	0.0	0.847	0.003
Hen harrier	Wind speed*Direction	1, 51	0.1	0.783	
Merlin	Visibility	1, 29	0.2	0.628	<0.001
Merlin	Wind speed	1, 29	0.0	0.967	-0.038
Merlin	Direction	1, 29	0.0	0.952	0.003
Merlin	Wind speed*Direction	1, 29	0.0	0.915	
Osprey	Visibility	1, 45	0.3	0.599	<-0.001
Osprey	Wind speed	1, 45	0.0	0.836	-0.174
Osprey	Direction	1, 45	0.6	0.429	-0.015
Osprey	Wind speed*Direction	1, 45	0.1	0.786	
Rough-legged buzzard	Visibility	1, 28	0.2	0.682	<-0.001
Rough-legged buzzard	Wind speed	1, 28	0.7	0.396	-0.258
Rough-legged buzzard	Direction	1, 28	0.0	0.836	-0.002
Rough-legged buzzard	Wind speed*Direction	1, 28	0.1	0.733	
White-tailed eagle	Visibility	1, 7	0.7	0.444	<0.001
White-tailed eagle	Wind speed	1, 7	0.5	0.501	0.271
White-tailed eagle	Direction	1, 7	0.7	0.440	-0.007
White-tailed eagle	Wind speed*Direction	1, 7	0.5	0.509	
Honey buzzard	Visibility	1, 104	5.6	**0.020**	<0.001
Honey buzzard	Wind speed	1, 104	0.4	0.514	0.124
Honey buzzard	Direction	1, 104	0.8	0.375	0.004
Honey buzzard	Wind speed*Direction	1, 104	1.5	0.219	
Hobby	Visibility	1, 28	0.2	0.697	<0.001
Hobby	Wind speed	1, 28	0.1	0.810	-0.176
Hobby	Direction	1, 28	0.1	0.819	-0.004

Hobby	Wind speed*Direction	1, 28	0.7	0.403	
Common buzzard	Visibility	1, 214	18.8	**<0.001**	<0.001
Common buzzard	Wind speed	1, 214	0.6	0.451	0.032
Common buzzard	Direction	1, 214	0.6	0.448	0.001
Common buzzard	Wind speed*Direction	1, 214	9.1	**0.003**	
Wood pigeon	Visibility	1, 102	8.1	**0.005**	<-0.001
Wood pigeon	Wind speed	1, 102	750.8	**<0.001**	-0.638
Wood pigeon	Direction	1, 102	0.3	0.583	-0.001
Wood pigeon	Wind speed*Direction	1, 102	3.1	0.083	
Red kite	Visibility	1, 40	0.0	0.909	<-0.001
Red kite	Wind speed	1, 40	4.8	**0.035**	-0.401
Red kite	Direction	1, 40	9.3	**0.004**	0.036
Red kite	Wind speed*Direction	1, 40	2.7	0.107	
Marsh harrier	Visibility	1, 63	1.8	0.188	<-0.001
Marsh harrier	Wind speed	1, 63	3.2	0.080	-0.891
Marsh harrier	Direction	1, 63	0.4	0.542	0.008
Marsh harrier	Wind speed*Direction	1, 63	5.3	**0.025**	
Black kite	Visibility	1, 9	0.0	0.864	<0.001
Black kite	Wind speed	1, 9	1.2	0.302	-1.462
Black kite	Direction	1, 9	0.4	0.523	-0.050
Black kite	Wind speed*Direction	1, 9	1.3	0.277	
Sparrowhawk	Visibility	1, 438	0.0	0.948	<-0.001
Sparrowhawk	Wind speed	1, 438	0.1	0.759	0.021
Sparrowhawk	Direction	1, 438	0.4	0.533	0.001
Sparrowhawk	Wind speed*Direction	1, 438	0.0	0.892	
Pallid harrier	Visibility	1, 20	0.5	0.487	<0.001
Pallid harrier	Wind speed	1, 20	0.1	0.712	0.421
Pallid harrier	Direction	1, 20	0.0	0.883	0.002
Pallid harrier	Wind speed*Direction	1, 20	0.0	0.949	
Common crane	Visibility	1, 12	3.0	0.106	<-0.001
Common crane	Wind speed	1, 12	6.6	**0.024**	0.878
Common crane	Direction	1, 12	0.7	0.424	0.014
Common crane	Wind speed*Direction	1, 12	0.1	0.792	
Kestrel	Visibility	1, 130	3.2	0.076	<0.001
Kestrel	Wind speed	1, 130	0.5	0.461	0.170
Kestrel	Direction	1, 130	0.6	0.456	-0.003
Kestrel	Wind speed*Direction	1, 130	1.2	0.276	

6.4 Conclusion

The analysis showed significant differences in the probability of return migration between species. In general, falcons, harriers, Honey buzzards and Ospreys showed a low probability of return migration, whereas Red kites, Rough-legged buzzard, Common buzzards showed a high probability of return migration.

For most species, the probability of return migration increased as the season progressed. It is very likely that the comparatively small probability of return migration in the early part of the migration period for each species reflects that the migrating individuals consist of older experienced individuals, for whom early arrival at the breeding grounds has importance. Whereas the high rate of return migration in the later part of the season may consist of young and less experienced individuals that might also defer breeding until later years and might have a lower state of fitness overall than adults. Uneven recordability between the age groups can introduce bias too. Notably, relatively fewer Rough-legged buzzard than Common buzzard was recorded early in the season introducing a bias towards high return migration rate in the former, in a species otherwise known to be a "strong flyer" not prone to return migration as the latter is.

The analyses test the probability of return migration, which means that there must be migration. Some species seem to only migrate under specific weather conditions. The direction of wind had little effect on the probability of return migration. This is likely to reflect that many species have specific preferences for wind directions in which they will migrate across large waterbodies. This was particularly true for wind direction, which affects the probability of migration for many species at Skagen (Bertel 1994). The apparent preferences means that the data set contains little variation in wind direction and thus limited potential for detecting an effect of wind direction on the probability of return migration. The overall weather system has also a profound effect on the occurrence of migration in Skagen. For instance, in stronger headwinds many species, e.g. falcons are more likely to follow coastlines and fly at lower altitudes and hence reach Skagen in sight from the ground at Grenen. Also, persistent Easterly winds can shift migration Westwards to reach Skagen in a species that otherwise follows a more Eastern route in the prevailing Westerly wind conditions.

6.4.1 Change in weather

Changes in wind speed, wind direction, and interaction between wind speed and wind direction could increase the probability of return migration. The counter intuitive result that increased visibility resulted in higher return migration could be related to changes in wind speed, which indeed have an effect either as a main effect or the interaction between wind speed and direction. Other parameters, which coincide with changes in visibility might also exert an effect on the probability of return migration; for instance, migrants roosting in the general Skagen area may react readily to a favorable change in the weather and attempt migration only to find out the weather was still not suitable for crossing of the waterbody.

6.4.2 Quantification of return migration

At Skagen it is documented that migrating raptors leave the coast in one place and if they make return migration, might reach the coast at another place on return migration (Bertel 1994). The location of the return migration further depends on wind direction. The different locations for migration and return migration could bias estimates of return migration and cause an underestimation of return migration under some weather conditions.

6.4.3 Implications for collision estimates

The high frequency of return migration for several species emphasizes the importance of accounting for return migration before using migration totals for estimating the collision risks for each species.

In the current report, we based the collision estimates on the migration totals corrected for return migration. The occurrence of return migration therefore has no influence on collision estimates presented in another chapter in this report.

7 Discussion and Conclusion

7.1 Some data issues and quality concerns

In the present compilation of data some comments have to be added to explain the results presented. This concerns some issues that have not yet been handled as well as some issues related to lack of data collection and lack of adequate data.

The transect observations were generally carried out in the mornings and during the day. In some cases, data from late afternoon, i.e., between 5 and 7 pm, were collected only on days with substantial migration. This means that migration intensity in these time intervals may potentially be overestimated, as the few 15-minute counts carried out between 5 and 7 pm, all represented high bird numbers. The vertical radar observations from 2023 and 2024 showed a substantial nocturnal migration of what the majority presumably represents passerine bird species, although the actual species involved are unknown.

It is important to keep in mind that the data collected during the present investigations covers three migration seasons that differs slightly in both the occurrence and in numbers of species recorded. Hence, even though birds are migrating northward to breeding areas during each spring period, variation will occur due to both local and regional conditions that may affect both phenology, volume and even flight behaviour. Consequently, some caution should be taken for the fact that more extreme seasonal variation may occur that can affect the occurrence of specific bird species at Skagen during spring migration, even though the present results from 2022, 2023 and 2024 generally show an overall similarity.

When considering bird migration, weather conditions is a factor that can affect migratory flight behaviour and migration pathways on both small and large scales. For example, flight altitudes of migrating birds are generally affected by wind conditions during migration attempts, with both wind direction and speed being of importance. Likewise, many migrating birds, especially raptors, are dependent upon a clear view to the distant coast of Sweden before migrating out from Skagen. Hence, misty and foggy condition are known to stop migratory movements of birds completely. The overall wind regime over northern Europe and Scandinavia during spring migration may affect the overall numbers of migrating birds that occur at Skagen, which accordingly is known to show some variation between years.

The results of the transect counts are likewise affected by the behaviour of the different species of birds relating to the reluctance to migrate over larger bodies of water, which vary greatly between bird species. Some species, especially soaring birds that depends on optimal weather conditions, are more sensitive to the prevailing wind regime during their migration, compared to species which mainly migrate actively by flapping flight. If conditions are not optimal, soaring birds may accumulate in the Skagen area, making multiple migratory attempts over shorter or longer periods (days/weeks), whereas high numbers may migrate when optimal weather conditions occur.

Adult birds are generally more determined to migrate than immature birds, as the latter ones are not breeding, and hence have no rush to arrive early at the breeding grounds to establish breeding territories. Consequently, immature birds may stay for longer periods at migration points, and such a pattern is known from the Skagen area, where immature birds often are seen making migration attempts much later than the main migration period. Often less determined migrating birds will make circular movements leaving the coast at one point and return over another given the wind direction and speed.

In the present study, higher bird numbers were registered as returning than numbers leaving on migration during some transect counts. This pattern may be seen if migrating birds leave the Skagen peninsula further south and make returns at the observation points. Likewise, since transect counts only covers a 15-minute period, some birds may have crossed the transect before the start of recording and have only been observed during return flights. The present study design is therefore sensitive to such biases, which, however, will be most pronounced for species that are recorded in low numbers.

For the species groups observed in small numbers (i.e., <30), the return rates are probably not representative. This also relates to species that make migration from Skagerrak into Kattegat, like some duck and diver species, and hence may pass the transect line in a return direction.

7.2 Bird numbers and migration

Overall, the migratory pattern recorded at Skagen in 2024 was comparable to the previous seasons in 2022 and 2023, when considering both phenology and flight behaviour. Some differences in numbers occurred, however, in some species, with higher estimated migration totals for Common Buzzard, Honey Buzzard, falcons and Wood Pigeons and lower estimated totals of Sparrowhawk and Jackdaw in 2024 than in both 2022 and 2023 (cf. Table 5). Likewise, minor differences in mean migration altitude and flight directions were recognizable between the three years. These differences most probably relate to differences in weather conditions between years, where both matches and mismatches been seasonal occurrence of the individual species and prevailing weather during the species prime migration periods, results in variation between years. As can be seen from figure 3a, c, prevailing wind directions were slightly different between years, with 2022 being dominated by more southwesterly winds, 2023 by more westerly winds, and 2024 by more northerly wind, and with longer periods of easterly wind directions in 2023 and 2024 than in 2022.

The differences in the wind regimes most probably resulted in higher numbers of Honey Buzzards and falcons recorded in 2023 and 2024 than in 2022, as their main migration period in May and June was dominated by calm and easterly winds in these years.

The visual counts performed for a 15-minute period each hour during 3 days of observation per week during the main migratory season (20 March – 15 June) was used to estimate total migration volume at Skagen. The estimated totals show a surprising match with the totals estimated by the Skagen Bird Observatory, considering that these totals are not fully compensated for multiple records and for return migration. However, the similarities, especially obvious for Honey Buzzard, harriers and Osprey (cf. Figure 14), indicate that the totals estimated in this study is a good approximation of the actual migration. Consequently, the data on migration volume is considered to reliably approximate actual raptor migration at Skagen.

Nocturnal radar recordings at Skagen showed that substantial bird migration took place during nighttime. As species identification cannot be made from the radar signals, we assume that most recordings concern passerine species that are known as nocturnal migrants, e.g., finches and thrushes. The nocturnal pattern showed a peak migration activity in April and early May and with peaks during late evening and early mornings. Sound recordings are needed if the species composition of the nocturnal migration at Skagen has to be verified.

The numbers of raptors recorded arriving at the three points at the Swedish coast during both 2022, 2023 and 2024 was, as expected, much lower than the numbers observed leaving Skagen in Denmark. However, the observations roughly correspond to the species composition observed at Skagen and thus reflects that birds leaving Skagen to a large extend migrate towards Sweden. It is noticeable that the numbers of Honey Buzzard recorded at the Swedish coast was negligible in 2024. However, observations ended in week 18 before the peak migration period of this species. The recorded flight altitudes of birds approaching the Swedish coast is generally lower than when leaving Skagen, a pattern that is in accordance with the lower altitude recorded in GPS-marked birds, showing a lower migration altitude when over open sea, compared to higher altitudes when leaving the coast and when arriving during, probably after having visual recognition of land.

One species shows a striking difference between Skagen and at the coast of Sweden. At Skagen, Wood Pigeon migrate in very high numbers (>24,000 in all years) but almost none are recorded at the Swedish observation points (N=2 in both 2022 and 2023 and N=0 in 2024). At Skagen Wood Pigeon show a very steep increase in altitude after leaving the coast, which indicates that Wood Pigeon probably cross the Swedish coastline in very high altitudes, outside the observers range.

7.3 Collision risk

It is important to emphasize that the expected number of collisions for each species or species group should be regarded as crude estimates, based on the three years of observations. We have therefore used relatively low avoidance rates between 99 and 95 % resulting in larger collision estimates compared to higher avoidance rates. However, the estimates must be interpreted with caution as we do not know how especially the gliding raptor species will behave in vicinity of wind turbine parks. The model of altitude distribution suggests that even if buzzards leave Skagen at altitudes above risk height they seem to descend to risk altitude over the water. In general, the model suggests that harriers do not evade risk height during migration across the sea. Our estimates were based on the migration directions observed at Skagen in 2022, 2023 and 2024, which to some degree depends on wind direction and speed. Springs with different wind directions and weather might produce other numbers of migrants and proportions migrating towards the wind turbine parks and hence different collision risk estimates. In general, the collision estimates for 2022, 2023, and 2024 showed similar results between years for all species except honey buzzard, that was not assigned a collision risk estimate in 2022 due to low numbers of birds.

7.4 GPS tagging of birds of prey

Altogether, 16 Common Buzzards were equipped with Ornitela GPS tags, attached to the birds by a Teflon harness. Of those 5 birds have shown migratory behaviour. All birds had a northeasterly spring migration and a southwestern autumn migration. This was data deriving from birds that passed relatively short marine passages over Storebælt and Øresund.

Flight altitude of Common Buzzard during marine passages was higher when leaving the coast than during the passage and when approaching the coast.

Via a collaboration with INBO in Belgium, we got access to data from Hen Harriers, Marsh Harriers and Montagu's Harriers, equipped with GPS tags. Being bird species with an active migration flight (as opposed to soaring Common Buzzard) the harriers were less confined to marine passages at very narrow points.

The harriers showed lower flight altitudes than the Common Buzzard and their flight altitude were higher when leaving or approaching the coast than during the central marine passage. This means that the flight altitude measured on the Swedish coast probably resemble the flight altitude in the wind turbine areas better than the flight altitude observed at Skagen although the impact in the collision estimates will be small.

The data on harrier migration included information on marine passages of the Biscay and the Mediterranean. Due to potential differences in flight altitudes during marine passages because of topographical conditions the analysis of harrier flight altitudes during marine passages have been carried out on data from the North Sea, Kattegat, and the Baltic solely. This selection was used in order to ensure comparability.

Information from GPS-tagged birds has improved our knowledge on migration habits of both passive migratory raptors (Common Buzzard) and active migrants (harriers). The fact that all the migratory Common Buzzards in this data were ringed and equipped with GPS tags on Funen and Langeland resulted in shorter marine passages across the Great Belt and Øresund. Information about flight altitudes from passages of larger marine bodies would have been desirable, but challenges in capturing the birds led to this situation.

Catching raptors was difficult. Captures that ensure information on flight behaviour across from Skagen to Sweden would have been preferred. In lack catch success in northern Jutland we decided to equip Common Buzzards in Funen and Langeland, with the aim to maximize the use of the GPS tags.

8 Acknowledgement

During this study several people contributed to carry out the observations, to operate the radar, to assist with the traps for raptor capturing, and/or supporting the general logistic in both Denmark and Sweden.

From Denmark we would especially like to thank Simon S. Christiansen from the BirdLife Denmark Bird Observatory at Skagen, who helped in coordinating volunteer observers engaged by the Skagen Bird Observatory, monitored the raptor trap when open, and for contributing with relevant knowledge about the pattern of bird migration at Skagen.

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9 Appendix

Table A1. The proportion of each species at risk altitude for the two wind turbine designs. We used the maximum risk altitude, which was the maximum proportion of birds at risk altitude in one of the 200 m distance segments relative to the coast.

Design	Alternative A	Alternative B
Common Buzzard	0.77	0.63
Crows	0.68	0.53
Falcons	0.80	0.80
Harriers	0.93	0.83
Osprey	0.78	0.78
Kites	0.88	0.87
Sparrowhawk	0.98	0.95
Wood Pigeon	0.93	0.85
Honey buzzard	0.82	0.67

Table A2. The wind turbine designs and specifications for alternative A and alternative B used in the Band collision model. The max chord estimate is a guess as the maximum width of the blade was not specified.

Design	Alternative A	Alternative B
Diameter (m)	310	230
Radius (m)	155	115
Nacell height (m)	185	145
Rpm	7	8
max chord (m)	8	7
N (North/South)	53/8	81/13
Inter-windturbine distance (km) (North/South)	1.8/1.9	1.8/1.9
Distance to Skagen (km) (North/South)	23.5/25	23.5/25

Appendix A3. Explanation of calculations involved in collision risk estimates based on observations from 2022.

The collision risk for a species is based on estimates of density in the wind turbine area, altitude distribution, layout of wind turbine park and wind turbine dimensions.

Note: Capital letters in parentheses in the text below refer to the parameters listed in Table A1.

Density estimates

For the projects in Skagerrak, we estimated density based on the number of individuals leaving Skagen (A) multiplied by the proportion of migrating individuals flying towards the wind turbine park (B), which gives the number of birds passing the wind turbine area.

The estimation of density at the wind turbine park assumes that the birds distribute equally in the wind turbine park. The wind turbine park is located a minimum of 23.5 km from Skagen and birds leaving Skagen with directions between 12 and 62 degrees (50 degrees) will pass the wind turbine area. To estimate the number of birds per kilometre (D) in the wind turbine area closest to Skagen, we estimated the length of a part (50/360) the perimeter of a circle with 23.5 km radius (C) and divided the number of birds passing the area (A*B) with I length (C). The length C underestimates the distance over which the birds are scattered, as the length of the projected wind turbine park is larger than the length of the perimeter part of the 23.5 km circle used. The underestimation of distance will result in a modest overestimation of density relative to the actual density, especially for the wind turbines furthest away from Skagen.

Altitude distribution

We estimated the proportion of individuals at risk altitude (E) for each 200 m segment relative to the coastline. As we do not know the altitude of the birds when they migrate over large waterbodies, we used the largest proportion detected for each species.

Wind turbine park layout

The combination of distance between wind turbines and their dimensions determines the proportion of the vertical area occupied by each wind turbine (G, H).

Wind turbine dimensions

The wind turbine dimensions do not only determine the proportion of birds at risk altitude and the sweep area. The dimensions of the wing and the rotation per minute also influence the chances that a bird passes unharmed through the sweep area. The chance that a bird passes also depends on the length, wingspan, and flight speed of bird through the wind turbine area. This collision chance (J) is a major part of Band collision model (Band et al. 2007).

Avoidance rates

We calculated collision risk with three different avoidance rates (L) (95 %, 97.75 % and 99 %) for one wind turbine and multiplied this estimate with the number of turbines planned. In addition, we expect that the wind turbines are not rotating due to maintenance or lack of wind about 6 % of the time (M).

Table A3. Example of calculation of collision risk estimate for common buzzard. In the current example, the following values were used in the estimation. Diameter: 0.29 km, Distance between turbines: 0.89 km, Number of wind turbines: 50.

Parameter	Source/formular	Common buzzard
A. Total Skagen	Table 5	3996
B. Proportion flying towards Poseidon	Table 6	17.3
C. Length of the part of the perimeter	(25/360)*2*Pi*25	10.9
D. Density (Individuals/km)	A*B/C	63.34
E. Proportion at risk altitude	Table A1	0.87
F. Number at risk altitude	D*E/100	55.10
G. Risk window	Diameter*distance btw. turbines	0.2581
H. Area occupied by rotor	Pi*radius^2	0.066
I. Numbers passing rotor	F*(H/G)	14.10
J. Collision chance	Calculated in the Band model	0.045
K. No. of collisions without avoidance	$N_{turbines}$*(J*I)	31.73
L. Avoidance	Estimates	0.99
M. Cut and maintenance	Estimates	0.94
N. Number of collisions with avoidance	K*(1-L)*M	0.30

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THE POSEIDON WIND FARM: BIRD MIGRATION AT SKAGEN AND THE WEST COAST OF SWEDEN – SPRING 2024

Data report on bird migration at Skagen, Denmark and the west coast of Sweden in relation to the planned offshore wind farm Poseidon in Kattegat

In spring 2024, bird migration observations from Skagen, Denmark, to the Swedish west coast were compiled to assess collision risks with wind turbines at the planned Poseidon offshore wind farm in Kattegat. Data on bird numbers, flight direction, and flight altitude of the most common migrants were recorded from March to June using visual observations, a laser rangefinder, and radar. Flight altitude of nocturnal bird migration was recorded with vertically positioned radar. To assess the flight altitude behaviour of raptors over open sea, data from GPS-tagged raptors across Europe were included. Based on this data, species-specific collision risk assessments were calculated for the planned Poseidon Wind Farm.