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Bird migration at Lista and Utsira 2023

Migration for Development

Line Cordes, Øyvind Hamre, Anna L.K. Nilsson, Aïda López, Diogo Portela, Jan Erik Røer & Roel May

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COVER PICTURE
Top left: Jaktfalk © Bård Stokke
Top middle: Stokkand © Bård Stokke
Top right: Grågås © Bård Stokke
Bottom: Fugleradar på Lista © Anna L.K. Nilsson

KEY WORDS
Robin Max radar, avian radar, radar tracks, bird migration, Lista (Farsund kommune), Utsira, temporal patterns, spatial patterns, wind, bird flight characteristics, observer annotated tracks, radar assigned categories, radar cross section

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Abstract

Cordes, L.S., Hamre, Ø., Nilsson, A.L.K., López, A., Portelo, D., Røer, J.E. & May, R. 2024. Bird migration at Lista and Utsira 2023. NINA Report 2483. Norwegian Institute for Nature Research.

The Migration for Development project is jointly funded by industry partners and implemented to complement and support the VisAviS collaborative research project funded by the Research Council of Norway. As part of the work, two avian radars were deployed at coastal locations in Norway to record seasonal bird migrations. Here, we present an investigation of the avian radar data collected at Lista (Farsund municipality) during the spring and autumn and at Utsira during the autumn of 2023. Firstly, using radar tracks annotated by an observer, we show case issues with how the radar classifies bird tracks (small, medium, large and flock). We used the data from annotated tracks to provide improved categories of radar tracks. Secondly, using all tracks collected by the radar, we filtered these based on likely migration flight characteristics, and present temporal and spatial patterns of probable migration tracks.

The length and definition of the migration season varied by location. Migration peaks most consistently occurred from late afternoon through the evening. There were significant site- and season-specific differences in flight height and the proportion of birds in the rotor swept zone. At Lista a significant proportion of birds flew within the clearance zone between the sea surface and the rotor swept zone. We recommend including the proportion of birds flying in this narrow band (20m) in considerations of impacts of wind energy developments. Birds tended to migrate with a tail or cross-tail wind. Lastly, there were site-specific differences in size groups detected at Lista and Utsira, with Utsira predominantly detecting birds in the intermediate category and just a few large flocks, but no small birds. At Lista, all categories were detected by the radar.

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Sammendrag

Cordes, L.S., Hamre, Ø., Nilsson, A.L.K., López, A., Portelo, D., Røer, J.E. & May, R. 2024. Fugletrekk på Lista og Utsira 2023. NINA Rapport 2483. Norsk institutt for naturforskning.

Migrasjon for utvikling-prosjektet er fellesfinansiert av industripartnere og er igangsatt for å komplementere og støtte VisAviS samarbeidsprosjekt finansiert av Norges forskningsråd. Som en del av arbeidet ble to fugleradarer utplassert på kystlokasjoner i Norge for å registrere sesongbaserte fugletrekk. Her presenterer vi en undersøkelse av fugleradardata samlet inn på Lista (Farsund kommune) i løpet av våren og høsten, og på Utsira i løpet av høsten i 2023. For det første, ved å bruke radarspor annotert av en observatør, viser vi problemer med hvordan radaren klassifiserer fuglespor (små, mellomstore, store og flokker). Vi brukte data fra annoterte spor for å gi forbedrede kategorier av radarspor. For det andre, ved å bruke alle spor samlet inn av radaren, filtrerte vi disse basert på sannsynlige trekkflygningskarakteristikker og presenterer trekkmønstre i tid og rom av sannsynlige trekkspor.

Lengden og avgrensningen av trekkperioden varierte etter lokasjon. Trekktopper oppsto mest konsistent fra sen ettermiddag til kveld. Det var betydelige sted- og sesongspesifikke forskjeller i flygehøyde og andelen fugler som beveget seg i samme høyde som rotor sveip-sonen på et vindkraftverk. På Lista fløy en betydelig andel av fuglene innenfor sonen mellom havoverflaten og rotor sveip-sonen. Vi anbefaler å inkludere andelen av fugler som flyr i dette smale båndet (20m) i vurderinger rundt virkninger av vindkraftutvikling. Fugler hadde en tendens til å migrere i medvind eller delvis medvind. Til slutt var det stedsspesifikke forskjeller i størrelsesgrupper oppdaget på Lista og Utsira, hvor Utsira hovedsakelig detekterte fugler i mellomkategorien og bare noen få store flokker, men ingen små fugler. På Lista ble alle kategorier detektert av radaren.

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Contents

Foreword

Within the VisAviS consortium, there has been expressed the interest from the industry partners to receive timely results especially from the local avian radars at Utsira and Lista to support their concession applications for development as well as help NVE in their concession evaluations and for inputs to baseline data needed for the next 5-10 years' time. For this purpose, the Joint Industry Project 'Migration for Development' was established as a side-project to the RCN-funded collaborative research project VisAviS (RCN Grant no. 336457). To stay up to date regarding the collected radar data at both Utsira and Lista, these will be analysed, visualized and reported bi-annually. This will ensure that the observed migration patterns can be utilized for concession applications without delay. This report details the exploration of avian radar data from 2023 at Lista and Utsira.

Trondheim, July 2024
Roel May, Project Leader

1 Introduction

The Migration for Development project was jointly funded by industry partners and put in place to support and complement the VisAviS project (RCN Grant no. 336457) funded by the Research Council of Norway. To ensure timely dissemination of the projects' outcomes, the Migration for Development project involves analysis, visualising, and reporting on data collected by avian radars at Utsira and Lista following migration seasons, ensuring that the observed migration patterns can be utilized for concession applications without delay. This report is a follow-up on the report detailing the first spring season at Lista (Cordes et al. 2023).

In spring 2023, avian radars were deployed at Lista and Utsira which are both known to be important for migrating birds and each have a bird observatory. The avian radar at Lista was operational from the end of March and has collected data almost continuously since then. The avian radar at Utsira was only operational during the first two weeks of March before data collection stopped, initially due to smaller technical issues and later due to larger problems. As Utsira is remote and difficult to access even small repairs took time to complete. Other outside factors delayed repairs even further (e.g., broken down ferry, Easter holidays). The radar was eventually moved to Finnmark for a different project, after which it was shipped to the Netherlands as full repairs were required. The radar was returned to Utsira at the end of the summer and has been collecting data since the 30th of August.

Here, we present patterns of migration from avian radar data collected during spring at Lista from April to June and during autumn from both Lista and Utsira from September to November 2023. This report provides an overview of temporal and spatial patterns in migration flight including how flight height changes over space and time. We also present preliminary exploration of annotated radar tracks (i.e., where species ID has been confirmed by an observer) and highlight issues regarding how the avian radar is classifying tracks.

2 Methods

2.1 Radar

A Robin Max 3D avian radar was deployed at Lista (58.109002 N, 6.566235 E) at a height of 2.5m above sea level and collected data from the 29th of March onwards (**Figure 1**). A similar radar was placed at Utsira (59.305762 N, 4.874604 E) at a height of 62m above sea level which collected data from the 30th of August onwards. Radar systems emit a radio frequency (RF) signal which reflects off an object, and this reflected signal is then received by the radar. The strength of the received signal is used to calculate the radar cross section (RCS, measured in dBm^2) of the target. The time difference between sending and receiving the reflected signal is used to calculate the range (in metres). This combined with the azimuth angle of the radar determines the location of the target. Lastly, the elevation angle of the target is measured by comparing the signal strength in two receive beams. The elevation angle and the distance to the target provides the height of the target in relation to the radar.

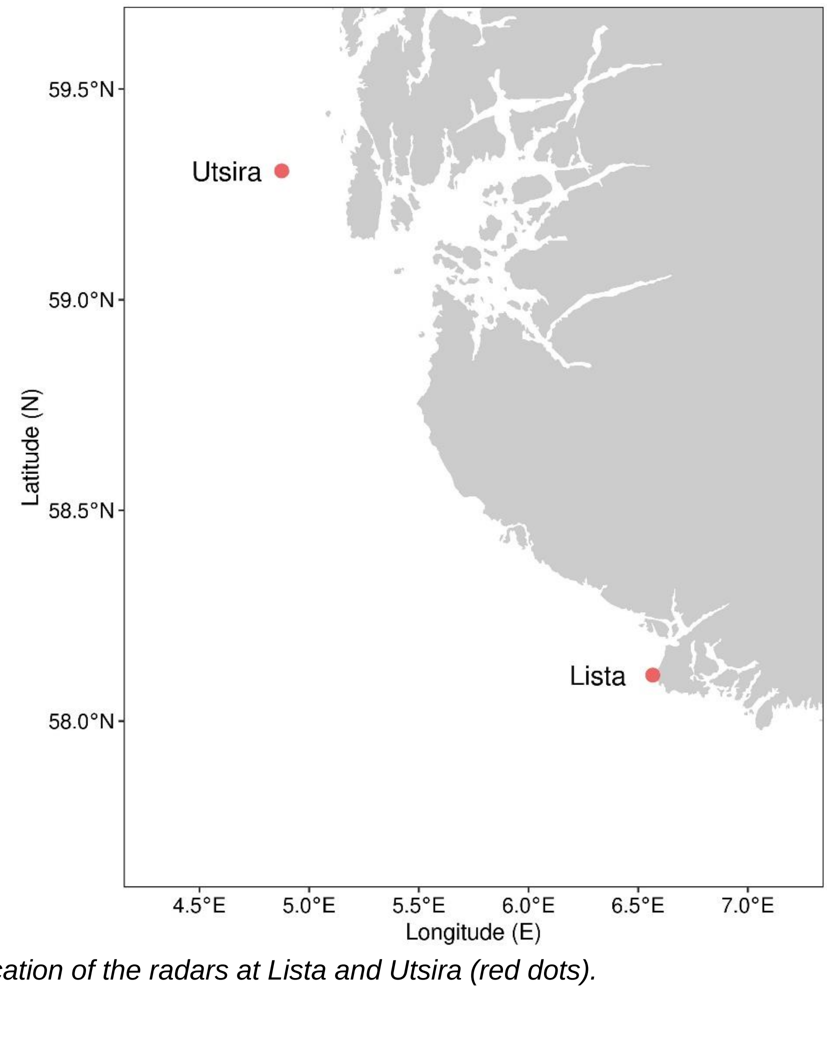

Figure 1. *Location of the radars at Lista and Utsira (red dots).*

The radar is not able to identify specific bird species but can inform on different groups of targets using the RCS for classification, such as small, medium, and large birds, flock, fast target, slow target, vehicle, aircraft, and unknown. Small birds are defined as having a median RCS value between -40 and -20 dBm^2, medium birds between -20 and -15 dBm^2, and large birds between -20 and 5 dBm^2. Flocks (“in blob formation”) are defined as having a median RCS value between -30 and 10 dBm^2, where at least three targets are detected, and each of the detections has a reliability score of ≥0.7. The individual targets within a flock must also travel within 100m from each other with a max speed difference of 5 m/s and have a maximum difference in direction from each other of 35 degrees. Vehicles are assigned if the track only moves on pre-defined roads (if these are set) and has no limits in terms of RCS values but should be assigned the property of “heavy”. Aircrafts also have no RCS limits.

2.2 Annotated radar tracks

At Lista and Utsira tracks were annotated by dedicated observers from the Lista and Utsira Bird Observatories in the area near the radars. On Lista, radar tracks were annotated for a full hour approximately every second day depending on conditions. On Utsira tracks were annotated during a block of 11 consecutive days. When a bird or flock of birds were observed and the species identified, this information was added to the track using an app showcasing live tracks detected by the radar. However, only annotated tracks from Lista are presented here as the species list at Utsira needs to be corrected and matched to Lista for these data to be used.

It is important to note that the time of day when tracks were annotated at Lista chosen at random, and typically did not cover periods of intense migration as this often occurred during darkness (especially in autumn). Instead, most annotated tracks were likely of local birds making shorter distance movements. Therefore, the annotated tracks at Lista likely only represents the range of species seen at Lista, and not the total number of tracks per species.

2.3 All radar tracks

For this preliminary investigation, we only included radar tracks which were originally labelled by the radar as birds (i.e., classified as flock, small, medium, or large birds). Tracks were also only included if these consisted of at least 6 relocations.

Less directional tracks were removed by filtering out tracks with a tortuosity < 0.60. Tortuosity is defined here as the straight-line distance from first to last location divided by the actual track length. Tracks with a tortuosity of 1 are therefore perfectly linear tracks. On the other hand, tracks with a tortuosity of 0.5 have a track length which is twice as long as the straight-line distance from the first and last location. Given what we know about migration speeds of different species of birds, we only included tracks with a mean speed between 5 - 28 m/s (Bruderer & Boldt 2001; Schmaljohann et al. 2008).

Radars cannot track birds behind buildings as these reflect the RF signal. At Lista a lighthouse is located only a short distance away from the radar. A cone shaped polygon was therefore drawn covering the (artificial) tracks behind the lighthouse and all tracks that overlapped or intersected with the polygon were removed. At Utsira the radar’s field of view was limited somewhat by the topography of the island, particularly to the north. This reduced the volume of space which is scanned by the radar and will likely influence the number of birds detected.

To eliminate waves which might be masquerading as birds, we applied a coarse “wave filter” whereby any tracks that started and ended over water and which had a maximum flight height of 4m were removed. Finally, to better filter out migration tracks from non-migration tracks, we identified days with peak activity (most likely migration tracks) from days with typical local activity using the R package ‘scorepeaks’ (Ochi 2019). We set the window size to the length of the migration season (~3 months) with a periodic boundary condition. It is important to note that within peak migration days there is still local movement included.

Due to the higher number of tracks recorded at Lista, we had to use a random subsample of tracks (1 million) to explore flight height and the spatial distributions. Wind data were downloaded from Norsk klimaservice senter (https://klimaservicesenter.no/).

3 Results

3.1 Annotated tracks

Species was assigned to 1365 radar tracks at Lista which are hereafter referred to as ‘annotated tracks’. The annotated tracks were collected on 67 days between the 12th of April and the 9th of November 2023 (**Figure 2**).

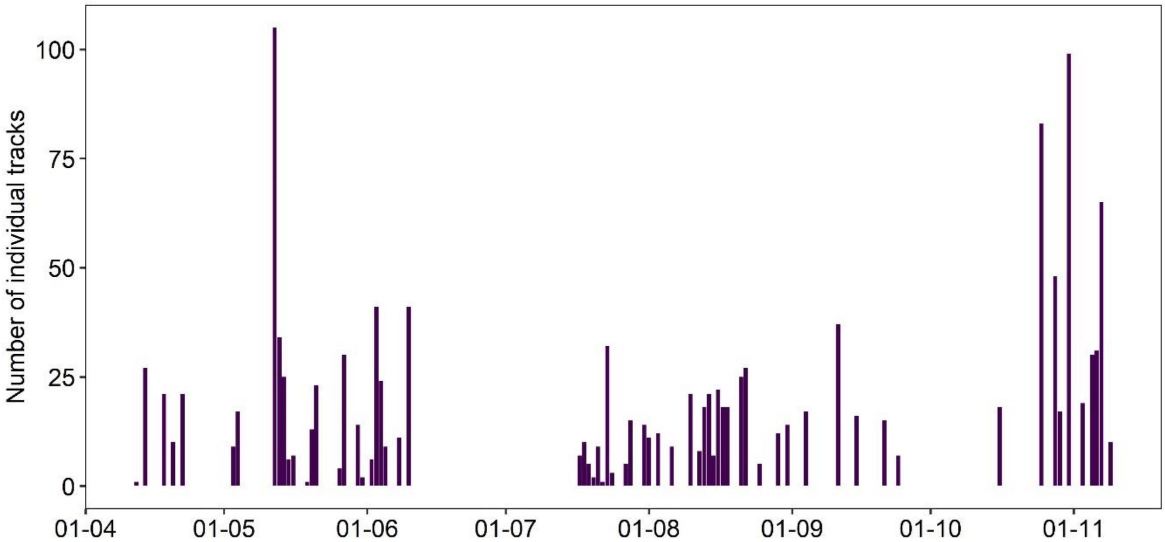

Figure 2. *Number of annotated tracks recorded per day at Lista.*

3.1.1 Radar assigned categories

The radar divided the 1365 annotated tracks into seven different categories, whereby falsely classifying 12.5% of annotated tracks as being something other than birds: small birds (n=795), medium birds (n=227), large birds (n=11), flock (n=161), slow target (n=4), vehicle (n=2) and unknown (n=165) (**Figure 3**).

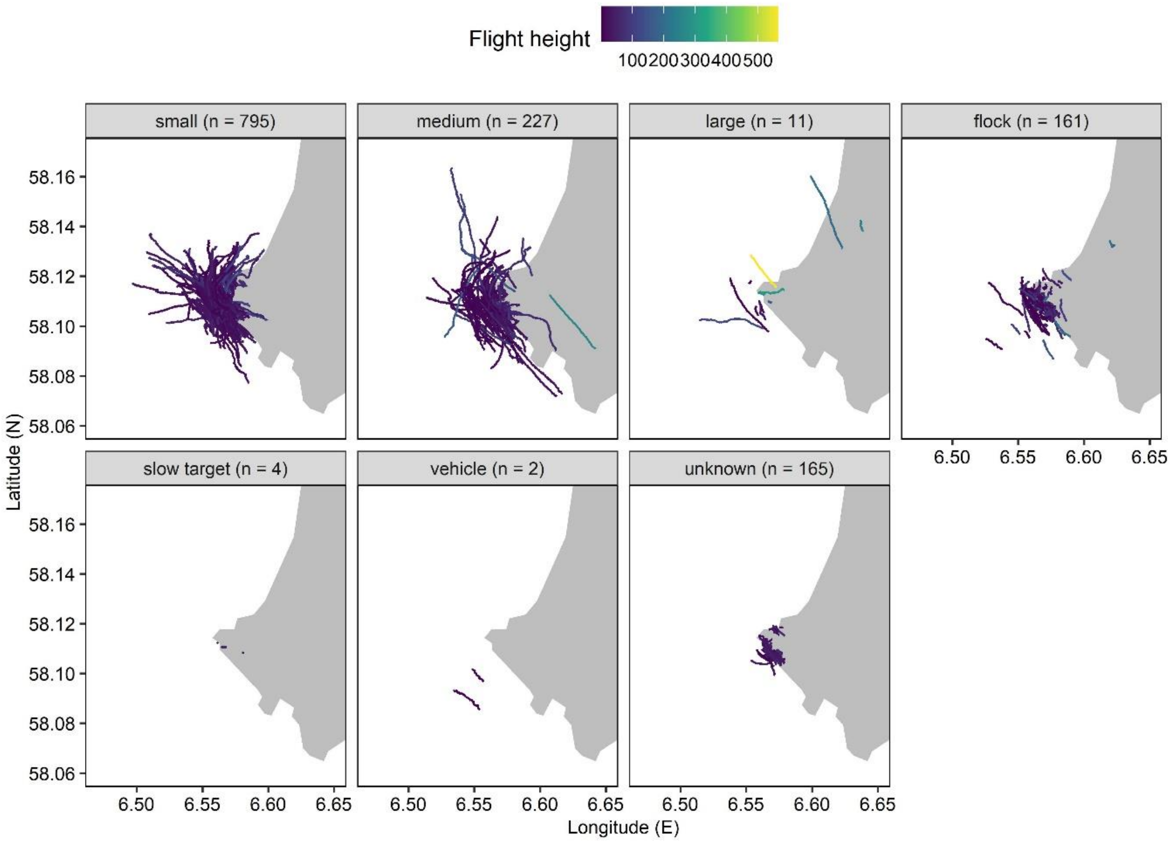

Figure 3. *Maps of the annotated tracks by category assigned by the radar and coloured by flight height (m).*

Investigating the radar cross section (RCS) for the seven different categories assigned by the radar, vehicle had the highest RCS. Unknown and slow targets had similar low RCS, and small birds had an RCS just above these. Small, medium and large birds were well separated with large birds having a narrow RCS range **(Figure 4**). Exploring other characteristics of the tracks assigned as non-birds, the two tracks assigned as vehicle where given the property of “heavy” and “in blob formation”, i.e. flock. These two tracks represent very large flocks of geese (200 and 300 individuals, respectively). Three out of four of the slow target tracks were recorded as “stationary” and the tracks indeed look relatively short (**Figure 3**). However, the recorded speeds are not outside of the bounds of what could be birds and most of the tracks show a significant change in altitude between the minimum and maximum values recorded. The tracks recorded as unknown typically only involved a single bird, typically small, and relatively low flying.

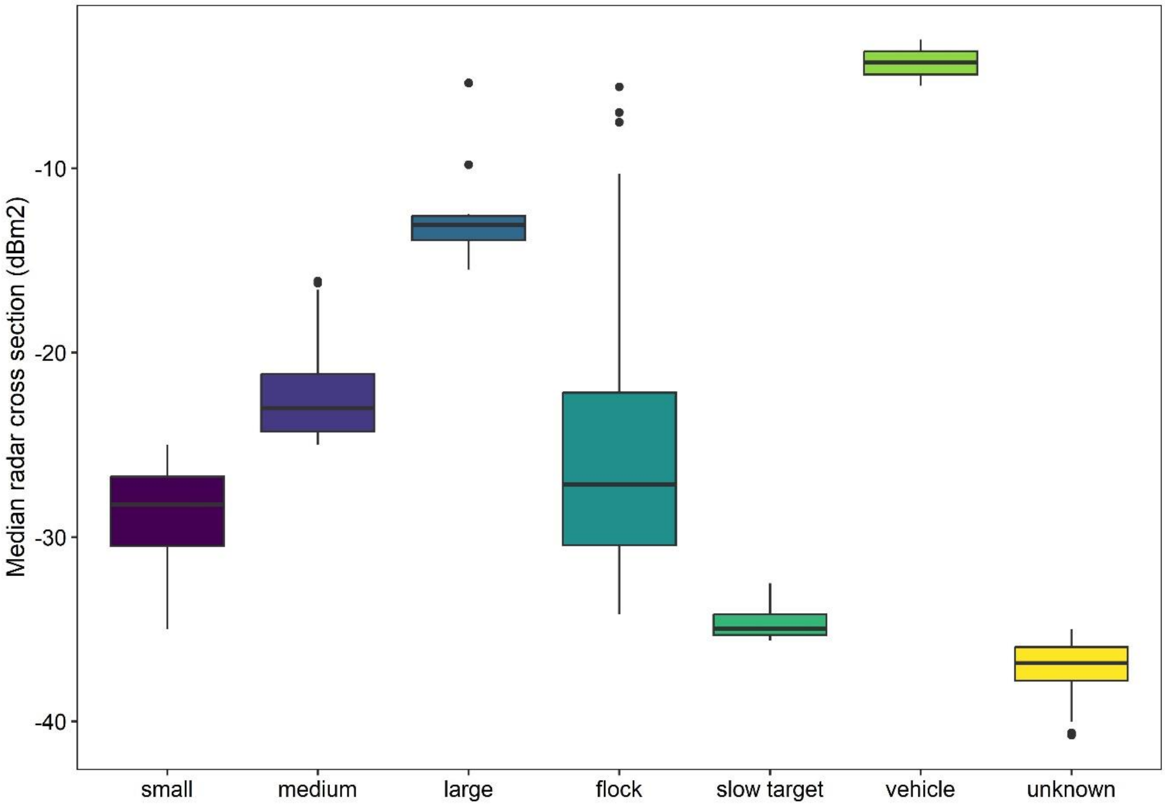

Figure 4. *Distribution of RCS (dBm^2) for each of the radar assigned categories.*

3.1.2 Corrected categories

We used information on maximum species mass to assign more informed categories to the annotated tracks. Birds with a mean maximum mass of 1600g or above were assigned as ‘large’, whereas birds with a mean maximum mass between 300-1600g were classed as ‘medium’, and birds with a mean maximum mass of less than 300g were assigned as ‘small’. Tracks which had a count of 3 or more individuals flying together were classed as ‘flock’. Given the new corrected categories, there were 292 tracks of small birds, 540 of medium birds, 267 of large birds, and 267 tracks of flocks (**Figure 5**).

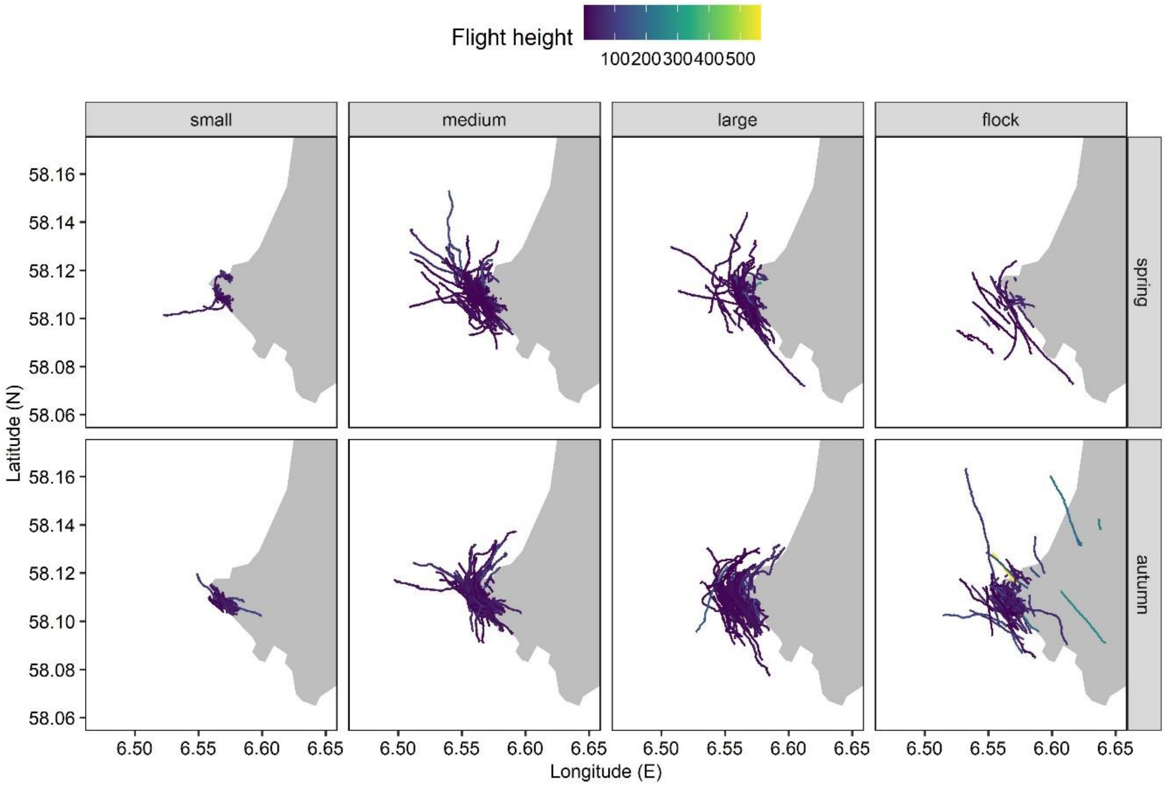

Figure 5. *Maps of the annotated tracks by corrected category and coloured by flight height (m).*

Twenty-two percent of tracks were of European herring gull. In fact, when just using data from the top ten most common species recorded, seabird species accounted for over 50% of tracks (**Figure 6**). As explained above (see Methods) this list represents the range of different species detected, but it likely does not represent the total number of tracks.

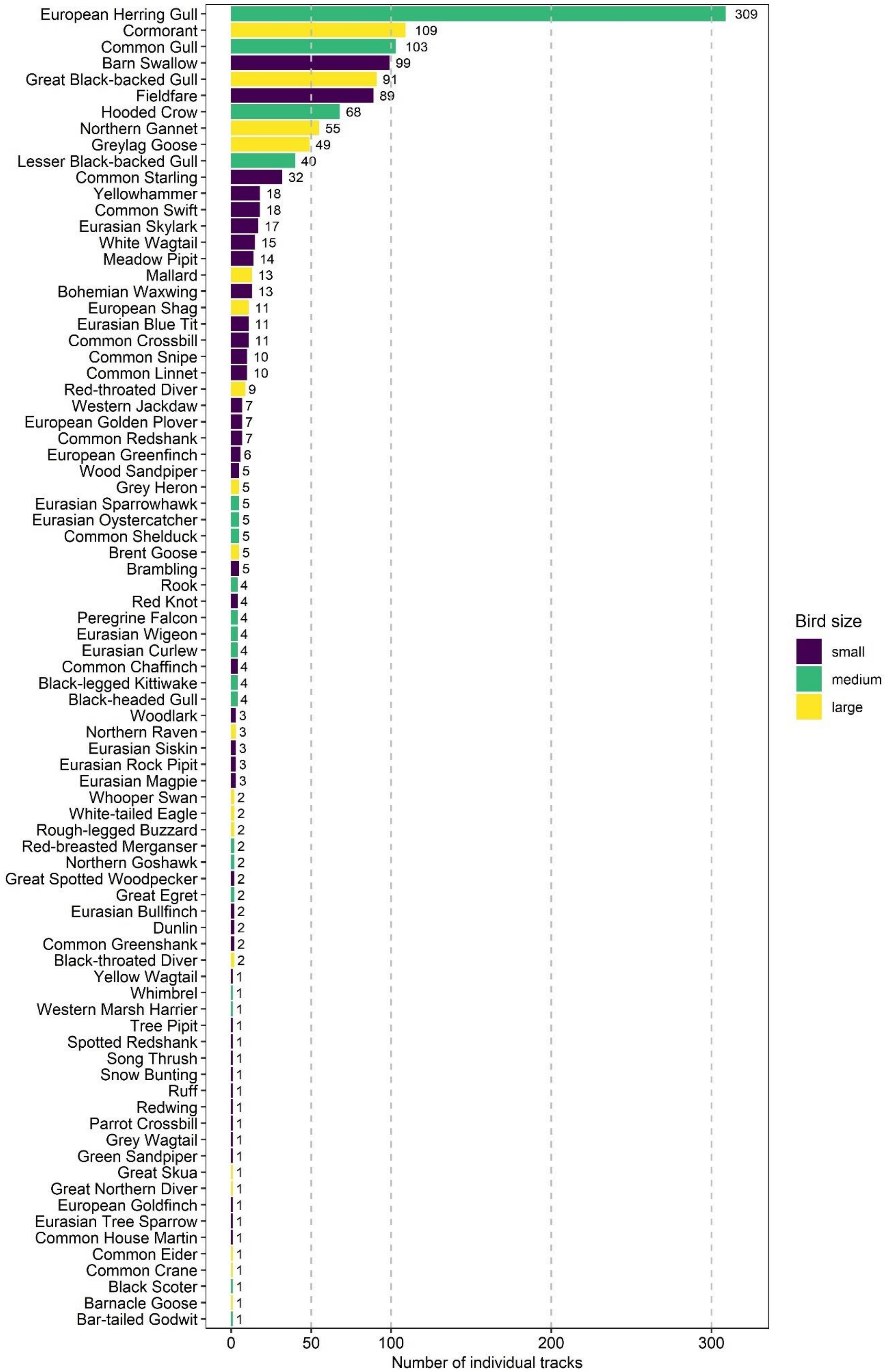

***Figure 6**. Number of individual annotated tracks collected by species.*

RCS for each of the four corrected size classes revealed that small birds appear to have a significantly lower RCS compared to the other categories and that some flocks have a much higher RCS compared to other categories, but also that RCS for flocks involved a lot of variation (**Figure 7**). From these data, it was clear that based on RCS alone separating medium and large birds is not possible due to the large amount of overlap. The red dotted line in Figure 6 indicates the RCS cut-off applied to all radar data to separate out small birds. It also appears that it may be possible to separate out some flocks. The RCS of flocks was explored further below.

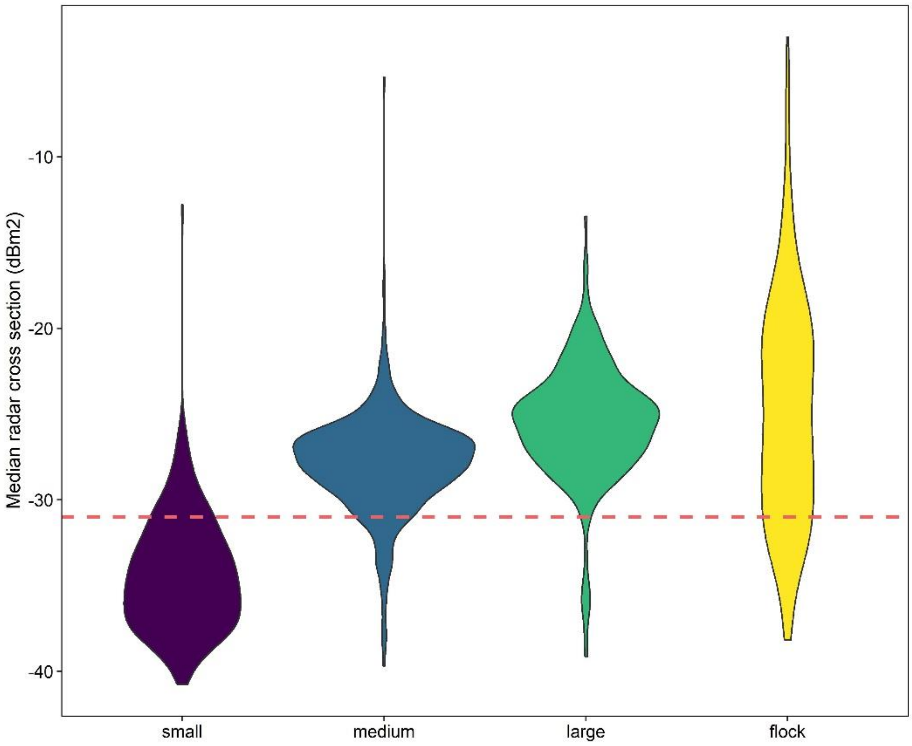

Figure 7. *Distribution of RCS for the corrected categories. The red dashed lines indicate a potential RCS boundary to separate small birds.*

Given that some flocks had the highest RCS values, we plotted the number of birds in a flock against the median RCS value and grouped these by the size category of the species observed (**Figure 8**). It appears that it may be possible to more accurately separate large flocks of large birds based on RCS (> -16 dBm^2), but that flocks of medium birds will overlap in RCS with detections of individual medium and large birds. However, ideally additional factors will be incorporated besides RCS to better classify tracks and more annotated tracks will be collected to increase sample size here. These approximate cut-offs generated three categories, 1) small birds under -31 dBm^2, 2) intermediate (including medium, large and some flocks) between -31 and -16 dBm^2, and 3) larger flocks of large birds above -15 dBm^2 to be applied to all radar data.

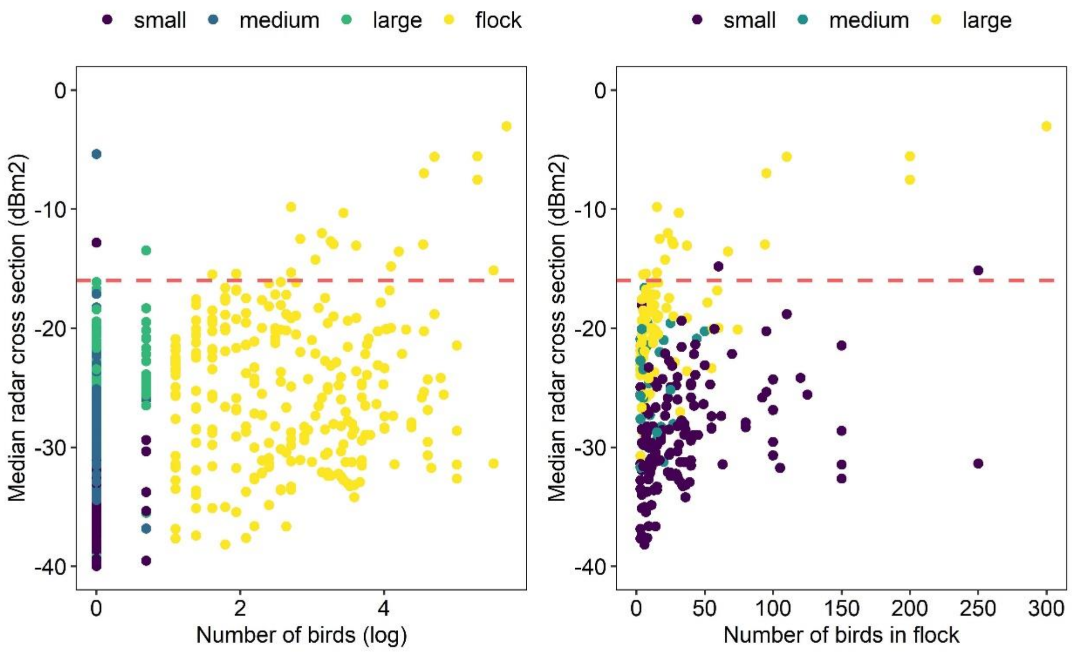

Figure 8. *Left) Median RCS plotted against the logged number of birds and coloured by corrected category. Right) Median RCS of flocks plotted against the number of birds in a flock and coloured by whether the flock was made up of small, medium or large birds. The red dashed line indicates an approximate cut-off for separating larger flocks.*

3.2 All radar data

3.2.1 Lista: Spring migration

From the 1st of April to the 30th of June between 7 208 and 280 226 tracks were recorded per day. Most tracks were classified as intermediate, but at times a significant number of large flocks of larger birds were also recorded. Lower levels of small birds were detected (**Figure 9**).

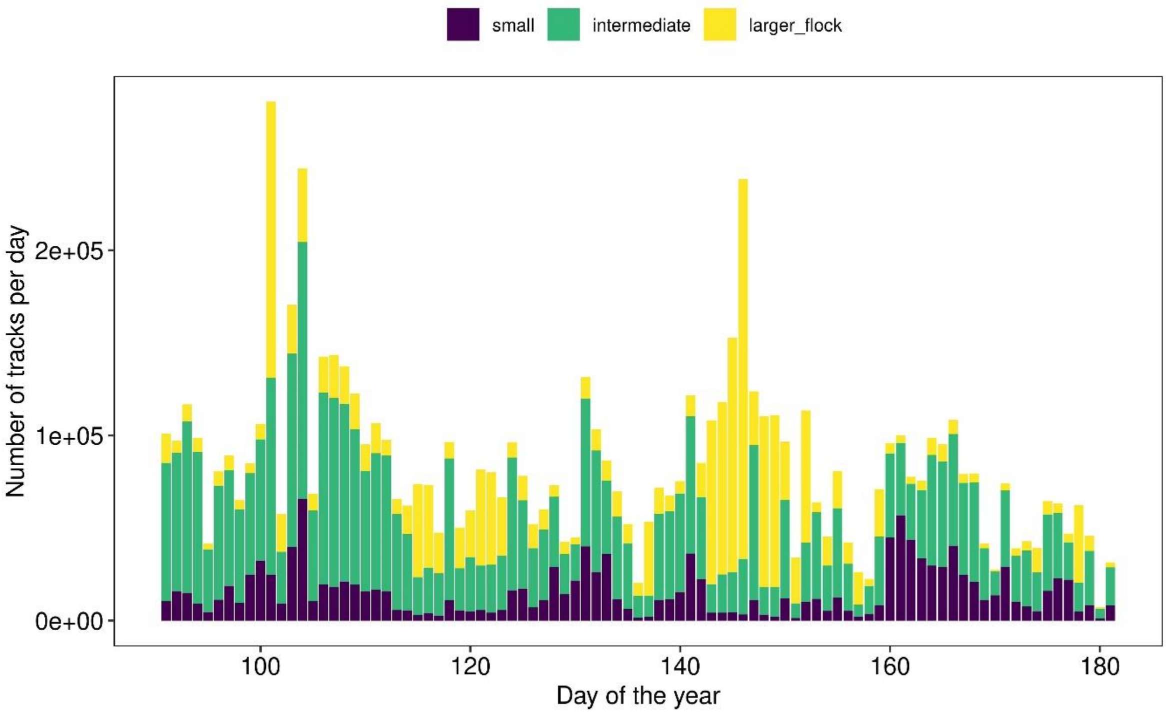

Figure 9. *Number of individual tracks recorded per day of the year during spring at Lista.*

The migration period was not concentrated and included relatively high levels of background activity across the period with a couple of defined peaks of elevated activity (**Figure 10**).

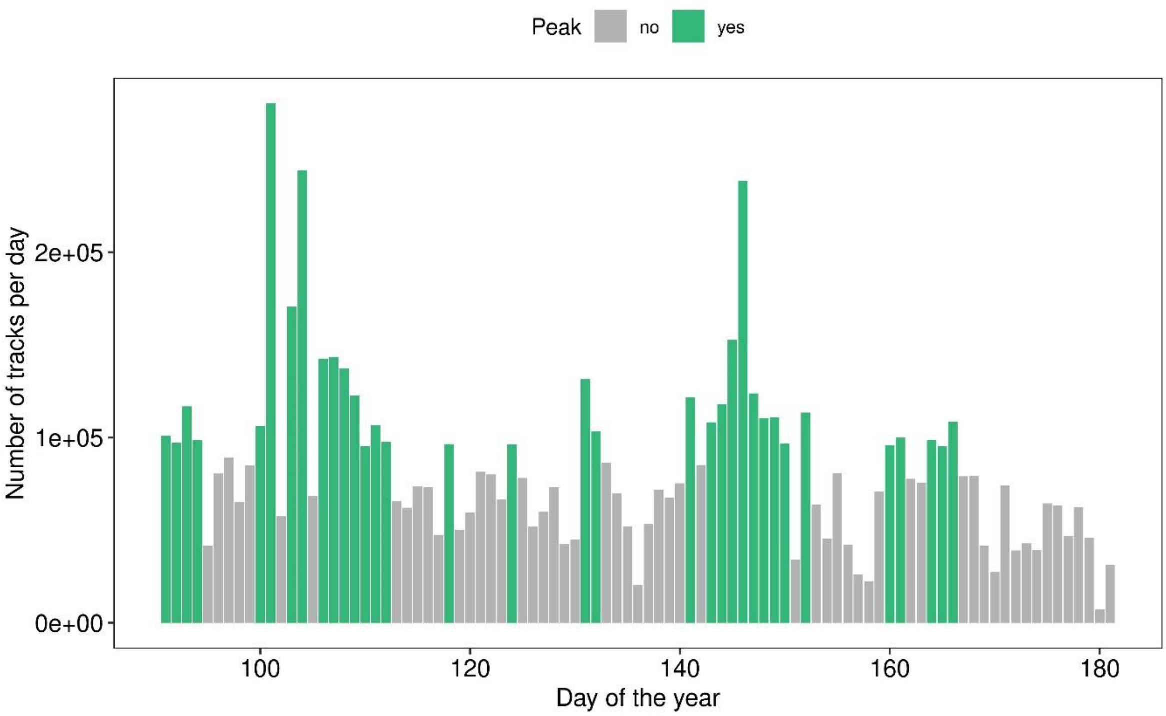

Figure 10. *Number of individual tracks recorded per day of the year during spring at Lista with identified days of peak migration indicated (green bars).*

From here on the data presented is from the days of peak activity levels (>4.2 million tracks). Activity levels across the day varied by week although typically elevated activity was observed from late afternoon through to early morning. This is particularly clear during week 21 where a significant number of large flocks of large birds were observed (**Figure 11**).

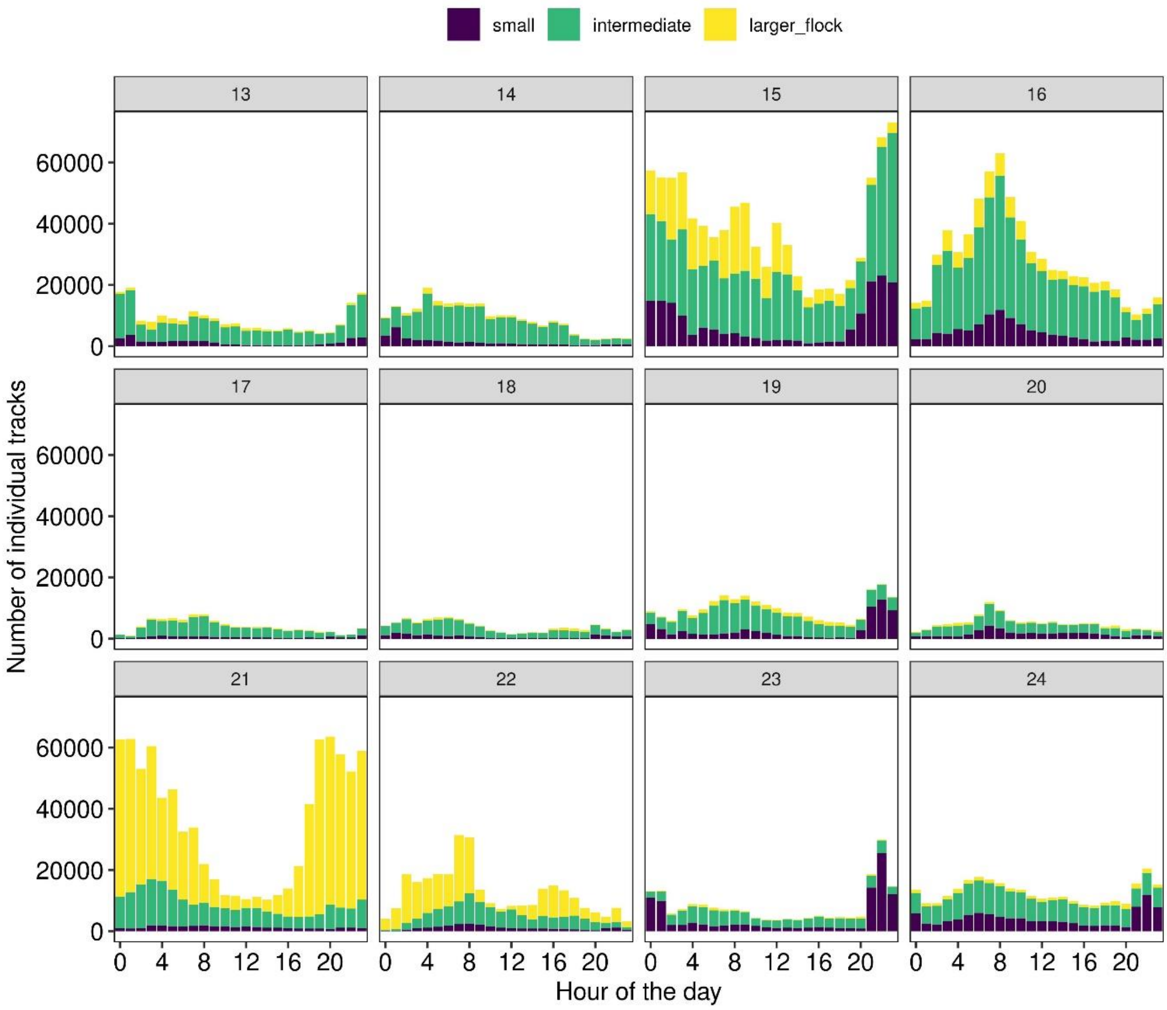

Figure 11. *Number of individual tracks that were recorded at Lista within each hour of the day per week (week number provided per panel) across the study period coloured by category. Time given in CET.*

Birds at Lista predominantly flew within the clearance zone which is the gap between the sea surface and the rotor blades (61.2%), while 27.6% of tracks were within the RSZ, and just 11.1% above tip height (**Figure 12**).

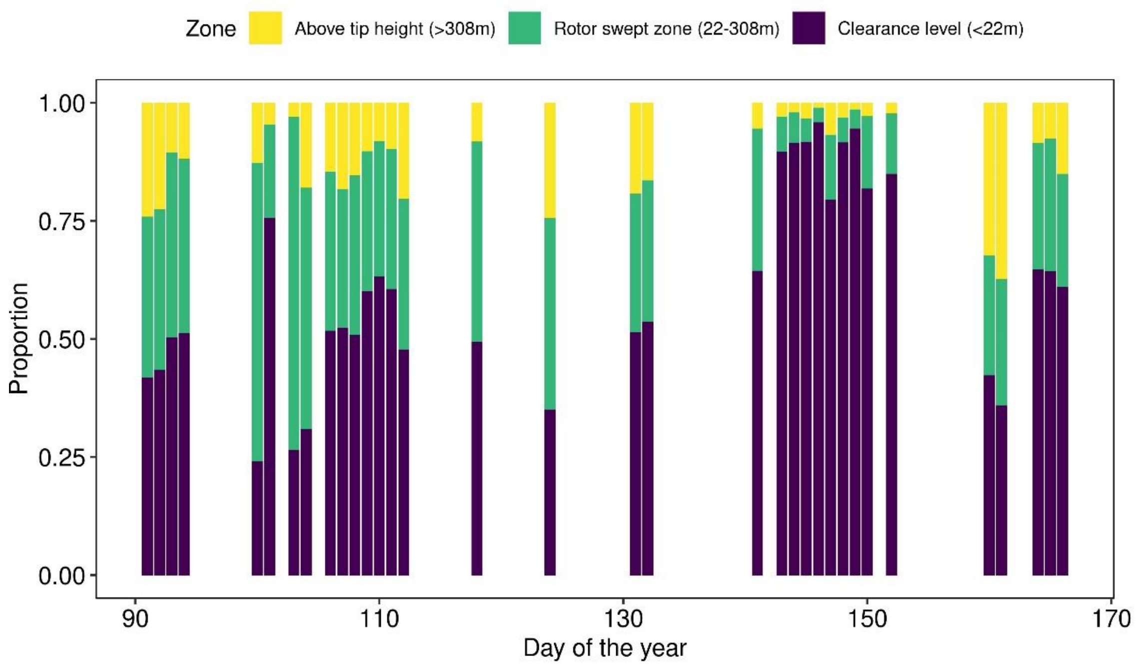

Figure 12. *Proportion of tracks located within the clearance zone between the rotor tip and the ground (<22m), rotor swept zone (RSZ) between 22-308m, and above tip height (>308m) at Lista using 1 000 000 randomly selected tracks.*

The wind direction at Lista during spring was relatively consistent, blowing mostly in a south-easterly direction. The overall bird flight direction was variable but mainly in a north-westerly or south-easterly direction. This resulted in birds predominantly flying in favourable tailwinds or cross-tailwinds. There were differences in direction between the three categories of tracks. Small birds appeared to fly in a westerly to northerly direction. Intermediate birds predominantly flew in north-westerly direction but also in a south-eastly direction. Lastly, large flocks of large birds generally flew in an easterly to southeasterly direction and showed the strongest preference for tailwinds (**Figure 13**).

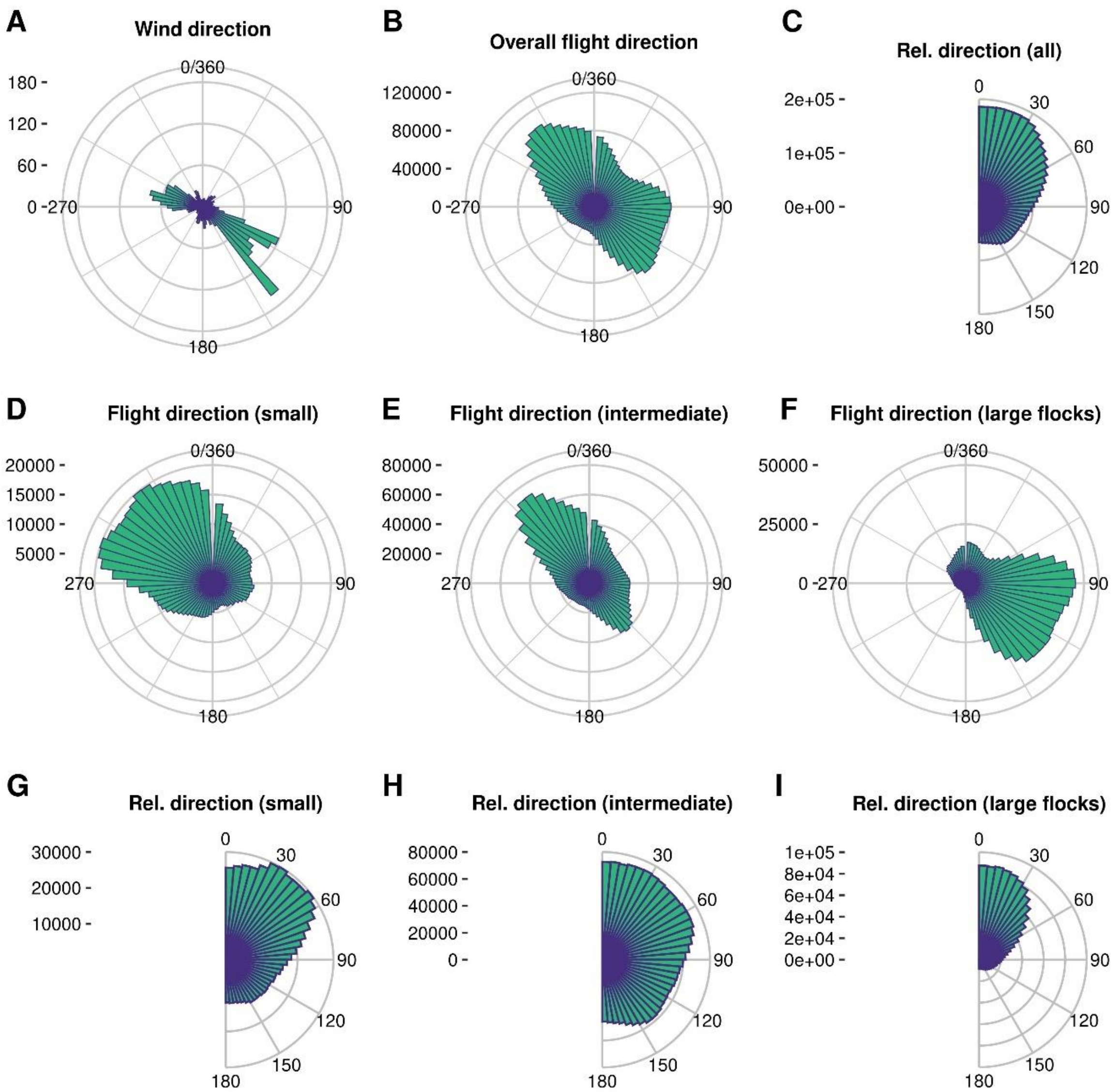

Figure 13. *A) The wind direction during spring at Lista (number of hours). B) Number of tracks with a given flight direction. The mean flight direction (thick purple line) and variance (dashed purple line) are indicated. C) The direction of the tracks relative to the wind direction (number of tracks) where 0° indicates a tailwind, 180° a headwind and 90° a crosswind. D-F) Number of tracks with a given flight direction split by category. G-I) The direction of the tracks relative to the wind direction (number of tracks) split by category.*

Although most intermediate birds were detected close to the radar, detections still covered a relatively large range. Small birds and large flocks of larger birds were more evenly spread although with a slight increase close to the radar. The spatial distribution of locations confirmed the larger detection range large flocks of large birds (**Figure 14**).

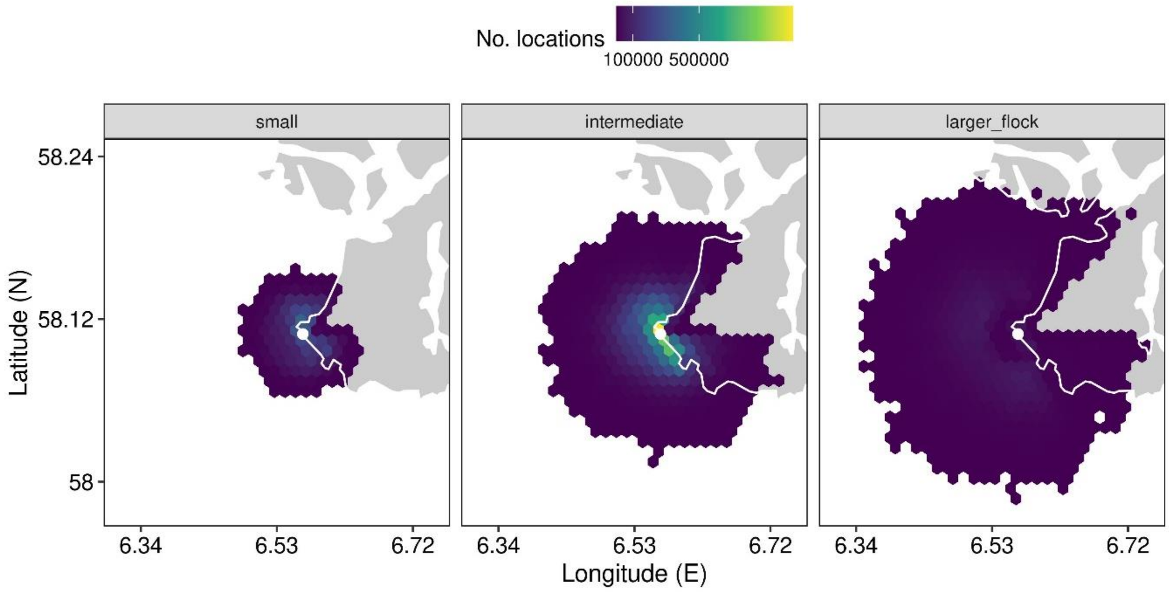

Figure 14. *Spatial distribution of the number of locations recorded by the radar across the three observed categories using 1 000 000 randomly selected tracks. The radar location at Lista is indicated by the white dot and the coastline is indicated in white.*

For small and intermediate birds, the flight heights recorded by the radar increased with distance from the radar, which may at least be partly explained by the fact that the radar beam points slightly upwards. So, with increasing distance from the radar, the space below the radar beam gets larger. Larger flocks generally flew very low except when flying over or in proximity of land (**Figure 15**).

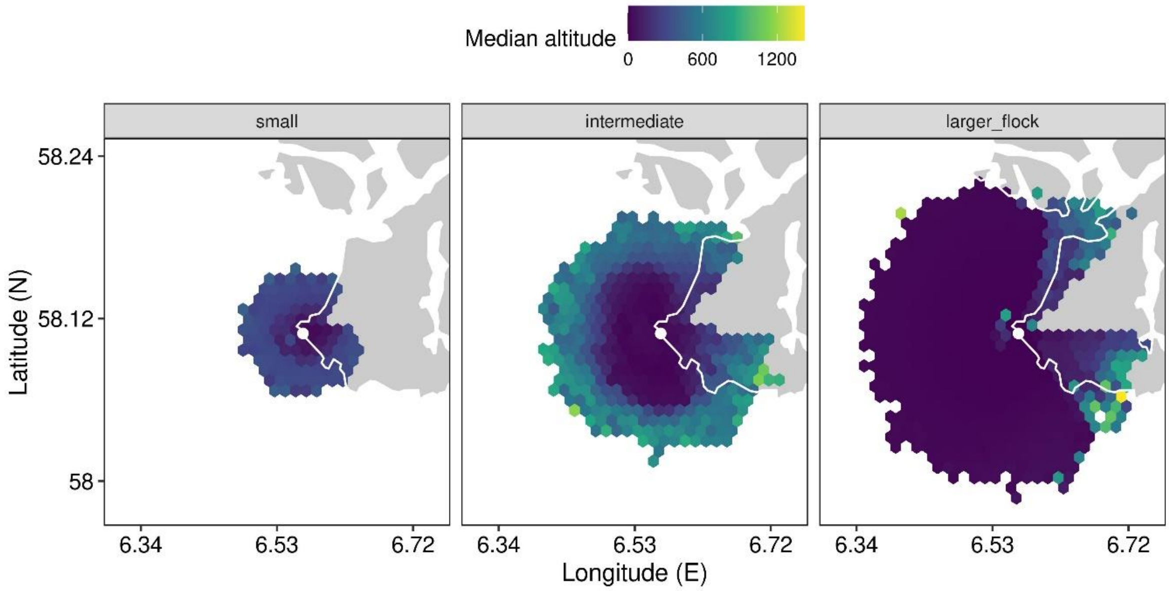

Figure 15. *Spatial distribution of mean flight altitude (m) of tracks recorded by the radar across the two observed categories using 1 000 000 randomly selected tracks. The radar location at Lista is indicated by the white dot and the coastline is indicated in white.*

Most small birds were detected within a range of ~500-3500m from the radar. Intermediate birds showed a distinct peak at ~3000m from the radar with detections mainly spanning from ~1000-5000m but a few tracks were also recorded at distances over 9000m. The sharp increase in detections of large flocks of large birds above 2500m from the radar will require further investigation (**Figure 16**).

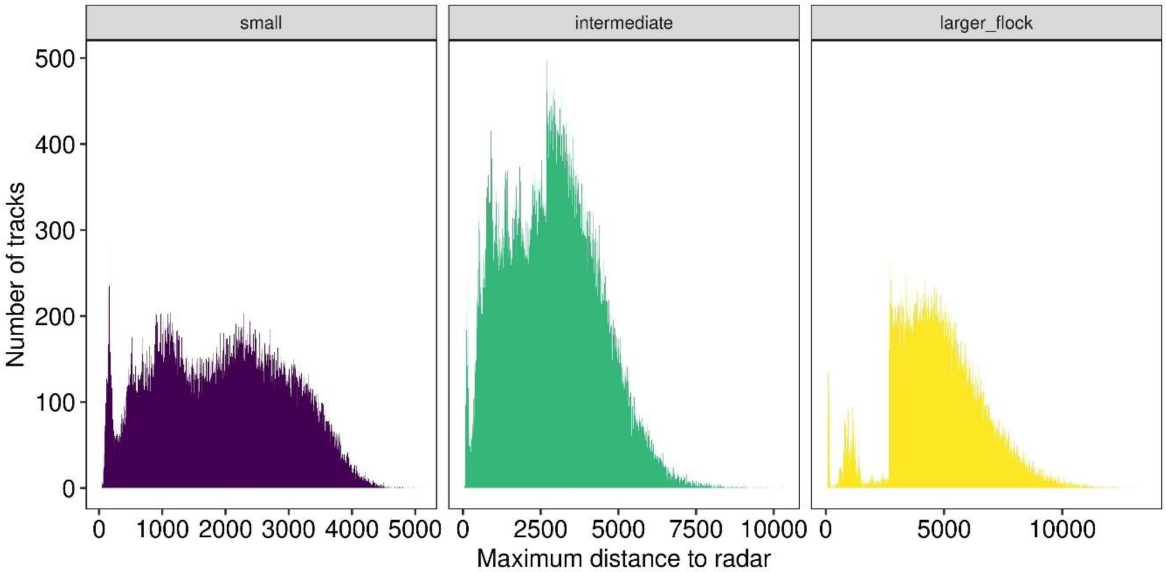

Figure 16. *Maximum distance from the radar for each individual track across the three categories at Lista.*

3.2.2 Lista: Autumn migration

From the 1st of September to the 30th of November between 2 587 and 627 308 tracks were recorded per day. Most tracks were classified as intermediate, but throughout the period a significant number of large flocks of larger birds were also recorded. Lower levels of small birds were detected (**Figure 17**).

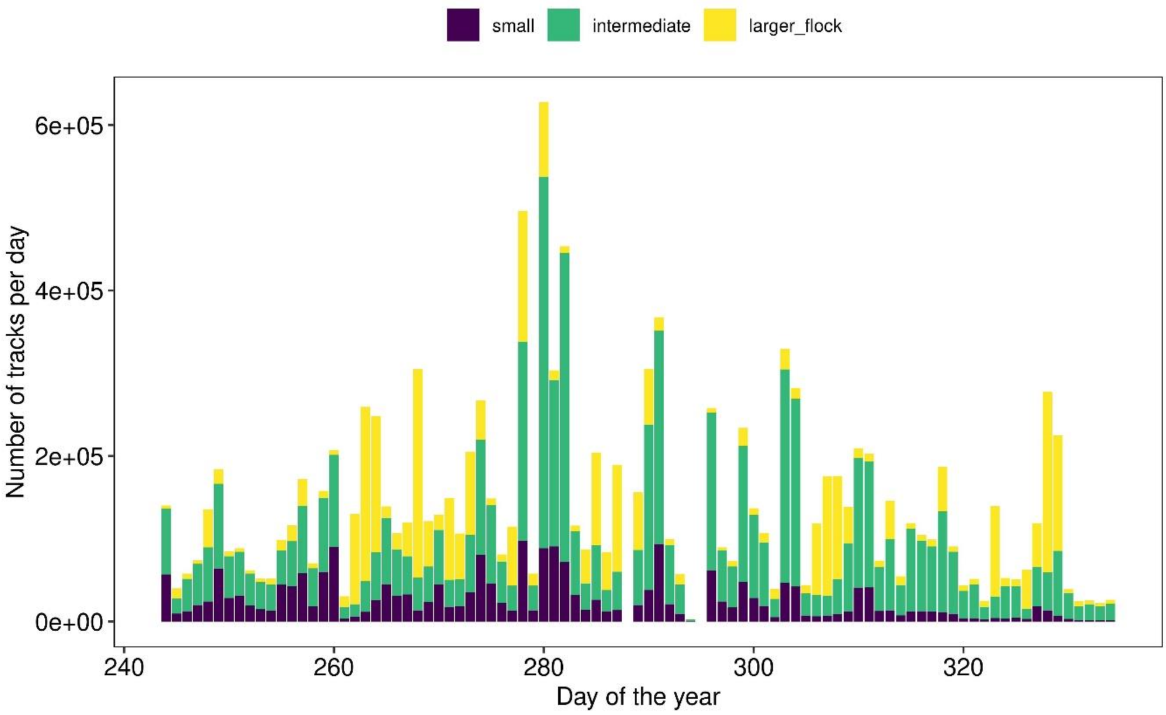

Figure 17. *Number of individual tracks recorded per day of the year during autumn at Lista.*

The migration period was not concentrated and included relatively high levels of background activity across the period with several defined short peaks of elevated activity (**Figure 18**).

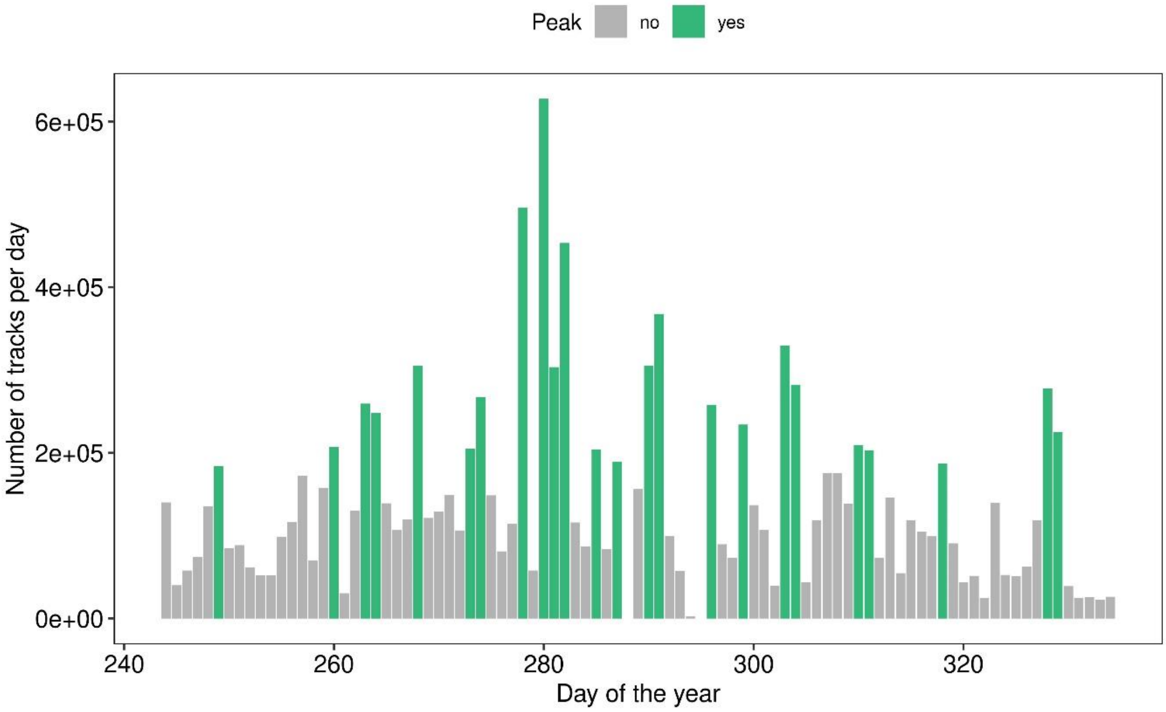

Figure 18. *Number of individual tracks recorded per day of the year during autumn at Lista with identified days of peak migration indicated (green bars).*

From here on the data presented is from the days of peak activity levels (>6.8 million tracks). Larger flocks of larger birds were present throughout the day, whereas intermediate and small birds peaked during late afternoon and evening (**Figure 19**).

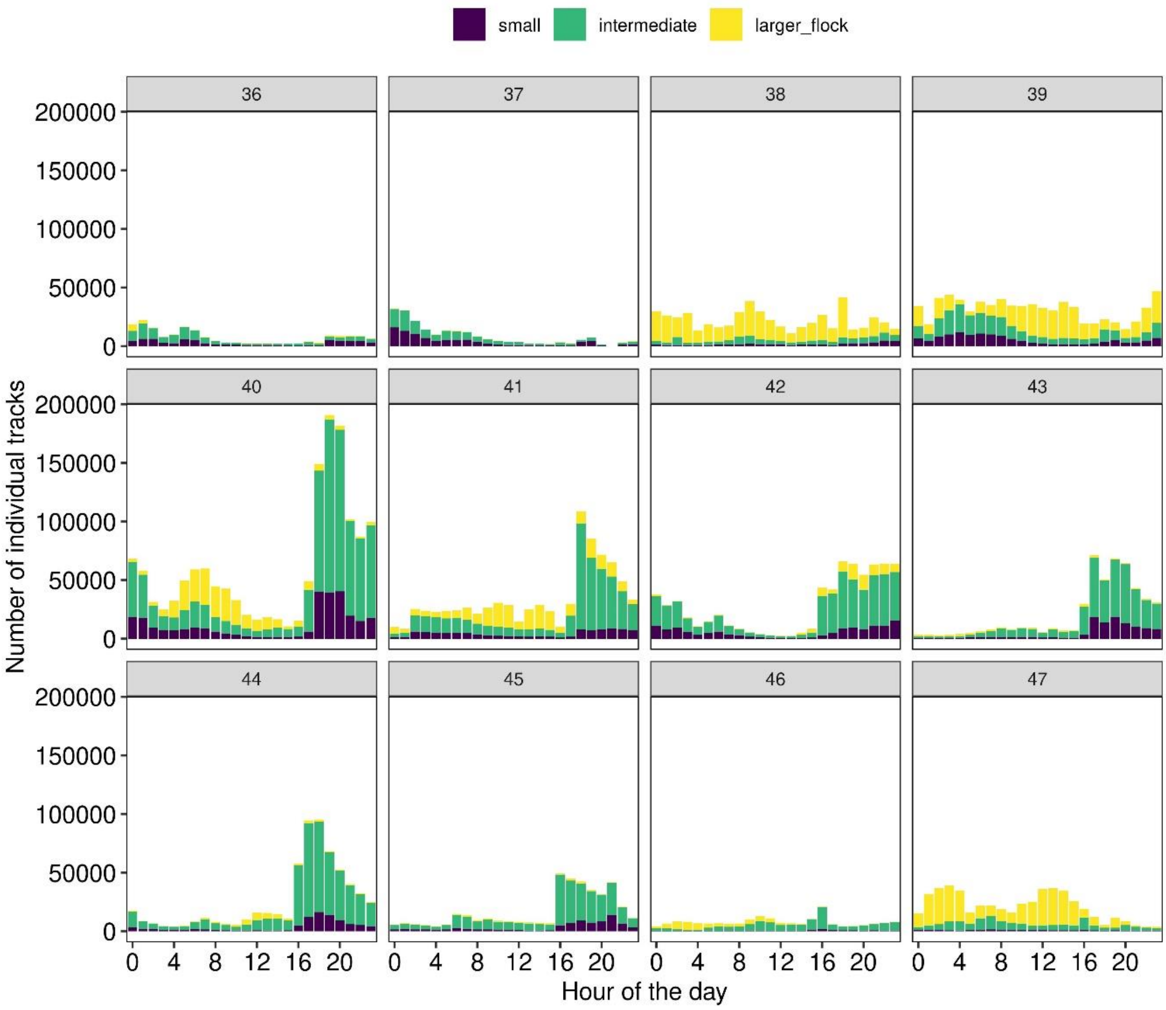

Figure 19. *Number of individual tracks that were recorded at Lista within each hour of the day across the study period coloured by category. Time is given in CET.*

There was temporal variation in the median flight height of birds at Lista during autumn with some periods of flight predominantly within the clearance zone, and other periods of higher flight heights in the RSZ and above tip height. This variation is unsurprising given the narrow band included in the clearance zone (20m). On average, 42.7% of tracks were recorded within the clearance zone, 26.8% of tracks were within the RSZ, and 30.5% were above tip height (**Figure 20**).

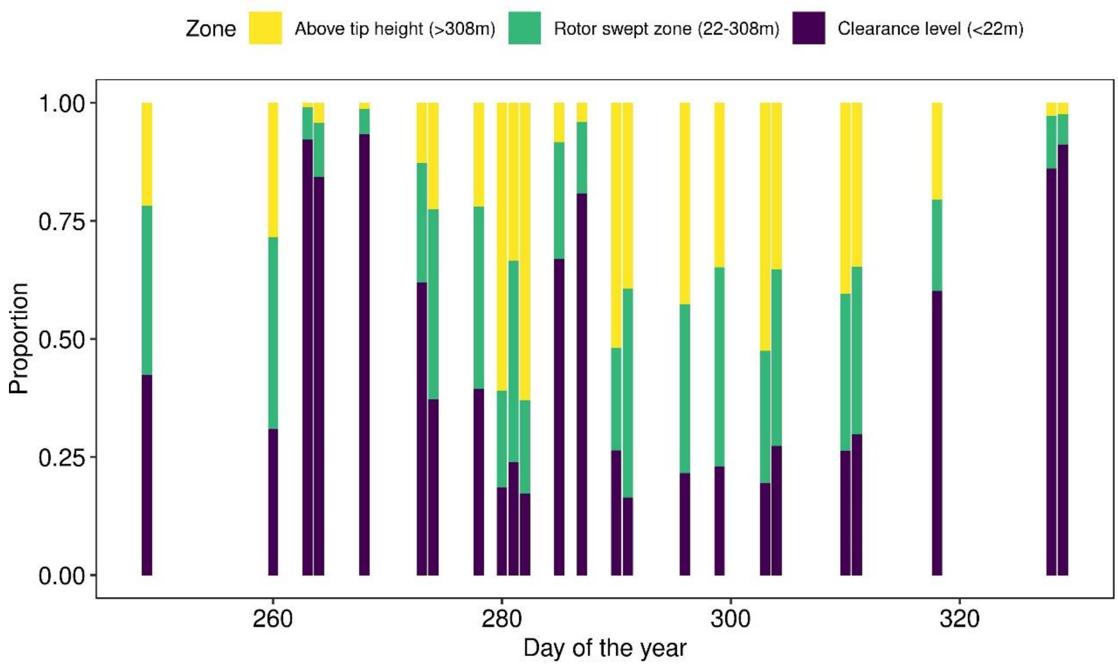

Figure 20. *Proportion of tracks located within the clearance zone between the rotor tip and the ground (<22m), rotor swept zone (RSZ) between 22-308m, and above tip height (>308m) at Lista using 1 000 000 randomly selected tracks.*

The wind direction at Lista during autumn was relatively consistent blowing mostly in a south-westerly direction, but also frequently in a south-easterly direction. The overall bird flight direction was variable but with a strong south-westerly preference as well as a north-east to south-east direction. This resulted in birds predominantly flying in anything from a cross- to a tailwind. There were differences in direction between the three categories of tracks. Small birds appeared highly variable in their flight directions. Intermediate birds were the most consistent, mainly flying in a south-westerly direction. Lastly, large flocks of large birds flew in an easterly to northeasterly direction. Larger flocks of larger birds appeared to select most strongly for a tailwind (**Figure 21**).

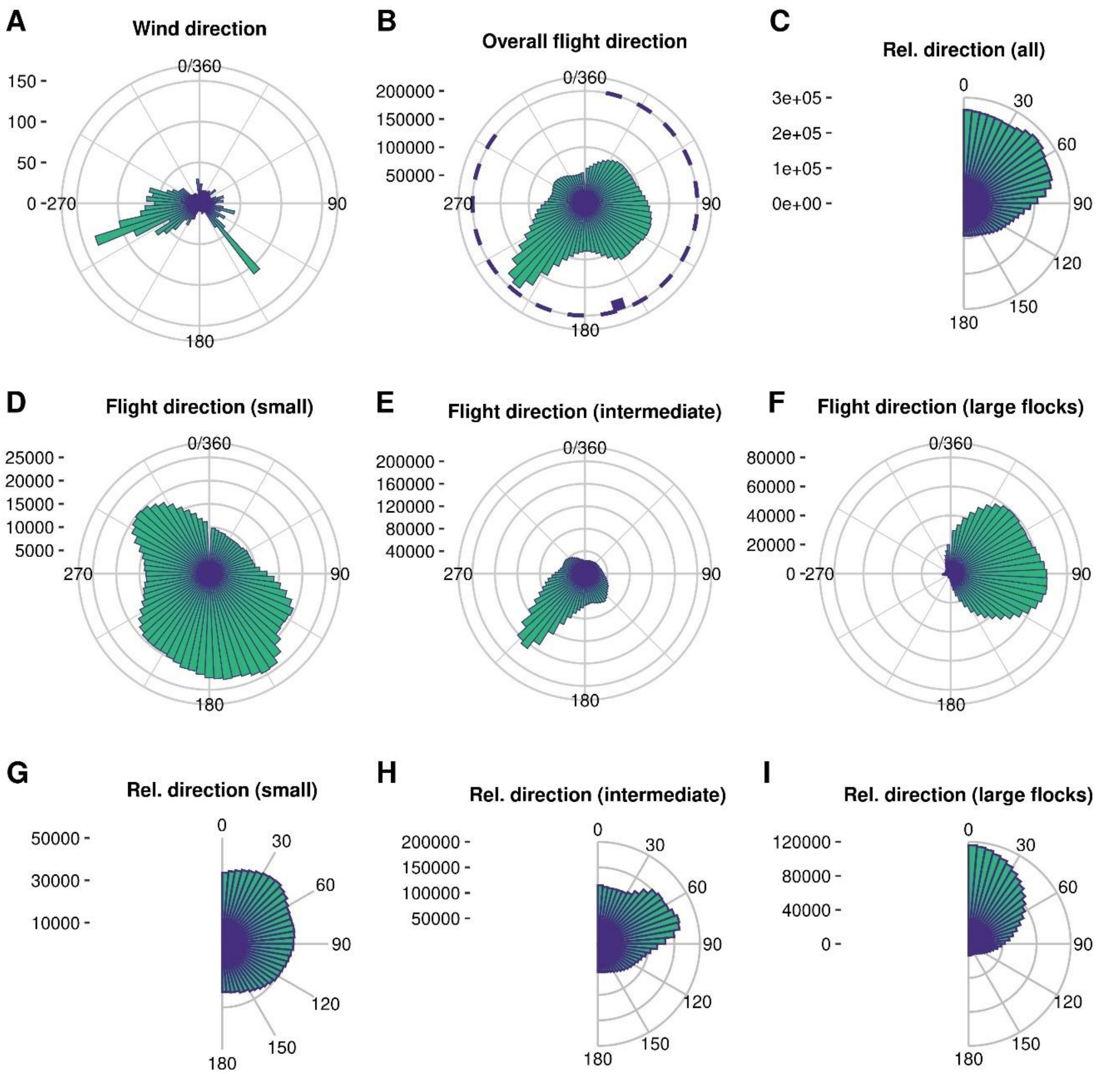

***Figure 21**. A) The wind direction during spring at Lista (number of hours). B) Number of tracks with a given flight direction. The mean flight direction (thick purple line) and variance (dashed purple line) are indicated. C) The direction of the tracks relative to the wind direction (number of tracks). D-F) Number of tracks with a given flight direction split by category. G-I) The direction of the tracks relative to the wind direction (number of tracks) split by category.*

A significant number of tracks classified as small and intermediate were detected close to the radar. Large flocks of larger birds were more evenly spread. The spatial distribution of locations confirmed the larger detection range of intermediate birds and flocks (**Figure 22**).

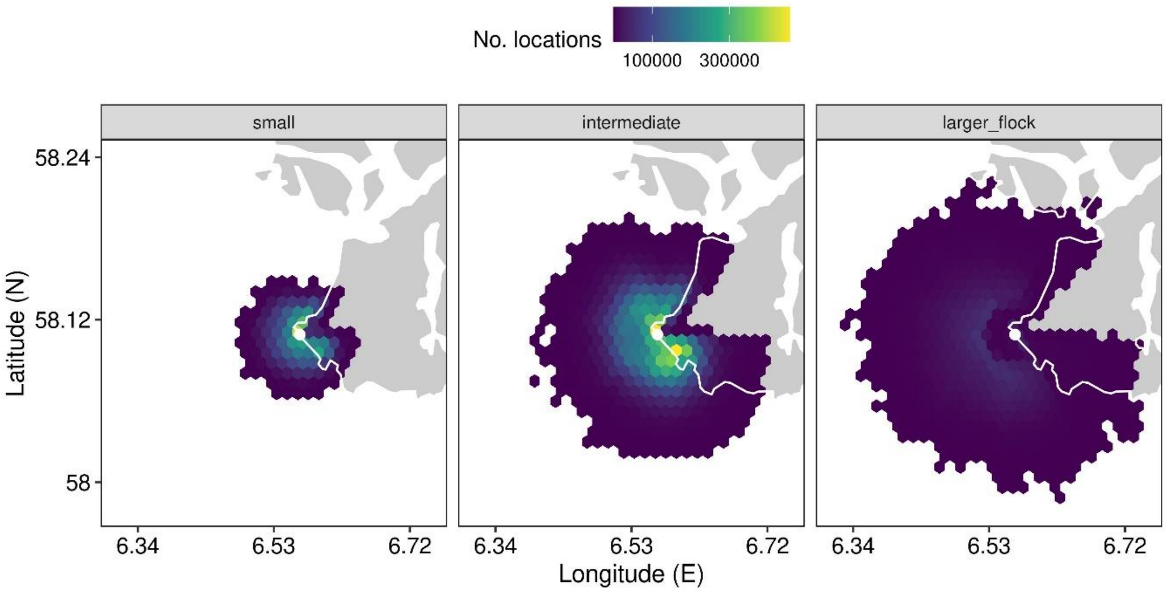

Figure 22. *Spatial distribution of the number of locations recorded by the radar across the three observed categories using 1 000 000 randomly selected tracks. The radar location at Lista is indicated by the white dot and the coastline is indicated in white.*

Intermediate birds flew highest, and the flight heights recorded by the radar increased with distance from the radar, which is expected. Larger flocks generally flew very low over water but much higher over land and to the southeast (**Figure 23**).

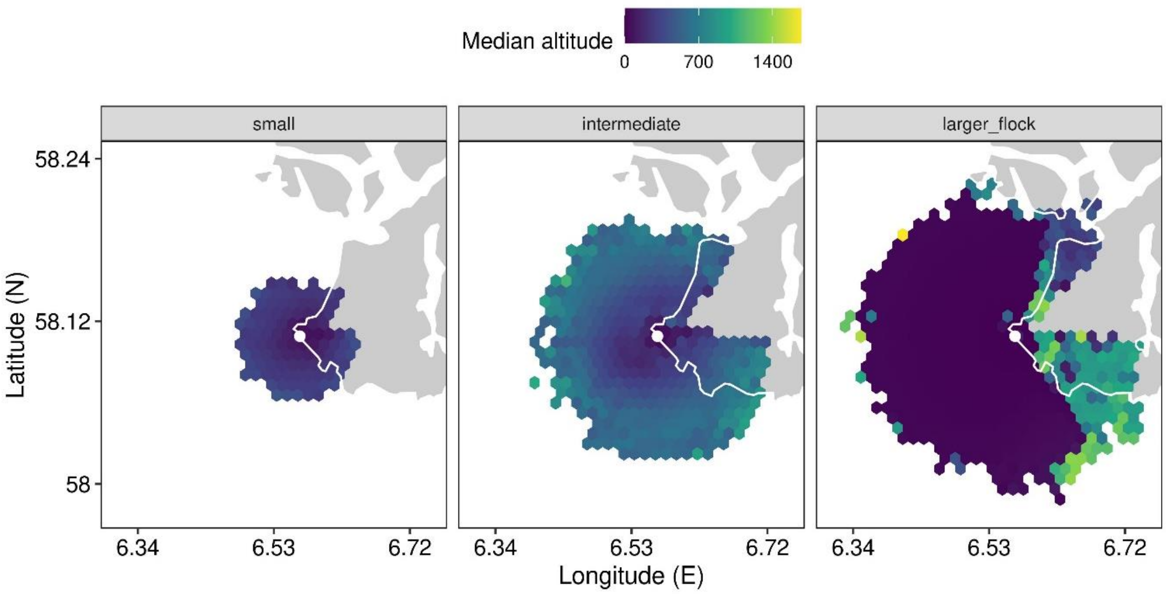

Figure 23. *Spatial distribution of mean flight altitude (m) of tracks recorded by the radar across the two observed categories using 1 000 000 randomly selected tracks. The radar location at Lista is indicated by the white dot and the coastline is indicated in white.*

Most small birds were detected within a range of ~500-3500m from the radar (**Figure 24**). Intermediate birds showed a distinct peak at just over 3000m from the radar with detections mainly spanning from ~1000-5000m but a few tracks were also recorded at distances over 9000m. The sharp increase in detections of large flocks of large birds above 2500m from the radar will require further investigation.

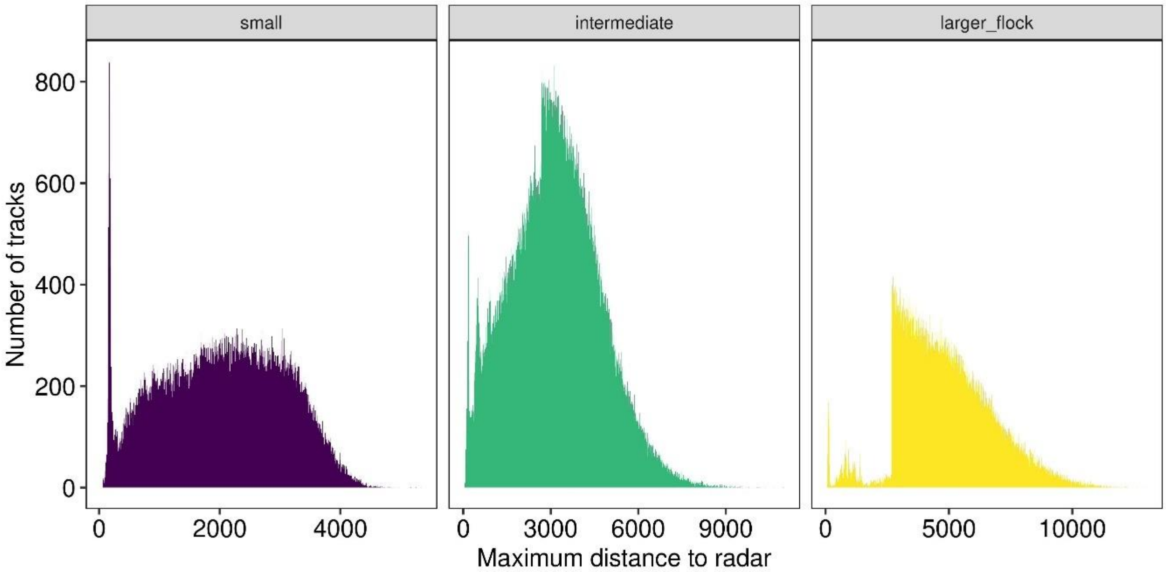

Figure 24. *Maximum distance from the radar for each individual track across the three categories at Lista.*

3.2.3 Utsira: Autumn migration

From the 1st of September to the 30th of November between 733 and 168 700 tracks were recorded per day. Most tracks were classified as intermediate. Some larger flocks of larger birds were also recorded, but no small birds (according to our classification) were detected by the radar. During autumn, relatively low numbers of birds are detected apart from during very clear days with peaks of migration activity (**Figure 25**).

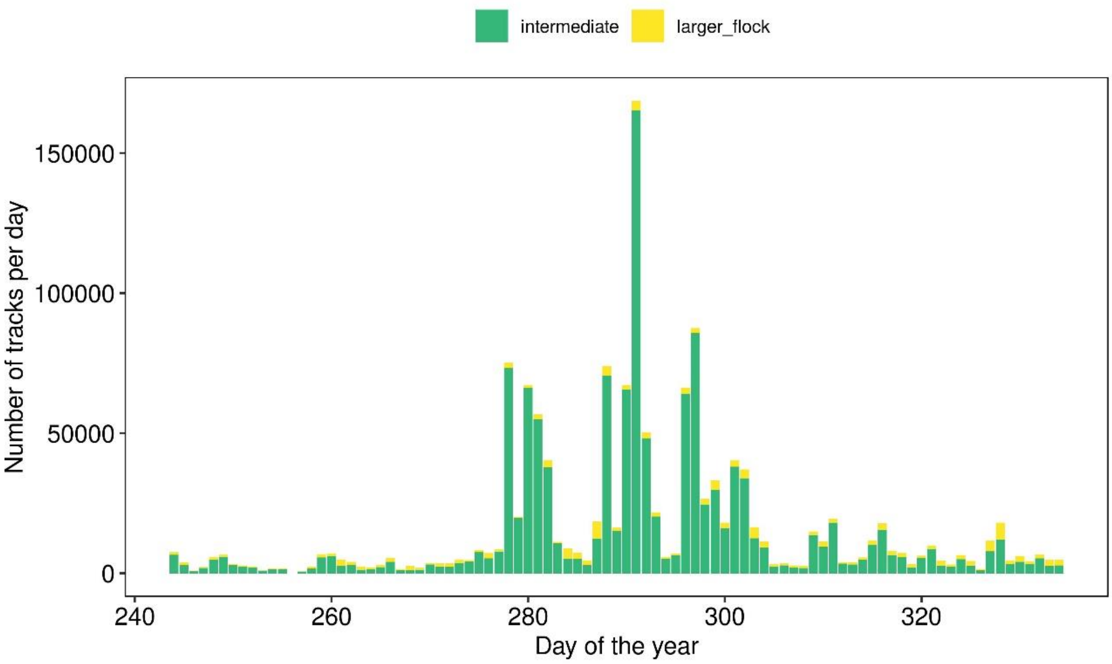

Figure 25. *Number of individual tracks recorded per day of the year during autumn at Utsira after filtering.*

From here on the data presented are from the days of peak activity levels (>900K tracks). The migration period was relatively concentrated lasting approximately 24 days with clear peaks of elevated activity (**Figure 26**).

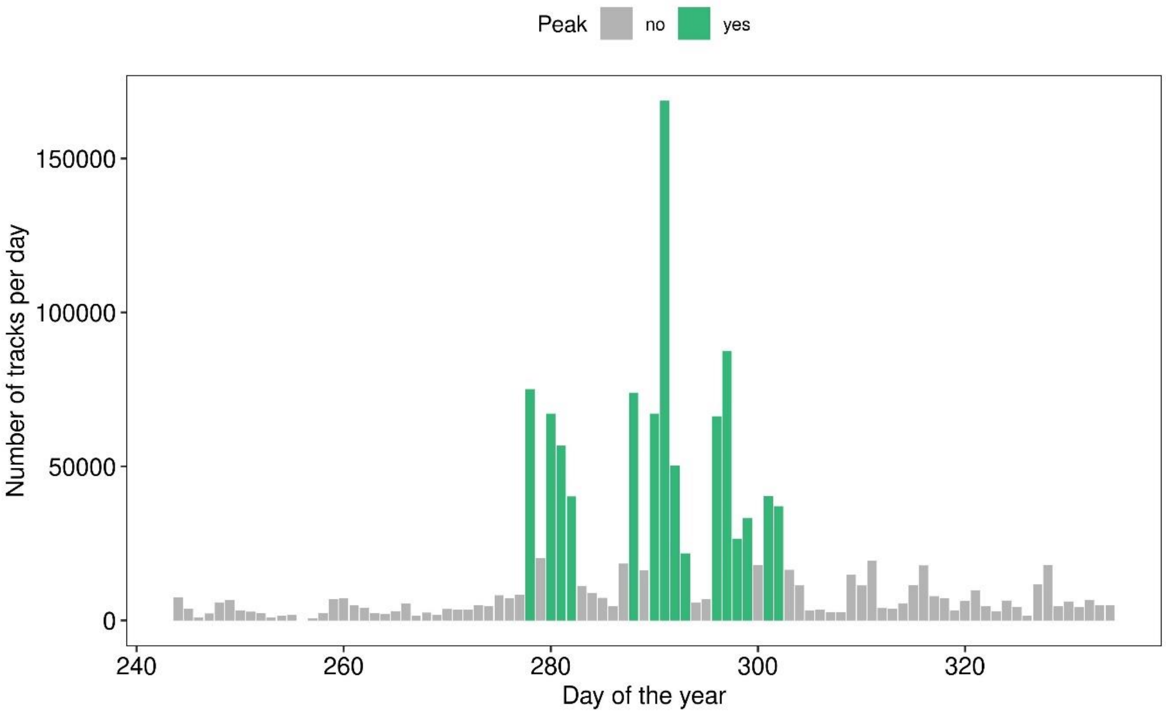

Figure 26. *Number of individual tracks recorded per day of the year during autumn at Utsira after filtering with identified days of peak migration indicated (green bars).*

Within days of peak activity, most tracks were recorded between the hours of 17:00-21:00 (CET) (**Figure 27**).

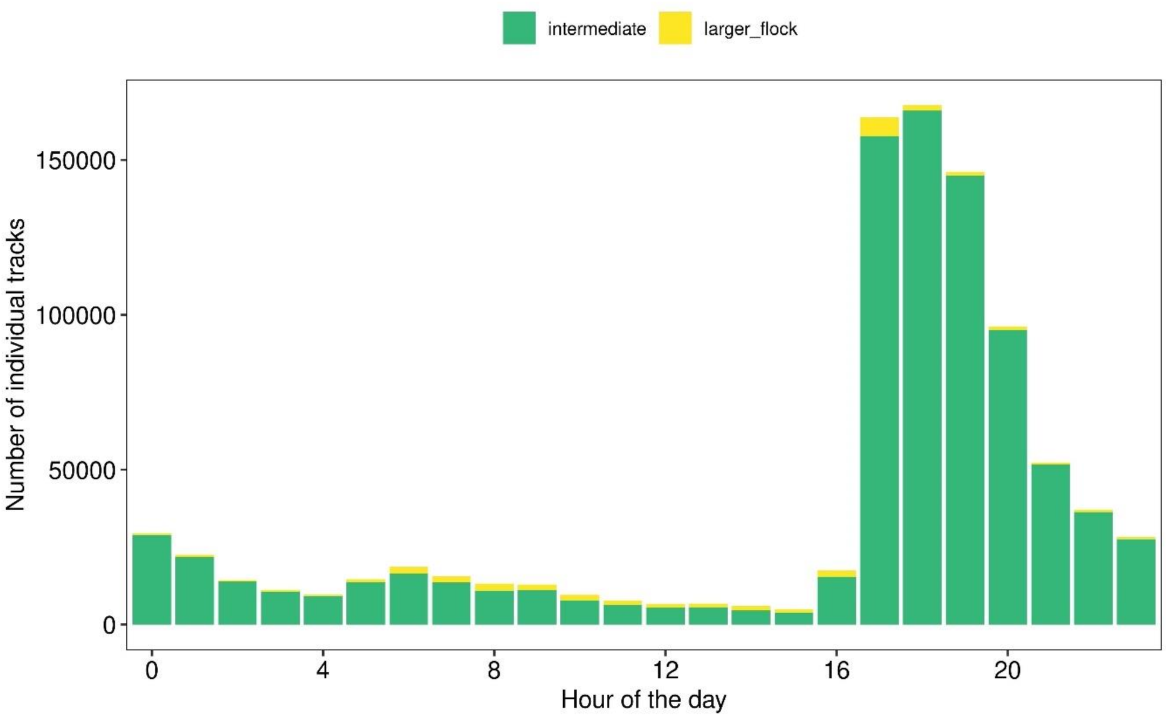

Figure 27. *Number of individual tracks that were recorded at Utsira within each hour of the day across the study period coloured by category. Time is given in CET.*

There was minimal temporal variation in the median flight height of birds at Utsira during autumn. Around 52.4% of tracks had a median flight height within the RSZ, while 45.1% flew above tip height, and just 2.5% of tracks were detected within the clearance zone in between the rotor blades and the sea surface or ground (**Figure 28**).

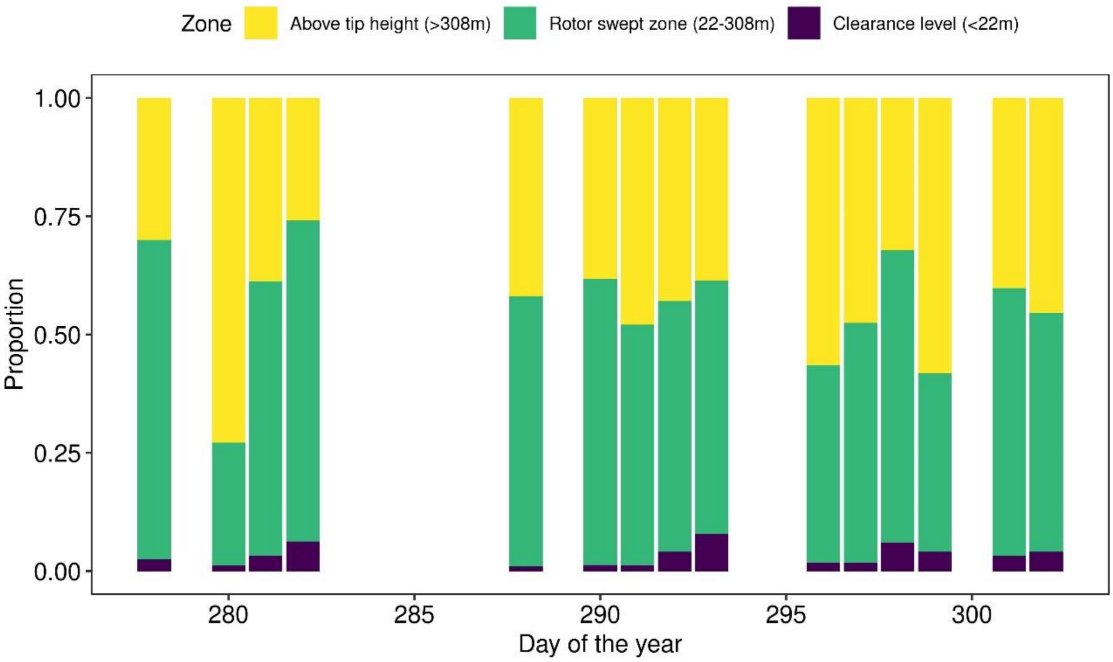

Figure 28. *Proportion of tracks located within the clearance zone between the rotor tip and the ground (<22m), rotor swept zone (RSZ) between 22-308m, and above tip height (>308m) at Utsira.*

Here we estimate the mean direction of tracks and the mean direction of the tracks relative to the wind direction. There was generally high consistency in the direction of tracks at Utsira during autumn (south-westerly). Birds consistently flew with a cross-tailwind (**Figure 29**).

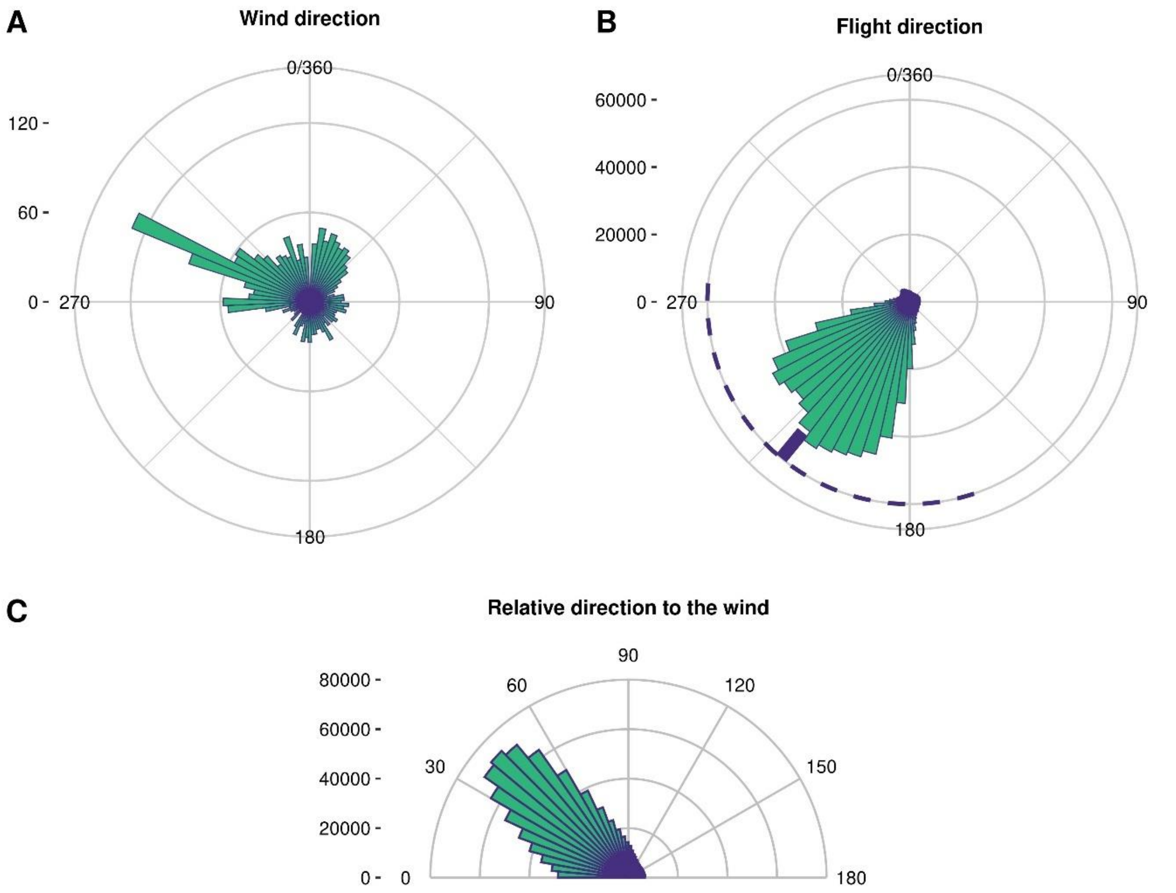

Figure 29. *A) The wind direction during spring at Utsira (number of hours). B) Number of bird tracks with a given flight direction. The mean flight direction (thick purple line) and variance (dashed purple line) are indicated. C) The direction of the birds relative to the wind direction (number of tracks).*

Most tracks classified as intermediate were detected southeast of the radar and in close proximity. Large flocks of larger birds were evenly spread, however, there were relatively few detections in this category at Utsira. The spatial distribution of locations confirmed the larger detection range of large flocks of large birds compared to intermediate birds (**Figure 30**).

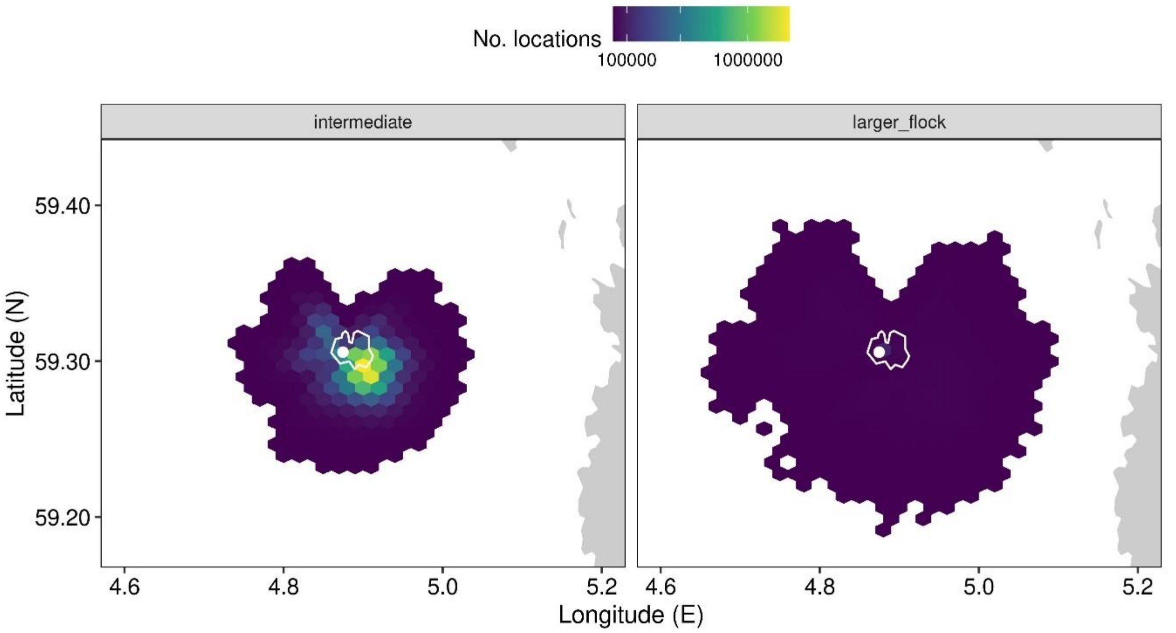

Figure 30. *Spatial distribution of the number of locations recorded by the radar across the two observed categories. The radar location is indicated by the white dot and the outline of Utsira is indicated in white.*

For intermediate birds, the flight heights recorded by the radar increased slightly with distance from the radar, which as explained before is likely at least partly driven by the tilt of the radar beam. Larger flocks had the lowest sample size hence the stronger and more variable colours. The lowest flight heights were recorded close to the radar (south-southwest) while the highest flight heights were recorded at the edge of the detection range (**Figure 31**).

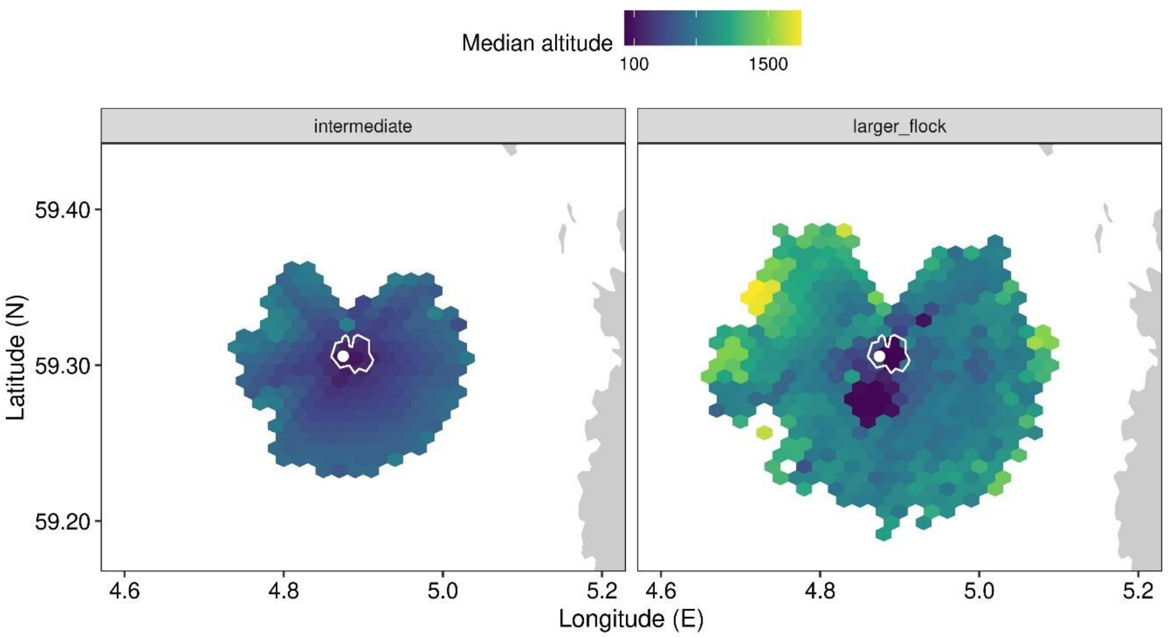

Figure 31. *Spatial distribution of mean flight altitude (m) of tracks recorded by the radar across the two observed categories. The radar location is indicated by the white dot and the outline of Utsira is indicated in white.*

Most intermediate tracks were detected within a range of ~500-4000m from the radar. There was a high number of detections of large flocks of large birds very close to the radar and a few detections at other distances up to ~10 000m (**Figure 32**).

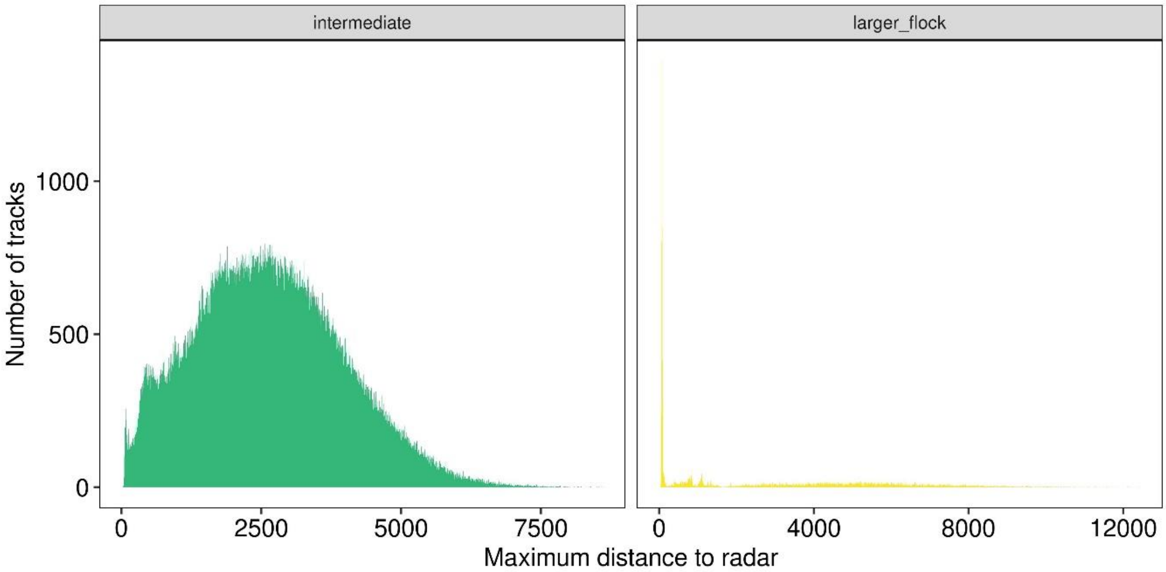

Figure 32. *Maximum distance from the radar for each individual track across the two observed categories at Utsira.*

4 Next steps

Here we have presented an exploration of the radar data collected from Lista during spring and autumn and from Utsira during autumn 2023. It is important to emphasise that the radar tracks presented in this report are those which the radar originally identified as being from a bird. However, previous and current exploration of the annotated data has flagged some issues surrounding the radar categories, and the number of tracks believed to be birds are very high in some cases. Therefore, we need to further explore ways of better classifying birds using other variables in addition to RCS. Ideally, radar systems would be developed where species or species groups could be obtained or logged in a more automated manner (e.g. either from flight characteristics or coupled with acoustic monitoring), or where the radar would be able to learn using AI from the annotated tracks that have been collected to classify other tracks more accurately.

Since the last report, we have improved the efficacy of processing large amounts of radar data. We have applied a method for extracting periods of elevated levels of activity which are more likely to be migration, and we have adjusted flight height of tracks over land according to the elevation of the ground. We have also emphasized the importance and requested that non-bird tracks also be annotated during the spring migration of 2024 to better distinguish between tracks of birds and non-birds (waves, weather, vehicles, vessels, planes etc.).

Going forward we will further explore the use of assignable properties recorded by the radar to separate birds from vehicles and aircraft using the “heavy” or “large” categories and overlap between tracks and roads or airstrips. We will investigate whether flocks can be reliably identified using the “in blob formation” category. Random forest models will be developed to separate birds from non-birds using annotated tracks of known birds and other objects (e.g., vessels, vehicles, waves, weather) when annotated tracks of non-birds accrue. From periods of peak activity, we will develop another random forest model to identify migration versus non-migration tracks based on extracted flight characteristics. Finally using annotated tracks of different bird species, we will attempt to better categorise the remaining tracks into species or size groups.

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