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Preliminary exploration of radar data from Lista covering the spring bird migration (2023)

Migration for Development

Line Cordes, Anna Nilsson, Øyvind Hamre & Roel May

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COVER PICTURE
Robin Max radar positioned at Lista © Anna Nilsson

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Abstract

Cordes, L.S., Nilsson, A., Hamre, Ø. & May, R. 2023. Preliminary exploration of radar data from Lista covering the spring bird migration (2023). NINA Report 2403. Norwegian Institute for Nature Research.

The Migration for Development project is jointly funded by industry partners and put in place 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 a preliminary investigation of the avian radar data collected at Lista (Farsund municipality) during spring 2023. Firstly, using radar tracks annotated by an observer, we showcase issues with how the radar classifies bird tracks (small, medium, large and flock). The radar tends to underestimate the size of birds and thereby provide an inflated estimate of numbers of small birds. We used the data from annotated tracks to provide improved categories of radar tracks and to explore flight characteristics of known bird species. 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. There was temporal variation in the number of tracks recorded per day by the radar. Within a day, larger numbers of small birds were typically detected during the evening or night. There was a large proportion of low flying birds in or below the rotor swept zone vulnerable to collision with turbines. The radar detection range varied by category from 5 km for small birds to 13.6 km for larger flocks of large birds. However, given the issues with the way the radar classifies tracks, this report only presents a preliminary view of the avian radar data collected, and we discuss the next steps to be taken and plans for actual analysis of these data to be presented in the following report.

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Sammendrag

Cordes, L.S., Nilsson, A., Hamre, Ø. & May, R. 2023. Foreløpig utforskning av radardata fra Lista som dekker vårfugletrekket (2023). NINA Rapport 2403. Norsk institutt for naturforskning.

Prosjektet Migrasjon for Utvikling er i fellesskap finansiert av industripartnere og igangsatt for å komplementere og støtte VisAviS-forskningsprosjektet finansiert av Norges Forskningsråd. Som en del av arbeidet ble to fugleradarer utplassert ved kystnære steder i Norge for å registrere sesongmessige fugletrekk. Her presenterer vi foreløpige resultater fra fugleradardataene samlet inn på Lista (Farsund kommune) våren 2023. For det første viser vi ved hjelp av radarspor annotert av en observatør problemer med hvordan radaren klassifiserer fuglespor (liten, middels, stor og flokk). Radaren har en tendens til å underestimere størrelsen på fugler og dermed gi et forhøyet estimat av antall småfugler. Vi brukte dataene fra kommenterte spor for å gi forbedrede kategorier av radarspor og for å utforske flyegenskaper til kjente fuglearter. For det andre, ved å bruke alle spor samlet av radaren, filtrerte vi disse basert på sannsynlige egenskaper for trekkende fugl, og presenterer tidsmessige og romlige mønstre av sannsynlige migrasjonsspor. Det var tidsmessig variasjon i antall spor registrert per dag av radaren. I løpet av et døgn ble større antall småfugler vanligvis oppdaget i løpet av kvelden eller natten. Det var en stor andel lavtflygende fugler i eller under rotorens sveip-sone som var sårbare for kollisjon med turbiner. Radardeteksjonsrekkevidden varierte etter kategori fra 5 km for småfugler til 13,6 km for større flokker med store fugler. Men gitt problemene med måten radaren klassifiserer spor på, presenterer denne rapporten bare en foreløpig oversikt over fugleradardataene som er samlet inn, og vi diskuterer de neste trinnene som skal tas og planer for faktisk analyse av disse dataene som skal presenteres i påfølgende rapporter.

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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 preliminary exploration of avian radar data from Lista during Spring 2023.

Trondheim, December 2023
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 will analyse, visualise, and report 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.

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 preliminary findings from avian radar data collected at Lista between the end of March and the end of May 2023 providing 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 an altitude of 2.5m above sea level and collected data from the 29 March onwards (**Figure 1**). In this report, we include data collected up until the 27th of May 2023. 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.

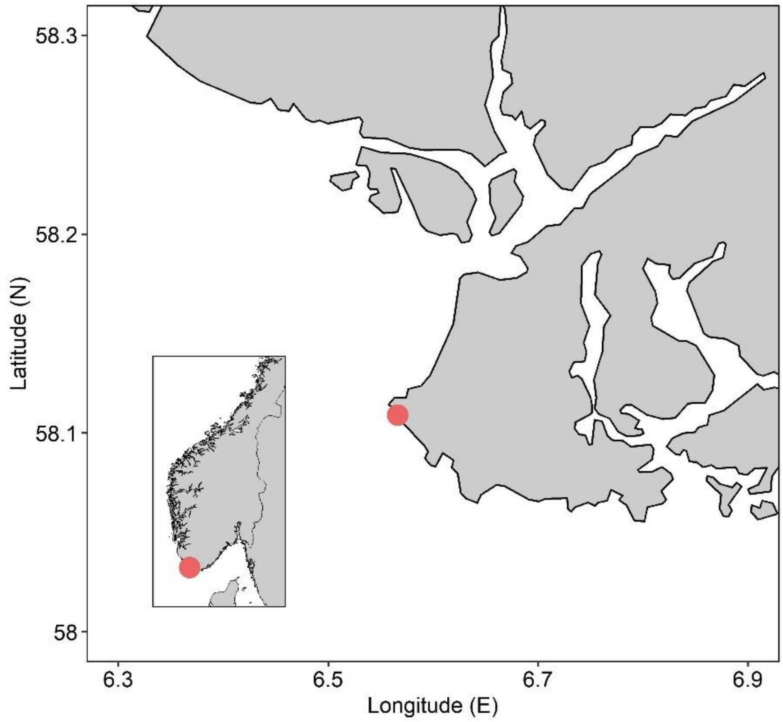

Figure 1. *Coastal location of the radar at Lista (red dot) with inset map showcasing the location in Norway.*

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 bird, 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 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 have 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 max 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. Aircrafts also have no RCS limits.

2.2 Annotated radar tracks

Radar tracks were annotated for a full hour approximately every second day depending on conditions by a dedicated observer from the Lista Bird Observatory in the area near the radar. 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.

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 firstly by filtering out tracks with a tortuosity < 0.65. 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).

Buildings can reflect RF signal and as a result it is not possible for the radar to track birds behind a building, such as the lighthouse at Lista located only a short distance away. In fact, the presence of the lighthouse resulted in artificial tracks extending from behind the lighthouse away from the radar. A cone shaped polygon was drawn from the lighthouse covering these artificial tracks and all tracks that overlapped or intersected with the polygon were removed.

Finally, to eliminate waves which might be masquerading as birds, we excluded tracks (over water) which moved in a similar direction to the wind where the flight altitude was less than 1m plus the predicted wave height (given the sea state) predicted by the wind conditions at the time, but only when the wind direction came in off the sea (i.e., bearing between 300-130 degrees).

3 Preliminary results

3.1 Annotated tracks

From the visual observations, species information was assigned to 354 radar tracks, providing an opportunity to explore tracks from known birds in more detail and investigate how the radar assigned these tracks. Tracks with species ID assigned are hereafter referred to as 'annotated tracks' and these also include information on numbers of birds flying together (i.e., if observed flying in a flock). The annotated tracks were collected over 17 days between 12 April and 27 May 2023 (**Figure 2**).

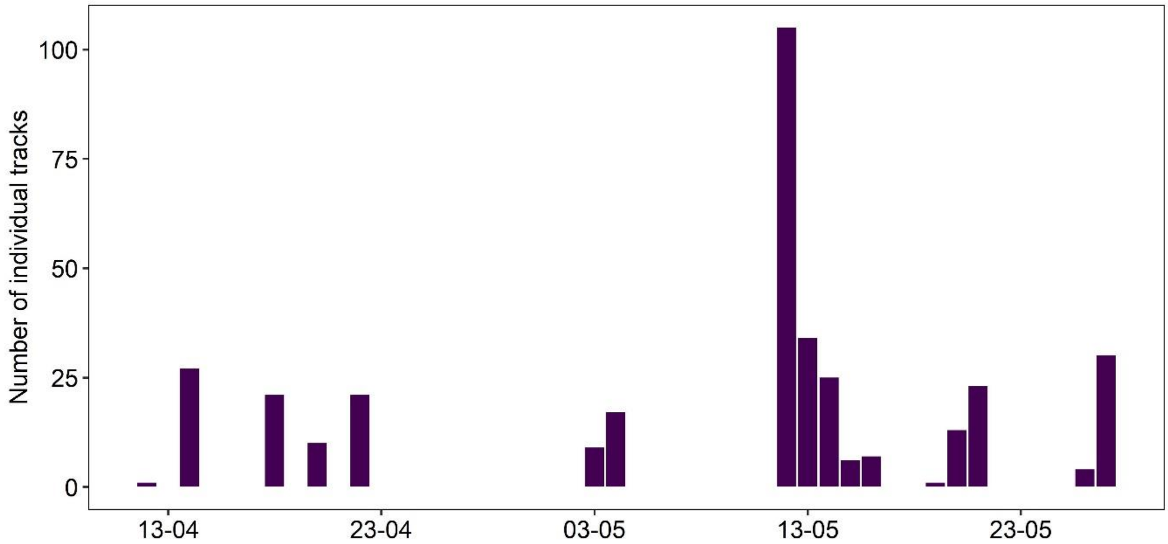

Figure 2. *Number of annotated tracks recorded per day between 12th of April and 27th of May 2023.*

3.1.1 Radar-assigned categories

The radar divided the 354 annotated tracks into seven different categories: flock (n=14), large birds (n=2), medium birds (n=68), small bird (n=208), slow target (n=4), unknown (n=56), and vehicle (n=2) (**Table 1, Figure 3**). The radar falsely classified 18% of these annotated tracks as being something other than birds. Ultimately, the classification by the radar indicates that mostly small birds were detected. However, when exploring the data it appears that the radar has a tendency to underestimate the size of birds especially larger species (see for example Cormorant, Great black-backed gull, Whooper swan). The large number of barn swallows classified as unknown is of concern. These birds were recorded in four separate clusters in time over four consecutive days (characterised by low winds).

Table 1. *Categories assigned by the radar to each of the annotated tracks where species ID was known with certainty.*

Species	Radar assigned categories						
	Small	Medium	Large	Flock	Slow	Vehicle	Unknown
Barn swallow	26			1			43
Black-headed gull	1						
Brent goose				3		2	
Common crane			1				
Common eider	1						

Common gull	52	1		5			
Common house martin							1
Common linnet							1
Common shelduck	2	1					
Common starling	5			1			
Cormorant	17	21		1			
Eurasian curlew				1			
Eurasian skylark	7		1		3		2
European golden plover	3						
European herring gull	57	17		1			1
Great black-backed gull	12	21					1
Green sandpiper							1
Greylag goose		2					
Hooded crow	14	2					3
Lesser black-backed gull	6	2			1		1
Mallard	2						1
Meadow pipit							1
Red-breasted merganser		1					
Western jackdaw				1			
White wagtail	2						
Whooper swan	1						

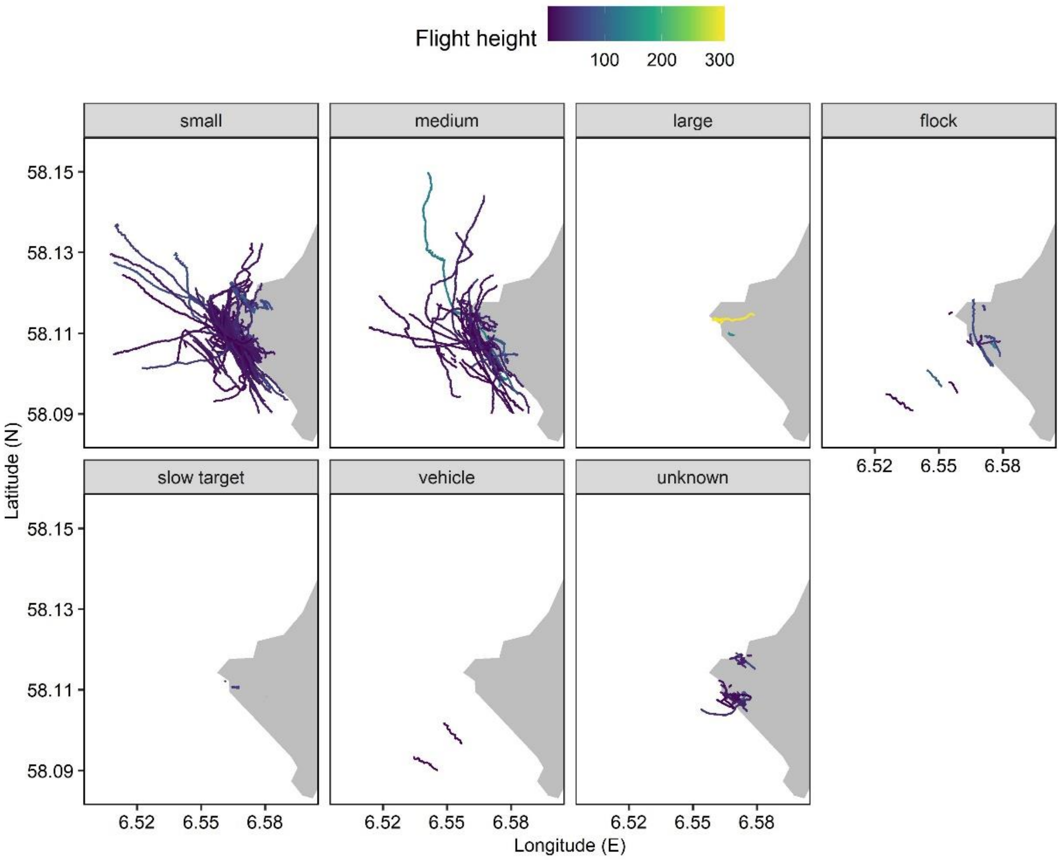

***Figure 3.** Maps of the annotated tracks by category assigned by the radar and coloured by flight height (m).*

Investigating the radar cross section (RCS) for the seven different categories assigned by the radar, vehicle has the highest RCS. Unknown and slow targets have a similar low RCS, and small birds have an RCS just above these. Small, medium and large birds were well separated with large birds having a narrow RCS range likely due to the small sample size (according to the radar) (**Figure 4**).

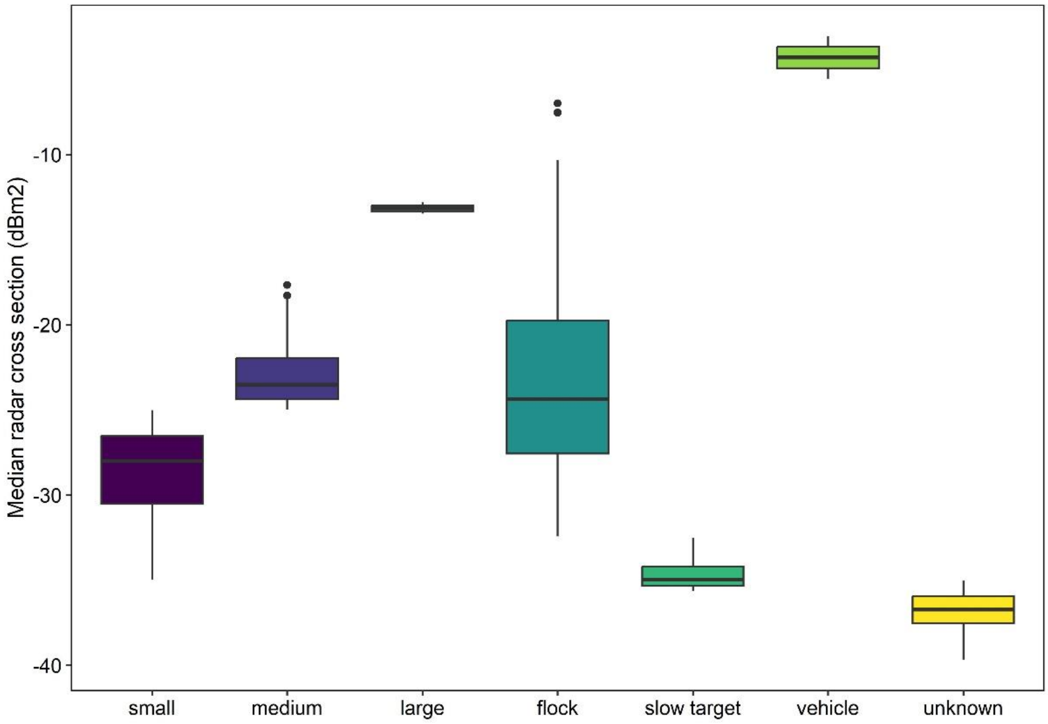

Figure 4. *Distribution of RCS (dBm^2) for each of the radar assigned categories.*

3.1.2 Corrected categories

We extracted information on maximum species mass, body length, and wingspan, and plotted these against RCS to assign more informed categories to the annotated tracks (**Table 2**). It is important to note that wings do not contribute much to the RCS value, and therefore RCS does not necessarily scale with size unless this involves a significant change in body mass and/or body length. In other words, birds with relatively large wingspans might not necessarily have a very large RCS value.

Table 2. *Number of annotated tracks per species split into the corrected categories based on information on species maximum weight, body length and wingspan.*

Species	Small	Medium	Large	Flock
Barn swallow	69			1
Black-headed gull		1		
Brent goose				5
Common crane			1	
Common eider			1	
Common gull		56		2
Common house martin	1			
Common linnet	1			
Common shelduck		2		1
Common starling	5			1
Cormorant			35	4
Eurasian curlew				1
Eurasian skylark	13			

European golden plover		3		
European herring gull		75		1
Great black-backed gull			34	
Green sandpiper	1			
Greylag goose			1	1
Hooded crow		19		
Lesser black-backed gull		10		
Mallard		3		
Meadow pipit	1			
Red-breasted merganser				1
Western jackdaw				1
White wagtail	2			
Whooper swan				1

Given the new corrected categories, there are 93 tracks of small birds, 169 of medium birds, 72 of large birds, and 20 tracks of flocks (**Table 3, Figure 5**). Concerningly, the radar falsely classified several small birds as unknown many of which were barn swallows. The RCS values for these birds appeared to be within the range the radar should accept as small birds (-40 to -20 dBm^2). If this is a recurring problem, there may be a risk of missing a significant number of small birds when filtering data from the radar believed to be birds (i.e., small, medium, large, flocks), and that other methods for filtering out birds should be explored.

Table 3. *Comparison of the radar assigned and corrected categories. The numbers in bold in the centre diagonal represent when there is a match between the two types of categories. Numbers above the centre diagonal represent cases where the radar has underestimated the size of the bird.*

		Corrected				
	Category	**Small**	**Medium**	**Large**	**Flock**	**Total**
Radar assigned	**Small**	**40**	137	30	1	208
	Medium		**22**	39	7	68
	Large	1		**1**		2
	Flock		3	1	**10**	14
	Slow target	3	1			4
	Vehicle				2	2
	Unknown	49	6	1		56
	Total	93	169	72	20	

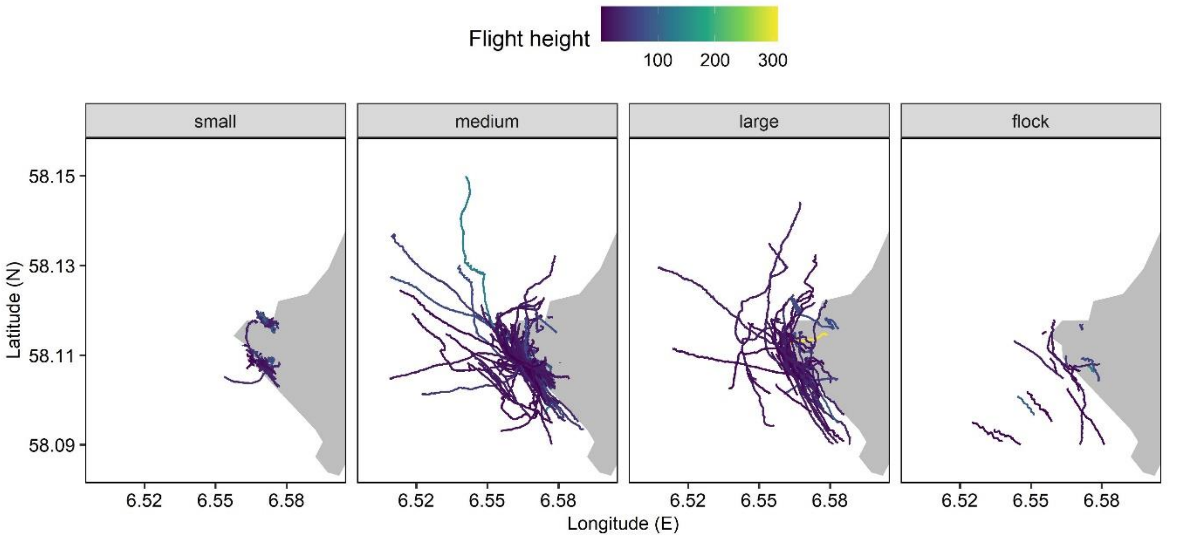

Figure 5. *Maps of the annotated tracks by corrected category and coloured by flight height (m).*

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 6**). It is also important to note that the sample size for flocks was quite low with just 16 flocks in total (5% of all tracks). 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.

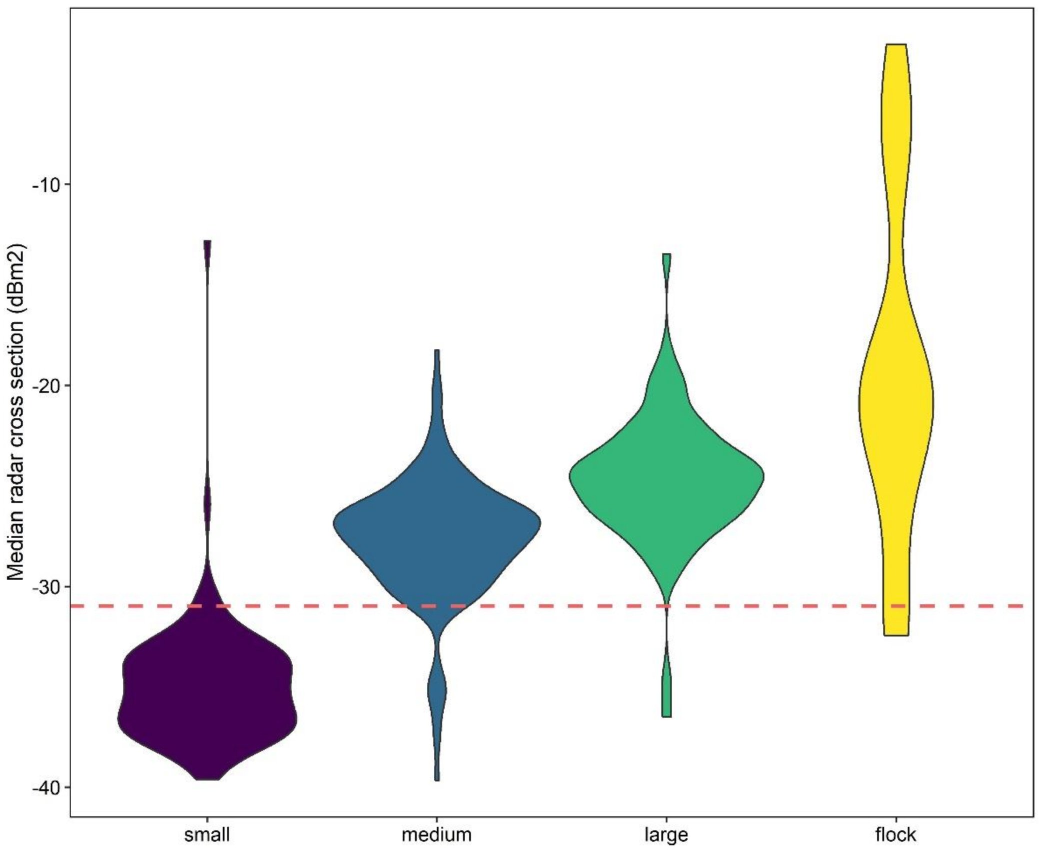

Figure 6. *Distribution of RCS for the corrected categories. The red dashed lines indicate potential RCS boundary to separate out small birds.*

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 7**). It appears that it may be possible to more accurately separate out large flocks of large birds based on RCS (> -15 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. It would also be interesting to annotate tracks of small and medium sized birds flying in larger flocks to understand the resulting RCS. 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 -15 dBm^2, and 3) larger flocks above -15 dBm^2 to be applied to all radar data.

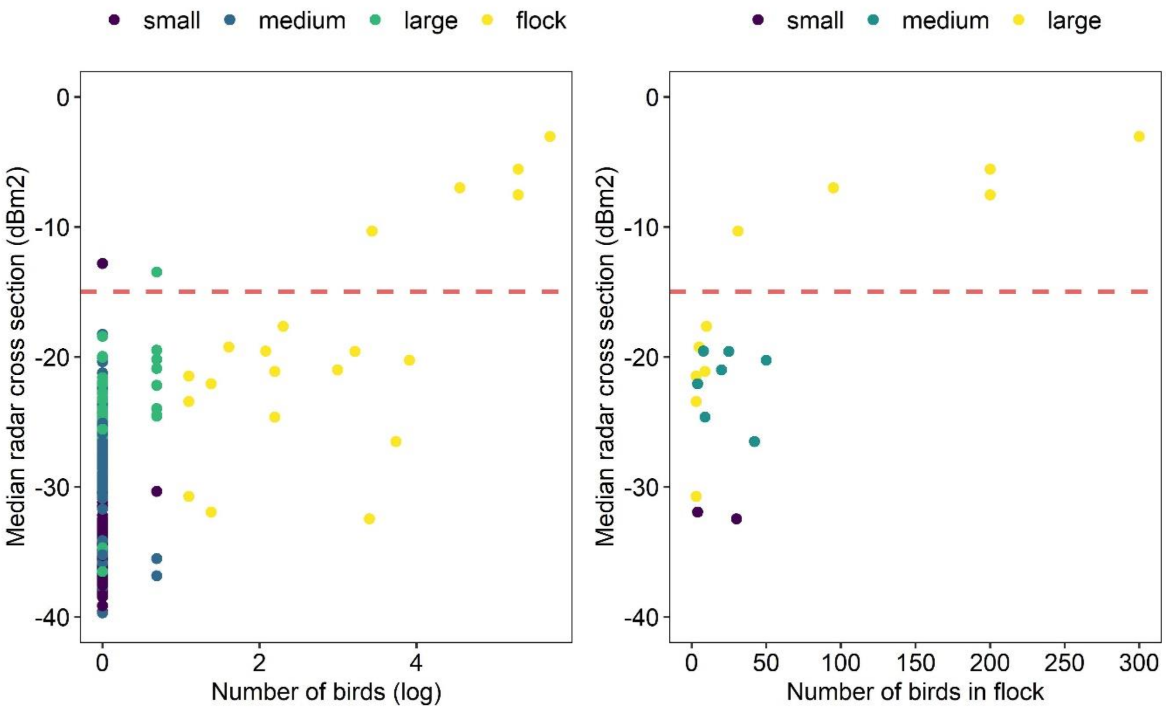

Figure 7. *Left) Median RCS plotted against logged number of birds and coloured by corrected category. Right) Median RCS of flocks plotted against number of birds in flock and coloured by whether the flock was made up of small, medium or large birds. Red dashed line indicates an approximate cut-off for separating out larger flocks.*

3.1.3 Exploring filters for migration flight

Recognising the issues with the radar assigned categories, we investigated the characteristics of the annotated tracks to understand how this information could be used to improve the classification of all radar tracks (**Figure 8**).

For the annotated tracks, the maximum distance from the radar that birds were detected varied between categories (small≈1200m, medium≈5100m, large≈5000m, and flocks≈3000m). For flocks and large birds, the detection distances would be expected to be larger, but this may simply be an effect of smaller sample size. Track distances increased with bird size which was expected as the larger the target the easier for the radar to detect and the further from the radar it can be detected. However, the relatively short track distances for flocks were surprising particularly given the number of large flocks of large birds.

From the size-specific distributions of RCS, small birds are most easily separated out from the others. This is also the case for other variables. For example, small birds fly slower, have less directional tracks, are mostly detected close to the radar, and have shorter track lengths. Flocks tend to travel fast and quite directed with a north-west bearing. Across all variables, medium and large birds had intermediate flight speeds, were fairly directional, and seem particularly difficult to separate, requiring further and more formal investigation.

The mean flight speeds of individual tracks ranged from 0.9 – 29.1 m/s (not filtered for migration flights). As shown previously, small birds fly slower, and flocks tend to fly faster with medium and large birds typically flying at intermediate speeds. Bruderer & Boldt (2001) and Schmaljohann *et al.* (2008) suggested that migrating birds typically fly at speeds between 8-28 m/s. However, applying this filter would eliminate a large proportion of slow flying small birds, which is a concern, although tracks of small birds had the lowest and most variable tortuosity indicating that these may not be migrating birds. On the other hand, these may simply be foraging in this area along their migration route.

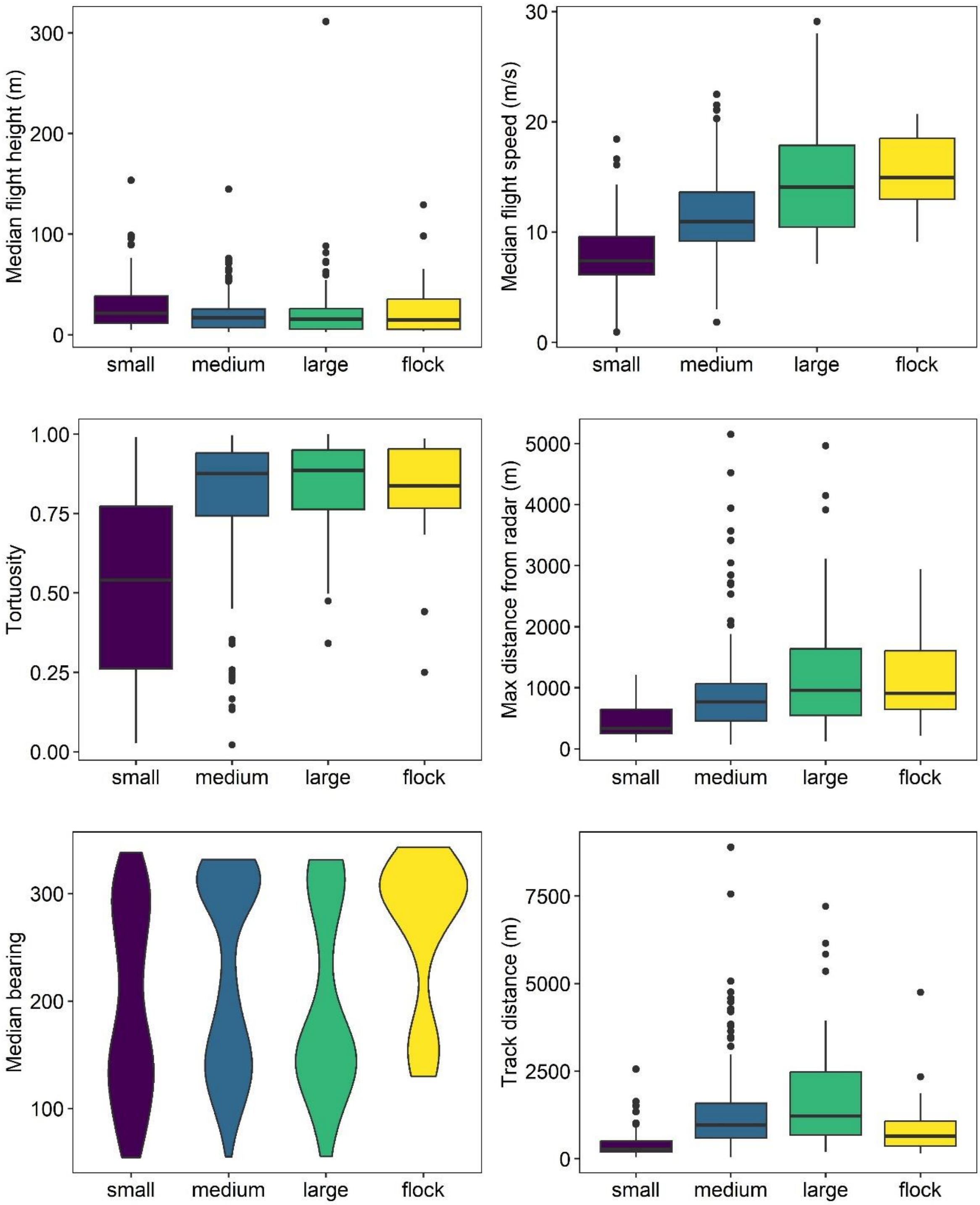

Figure 8. *Comparison of flight characteristics across the corrected categories.*

3.2 All radar data

To extract probable migration tracks from all the radar data collected, we only retained tracks with a median travel speed between 5 and 28 m/s, a tortuosity above 0.65, and a median turning angle less than 40 degrees, while eliminating tracks which could be waves (see methods). Of the 59,164 probable migration tracks collected by the radar (between the 29 March and 27 May) and applying the new groupings based on RCS values, 12,987 tracks were classified as small birds, 42,273 as intermediate (consisting of medium and large birds as well as some flocks), and 3,904 as larger flocks of larger birds.

Exploring the flight characteristics of the three categories (**Figure 9**), larger flocks tended to fly faster compared to intermediate birds, and small birds fly slowest, although there is a lot of overlap between the categories. Across the three categories, there was a preference for movements in a north-west direction as well as, and to a lesser extent, in the south-eastern direction. Flocks generally flew very low, but also showcased the highest flight heights in a few cases. However, see further down regarding apparent low flying flocks recorded further from the radar than we would expect possible. It is also worth mentioning the differences in tortuosity and bearing between flocks in the annotated data and flocks using all radar data (see **Figure 8 & 9**).

The detection range was 5.2 km for small birds, 9 km for tracks classed as intermediate, and 13.6 km for larger flocks, but across all categories, the max distance to the radar was typically much shorter than the detection ranges (**Figure 9**). Small birds generally flew slightly higher compared to tracks classed as intermediate. Tracks classified as small and intermediate appeared more directed in their movements compared to flocks. Changes in flight characteristics where also explored over time but no patterns or changes were apparent.

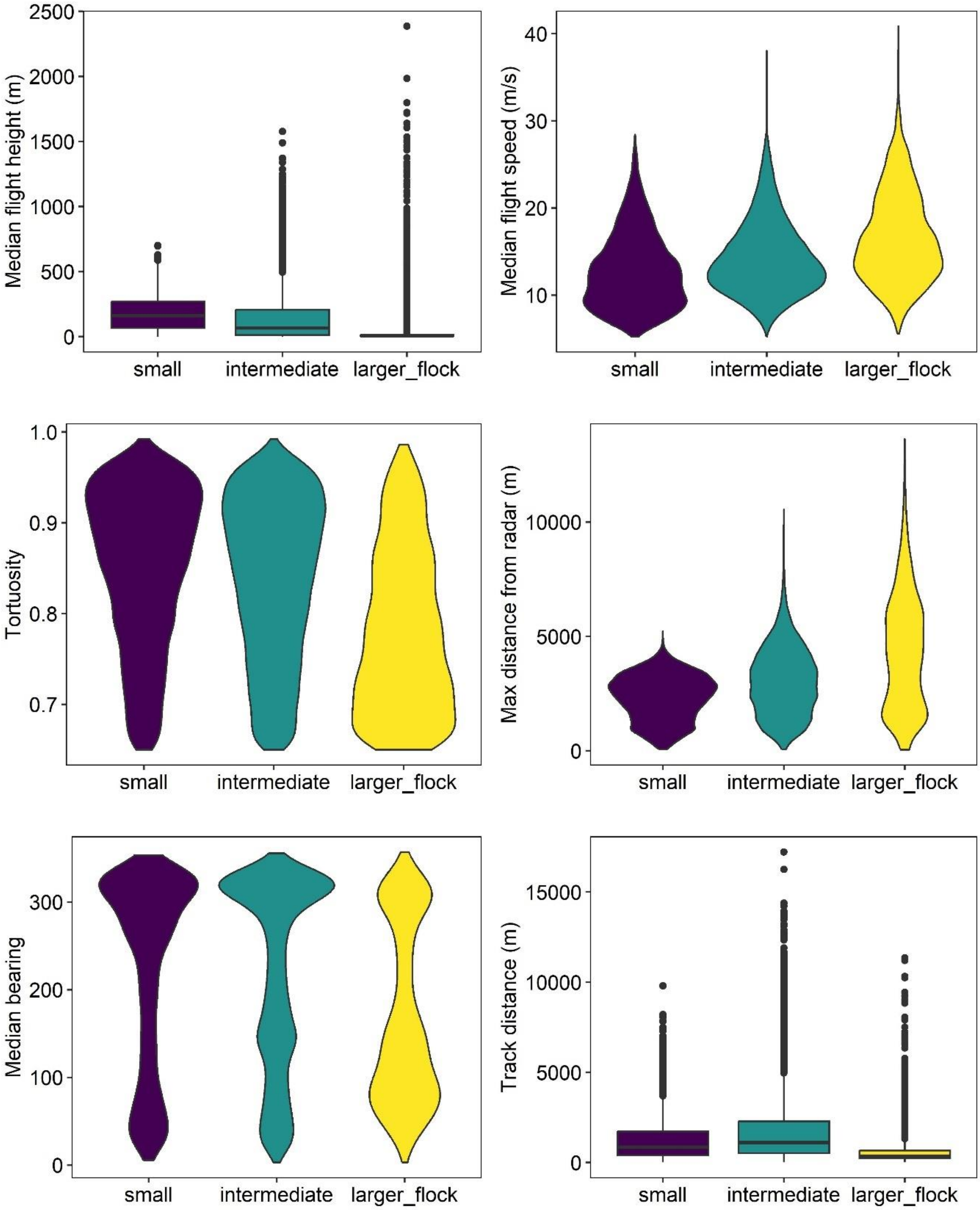

Figure 9. *Comparison of flight characteristics of small, intermediate and flocks. The median and maximum values for each individual track were extracted for comparison.*

3.2.1 Temporal patterns

From the 29th of March to the 27th of May between 139 and 3384 tracks were collected per day (**Figure 10**) with higher numbers of birds detected in the former half of the data collection period. Most tracks were classified as intermediate, but there were periods of increased percentage of small birds.

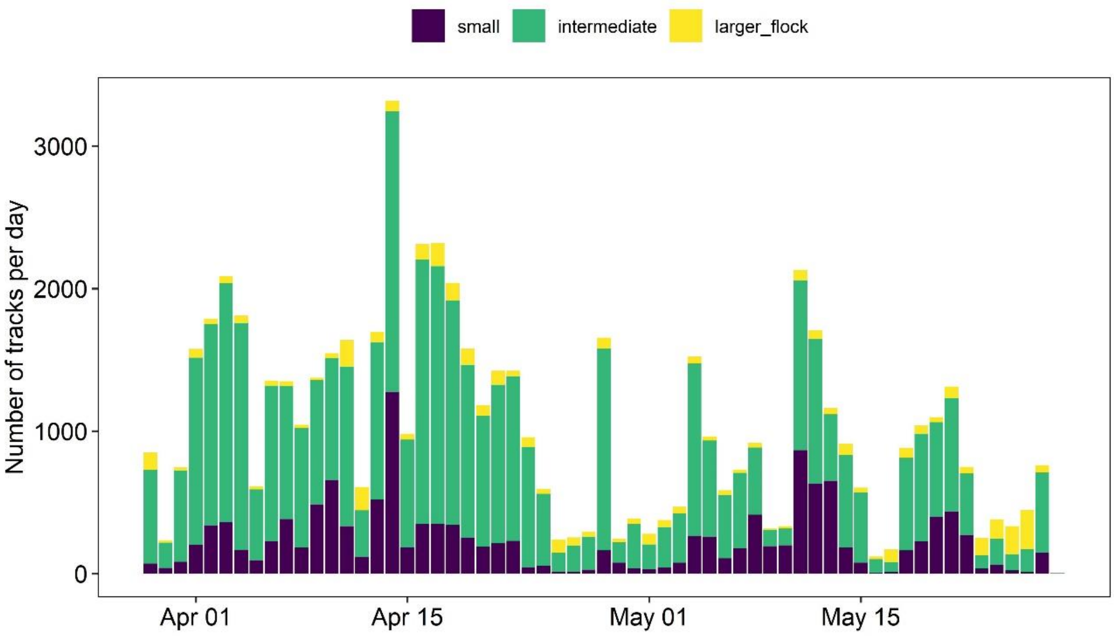

Figure 10. *Number of tracks per day coloured by corrected category.*

Most migration flights took place between sunrise and sunset (i.e., during daytime) with only around 10 days characterised by mostly nighttime migration (**Figure 11**). There was a cluster of nighttime activity during the former half of the time period, but otherwise these were more sporadic. It is possible that only the days with nighttime peaks are migration and the rest is local migration or local movement.

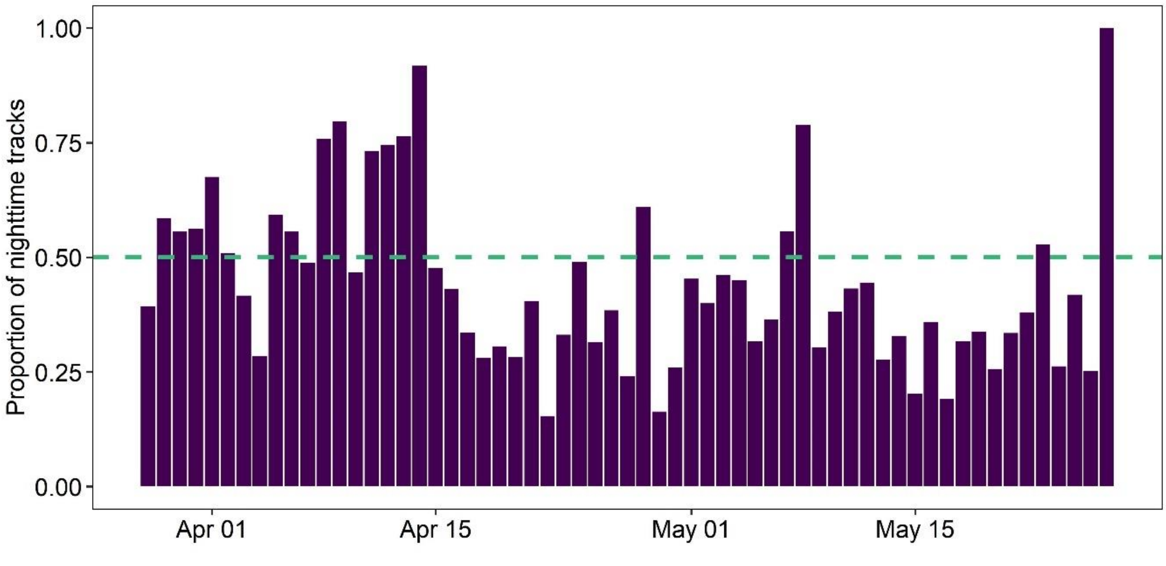

Figure 11*. Proportion of tracks that took place at nighttime between sunset and sunrise. Time given in CEST.*

Between weeks, there was variation in numbers of migrating birds and the time of day that these were detected (**Figure 12**). Tracks classed as intermediate were detected throughout the day with no consistent peaks at any time of day. Similarly larger flocks were detected throughout the day with no consistent pattern, but in much smaller numbers compared to intermediate. On the other hand, small birds showed peaks of activity during the evening and night in a few of the weeks (e.g., weeks 14, 15, 19) and where otherwise present in relatively small numbers.

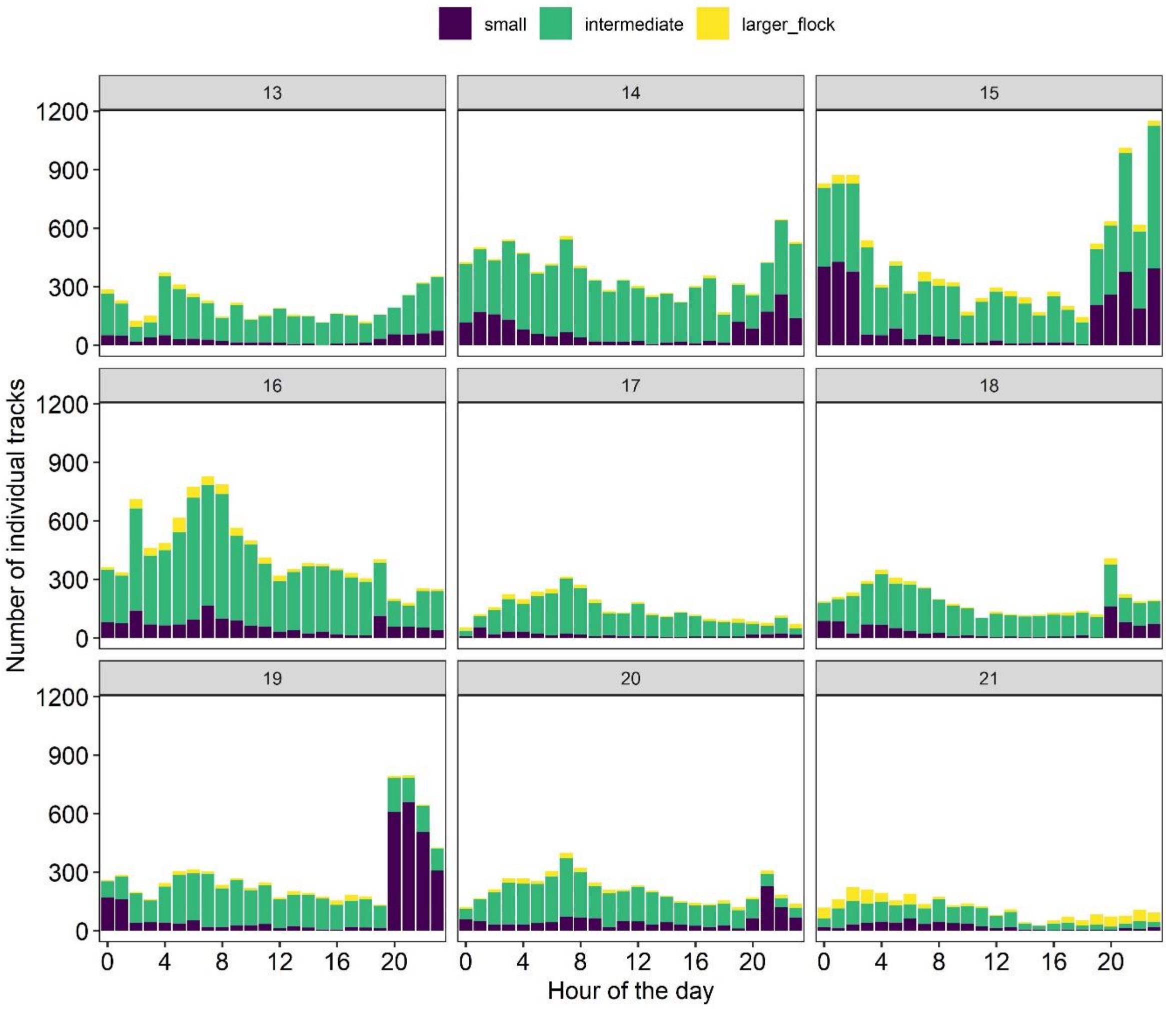

Figure 12. *Total number of individual tracks that were recorded within each hour of the day for each week of the study period coloured by category. Time given in CEST.*

The rotor swept zone, the area where birds are vulnerable to collision, will depend on the height of the turbine tower and the size of the rotor blades. Here we define the rotor swept zone as the area between 25 – 250m elevation. However, due to the very narrow airspace underneath the rotors when a blade is positioned vertically (0-25m), we also consider birds flying at altitudes less than 25m to be vulnerable. The average proportion of tracks in the rotor swept zone over time was 45% and in the lower vulnerable zone 36% (0-25m), resulting in a combined 81% of tracks located in the zone between 0-250m (**Figure 13**).

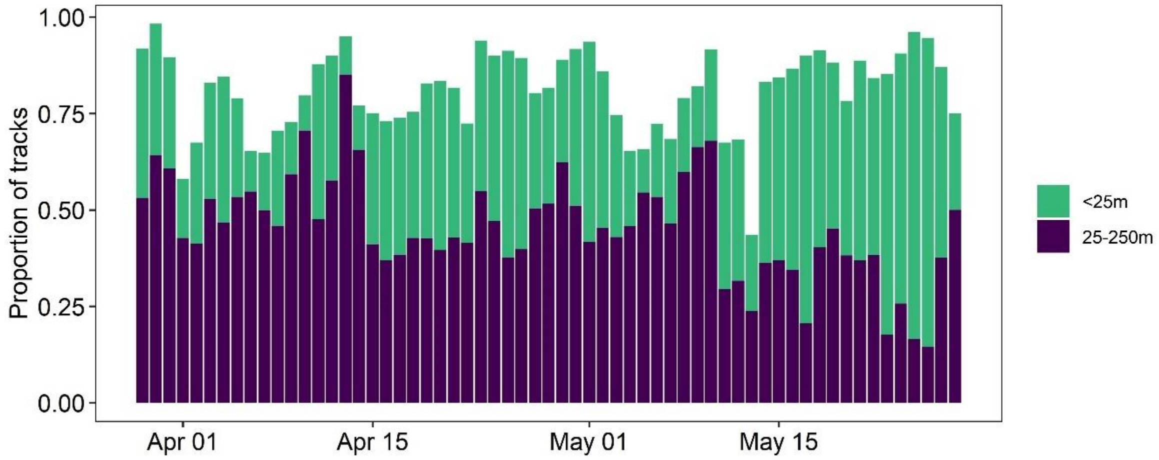

Figure 13. *Proportion of tracks located in the rotor swept zone (RSZ) between 25-250m and the lower vulnerable zone between 0-25m.*

A slightly larger proportion of flight in the zone between 0-250m took place during the day (86% on average; of which 46% on average took place in the RSZ) compared to during the night (74% on average; of which 42% on average took place in the RSZ) (**Figure 14**). The proportion of tracks in the RSZ during the day was more consistent showcasing a slight decline over time, whereas during the night the proportion of flight in the RSZ was more variable, sometimes accounting for most of the activity.

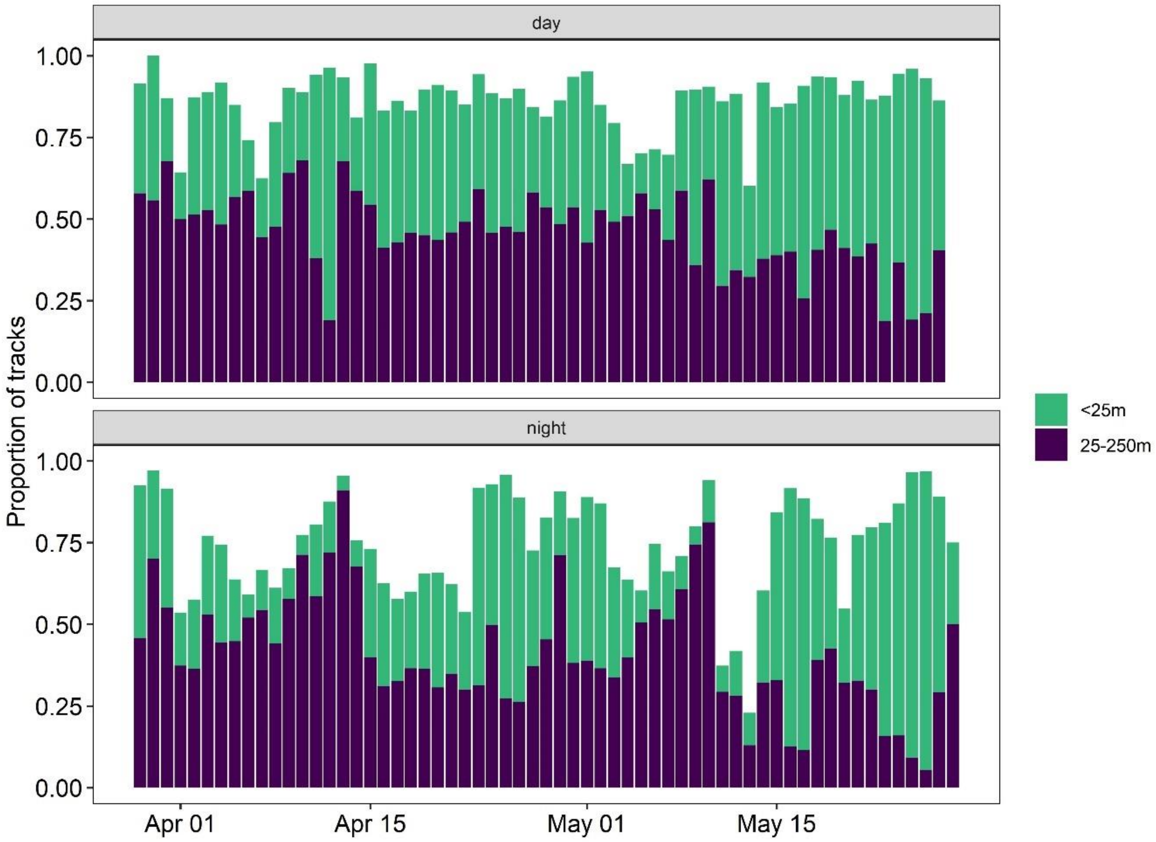

Figure 14. *Proportion of tracks located in the rotor swept zone (RSZ) between 25-250m and the lower vulnerable zone between 0-25m during the day (top) and during the night (bottom).*

The flight direction of birds may also be influenced by the wind speed and direction. The wind speed between weeks was relatively consistent although with a few weeks experiencing higher winds (**Figure 15**). Wind direction was more variable but typically either from the west or east.

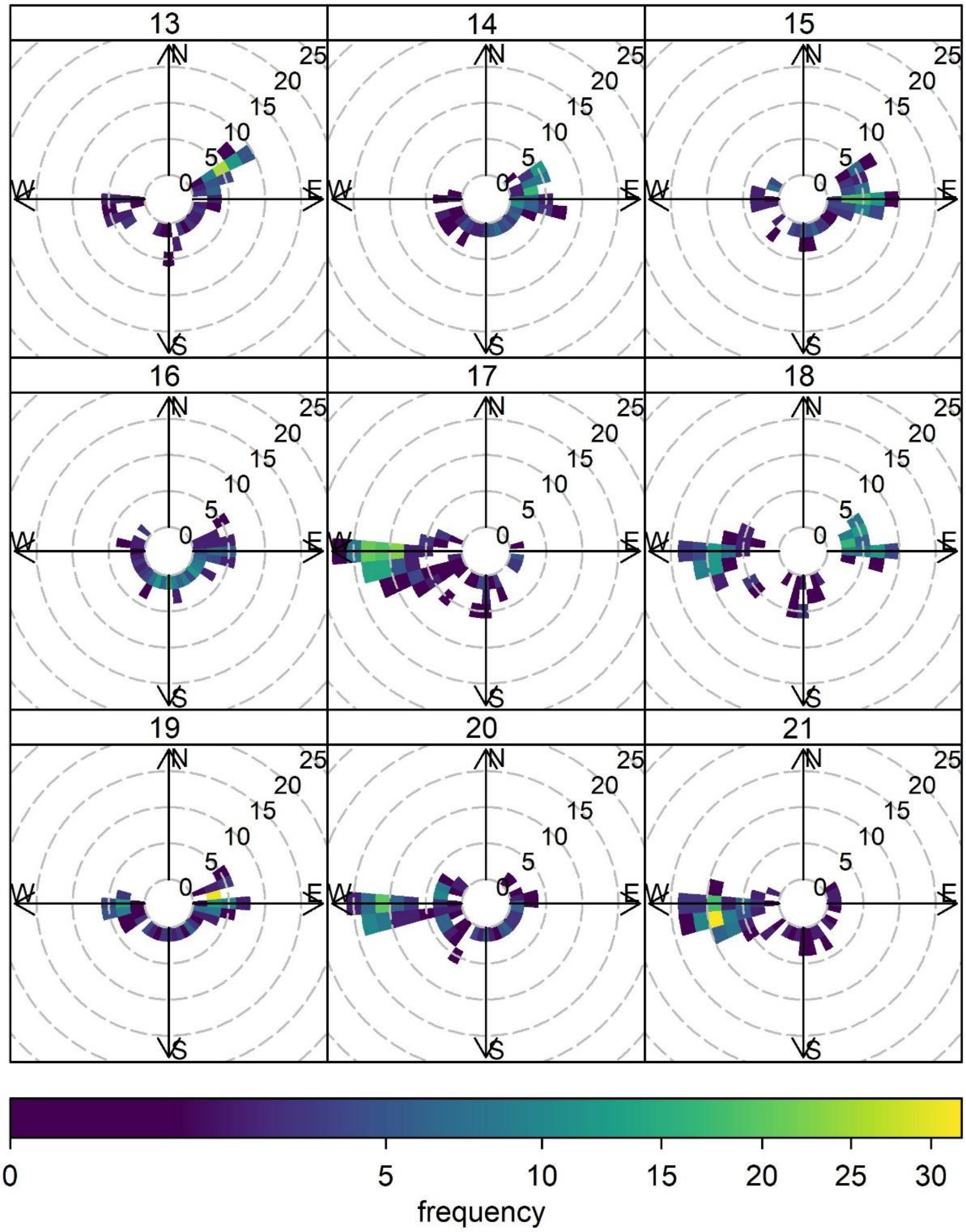

Figure 15. *Patterns in weekly windspeed (see values in the rings in m/s) and direction. Frequency indicates the number of hours with a given windspeed and direction.*

Bird flight speeds were fairly consistent, but there was great variability in flight directions although with some indications of a preference for moving in a north west direction during some weeks (**Figure 16**).

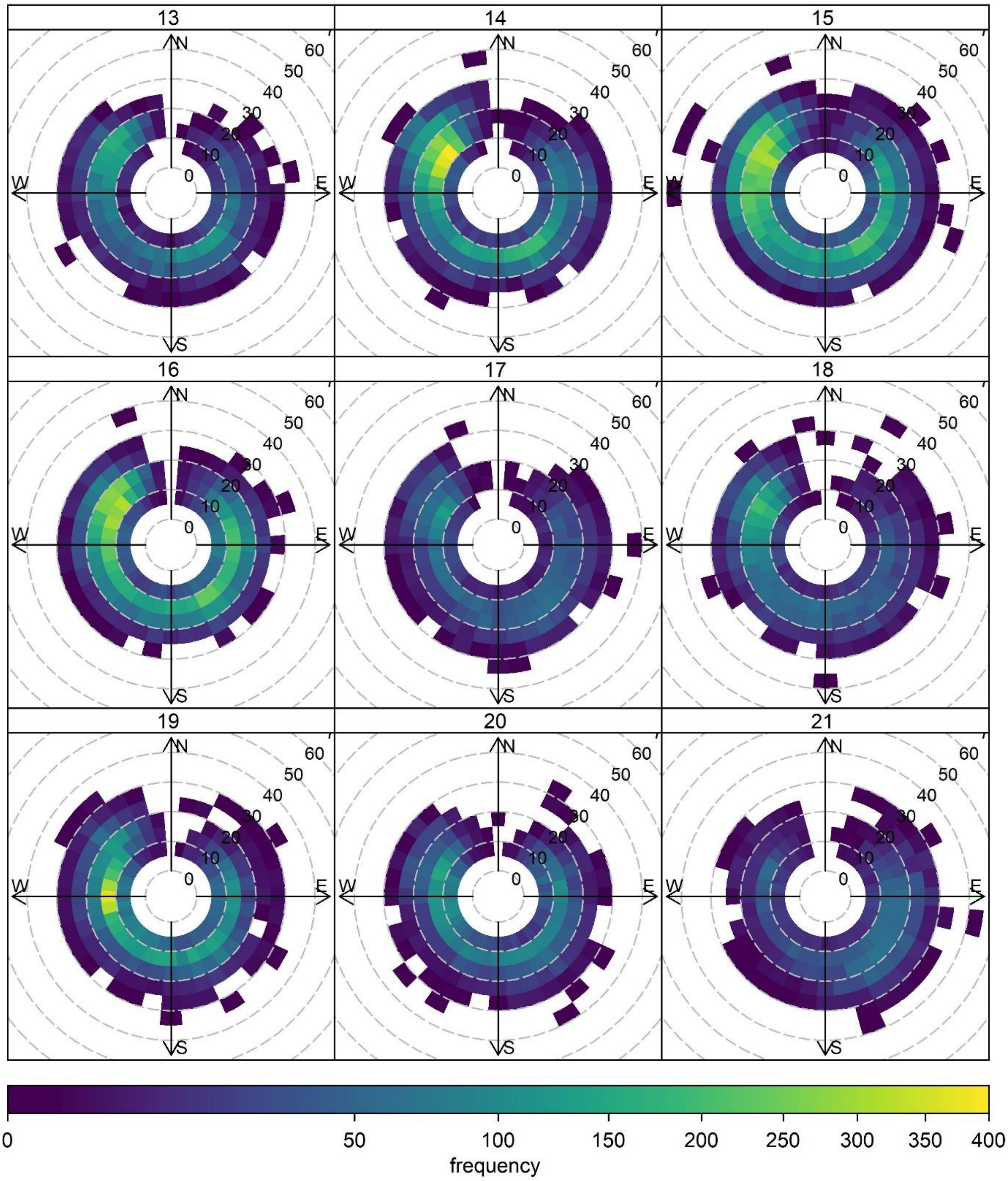

Figure 16. *Patterns in weekly flight speed (see values in the rings in m/s) and direction for individual tracks. Frequency indicates the number of tracks with a given speed and direction.*

The strength of directionality in bird tracks was generally low, but may increase during windier days, where it appears that birds tend to fly in a cross wind (**Figure 17**). There seemed to be a fairly clear pattern of more birds being present on the less windy days compared to those characterised with higher winds.

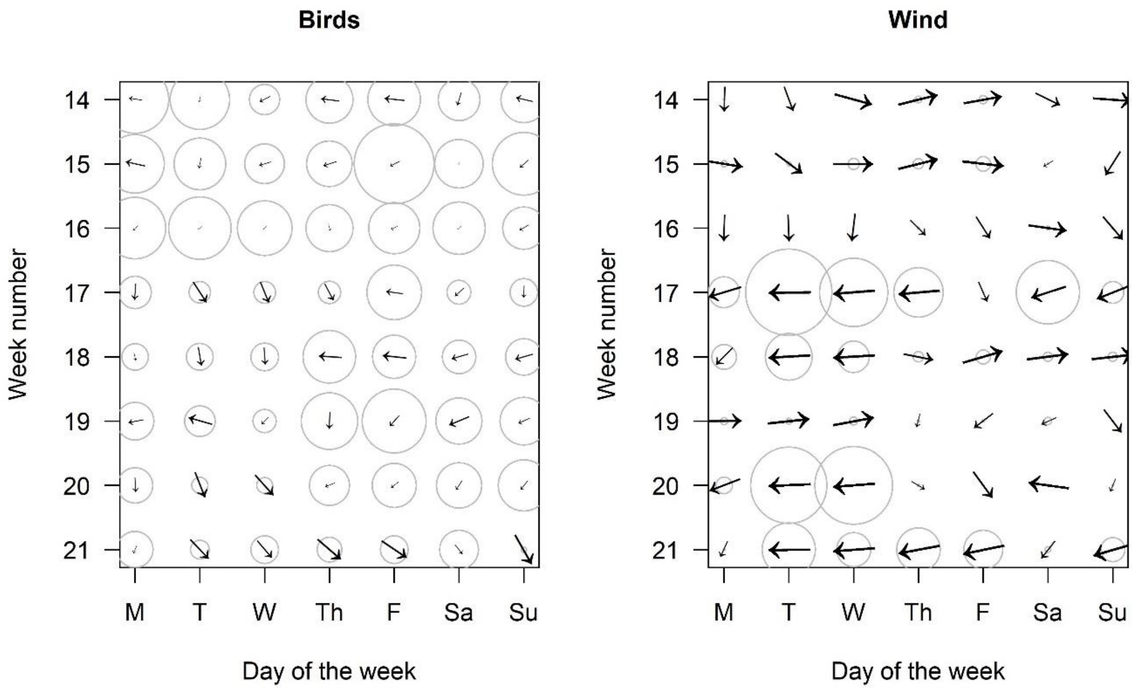

Figure 17. *Directionality in daily and weekly bird activity and wind conditions. Circular mean direction is given per day of the week and week number. The arrow size indicates the strength of directionality (i.e., a large arrow indicates low variation in heading). The size of the circles in the left-hand panel gives a measure for the number of bird tracks recorded by the radar, while the circles in the right-hand panel indicate wind speed.*

For birds the strength of directionality appeared stronger during the evening and nighttime hours compared to midday, especially during those weeks characterised by a significant number of small birds detected during this period of the day (**Figure 18**).

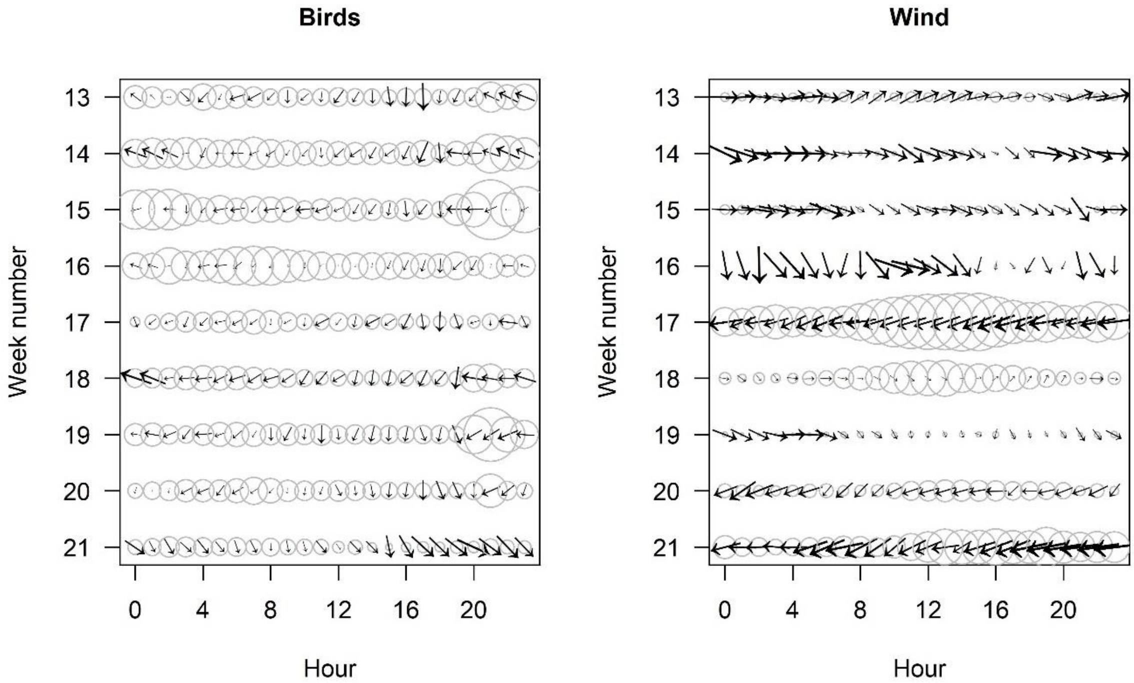

Figure 18. *Directionality in hourly and weekly bird activity and wind conditions. Circular mean direction is given per hour of the day and week. The arrow size indicates the strength of directionality (i.e., a large arrow indicates low variation in heading). The size of the circles in the left-hand panel gives a measure for the number of bird tracks recorded by the radar, while the circles in the right-hand panel indicate wind speed.*

3.2.2 Spatial patterns

To provide an idea of what tracks collected by the radar look like, we have plotted tracks from selected days with higher amounts of activity below (**Figure 19**). For example, on certain days activity by small birds typically took place during nighttime, but tracks could vary in their directionality from being highly directional heading in a north-west direction (generally post-midnight; see day of the year 100) to more random flight patterns in all directions (generally pre-midnight; see day of the year 132).

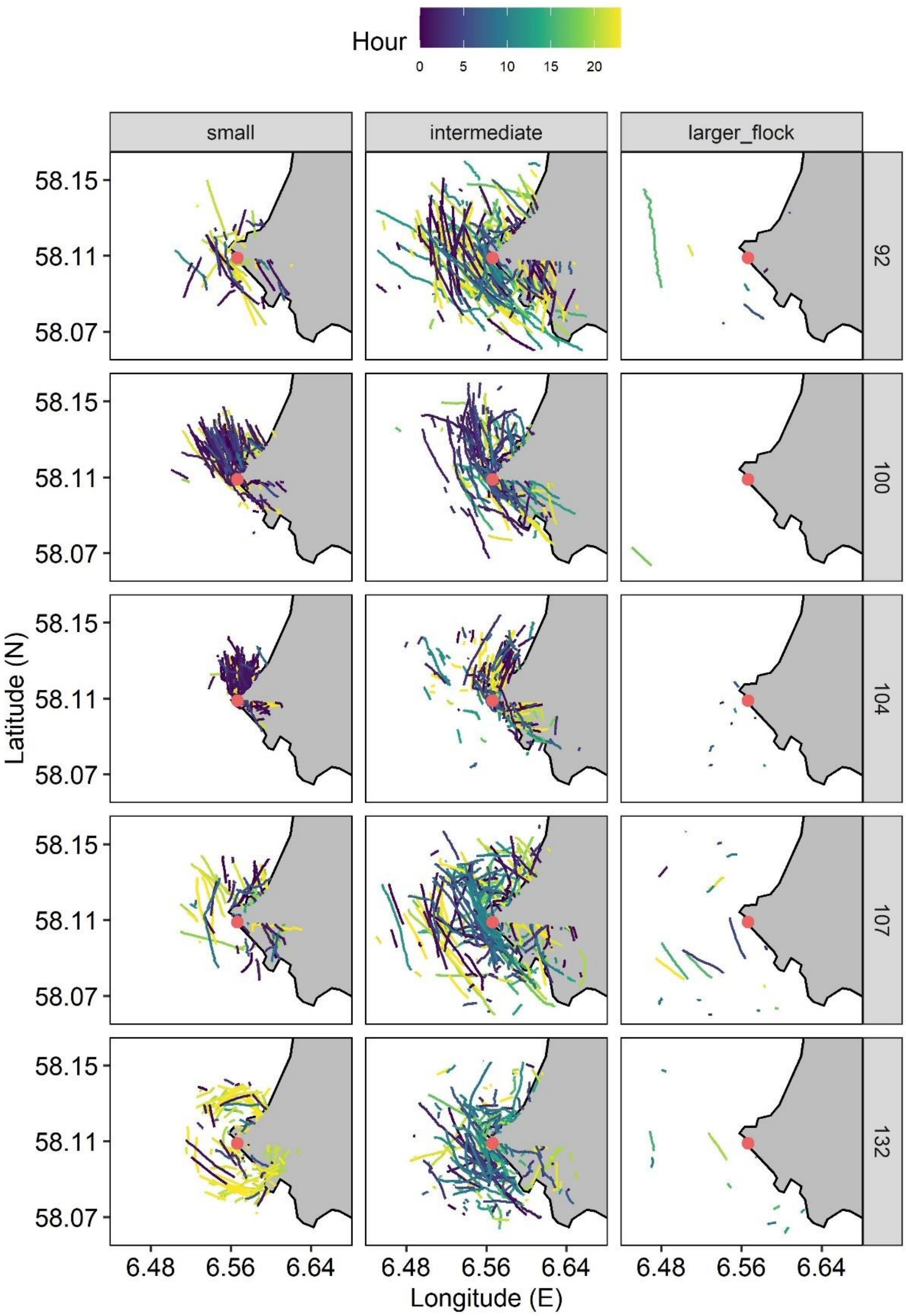

Figure 19. *Tracks of small birds, intermediate birds, and larger flocks on selected days with higher activity (day of the year 92, 100, 104, 107, and 132). These days were split at noon instead of midnight to capture the complete nighttime activity. A random sample of 1800 tracks are plotted from these days to make the general patterns more obvious. Tracks are coloured by the hour of the day they were recorded.*

Most tracks classified as intermediate were detected close to the radar (**Figure 20**). Small birds also showed a slightly higher number of locations close to the radar, but more on the northward side. Flocks were more evenly spread, but also had the smallest sample size. The spatial distribution of locations confirmed the much smaller detection range of small birds compared to larger birds and flocks.

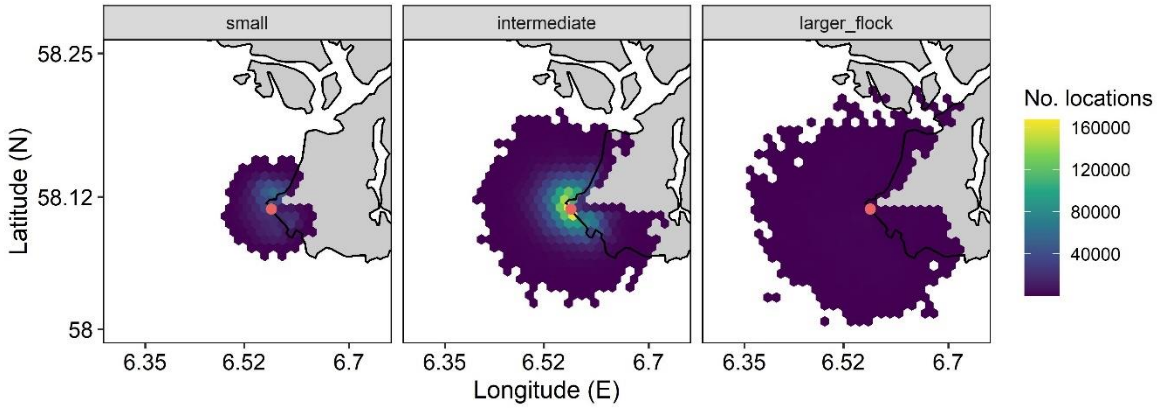

Figure 20. *Spatial distribution of the number of locations recorded by the radar across the three different categories. Radar location indicated by the red dot.*

Across all three categories, with increasing distance from the radar flight heights also increased reflecting the fact that lower flying birds are not detected further away from the radar (**Figure 21**). Larger flocks had the lowest sample size hence the stronger and more variable colours. The distribution of flight altitudes with distance from the radar for small and intermediate birds was as expected, and especially for intermediate birds it is also evident that only birds with a higher RCS are detected at the extreme end of the range. However, the long tail of low flying larger flocks beyond 8-9 km from the radar is unusual. All these flocks have very high RCS values (**Figure 21**) with some values higher than zero, which was not observed in any of the annotated tracks of known flocks or large birds.

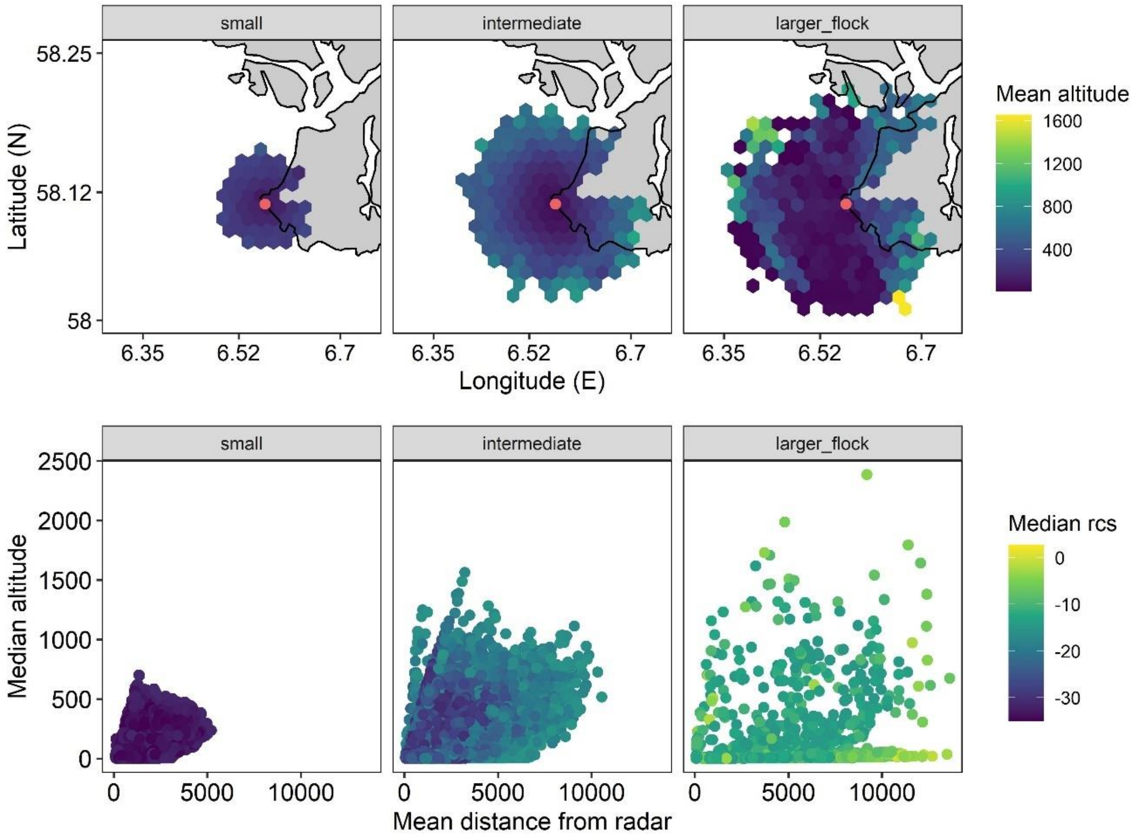

Figure 21. *Top) Spatial distribution of mean flight altitude (m) of tracks recorded by the radar across the three different categories. Radar location indicated by the red dot. Bottom) Mean flight altitude (m) per track plotted against mean distance from the radar (m) across the three categories with data points coloured by the mean RCS value.*

All low flying larger flocks far from the radar were detected over water and appear to be moving in a highly directional manner (**Figure 22**). We suspect that these tracks may be from vessels, but this will need exploring further.

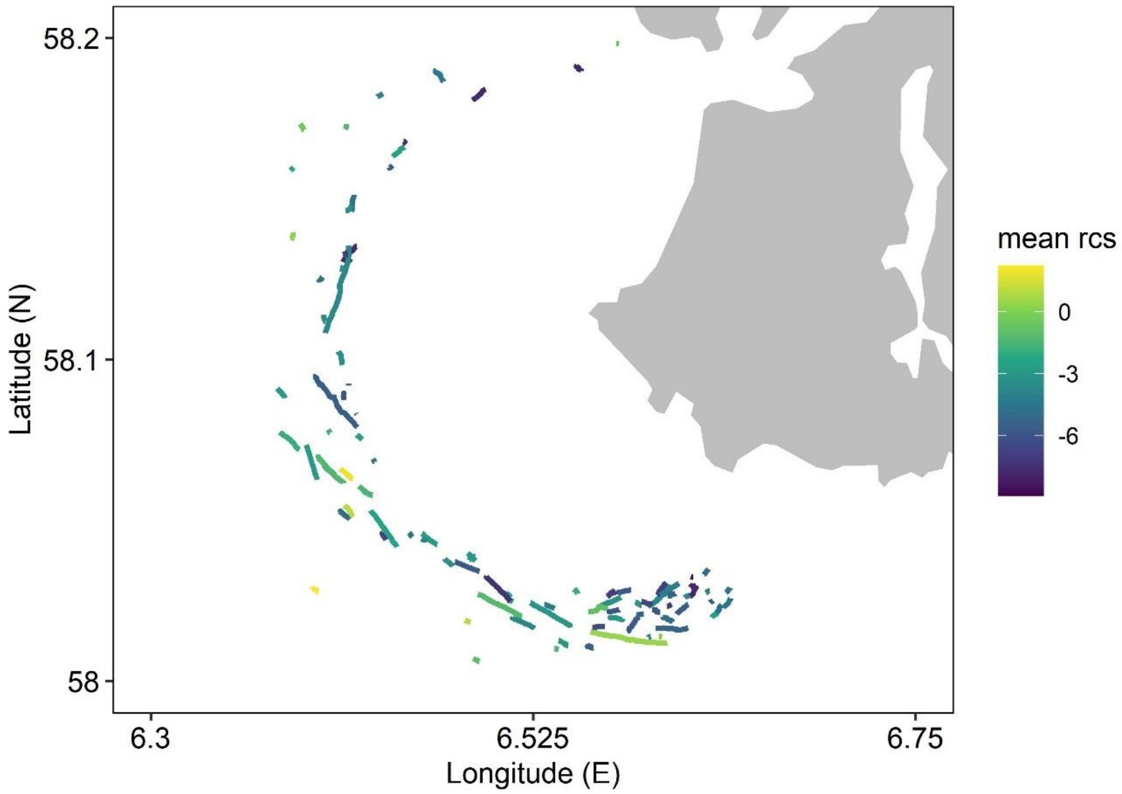

Figure 22. *Map showing the distribution and characteristics of apparently low flying larger flocks far from the radar (coloured by mean RCS).*

4 Next steps

Here we have presented a preliminary exploration of the radar data collected at Lista during spring 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, exploration of the annotated data has flagged some issues surrounding the radar categories. Therefore, we need to further explore ways of better classifying birds using other variables than just RCS. Ideally radar systems would be developed where species could be obtained or logged in a more automated manner, and the radar would be able to learn from the annotated tracks that have been collected to classify other tracks more accurately. It is particularly concerning if there is pattern of classifying large amounts of small birds as unknown. However, this only seemed to happen for one species of small birds on consecutive days so there may have been other factors influencing this.

Going forward we will explore using unsupervised cluster analyses or random forest models to separate birds from non-birds using annotated tracks of known birds and other objects (e.g., vessels, vehicles, waves, weather). We will then apply time series analysis to identify periods of peak activity (i.e. likely migration), and from those periods we will apply cluster analysis or random forest model to identify migration versus non-migration tracks based on extracted flight characteristics, and using annotated tracks of different bird species better categorise the remaining tracks into species or size groups.

We will continue to annotate more than just birds, namely large waves, cars, and different types of vessels, which will help improve classification of all tracks. Ultimately classifying more tracks of vessels will serve a better purpose in our cluster or random forest analyses than matching up radar tracks with AIS tracks of vessels as several of the suspected vessel tracks obtained from the radar are too short.

We need to adjust flight heights of tracks over land so that these are calculated against the height above ground instead of mean sea level. This is not a big issue with the preliminary data presented here as most of the land that birds cross at Lista is low lying (~5-10 m above sea level), although, to the north the land rises to ~150 m. Furthermore, most tracks over land behind the lighthouse are removed and most other activity was over water.

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